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Divided Attention in Younger and Older Adults: Effects of Strategy and Relatedness on Memory Performance and Secondary Task Costs

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Divided attention at encoding leads to a significant decline in memory performance, whereas divided attention during retrieval has relatively little effect; nevertheless, retrieval carries significant secondary task costs, especially for older adults. The authors further investigated the effects of divided attention in younger and older adults by using a cued-recall task and by measuring retrieval accuracy, retrieval latency, and the temporal distribution of attentional costs at encoding and retrieval. An age-related memory deficit was reduced by pair relatedness, whereas strategy instructions benefited both age groups equally. Attentional costs were greater for retrieval than for encoding, especially for older adults. These findings are interpreted in light of notions of an age-related associative deficit (M. Naveh-Benjamin, 2000) and age-related differences in the use of self-initiated activities and environmental support (F. I. M. Craik, 1983, 1986).

The effects of divided attention (DA) on memory performance are of great interest to memory researchers. Studies of such effects have increased our understanding of the interplay between attention and memory and, additionally, have shed light on the many real-world situations in which people encode or retrieve information under DA conditions. One classic case concerns introductions to new acquaintances: Attention is typically divided between registering the person's name, on the one hand, and attending to competing social cues, on the other, with the result that the new name is often forgotten. Another example concerns situations in which a person attempts to retrieve information while carrying out a second complex task—answering difficult questions while driving in heavy traffic, for example. In this case, most people defer answering until the hazard has been negotiated. These situations and many similar ones require people to split their attention among several sources of information, at least some of which they have to remember later on. Recent studies indicate that whether DA has a detrimental effect on memory performance depends on whether it happens during encoding of the information or during its retrieval. Baddeley, Lewis, Eldridge, and Thomson (1984) and Craik, Govoni, Naveh-Benjamin, and Anderson (1996) have shown that when attention is divided during encoding, both memory performance and secondary task performance suffer relative to full attention conditions. These secondary task costs have been interpreted to reflect the amount of attentional resources required by encoding processes (Craik, Naveh-Benjamin, & Anderson, 1998; Kerr, 1973). In contrast, DA at retrieval has been shown to affect memory performance minimally, although secondary task performance is negatively affected. This confluence of results has been taken to reflect the resistance of retrieval processes to interference, although protection of retrieval requires substantial effort (Craik et al., 1996; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000).

One interesting question concerns the degree to which older adults are affected by DA. Many studies have addressed this topic, although a number of issues remain unresolved. First, it is not yet clear whether encoding processes are more disrupted by a second task in older than in younger adults. Some studies (Park, Smith, Dudley, & Lafronza, 1989; Salthouse, Rogan, & Prill, 1984) found larger memory decrements for older than for younger adults when attention was divided at encoding. However, in other studies (Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Light & Prull, 1995; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park, Puglisi, & Smith, 1986; Park, Puglisi, Smith, & Dudley, 1987), older adults showed the same decrease in performance under DA at encoding conditions as did younger adults. With regard to the amount of attentional resources required at encoding, Anderson et al. (1998) reported larger attentional costs for older adults, but Duchek (1984) and Jennings, Nebes, and Yovetich (1990) found the same

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costs for the two age groups. With respect to DA at retrieval, the picture is more consistent. Several studies have shown that both younger and older adults are only slightly affected by the introduction of a secondary task during the retrieval of information (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997). However, older adults seem to require more attentional resources for retrieval than do the young, as reflected by their greater secondary task costs (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997). The preceding results can be interpreted in terms of the notion that older adults have reduced attentional resources (Craik, 1983; Craik & Byrd, 1982). According to this hypothesis, the ability to engage in demanding mnemonic strategies either at encoding or at retrieval is compromised by age. As a result, older adults require more attentional resources to carry out encoding and retrieval operations, which results in larger secondary task costs for older adults both at encoding and at retrieval.

The present experiments were carried out to follow up on the above-mentioned studies, with the intention of clarifying several unresolved issues. First, as only a few studies in the literature have assessed memory and secondary task costs at both encoding and retrieval, we wish to assess the reliability and validity of the above results by looking at age-related effects of DA separately at encoding and at retrieval on both memory and secondary task performance. Second, we want to assess more analytically the larger secondary task costs of older adults at encoding and at retrieval. In particular, the question we ask is whether there are specific processes during retrieval and encoding that consume more attentional resources in older adults.

To answer these questions, we used a cued-recall task previously shown to impose high demands for resources both at encoding and at retrieval (e.g., Craik et al., 1996) as well as a tracking procedure similar to the one used by Naveh-Benjamin, Craik, Guez, and Dori (1998) and by Naveh-Benjamin and Guez (2000) as the secondary task to be performed along with encoding (Experiment 1) or retrieval (Experiment 2). This procedure allows a microlevel analysis of momentary changes in participants' performance by requiring participants to track a fast-moving target on a computer screen with a computer mouse. In addition to providing an overall measure of attentional costs, the program provides a temporal distribution measure of performance, which is the spatial distance between the target and the tracker every 50 ms in a continuous fashion. The exact times when stimuli or cues are presented auditorily by the experimenter during encoding and retrieval and when participants' vocal responses are provided during retrieval are recorded by the computer through the use of a voice-operated relay and are superimposed on the continuous distance measure. This enables the measurement of tracking task performance at virtually any moment during the encoding and retrieval phases. Because performance did not reach ceiling on either task performed singly, we contend that each task required full attention when performed alone. When performed together, the tasks allowed the assessment of performance throughout the dual-task interval. In particular, the secondary tracking task monitors and reflects the changes in attentional resources devoted to the encoding and retrieval of the words.

In the retrieval part of the experiment, we analyzed the attentional resources required for the cued-recall task as three subcomponents: cue encoding, cue-elaboration/search processes for a specific word, and the operation of a retrieval mode. We achieved this by dividing each retrieval interval into three phases (partially on the basis of Tulving's, 1983, taxonomy of retrieval subprocesses) and evaluating the attentional requirement for each phase. The first phase includes the period until the end of cue presentation, which presumably consists mostly of cue-encoding operations. The second phase, consisting of cue-elaboration/search processes, extends from the end of the first phase until the participant furnishes a retrieved response. The demand for resources associated with cue-elaboration/search processes is differentiated from the attentional requirements of a general retrieval mode, which can be evaluated during the period following successful retrieval and before the next cue is presented. During this period, participants are in a cognitive mode of retrieval readiness without a specific cue directing them to search for a particular target. For comparison purposes, we evaluated the same time periods during encoding, although during this period the main distinction is between the initial phase, involving stimulus perception and encoding, and the rest of the period, involving rehearsal and learning operations.

The results of both experiments reported by Naveh-Benjamin and Guez (2000) indicate that, for younger adults, retrieval does not require uniform attentional resources. The first phase of cue encoding requires some resources, much like the requirement for resources during initial encoding. The second phase, involving cue-elaboration/search processes, requires substantial resources for its execution. Naveh-Benjamin and Guez showed this in two ways. First, for successful retrievals, the period after cue encoding and prior to the retrieved response was associated with poorer performance on the secondary task (greater discrepancies between the tracker and the target) than either the respective period at encoding or the retrieval period following the retrieval response. Second, the use of a cued-recall task allowed the authors to measure attentional resources associated with both successful and unsuccessful retrievals. Performance on the secondary task for unsuccessful retrievals (in which no retrieved response was provided by the participant) was poor throughout the retrieval period. Specifically, although unsuccessful retrievals consume as much attentional resource as successful retrievals up to the point of the retrieved response, these unsuccessful retrievals continue to require resources for the whole retrieval period, presumably reflecting the continuation of cue-elaboration/search processes. In addition, it seems that being in a retrieval state of mind (or retrieval mode; Tulving, 1983) also requires attentional resource, though not as much as that required by cue elaboration/search. Naveh-Benjamin and Guez (2000) evaluated this cost by looking at the interval after a successful retrieval but before the next cue. During this period, when participants were not trying to retrieve any given word (they did not know which cue would be presented next), although secondary task performance was better than during the previous cue-elaboration/search period, costs were substantially above those incurred in the secondary task baseline condition.

Using this taxonomy of retrieval subprocesses, we address several questions regarding older adults' performance. First, does the reported age-related increase in attentional costs during retrieval (e.g., Anderson et al., 1998) reflect costs associated with specific subprocesses? One possibility is that older age is characterized by larger overall demands for attentional resources that are not unique to any particular retrieval subprocess. If this is the case, we expect older adults to show an overall elevation in secondary task costs throughout the retrieval period. Alternatively, older age might be associated with difficulty with specific processes. For example, it might be the case that the cue-elaboration/search component is especially difficult and demanding in older age. In this case, we expect larger age-related increases in the secondary task during the time when such processes are carried out. Increased attentional costs in older adults could also be associated with maintaining a retrieval mode. For example, downloading retrieval procedures and holding them in working memory may require more attentional capacity for older than for younger adults. Furthermore, a reasonable hypothesis is that older adults' increased attentional costs at retrieval are due to the larger number of unsuccessful retrievals. Naveh-Benjamin and Guez (2000) have shown that unsuccessful retrievals in young adults require more attentional resources than successful ones, especially after the cue-elaboration phase, reflecting a continuous effort to retrieve the target. Because older adults usually have more unsuccessful retrievals, as reflected by their lower memory accuracy, it seems reasonable to hypothesize that the extra secondary task costs at retrieval are due to the larger proportions of unsuccessful retrievals in this group. With respect to attentional costs during encoding, the overall extra costs shown in previous research by the older adults could be related to differences in initial perception and encoding of the word pair, differences in later encoding processes to memorize the pairs, or differences in both.

The second purpose of the current studies is to test several theoretical predictions made by Craik (1983, 1986) regarding age-related changes in episodic memory. Craik suggested that cognitive processing reflects an interaction between processes that are driven by external simulation and those that are initiated by the individual. These latter processes are dependent to a great degree on available processing resources and may decline in effectiveness as the person ages. One can reduce such decreases in performance by minimizing the demands on diminished resources and maximizing the contributions of external stimulation and environmental support. Preexisting knowledge may also be used to support the formation of richer encoded representations and to guide retrieval processes. Use of such knowledge in episodic memory tasks can serve as schematic support (Craik & Bosman, 1992), in a manner analogous to environmental support, and may also reduce age-related memory decrements. To assess the self-initiation/environmental support framework, we manipulated two variables in the following experiments: one that provides schematic support, and another that relies more on self-initiated activity. For the schematic support manipulation, we compared a condition in which pairs of unrelated words were presented with a condition in which the two words in each pair were related semantically to each other. The latter condition allows participants to rely on preexisting knowledge to relate these word pairs at encoding and to use the cue word to access the target at retrieval. For the self-initiation manipulation, we compared a condition in which participants simply tried to encode and retrieve the pairs with one in which (different) participants were taught associative strategies involving sentence generation or construction of mental images.

