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2 authors:


Myra A Fernandes
University of Waterloo


Morris Moscovitch
University of Toronto

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Interference Effects From Divided Attention During Retrieval in Younger and Older Adults

Myra A. Fernandes
Rotman Research Institute, Baycrest Centre for Geriatric Care

Morris Moscovitch
Rotman Research Institute, Baycrest Centre for Geriatric Care, and University of Toronto

The authors examined how retrieval, under divided attention (DA) conditions, is affected by the type of material in a concurrent task, and whether aging produces larger interference effects on memory. Young and old adults studied a list of unrelated words under full attention, and recalled them while performing either an animacy decision task to words or an odd-digit identification task to numbers. The animacy-distracting task interfered substantially with retrieval, and the size of the effect was not amplified in older compared with younger adults. DA using the odd-digit task did not produce as large an interference effect. These findings support the component-process model of memory, and pose problems for resource models of interference from DA at retrieval.

Remembering is an activity we carry out, sometimes with relative ease and at other times with much effort. Explaining how memory retrieval operates has been a goal of cognitive psychologists for many years. Several investigators have considered whether the amount of attention available for retrieval influences the process. That is, does retrieving items or events from memory, amidst other activities, and in situations where there are competing irrelevant stimuli, compromise performance? From an intuitive perspective one might think that in these situations retrieval would be negatively affected, but research has shown that retrieval is surprisingly