In light of the above distinction, one question is which type of support is more beneficial for older adults. The use of preexperimental knowledge to encode and retrieve word pairs has had mixed effects in the past (e.g., Naveh-Benjamin, Craik, & Ben-Shaul, 2002), in some cases benefitting younger adults' performance, in others benefitting older adults, and in still others supporting the performance of both groups equally. Another question addresses the amount of attentional resource required by such a manipulation. If, as Craik (1983, 1986) claimed, schematic support is beneficial for older adults because it reduces demands on their limited attentional resources, we might expect either no increase or even a decrease in attentional costs associated with the memory improvement in the related pairs condition for both older and younger participants.

The effects of strategy instructions have also been debated in the literature. Some researchers have claimed that older adults' deficient memory performance is due to a decline in spontaneous use of helpful strategies to encode and retrieve the information (the production deficiency hypothesis; Craik & Byrd, 1982; Perlmutter & Mitchell, 1982). Such a view predicts that older adults benefit more than younger ones from instructions to use specific strategies. Others have claimed that even if older adults are provided with useful strategies, they will still show memory deficits, as the use of such strategies requires substantial effort that taxes the limited attentional resources of the older adults (Shaw & Craik, 1989). This, in turn, does limit their ability to use the strategies in an efficient manner. This second position predicts either similar benefits for both age groups or a larger benefit for the young from instructions to use strategies. In the present research, we wish to assess the effectiveness of providing a useful strategy, determining whether older adults can exploit and use the strategy to improve their memory performance and whether such an improvement is of a smaller, similar, or larger magnitude than that of younger adults. In addition, we wish to assess the degree to which using such a strategy is more attentionally demanding for older adults than for younger adults, both at encoding and at retrieval, as predicted by the self-initiation/environmental support framework.

In overview, we report two experiments that further explore the effects of DA on memory in younger and older adults. We measured memory performance using paired-associate learning followed by cued recall; the word pairs were either related semantically or unrelated, and participants either were given encoding strategy instructions or were not given special instructions. We assessed the attentional costs of encoding and retrieval under these various conditions by means of a concurrent visual tracking task, which also constituted the DA manipulation. The DA task was manipulated at encoding in Experiment 1 and at retrieval in Experiment 2.

Experiment 1

Method

Participants. Participants were 32 younger and 32 older adults. The younger participants were undergraduate students at the University of Toronto who participated in the experiment as part of their course requirements. The older participants were volunteer residents of Toronto who lived independently in the community. The mean age and education level as well as the gender distribution for each group in each of the experiments reported in this article appear in Table 1. All of the older adults in this experiment reported being in good health and having good hearing and vision.

Design. Within each of the two age groups, three independent variables were used. One was attention: either full attention or DA at encoding

Table 1
Demographic Information for Both Experiments

Demographic information	Younger adults: No strategy *M*	*SD*	Younger adults: Strategy *M*	*SD*	Older adults: No strategy *M*	*SD*	Older adults: Strategy *M*	*SD*
Experiment 1								
Age (years)	20.4	2.3	20.7	2.9	70.8	4.5	70.0	2.9
Years education	15.2	0.8	15.5	1.6	15.9	3.4	14.9	3.0
Men	5		3		4		3	
Women	11		13		12		13	
Experiment 2								
Age (years)	20.9	2.2	21.2	3.8	71.1	4.2	70.2	5.2
Years education	14.9	0.9	15.1	1.1	16.1	3.9	15.5	3.7
Men	6		4		3		5	
Women	10		12		13		11	

(within subject). The second was the semantic relatedness of the word pairs (related vs. unrelated semantically; within subject). The third variable was strategy (strategy vs. no strategy instructions; between subjects). The dependent variables were proportion of correctly recalled targets, retrieval latency, and performance on the secondary tracking task.

Materials. Study stimuli were 12 lists of 12 word pairs—6 lists with related pairs, and 6 with unrelated pairs. The words used were high-frequency two- or three-syllable concrete nouns taken from Kucera and Francis (1967). In both relatedness conditions, there were no intended semantic relations between words of different pairs or between words in the different lists. The *A–B* pairs were presented auditorily at study at a pace of one every 6 s. At test, the *A* word of each pair was presented as a cue, and the participant had to produce the *B* response within 6 s (pilot work showed that there were very few responses after 6 s).

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

Procedure. Each participant was presented with the 12 lists, consisting of two replications of the full attention condition with the two relatedness levels and four replications of the DA condition with the two relatedness levels (we used more replications in the DA condition to provide more data points for the secondary tracking task measures). In addition, each participant performed the tracking task alone (baseline) four times, each time for 72 s (which was the length of both the encoding and the retrieval phases). For each list, 12 word pairs were presented auditorily at a pace of 1 pair every 6 s, for a total of 72 s of encoding. The two words in each pair were spoken during the first 2–3 s in each 6-s time slot. Participants then engaged in a 90-s distractor activity in which they had to subtract a succession of 7s from a number that appeared on the screen and write their responses down on a sheet. Participants were told to perform the distractor task as quickly and as accurately as possible. After this interpolated activity, the cued-recall phase began; participants were given the *A* word of each pair as a cue and then had to produce the *B* response within 6 s. They did this for each pair, for a total of 72 s of retrieval. The input order of the cues at retrieval was randomized.

Under the full-attention condition, participants were told to pay full attention to the lists to encode and retrieve them. In the tracking baseline condition, participants were instructed to catch the asterisk target or to follow it as closely as possible. In the DA conditions, they were told to pay equal attention to encoding the word pairs and to performing the tracking task. Prior to each list, participants were told which attention condition to expect. The presentation of each word pair at encoding (via the tape recorder), the cue word at retrieval, and participants' vocal retrieval of each response word all triggered the voice-operated relay, which recorded the exact time each of these events was initiated.

There were three experimental tasks:

1. A single task assessing memory performance under full attention (four trials, two with related and two with unrelated pairs). In this task, participants were instructed to encode and retrieve information under full attention conditions.

2. A single task assessing tracking performance (four trials). Participants performed the tracking task alone for 72 s. Each of the trials used one of the four basic paths.

3. A dual task that involved DA at encoding (eight trials, four with related and four with unrelated pairs). On these trials, participants performed the encoding and tracking tasks simultaneously, under instructions to pay equal attention to each. Retrieval was performed under full attention. Each of the trials used one of the four basic tracking paths.

Half of the participants in each age group received intentional instructions to try to memorize the word pairs as best as they could to prepare for the later cued-recall task. The remaining participants received the same instructions but were also told that previous research has shown that people can improve their memory performance by using the strategy of relating members of each word pair meaningfully, either by creating a sentence linking the words or by forming an interactive mental image of the two. Participants were strongly encouraged to use this strategy. Participants initially practiced the tracking task alone, the memory task alone (full attention), and their combination at encoding (DA at encoding). They then continued with the experimental trials. Twelve formats of order of tasks were used, in which the order of the 12 memory trials was counterbalanced with a Latin square design. The four single tracking task trials were performed before the 1st list and after the 4th, 8th, and 12th lists. Participants' reports after the experiment indicated that they did not realize that the same four tracking task paths were repeated in the single- and dual-task conditions but perceived the movement of the asterisk to be random.

Results

Memory performance. The mean proportions of words recalled correctly across trials and participants for each condition in each age group appear in Table 2. A 2 × 2 × 2 × 2 four-way analysis of variance (ANOVA) with age, attention condition, pair relatedness, and strategy as the four variables found a significant effect of age, $F(1, 30) = 27.18$, $p < .01$, $MSE = 0.15$, indicating that younger adults ($M = 0.67$) performed better than the older adults ($M = 0.42$), and a significant effect of attention, $F(1, 30) = 45.71$, $p < .01$, $MSE = 0.011$, indicating that performance in the full attention condition ($M = 0.59$) was better than in the DA at encoding condition ($M = 0.49$). In addition, the analysis found a significant effect of pair relatedness, $F(1, 30) = 281.56$, $p < .01$, $MSE = 0.011$, showing that semantically related word pairs ($M = 0.66$) were better remembered than unrelated pairs ($M = 0.44$), and a significant effect of strategy, $F(1, 30) = 11.55$, $p < .01$, $MSE = 0.085$, showing that memory performance was better under strategy ($M = 0.61$) than no-strategy ($M = 0.49$) instructions.

The ANOVA also found two significant interaction effects. First, the interaction of age and relatedness was significant, $F(1, 30) = 42.46$, $p < .01$, $MSE = 0.01$. This interaction reflects the fact that older participants improved more from the unrelated to the related condition (*M*s = 0.26 to 0.57) than did younger ones (*M*s = 0.60 to 0.74). The other significant interaction was between attention and strategy, in which participants in the full attention conditions improved more from no-strategy to strategy groups (*M*s = 0.51 and 0.67, respectively) than did participants in the DA conditions (*M*s = 0.45 and 0.54, respectively).

Retrieval latency. Mean latencies for successful retrievals averaged over trials and participants for each condition appear in Table 3. A 2 × 2 × 2 × 2 four-way ANOVA with age, attention condition, pair relatedness, and strategy as the four variables found a significant effect of age, $F(1, 30) = 20.73$, $p < .01$, $MSE = 630{,}917$, indicating that older adults ($M = 2{,}468$ ms) retrieved targets at a slower pace than younger adults ($M = 2{,}016$ ms), and a significant effect of pair relatedness, $F(1, 30) = 74.51$, $p < .01$, $MSE = 119{,}340$, showing that semantically related word pairs ($M = 2{,}055$ ms) were retrieved faster than unrelated pairs ($M = 2{,}428$ ms). The effect of strategy approached significance, $F(1, 30) = 3.70$, $p = .06$, $MSE = 449{,}717$, reflecting the fact that participants retrieved the targets somewhat faster under strategy instructions ($M = 2{,}161$ ms) than without such instructions ($M = 2{,}323$ ms). As can be seen in Table 3, the trend for the attention variable was in the same direction as for the memory accuracy data; latency was faster under full attention than under DA conditions. However, this effect was not significant, $F(1, 30) = 1.97$. The only other significant effect was the interaction between age and relatedness, $F(1, 30) = 6.46$, $p < .05$, $MSE = 189{,}177$. This interaction reflects the fact that the retrieval latency of older adults decreased more than that of the young adults in the related relative to the unrelated condition (*M*s = 2,212 and 2,723 ms for the older adults, and *M*s = 1,899 and 2,133 ms for the younger adults in the related and unrelated conditions, respectively).

Table 2
Memory Performance: Proportion Correctly Recalled Words in Experiment 1

Strategy condition and age	Full attention				Attention divided at encoding			
	Unrelated		Related		Unrelated		Related	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No strategy								
Young	.55	.29	.71	.19	.50	.20	.67	.20
Old	.24	.19	.55	.18	.16	.12	.49	.16
Strategy								
Young	.75	.15	.83	.13	.60	.19	.76	.14
Old	.40	.22	.68	.21	.26	.22	.56	.22

Overall, the results for memory accuracy and retrieval latency converge in several respects. First, younger adults showed both higher accuracy and faster retrieval than older adults. In addition, related pairs were retrieved more successfully and quickly than unrelated pairs. Also, target words were retrieved more successfully and quickly under full attention conditions and under strategy instructions, although these effects were significant only for the accuracy measure. More relevant to the purpose of the current studies are the patterns of the interactions obtained. First, the lack of interaction of age and attention (for both the accuracy and the latency measures) indicates that DA at encoding disrupted memory performance to the same degree in the younger and the older adults. Second, older adults benefited more than younger ones when related rather than unrelated pairs were used. It is interesting that the interaction between age and strategy was not significant, indicating that older and younger adults showed equivalent benefits from the use of a strategy.

Tracking task performance. As described previously, participants performed the tracking task by itself as well as under dual-task conditions. From these single-task conditions, each participant's tracking performance (the discrepancy in millimeters between the target asterisk and the mouse-controlled tracking symbol) was aggregated over successive 6-s intervals, and this aggregated performance level served as the baseline for that participant. The same procedure was followed for the dual-task conditions; that is, tracking performance during concurrent encoding was again aggregated over the 6-s encoding trials. From these measurements, we calculated both absolute costs (the arithmetic difference between single- and dual-task performance) and relative costs (the absolute difference divided by single-task performance × 100). The relative measure was suggested by Somberg and Salthouse (1982) as a more satisfactory method of assessing age-related differences, given that baseline performance of older adults may be substantially poorer than that of their younger counterparts. The underlying assumption is that tracking costs are greater at times when more attentional resources are required for encoding (or retrieval) operations.

Because the analyses that we did using absolute and relative costs showed very similar patterns, we report only the absolute costs. Results using measures of both absolute and relative costs appear in Appendix A. To analyze the attentional costs associated with different phases of the encoding process, we broke the aggregated 6-s encoding segments into the same three components used to analyze retrieval processes. For retrieval, these phases

Table 3
Experiment 1: Retrieval Latency (Milliseconds)

Strategy condition and age	Full attention				Attention divided at encoding			
	Unrelated		Related		Unrelated		Related	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No strategy								
Young	2,081	525	1,910	252	2,270	407	1,972	295
Old	2,963	1,151	2,320	453	2,720	485	2,345	398
Strategy								
Young	1,990	317	1,832	252	2,193	354	1,881	267
Old	2,563	531	2,046	335	2,649	607	2,139	297

were cue perception (the first 650 ms), cue elaboration and search (the next 1.5 s), and retrieval mode (the final 3.85 s). In the case of encoding, these three phases may be thought of as stimulus perception, elaboration, and learning, respectively. The average absolute costs for these three phases are shown for the various groups and conditions in Appendix A. To assess the patterns obtained, we conducted a 2 × 2 × 2 × 2 four-way ANOVA with age, time phase, pair relatedness, and strategy as the four variables. The cell means for this analysis appear in Appendix A. The analysis found a significant effect of age, $F(1, 60) = 5.42$, $p < .05$, $MSE = 71.53$, showing that older adults ($M = 3.65$ mm) had higher costs than the younger adults ($M = 1.64$ mm), and a significant effect of phase, $F(1, 30) = 16.64$, $p < .01$, $MSE = 8.03$. Follow-up comparisons showed that the attentional costs were significantly higher during the second and the third phases than during the first phase, $F(1, 60) = 39.87$, $MSE = 39.88$, and $F(1, 60) = 6.55$, $MSE = 11.53$, respectively. The attentional costs during the second phase were also significantly higher than those in the third phase, $F(1, 60) = 9.96$, $MSE = 5.86$. The effect of pair relatedness was not significant ($F < 1$), reflecting the fact that semantically related word pairs ($M = 2.67$ mm) required the same attentional costs as did unrelated pairs ($M = 2.62$ mm). The effect of strategy was not significant either, indicating similar attentional costs in the strategy condition ($M = 2.93$ mm) and in the no-strategy condition ($M = 2.34$ mm; $F < 1$.).

The ANOVA also indicated three significant interaction effects. First, the interaction of age and encoding phase was significant, $F(2, 120) = 4.28$, $MSE = 8.03$, reflecting the fact that there were no differences between younger and older adults in attentional costs during the first phase, $F(1, 60) = 0.71$, *ns*, $MSE = 36.75$, but that these differences were significant in the second, $F(1, 60) = 6.02$, $p < .05$, $MSE = 24.70$, and third phases, $F(1, 60) = 10.76$, $p < .01$, $MSE = 26.15$. This pattern (which can be seen in Figure 1) reflects the fact that in both age groups (more for the older adults) the attentional costs grew larger during the second phase. However, whereas for the older adults these costs stayed the same during the third phase, for the young adults costs returned to same level as in the first phase. This pairwise interaction is qualified by the triple interaction of age, phase, and strategy, discussed below.

Second, the interaction of phase and strategy was also significant, $F(2, 120) = 4.04$, $MSE = 8.03$. This reflects the fact that whereas the increase in attentional costs from the first to the second encoding phase was significant for both the strategy and the no-strategy conditions, $F(1, 60) = 27.43$, $MSE = 6.69$, and $F(1, 60) = 13.63$, $MSE = 6.69$, respectively, during the third phase, there was a decrease in attentional resources in the no-strategy group, $F(1, 60) = 13.87$, $MSE = 5.86$, but no change in the strategy group ($F < 1$).

The third significant interaction was among age, strategy, and phase, $F(2, 120) = 2.98$, $p < .05$, $MSE = 8.03$. Follow-up interaction comparisons indicated that whereas there was no interaction between age and phase in the no-strategy condition ($F < 1$), the interaction of age and phase was significant in the strategy condition, $F(2, 60) = 4.96$, $p < .01$, $MSE = 11.23$. The source of this interaction was the different time patterns for each age group. In particular, whereas the attentional costs increased significantly from the first to the second encoding phase for both age groups, $F(1, 30) = 4.79$, $MSE = 7.99$, and $F(1, 30) = 21.06$, $MSE = 7.99$, for younger and older adults, respectively, there was a drop in attentional costs from the second to the third phase for the younger adults, $F(1, 30) = 4.06$, $MSE = 8.72$, but no change for the older adults ($F < 1$). As can be seen in Figure 2, these results reflect the fact that whereas the younger adults showed the exact same pattern of attentional costs (an increase and a decrease over the three

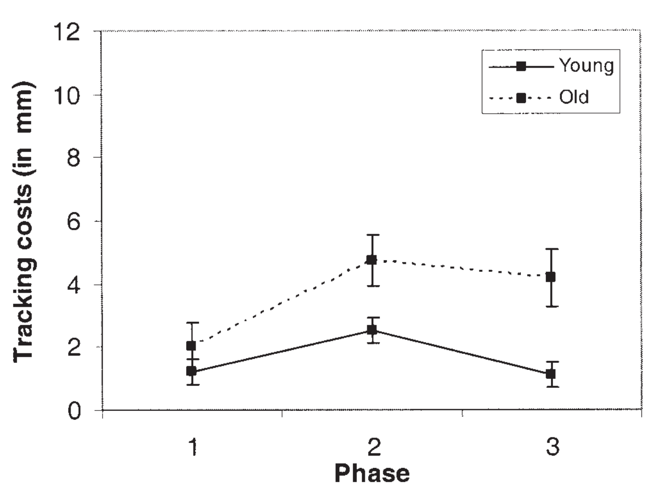

Figure 1. Experiment 1: Temporal distribution of performance on the secondary tracking task for younger and older adults for the three phases of the encoding period, aggregated over 6-s encoding segments after subtraction of single-task tracking performance (distance in millimeters).

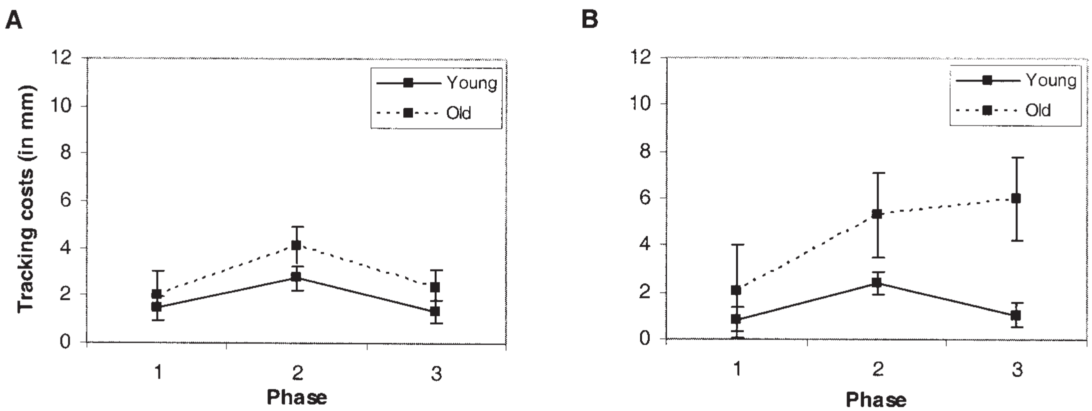

Figure 2. Experiment 1: Temporal distribution of performance on the secondary tracking task for younger and older adults for the three phases of the encoding period in the no-strategy (A) and strategy (B) conditions, aggregated over 6-s encoding segments after subtraction of single-task tracking performance (distance in millimeters).

phases) under both strategy and no-strategy instructions, older adults showed an increase in attentional costs from Phase 1 to Phase 2 under strategy instructions, and this increase was maintained in Phase 3.

The pattern of results using relative scores was very similar, except that the main effect of age did not reach statistical significance (see Appendix A).

Discussion

These results reveal several patterns, some expected, and others not. First, as expected, older adults showed poorer cued-recall performance relative to younger adults. Second, as expected, DA at encoding decreased memory performance. The results thus replicate those reported by Craik et al. (1996) and Naveh-Benjamin et al. (1998, 2000). It is interesting that DA at encoding reduced cued-recall levels for younger and older adults to the same degree. This pattern is in line with the findings reported by Anderson et al. (1998) and others but not by Park et al. (1989) or by Salthouse et al. (1984). It is not immediately clear under what conditions each of these patterns is obtained. One possibility is that the performance of older adults declines more when the secondary task is very demanding and requires conceptual processing (Park et al., 1989; digit monitoring; Salthouse et al., 1984; retrieving another list). However, when the secondary task requires only perceptual-motor processing, as with the tracking task used in this study, older adults' encoding processes are not disrupted more than those of the young. As for the attentional costs measure, the results show that whether older adults required more processing resources than the young adults depended on the measure used. Older adults showed larger absolute but equivalent relative costs compared with the younger adults.

The deficit shown by older adults in the cued-recall task was ameliorated by the relatedness of the word pairs. When the pairs were unrelated, older adults showed a large deficit, but the deficit was much smaller when semantically related pairs were used (see also Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). This result is in line with the support notion suggested by Craik (1983, 1986); older adults took more advantage than the young of the supporting conditions—in this case relying on preexperimental knowledge to encode and retrieve the associations among pairs. Similar patterns were shown in the retrieval latency measure, for which older adults showed relatively faster retrieval latencies in the related pairs condition. It is interesting that this improvement in older adults was not associated with additional attentional resources required to encode the related pairs.

In contrast to the relatedness effect, younger and older adults improved their memory performance to the same degree from instructions to use a strategy. The fact that older adults did not benefit more than the young from strategy instructions implies that their poorer memory performance was not related only to a lack of spontaneous use of strategies. It may indicate, instead, that they were not using the strategies as efficiently as young people did, leading to overall poorer memory performance under this condition (see Dunlosky & Hertzog, 1998). One possibility is that the use of strategy during encoding requires appreciable attentional resources, which the older adults lack. The results of the attentional resource measures support this assertion, as they indicate that older adults need to deploy more attentional resources to gain as much as younger adults in memory accuracy. Whereas in all conditions both age groups showed an increase in processing resources associated with the first 2 s of the encoding phase, older adults under strategy instructions continued to devote resources throughout the encoding period, presumably in support of the implementation of the strategy they were using. In contrast, younger adults reduced the resources deployed for strategy use after the first 2 s, possibly reflecting their more efficient use of strategic processing.

The compatible patterns of results for the memory and attentional cost measures are in line with Craik's (1983, 1986) environmental support framework. Older adults benefit from increases in environmental or schematic support (pair relatedness, in our case), without any extra attentional costs being required for the increased performance under these conditions. In contrast, when self-initiated manipulations are used (in our case, a strategy induction), older adults' memory performance improves to the same extent as that of younger adults. However, such an improvement requires extra attentional resources on the part of older adults, implying an increased effort invested in using these processes. Young adults, conversely, appear to exploit these self-initiated processes at no extra attentional cost. These converging patterns for memory accuracy, retrieval latency, and the attentional cost measures can be seen in Figure 3.

Experiment 2

Experiment 2 is intended to explore several issues. First, we wish to confirm the effects of DA on retrieval in younger and older adults' recall performance. As detailed in the introduction, memory performance appears to be largely unaffected by DA at retrieval for both younger and older adults (e.g., Anderson et al., 1998). Second, we wish to assess the attentional costs associated with retrieval processes. As previously discussed, several studies (e.g., Anderson et al., 1998) have shown that older adults require larger amounts of attentional resource to complete the retrieval task. Third, in this experiment, as in Experiment 1, we also manipulated pair relatedness and strategy instructions at encoding. We wish to assess the degree to which the use of either semantically related pairs or an encoding strategy is affected differentially in younger and older adults by the DA at retrieval manipulation. We also wish to assess (as in Experiment 1) the degree to which older adults require extra attentional resources to retrieve information about related pairs and about pairs encoded via a strategy. To answer these questions, we used the multimeasures approach used in Experiment 1, implementing measures of memory accuracy, retrieval latency, attentional costs, and the temporal distribution of attentional costs during retrieval. We used a secondary task methodology similar to that used in Experiment 1.

Method

Participants. Participants were 32 younger and 32 older adults (different than those who participated in Experiment 1). The younger participants were undergraduate students at the University of Toronto who participated in the experiment as part of their course requirements. The older participants were volunteer residents of Toronto who lived independently in the community. The mean age and education level for each group in both of the experiments reported in this article appear in Table 1. All of the older adults in this experiment reported being in good health and having good hearing and vision.

Design. The same variables were used as in Experiment 1, except that the levels of the attention manipulation were either full attention or DA during retrieval.

Materials. Study stimuli were 12 lists of 12 word pairs—the same ones used in Experiment 1. The tracking task was also the same one used in Experiment 1.

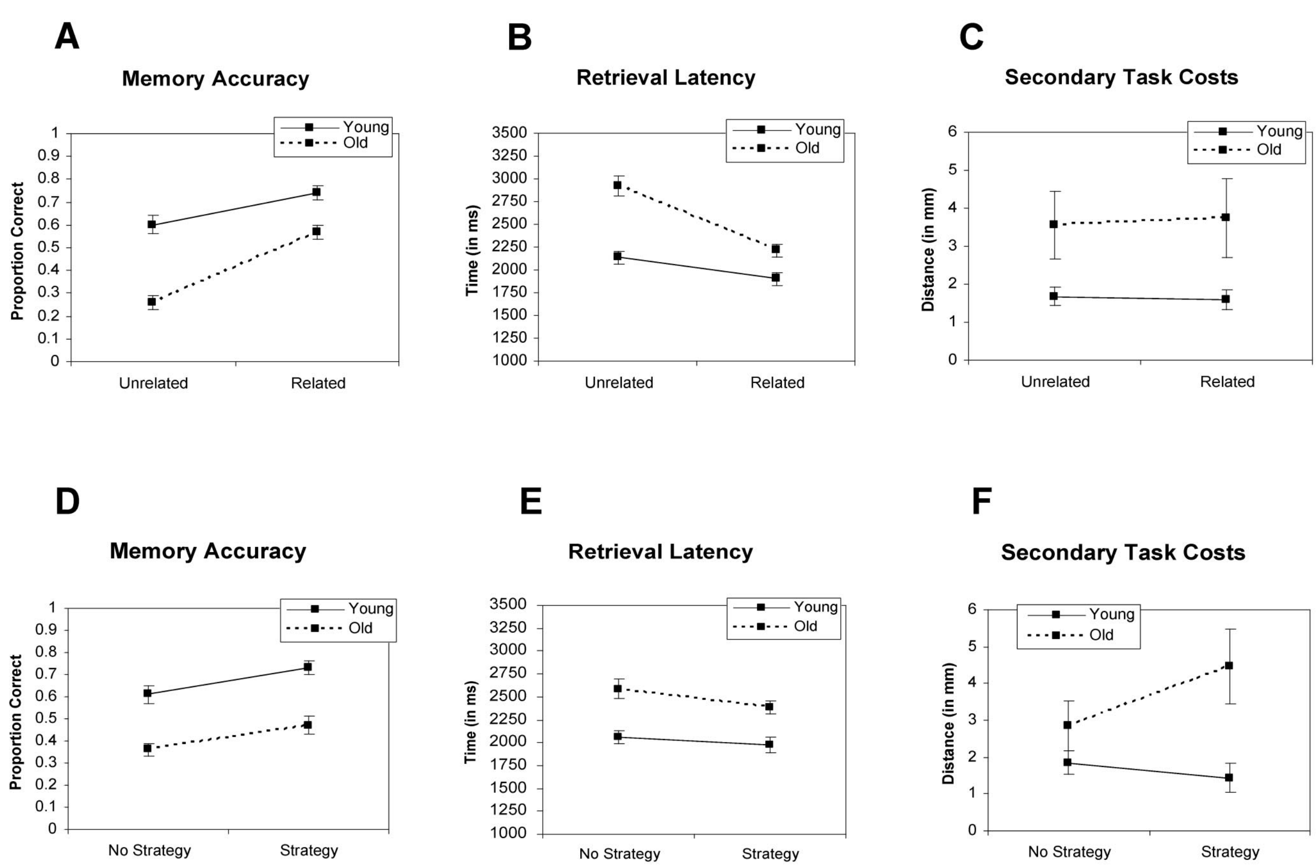

Figure 3. Experiment 1: Memory accuracy, retrieval latency, and secondary task attentional costs at encoding for younger and older adults. Panels A–C: effects of relatedness. Panels D–F: effects of strategy.

Procedure. Each participant was presented with the 12 lists and with the tracking baseline task, as in Experiment 1. For each list, the same presentation procedure used in Experiment 1 was followed. In the full attention conditions, participants were told to pay full attention to the lists to encode and retrieve them. In the tracking baseline condition, participants were instructed to catch the asterisk target or to follow it as closely as possible. In the DA conditions, they were told to pay equal attention to retrieval and to the tracking task. Prior to each list, participants were told which attention condition to expect.

There were three experimental tasks:

1. A single task assessing memory performance under full attention (four trials, two with related and two with unrelated pairs). In this task, participants were instructed to encode and retrieve information under full attention conditions.

2. A single task assessing tracking performance (four trials). Participants performed the tracking task alone for 72 s. Each of the trials used one of the four basic paths.

3. A dual task that involved DA at retrieval (eight trials, four with related and four with unrelated pairs). On these trials, participants performed the retrieval and the tracking task simultaneously, under instructions to pay equal attention to each; they performed encoding under full attention. Each of the trials used one of the four basic tracking paths.

As in Experiment 1, the presentation of each word pair at encoding (via the tape recorder), the presentation of the cue word at retrieval, and participants' vocal retrieval of each word triggered the voice-operated relay, which recorded the exact time each of these events was initiated. The strategy and no-strategy instructions were given in the same way as in Experiment 1, and the same counterbalancing was used as in Experiment 1.

Results

Memory performance. Mean proportions of words recalled correctly across trials and participants for each condition are shown in Table 4. A 2 × 2 × 2 × 2 four-way ANOVA with age, attention condition, pair relatedness, and strategy as the four variables indicated a significant effect of age, $F(1, 30) = 37.32$, $p < .01$, $MSE = 0.12$, showing that younger adults ($M = 0.73$) performed better than older adults ($M = 0.47$), and a significant effect of attention, $F(1, 30) = 7.03$, $p < .05$, $MSE = 0.011$, indicating that performance under full attention ($M = 0.62$) was better than under DA at retrieval ($M = 0.59$). This main effect was qualified by the interaction of attention and age described below. In addition, there was a significant effect of pair relatedness, $F(1, 30) = 286.36$, $p < .01$, $MSE = 0.012$, showing that semantically related word pairs ($M = 0.72$) were better remembered than unrelated pairs ($M = 0.49$), and a marginally significant effect of strategy, $F(1, 30) = 3.02$, $p < .10$, $MSE = 0.14$, reflecting the finding that word pairs studied under strategy instructions ($M = 0.64$) were remembered slightly better than those studied under no-strategy conditions ($M = 0.57$).

Table 4
Memory Performance: Proportion Correctly Recalled Words in Experiment 2

Strategy condition and age	Full attention				Attention divided at retrieval			
	Unrelated		Related		Unrelated		Related	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No strategy								
Young	.63	.27	.76	.23	.62	.26	.76	.23
Old	.30	.23	.61	.22	.23	.18	.57	.17
Strategy								
Young	.71	.13	.84	.10	.71	.14	.83	.10
Old	.39	.18	.68	.19	.31	.19	.66	.15

The ANOVA also indicated two significant interaction effects. First, the interaction of age and relatedness was significant, $F(1, 30) = 75.24$, $p < .01$, $MSE = 0.007$, reflecting the fact that older adults improved more from the unrelated to the related condition (*M*s = 0.31 to 0.63) than did younger participants (*M*s = 0.67 to 0.80). The other significant interaction was between age and attention, $F(1, 30) = 4.51$, $p < .05$, $MSE = 0.008$, reflecting the finding that whereas older adults' performance declined from the full attention to the DA condition (*M*s = 0.49 and 0.44, respectively), $t(31) = 2.09$, $p < .05$, performance in the younger group did not (*M*s = 0.73 and 0.73, respectively).

Retrieval latency. For each condition, we averaged the latency for all successful retrievals in each trial. Mean latencies across trials and participants for each condition appear in Table 5. A 2 × 2 × 2 × 2 four-way ANOVA with age, attention condition, pair relatedness, and strategy as the four variables yielded a significant effect of age, $F(1, 30) = 22.22$, $p < .01$, $MSE = 368{,}945$, indicating that older adults ($M = 2{,}288$ ms) retrieved the targets more slowly than the younger adults ($M = 1{,}939$ ms), and a significant effect of pair relatedness, $F(1, 30) = 44.97$, $p < .01$, $MSE = 124{,}033$, showing that semantically related word pairs ($M = 1{,}962$ ms) were retrieved more quickly than unrelated pairs ($M = 2{,}257$ ms). The only other significant effect was the interaction of age and relatedness, $F(1, 30) = 5.23$, $p < .05$, $MSE = 83{,}243$. This interaction reflects the fact that the retrieval latency of the older adults increased more than that of the younger adults from the related to the unrelated condition (*M*s = 2,099 and 2,477 ms for the older adults, and *M*s = 1,824 and 2,036 ms for the younger adults in the related and unrelated conditions, respectively).

Overall, the memory accuracy and retrieval latency findings point to several conclusions. First, younger adults have better memory performance than older adults, in terms of both higher accuracy and faster retrieval responses. Second, the manipulations of pair relatedness and strategy affected performance in the same way as in Experiment 1: Related pairs were better remembered than unrelated pairs, and strategy instructions resulted in better memory performance than no-strategy instructions (although only in the accuracy measure).

More relevant to the purpose of the present studies are the patterns of interactions. First, in contrast to Experiment 1, the interaction of age and attention was significant, reflecting the fact that older adults but not younger adults showed a decrease in performance under DA conditions during retrieval relative to performance under full attention conditions. Second, as in Experiment 1, there was a significant interaction between relatedness and age; older adults improved their performance more than the younger adults when related pairs were used. Third, as in Experiment 1, both younger and older adults took the same advantage of the instructions to use a strategy, raising their performance to the

Table 5
Experiment 2: Retrieval Latency (Milliseconds)

Strategy condition and age	Full attention				Attention divided at retrieval			
	Unrelated		Related		Unrelated		Related	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No strategy								
Young	1,975	544	1,918	380	2,057	434	1,781	220
Old	2,619	671	2,122	274	2,510	370	2,162	228
Strategy								
Young	2,056	313	1,829	244	2,059	313	1,767	274
Old	2,325	629	2,111	554	2,454	489	2,003	451

same degree relative to their performance under no-strategy instructions.

Tracking task performance. Because, as in Experiment 1, the analyses using absolute costs and those using relative costs show very similar patterns, we report only the absolute costs. Results using measures of both absolute and relative costs appear in Appendices B and C. As in Experiment 1, for each DA trial, we averaged the discrepancy (in millimeters) between the target and the tracker after each 50-ms interval over the whole trial. To provide an overall measurement of retrieval DA costs, we subtracted the average baseline discrepancy from each trial, as we did in Experiment 1 for encoding. The resultant overall tracking discrepancy was 5.38 mm. This finding indicates that retrieval processes required resources for their execution, given that the discrepancy measure was significantly larger than 0.0 mm, $t(63) = 5.57$, $p < .01$. This was evident both in younger adults (average distance = 1.90), $t(31) = 3.30$, $p < .01$, and in older adults (average distance = 8.87), $t(31) = 5.31$, $p < .01$.

The measurement of tracking costs at retrieval brings up a special problem. At encoding, once the stimulus pair is perceived, the remainder of the 6-s period is presumably occupied by processes of elaboration and rehearsal. At retrieval, however, the participant may or may not emit a retrieved response, and if retrieval is successful, the timing of the response varies from trial to trial. Clearly, attentional demands vary substantially before and after production of the retrieved response. To deal with these problems, we adopted the method devised by Naveh-Benjamin and Guez (2000). First, for trials without a retrieval response, we used the full 6-s segment, as recorded. However, for trials with a retrieval response, we standardized the periods before and after the response in the following manner. The average retrieval latency for young adults was 2,000 ms; if the actual retrieval latency was shorter than 2,000 ms on a specific trial (e.g., 1,500 ms), we stretched the first 1,500 ms of tracking performance to 2,000 ms and compressed the remaining 4,500 ms to 4,000 ms. Similarly, if a retrieval response had a latency of 3.5 s, we compressed the first 3,500 ms to 2,000 ms and expanded the remaining 2,500 ms to fit 4,000 ms. We carried out the same procedure for the older adults, but using their mean retrieval latency of 2,400 ms. That is, all preretrieval segments were stretched or compressed to fit 2,400 ms, and all postretrieval segments were compressed or stretched to fit 3,600 ms. See Naveh-Benjamin and Guez (2000) for further details.

In the next step, we separated trials in which no retrieval response was given from trials in which any retrieved response was given (95% of retrieved responses were correct); this separation enabled us to calculate retrieval costs separately for successful and unsuccessful retrieval attempts. We then aggregated the relevant 6-s segments over trials and replications for each participant. Finally, we subtracted performance on the single-task tracking baseline from dual-task performance for each participant to yield a distribution of tracking costs across the 6-s retrieval interval. To analyze the attentional costs associated with different phases of the retrieval process, we broke down the 6-s retrieval intervals into three components, as we did for encoding. The first component involved perception and encoding of the cue word (500 ms[1]). The second component involved cue elaboration or search for the appropriate target word, which started once the cue word was encoded and ended when the participant overtly retrieved the target word. As the average retrieval latency was 2,000 ms for younger and 2,400 ms for older adults, the time between 500 ms and 2,000 ms for younger adults, and between 500 ms and 2,400 ms for older adults, was designated as the cue-elaboration/search time for retrievals. Finally, the time between a successful retrieval and the appearance of the next cue was taken as reflecting retrieval mode only, as participants were presumably not engaged in any active retrieval during this period. As previously described, the attentional costs for trials with no retrieval response were calculated separately.

Secondary task tracking performance for each retrieval phase (discrepancy between tracker and target in millimeters) averaged across all participants for the aggregated 6-s successful and unsuccessful retrieval segments for younger and older adults, after single-task tracking performance was subtracted, can be seen in Appendix B. A $2 \times 2 \times 2 \times 2 \times 3$ five-way ANOVA with age, pair relatedness, strategy, retrieval success, and phase was conducted. The results of this analysis indicate a significant effect of age in which the average discrepancy for older adults ($M = 8.50$ mm) was larger than that for younger adults ($M = 1.90$ mm), $F(1, 60) = 17.10$, $p < .001$, $MSE = 488.69$, and a marginally signif-

[1] There might be a small age-related difference in the time involved in the perception and encoding of the cue word. However, we have decided to keep this time constant at 500 ms for the analyses of attentional costs for both age groups for two reasons: First, 500 ms was the actual average time taken to utter the recorded cue words during the retrieval phase. Second, an analysis of the attentional costs associated with this stage that used a somewhat lengthier time segment in the older adults (600 ms) showed results identical to those reported.

icant effect of strategy (which was significant according to relative costs measures), showing that costs were larger under strategy ($M = 6.67$ mm) than no-strategy instructions ($M = 3.72$ mm), $F(1, 60) = 3.43$, $p < .07$, $MSE = 488.69$. This effect was qualified by the significant interaction of age and strategy described below. The effect of retrieval phase was also significant, $F(2, 120) = 10.72$, $MSE = 29.13$. Follow-up comparisons indicated that the distance measure increased significantly from the first ($M = 4.29$ mm) to the second ($M = 6.43$ mm) retrieval phase, $F(1, 60) = 14.77$, $MSE = 39.63$, and then decreased significantly from the second to the third phase ($M = 4.88$ mm), $F(1, 60) = 13.82$, $MSE = 22.19$. This effect of phase was qualified by the interaction of age and phase, as reported below.

Several interactions were also significant. First, the interaction of age and strategy approached significance, $F(1, 60) = 2.96$, $p < .09$, $MSE = 488.69$ (and was significant when relative costs measures were used). Follow-up comparisons indicated that the source of this interaction was the lack of difference between the strategy ($M = 1.79$ mm) and the no-strategy conditions ($M = 2.00$ mm) in the younger adult group ($F < 1$) and the significant difference between these conditions (*M*s = 11.34 mm and 5.65 mm for strategy and no-strategy conditions, respectively) in the older adult group, $F(1, 60) = 6.37$, $MSE = 488.69$. In addition, the interaction of age and phase was significant, $F(2, 120) = 4.81$, $MSE = 29.13$. Follow-up interaction comparisons indicated that whereas the increase in the distance measure from the first to the second phase was larger for older (*M*s = 6.80 mm and 10.41 mm, respectively) than for younger adults (*M*s = 1.76 mm and 2.43 mm, respectively), $F(1, 60) = 6.99$, $MSE = 39.63$, the decrease from the second to the third phase was equal for both age groups (*M*s = 2.43 mm and 1.52 mm for younger adults, and *M*s = 10.41 mm and 8.60 mm for older adults), $F(1, 60) = 2.10$, *ns*, $MSE = 22.19$. As can be seen in Figure 4, this pattern was evident in both the successful and unsuccessful retrievals.

The final significant interaction was between retrieval success and retrieval phase, $F(2, 120) = 3.11$, $p < .05$, $MSE = 23.39$. Whereas attentional costs increased for both types of retrieval from the first to the second phase (from 3.70 mm to 5.51 mm for unsuccessful retrievals, and from 4.87 mm to 7.34 mm for successful retrievals), $F(1, 60) = 5.61$, $MSE = 37.25$, and $F(1, 60) = 12.89$, $MSE = 30.27$, respectively, resource costs decreased from the second to the third phase for the successful (7.34 mm to 4.75 mm), $F(1, 60) = 20.22$, $MSE = 21.25$, but not for the unsuccessful retrievals (5.51 mm to 5.01 mm; $F < 1$). This pattern was similar for both age groups (see Figure 4).

To sum up these rather complex tracking costs, the same pattern held for absolute and relative costs, although the statistics differed slightly. Older adults used more attentional resources than young adults, and strategic instructions were associated with greater costs than were nonstrategic instructions ($p < .07$ for absolute costs, and $p < .05$ for relative costs), although this effect was qualified by the significant interaction of age and strategy, discussed below. In addition, costs rose from Phase 1 to Phase 2 and then declined to Phase 3. In terms of interactions, young adults' costs were equivalent in the strategy and no-strategy groups, whereas costs were greater for the strategy group in older adults ($p < .09$ for absolute costs, and $p < .05$ for relative costs). Costs increased from the first to the second phase for both successful and unsuccessful retrievals, whereas costs declined again from the second to the third phase for successful but not for unsuccessful retrievals. It is important to note that whereas costs increased more from the first to the second phase for older adults, the decline in costs from the second to the third phase was equivalent in the two age groups. Finally, older adults did not show larger attentional costs during unsuccessful than during successful retrievals.

Discussion

The results of Experiment 2 illustrate a number of points. First, as in Experiment 1, older adults showed poorer cued-recall performance relative to younger adults. Second, DA during retrieval resulted in different patterns in younger and older participants. Whereas it had no effect on the memory performance of the younger adults, DA reduced performance slightly but significantly in the older adults. The result for younger adults is similar to that from other studies (Baddeley et al., 1984; Craik et al., 1996;

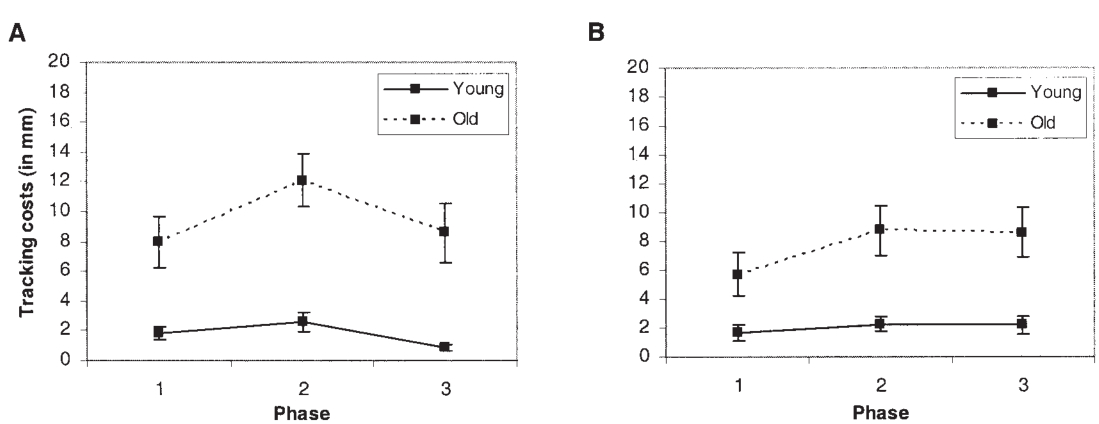

Figure 4. Experiment 2: Temporal distribution of performance on the secondary tracking task for younger and older adults for the three phases of the retrieval period for successful (A) and unsuccessful (B) retrievals, aggregated over 6-s retrieval segments after subtraction of single-task tracking performance (distance in millimeters).

Naveh-Benjamin et al., 2000) that have also shown little or no effect of a secondary task during retrieval. In the current study, older adults showed a small decrement in performance (Anderson et al., 1998; Park et al., 1989). It is interesting that the results for retrieval accuracy and latency are different with respect to the effects of division of attention. Whereas DA at retrieval affected memory accuracy, at least in the older adults, it did not slow retrieval in either age group. This result is similar to that obtained by Naveh-Benjamin and Guez (2000) for younger adults and is not in line with the predictions of bottleneck models of DA (e.g., Carrier & Pashler, 1995). Although memory performance (especially in the younger adults) was protected under DA during retrieval, the attentional resource measure showed robust costs for younger adults and even greater costs for older adults. As in previous studies (e.g., Anderson et al., 1998; Craik & McDowd, 1987; Nyberg et al., 1997), although memory was only slightly affected by the secondary task, the costs associated with the operation of retrieval processes were substantial, especially for older adults. This pattern was evident with both absolute and relative cost measures.

As in Experiment 1, we varied both the relatedness of word pairs and the provision of strategy instructions. Both manipulations increased recall performance, to the same extent in younger and older groups in the case of strategy, but to a greater extent in the older adults in the case of relatedness. As in Experiment 1, there was a significant interaction between age and relatedness (see also Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003). With regard to resource costs, the increase in memory performance associated with relatedness was achieved with no increase in costs, whereas the use of strategy did consume extra resources, mostly in older adults. These converging patterns for memory accuracy, retrieval latency, and the attentional cost measure can be seen in Figure 5.

It is interesting to note that attentional costs varied in the different phases of the retrieval process. Costs increased from initial perception (first 500 ms) to the cue elaboration, search, and response preparation phases (next 1,500 or 1,900 ms for younger and older adults, respectively). Costs then decreased substantially if a response was given—no further search was necessary—but stayed relatively high if no response was given, indicating that the participant continued to expend resources in the continuing search. Finally, cost increased more from the first to the second phase for older adults than for younger adults, which shows that the active search component of retrieval is particularly resource demanding for older adults. One possibility suggested in the introduction is that the greater retrieval costs in older adults might be attributable partly to these particpants' greater number of unsuccessful retrievals; such trials have been shown to be associated with greater attentional demands (Naveh-Benjamin, Craik, Guez, & Dori, 1998; Naveh-Benjamin & Guez, 2000). However, this hypothesis

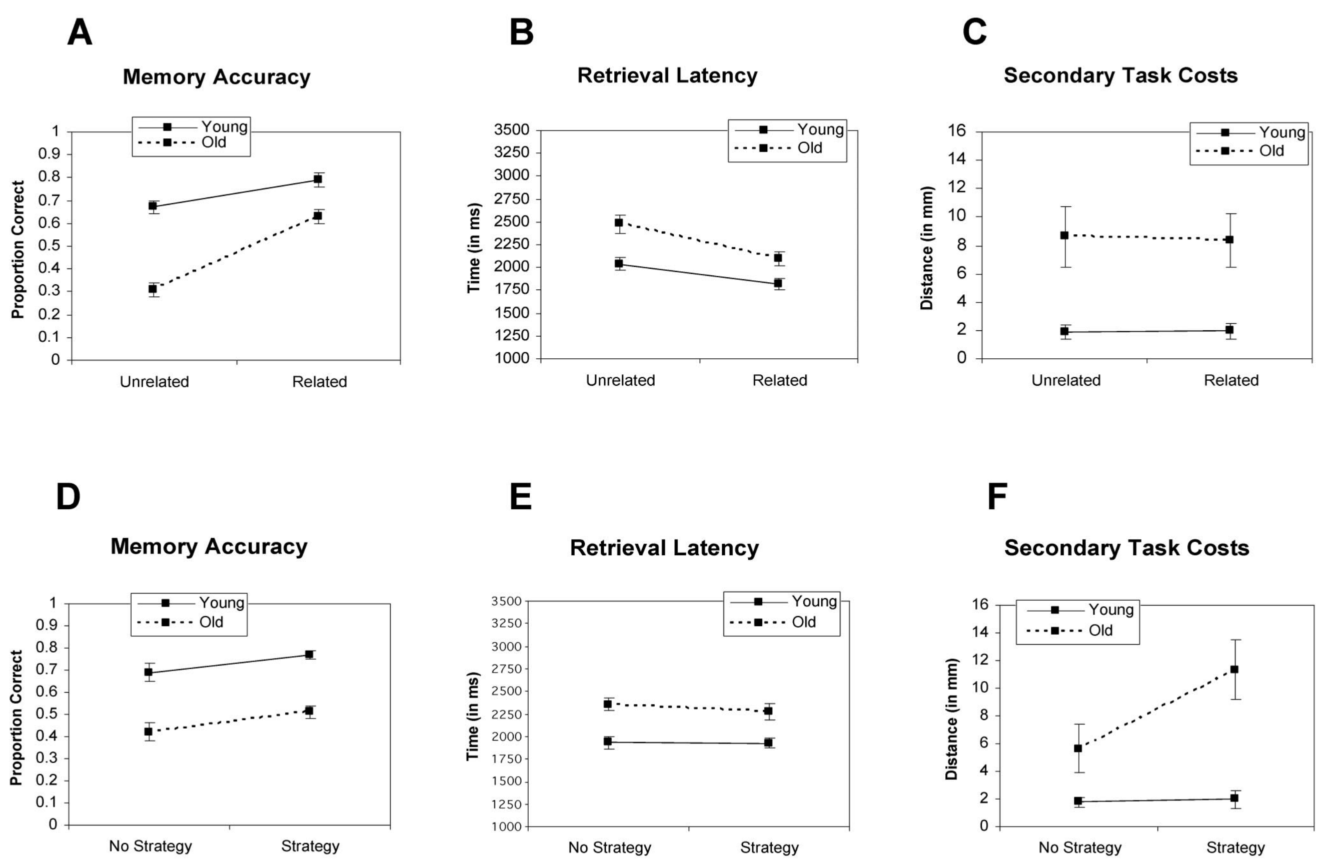

Figure 5. Experiment 2: Memory accuracy, retrieval latency, and secondary task attentional costs at retrieval for younger and older adults. Panels A–C: effects of relatedness. Panels D–F: effects of strategy.

is not supported by the present results. Older adults' costs were either larger in the successful trials (during the cue-encoding and the cue-elaboration/search phases) or similar to those in the unsuccessful trials (during the retrieval mode phase; see Figure 4). A final result of note is that older adults had substantially greater tracking costs than younger adults in the third phase of successful retrieval trials (see Figure 4). We attribute these costs to the maintenance of a retrieval mode, given that specific retrieval processes cannot be initiated until the next cue is presented. This conclusion is also supported by the large age-related differences during the first, cue-encoding, phase, which was associated with much larger attentional costs in the older adults. This cannot be interpreted as reflecting larger age-related demand for cue-encoding processes, as such, because Experiment 1 showed no such age-related differences at this stage during the encoding phase. It appears, then, that the maintenance of a retrieval mode is more costly in older than in younger adults.

General Discussion

The main purpose of the present study is to gain further information and to test several predictions regarding the effects of DA on encoding and retrieval processes in younger and older adults. The incorporation of the visual-motor tracking task enabled us to measure moment-to-moment fluctuations in resource demands as well as the effects of DA on memory performance. Additionally, the design included two manipulations that we hypothesized would lead to improvements in memory, each for a different reason. We hypothesized that an increase in the semantic relatedness of the word pairs would be associated with a relatively automatic increase in recall: Participants could take advantage of the greater schematic support afforded by related pairs, and this advantage would not require additional processing resources. Conversely, the groups who received strategy instructions would also improve their recall performance, but in this case by the involvement of active, self-initiated processing activities that would presumably require additional processing resources. With regard to aging, whether the relatedness manipulation would affect both age groups similarly or differently was an open empirical question. Furthermore, the predicted age-related effects of the strategy manipulation depend on the theoretical position taken, with those who attribute age-related differences in memory performance to the decline in spontaneous use of strategies predicting a larger benefit of strategy induction for the old. In contrast, those claiming that age-related declines in memory performance are due to the inability of older people to use strategies efficiently (possibly because of insufficient attentional resources) predict similar or larger benefits for the young as a result of strategy induction. The results obtained in the current experiments provided answers, some unexpected, to these questions.

Memory Performance

In Experiment 1, attention was divided during the encoding phase; retrieval was carried out under full attention conditions. Recall performance was reduced by DA at encoding, which thereby replicated the effects reported by Baddeley et al. (1984) and by Craik et al. (1996). Performance was also lower in the older adult group, but the effects of DA were equivalent in the two age groups. This result replicates the findings of most previous studies. The manipulations of relatedness and strategy increased recall performance, as expected. It is interesting, however, that the use of strategy benefited both age groups equally, whereas increased relatedness benefited older adults more than younger adults (see the later further discussion of this topic). The final significant interaction was between attention and strategy: The strategy groups benefited more under conditions of full attention, presumably because of the availability of more processing resources and a greater freedom to plan and execute beneficial strategies. The retrieval latency data showed significant effects of age (younger adults were faster than older adults) and relatedness (related pairs were retrieved more quickly) and an Age × Relatedness interaction (older adults benefited more from relatedness than their younger counterparts). These latency results are perfectly congruent with the recall results.

Attention was divided at retrieval in Experiment 2. Recall performance was significantly reduced by age and by DA, although this second result was qualified by an Age × DA interaction. That is, DA reduced recall performance in older adults but not in younger adults. The absence of an effect of DA on retrieval is in line with previous results (Baddeley et al., 1984; Craik et al., 1996), but it should be noted that the present study, like the previous studies, used a sensory-motor task as the DA task. Experiments that use DA tasks involving materials similar to those in the memory task have typically found that DA at retrieval does reduce memory performance (Fernandes & Moscovitch, 2000, 2002). In addition to these effects, memory performance was increased by greater relatedness and (marginally) by use of strategies. As in Experiment 1, older adults benefited from relatedness more than did younger adults. Retrieval latency results showed the same pattern as in Experiment 1: There were significant positive effects of age (younger adults were faster than older adults) and relatedness, and the Age × Relatedness interaction was also significant, showing that older adults were differentially faster than young adults when retrieving related as opposed to unrelated word pairs. It was surprising that DA at retrieval did not lead to an increase in retrieval latency (see Table 5).

Attentional Costs

The assumption underlying use of the tracking task in this and in previous experiments is that greater attentional resource needs for encoding or retrieval processes result in greater deviations between the chaser and the target. Each participant carried out the tracking task by itself for four trials in both experiments; the measure used to assess processing costs was the difference between performance on the tracking task alone and when it was combined with either encoding or retrieval. We hypothesized that processing costs, measured in this way, would be larger for older adults, for groups using strategies, and for retrieval compared with encoding (Craik et al., 1996). In addition, the fine-grain analysis made possible by the continuous tracking task allowed us to compare the costs associated with the three phases of encoding and retrieval. We analyzed the results in terms of both absolute and relative costs. The patterns of results were identical between these two sets of measures, although the levels of statistical significance sometimes differed. We stress the general patterns of findings in this concluding discussion.

When attention was divided at encoding (Experiment 1), older participants showed greater costs than younger participants (although this effect did not reach statistical significance when we used relative costs), so, on the whole, it appears that encoding processes are generally more resource demanding for older adults. Neither relatedness nor strategy was associated with overall increased costs. When encoding was divided into the three phases of perception, elaboration, and learning, results showed that the second phase was the most resource demanding. The effect of phase also interacted with age, such that costs continued to be high in the third phase for older but not younger adults. Finally, there was a three-way interaction among age, phase, and strategy, in that the continued high use of attentional costs in the third phase for strategy groups was particularly notable in older participants (see Figure 2). These results justify the tracking measure as a way of assessing attentional resource needs and fluctuations.

In Experiment 2, attention was divided at retrieval. In addition to overall attentional costs, we also assessed costs separately for successful versus unsuccessful retrieval attempts. There was no overall effect of retrieval success, but there was an interaction with phase in that costs were maintained in the third phase for unsuccessful trials, reflecting continuing retrieval attempts, but dropped following a successful retrieval. In this experiment, older adults consumed more resources than younger adults; that is, retrieval processes were costly for older participants. Further, age interacted with strategy and with phase. That is, the increased costs for older people were particularly marked in the strategy condition and for the second phase of retrieval.

One purpose of the present study is to determine the reasons for the substantial attentional costs required by older adults during retrieval. One possibility is that older adults have a greater number of unsuccessful retrievals—such trials are associated with large attentional cost requirements in young adults—but this possibility is not supported by the present results. Despite the larger overall attentional costs required by older than by younger adults, confirming the results by Anderson et al. (1998), this increase was not related to special deployment of resources by older adults during unsuccessful retrieval; older adults' costs were approximately equivalent for successful and unsuccessful trials, and the substantial age-related increase in costs for retrieval is clearly evident in successful trials (see Figure 4). The finding that costs were largest for the second phase of retrieval (from 500 ms to the point of retrieval) replicates findings reported by Naveh-Benjamin and Guez (2000) for younger adults. This large increase in secondary task costs for successful retrievals may also be associated with costs of production of the retrieved word. Furthermore, the fact that age-related costs increased markedly during this second phase of retrieval indicates that the processes involved in cue elaboration, search, and word production are particularly demanding for older adults.

The overall pattern of attentional costs for younger and older participants during encoding and retrieval is well illustrated in Figure 6, which shows absolute costs for successful retrieval trials across the full 6-s encoding or retrieval segment. The figure shows the large costs for older adults, especially during retrieval. For encoding trials, costs rose for the first 2 s and then fell for younger adults but were maintained for the older group. Similarly, for retrieval trials, costs rose for both groups over the first 3 s and then fell almost to baseline for the younger adults (for successfully recalled items) but remained substantially above baseline for the older adults. We attribute this last observation to the notion that the maintenance of retrieval mode is quite costly in older adults. Note that the larger cue-elaboration and postretrieval costs for the older adults may also represent postretrieval checks on the information retrieved, reflecting older adults' lower confidence in their retrieval responses.

One point merits consideration regarding potential scale effects. Because tracking task costs were relatively small in younger adults, they may reflect floor effects that possibly bias the age-differences picture of the attentional costs measure. However, we do not think this is the case, for several reasons. First, the attentional costs for younger adults were significantly above baseline,

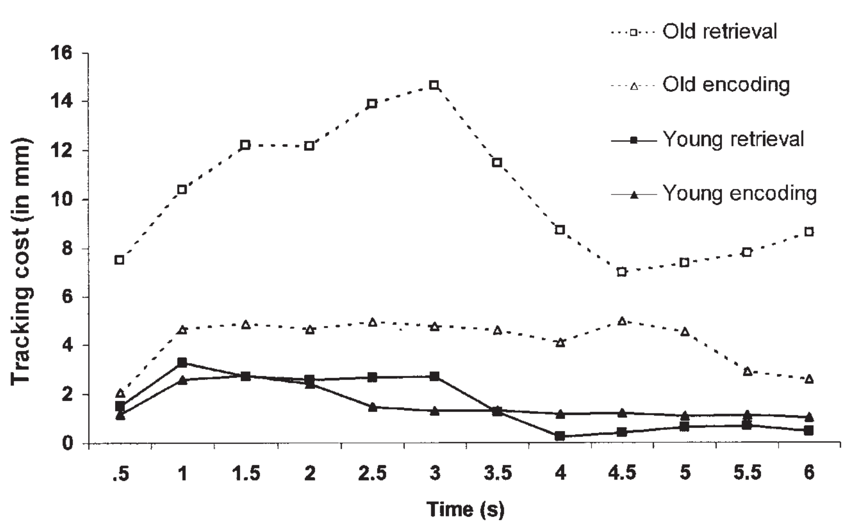

Figure 6. Experiments 1 and 2: Temporal distribution of performance on the secondary tracking task for younger and older adults for the aggregated 6-s encoding and retrieval segments after subtraction of single-task tracking performance (distance in millimeters).

as reported in both experiments. Second, the obtained results for the younger adults in both experiments closely replicate the pattern of results as well as the actual values reported in previous studies (e.g., Naveh-Benjamin & Guez, 2000). Third, in several cases, the pattern of results was reversed in the younger and the older adults. For example, at encoding, whereas older adults showed an increase in attentional costs under strategy instructions, younger adults showed the opposite trend (see Figure 2 and Figure 3, bottom right panel). In addition, under strategy instruction conditions at encoding, whereas older adults showed an increase from the second to the third phase, younger adults again showed the opposite trend (see Figure 2, right panel). If the pattern of the results for younger adults did, indeed, reflect floor effects, we would not have seen these patterns of significant decline. Finally, we have run a control experiment with 12 younger adults in which we made both the encoding and the retrieval tasks more difficult by using triplets rather than pairs of words at study. During retrieval, the first word was presented as a cue to retrieve the other two words. The results of this experiment indicate an overall increase in attentional costs relative to those observed in the young participants of the current experiments, both at encoding and at retrieval; however, the patterns of results with respect to the effect of strategy and processing phase are similar to those reported in the current article.

Theoretical Implications

The results of the two experiments address current theoretical issues. First, they provide further evidence that DA at encoding is more disruptive to later memory performance than is DA at retrieval (Baddeley et al., 1984; Craik et al., 1996). This asymmetry cannot be attributed to a differential trade-off between memory and secondary task processing, at least in the young, as Figure 6 shows no marked differences between encoding and retrieval costs. The story is different for older adults, however, given their substantial secondary task costs at retrieval; therefore, perhaps older adults do retrieve (or attempt to retrieve) further memory items by giving retrieval processing priority over secondary task processing.

A second theoretical point concerns the distinction between self-initiated activities, which are considered to be less effective and more resource demanding for older adults, and environmental support, which is considered to provide cost-free benefits to memory performance that are particularly helpful for older adults (Craik, 1983, 1986). In the current experiments, self-initiated activities were represented by strategy instructions, and environmental support was instantiated by the schematic support provided by relatedness. In line with Craik's analysis, relatedness benefited older adults more than younger adults at no cost to resources, indicating that as long as performance can be mediated by the use of semantic knowledge, episodic memory performance holds up fairly well into old age. Use of this knowledge apparently requires no extra attentional effort in older adults (see Figures 3 and 5). In contrast, older adults have problems when the task mostly requires access to episodic knowledge, as is the case with unrelated pairs. Conversely, strategy instructions boosted memory performance equally for the two age groups, at no cost to the younger group but at some cost to the older group at both encoding and retrieval (see Figures 3 and 5). It therefore appears that, in the present experiments at least, younger adults can switch to more effective encoding procedures (and benefit from these procedures at retrieval) without using further resources, whereas older adults can also benefit, but only at the cost of drawing heavily on attentional resources. Furthermore, these results are more in line with the inefficient strategy use hypothesis (Shaw & Craik, 1989) than with the notion of production deficiency (Craik & Byrd, 1982), because even under conditions in which useful strategies were provided, older adults still showed memory deficits. In the current studies, these age-related deficits were associated with a substantial increase in the attentional resources required by older adults at both encoding and retrieval, illustrating the less efficient use of strategies in these participants.

A third point concerns the phase analysis for both encoding and retrieval. In general, the results show greater costs associated with the second phase, representing the organization of encoding activities and the peak effort for retrieval. For encoding, the initial perception of the stimuli is associated with similar attentional costs for younger and older adults. After this stage, older adults require more attentional resources to support organization and elaboration of encoding activities than younger adults do, especially under strategy instruction. One purpose of the present studies was to find the sources of the larger overall demands for attentional resources in older adults at retrieval, and we raised several hypotheses regarding the underlying mechanisms. The results do not support the hypothesis that these extra costs are due to the larger proportion of unsuccessful retrievals in this group. Rather, the results are more in line with the hypothesis that older age is associated with difficulty with specific processes. In particular, cue-elaboration, search, and production processes, as well as maintaining a retrieval mode, appear to be especially difficult and resource demanding in old age.

Finally, Naveh-Benjamin (2000) and Naveh-Benjamin, Guez, Kilb, and Reedy (2004) have provided evidence of an associative deficit in older adults. According to such a view, one of the major factors underlying age-related memory problems appears to be the difficulty in binding items together and integrating events with their contexts. The present experiments provide further evidence of this age-related difficulty, illustrate ways the deficit can be ameliorated (see also Naveh-Benjamin et al., 2003), and demonstrate the attentional resource costs associated with different conditions and phases of encoding and retrieval.

References

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

Baddeley, A. D., Lewis, V., Eldridge, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 13,* 518–540.

Baddeley, A. D., Logie, R., Bressi, S., Della Sala, S., & Spinnler, H. (1986). Dementia and working memory. *Quarterly Journal of Experimental Psychology, 38A,* 603–618.

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

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transaction of the Royal Society of London, Series B, 302,* 341–359.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities, mechanisms and performance* (pp. 409–422). Amsterdam: Elsevier.

Craik, F. I. M., & Bosman, E. A. (1992). Age-related changes in memory and learning. In H. Bouma & J. A. M. Graafmans (Eds.), *Gerontechnology* (pp. 79–92). Amsterdam: IOS Press.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. E. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum Press.

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

Craik, F. I. M., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 474–479.

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

Duchek, J. M. (1984). Encoding and retrieval differences between young and old: The impact of attentional capacity usage. *Developmental Psychology, 20,* 1173–1180.

Dunlosky, J., & Hertzog, C. (1998). Aging and deficits in associative memory: What is the role of strategy production? *Psychology and Aging, 13,* 597–607.

Fernandes, M. A., & Moscovitch, M. (2000). Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology: General, 129,* 155–176.

Fernandes, M. A., & Moscovitch, M. (2002). Factors modulating the effect of divided attention during retrieval of words. *Memory & Cognition, 30,* 731–744.

Jennings, J. R., Nebes, R. D., & Yovetich, N. A. (1990). Aging increases the energetic demands of episodic memory: A cardiovascular analysis. *Journal of Experimental Psychology: General, 119,* 77–91.

Kerr, B. (1973). Processing demands during mental operation. *Memory & Cognition, 1,* 401–412.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Light, L. L., & Prull, M. W. (1995). Aging, divided attention, and repetition priming. *Swiss Journal of Psychology, 54,* 87–101.

Macht, M. L., & Buschke, H. (1983). Age differences in cognitive effort in recall. *Journal of Gerontology, 28,* 695–700.

Naveh-Benjamin, M. (2000). Adult-age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Naveh-Benjamin, M., Craik, F. I. M., & Ben-Shaul, L. (2002). Age-related differences in cued recall: Effects of support at encoding and retrieval. *Aging, Neuropsychology, and Cognition, 9,* 276–287.

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

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

Naveh-Benjamin, M., & Guez, J. (2000). The effects of divided attention on encoding and retrieval processes: Assessment of attentional costs and a componential analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1461–1482.

Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative deficit of older adults: Further support using face–name associations. *Psychology and Aging, 19,* 541–546.

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult-age differences in episodic memory: Further support for an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 826–837.

Nyberg, L., Nilsson, L.-G., Olofsson, U., & Bäckman, L. (1997). Effects of division of attention during encoding and retrieval on age differences in episodic memory. *Experimental Aging Research, 23,* 137–143.

Park, D. C., Puglisi, J. T., & Smith, A. D. (1986). Memory for pictures: Does an age-related decline exist? *Psychology and Aging, 1,* 11–17.

Park, D. C., Puglisi, J. T., Smith, A. D., & Dudley, W. N. (1987). Cue utilization and encoding specificity in picture recognition by older adults. *Journal of Gerontology, 42,* 423–425.

Park, D. C., Smith, A. D., Dudley, W. N., & Lafronza, V. N. (1989). Effects of age and a divided attention task presented during encoding and retrieval on memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1185–1191.

Perlmutter, M., & Mitchell, D. B. (1982). The appearance and disappearance of age differences in adult memory. In F. I. M. Craik & S. E. Trehub (Eds.), *Aging and cognitive processes* (pp. 127–144). New York: Plenum Press.

Salthouse, T. A., Rogan, J. D., & Prill, K. A. (1984). Division of attention: Age differences on a visually presented memory task. *Memory & Cognition, 23,* 59–71.

Shaw, R. J., & Craik, F. I. M. (1989). Age differences in predictions and performance on a cued recall task. *Psychology and Aging, 4,* 131–135.

Somberg, B., & Salthouse, T. A. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 651–663.

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

Whiting, W. L., & Smith, A. D. (1997). Differential age-related processing limitations in recall and recognition tasks. *Psychology and Aging, 12,* 216–224.

(*Appendixes follow*)

Appendix A

Tracking Task: Absolute and Relative Attentional Costs at Encoding (Millimeters) in Experiment 1

Absolute and relative cost, strategy, and age	Unrelated pairs						Related pairs					
	Phase 1		Phase 2		Phase 3		Phase 1		Phase 2		Phase 3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Absolute costs												
No strategy												
Young	1.39	2.09	2.62	1.75	1.44	1.69	1.51	1.95	2.87	1.43	1.26	1.89
Old	1.96	2.69	4.57	2.86	2.06	3.73	2.15	2.98	3.72	3.54	2.62	2.64
Strategy												
Young	0.84	1.14	2.51	0.99	1.27	0.97	0.84	1.42	2.26	1.01	0.84	0.90
Old	1.50	2.47	4.61	2.60	6.66	2.61	2.60	3.04	5.98	2.60	5.34	2.59
Relative costs												
No strategy												
Young	8.81	13.47	17.92	13.37	8.42	9.35	8.89	11.75	18.89	10.26	7.60	11.80
Old	6.02	8.37	17.75	9.91	7.35	11.12	6.24	20.03	14.19	12.66	9.81	10.33
Strategy												
Young	4.89	7.29	17.20	8.15	7.97	5.71	5.74	8.42	15.33	7.84	5.16	5.08
Old	7.78	9.92	15.10	11.32	18.79	7.10	10.78	12.81	18.81	10.60	15.16	8.87

Appendix B

Tracking Task: Absolute Attentional Costs at Retrieval (Millimeters) in Experiment 2

Type of retrieval, strategy condition, and age	Unrelated pairs						Related pairs					
	Phase 1		Phase 2		Phase 3		Phase 1		Phase 2		Phase 3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Unsuccessful retrievals												
No strategy												
Young	1.75	2.18	2.01	1.94	2.08	2.37	1.12	1.97	2.44	1.68	1.57	1.97
Old	3.43	4.83	5.44	3.85	3.65	4.15	1.38	3.08	3.49	3.60	5.85	3.76
Strategy												
Young	1.01	2.71	1.60	3.85	1.83	2.93	2.96	5.64	3.01	4.49	2.69	5.64
Old	7.20	5.66	14.72	6.12	10.41	6.57	10.76	8.63	11.34	8.71	11.95	8.94
Successful retrievals												
No strategy												
Young	2.06	2.73	2.67	3.52	1.39	1.09	1.63	1.52	1.68	1.66	1.13	1.34
Old	4.08	6.37	7.42	8.25	10.39	6.24	5.89	6.65	11.32	7.04	5.37	4.85
Strategy												
Young	2.11	3.46	3.17	6.04	0.52	0.79	1.47	2.10	2.85	3.84	0.74	2.37
Old	11.75	6.38	15.50	11.78	9.47	4.43	9.93	6.21	14.06	6.88	9.00	5.67

Appendix C

Tracking Task: Relative Attentional Costs at Retrieval in Experiment 2

Type of retrieval, strategy condition, and age	Unrelated pairs						Related pairs					
	Phase 1		Phase 2		Phase 3		Phase 1		Phase 2		Phase 3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Unsuccessful retrievals												
No strategy												
Young	13.87	17.53	14.92	13.93	15.92	17.24	9.31	16.87	18.69	12.88	11.67	13.94
Old	12.20	28.30	19.91	22.83	11.37	20.77	5.58	22.81	9.69	21.65	19.22	22.65
Strategy												
Young	5.41	17.32	8.50	21.20	10.45	14.15	18.86	37.87	17.52	19.15	13.98	23.74
Old	23.07	24.02	48.97	33.74	37.73	22.42	40.94	35.87	42.82	31.45	44.83	37.62
Successful retrievals												
No strategy												
Young	15.32	18.61	19.97	18.91	10.02	7.43	12.51	11.88	13.01	12.95	8.47	9.94
Old	10.92	22.30	23.08	27.16	26.45	13.56	14.57	17.50	31.48	21.31	14.11	13.52
Strategy												
Young	12.21	14.57	17.53	26.70	3.50	5.61	8.81	9.44	16.96	15.24	3.66	10.55
Old	46.05	22.07	50.84	33.16	33.50	10.93	38.39	21.92	51.65	23.52	28.73	17.34

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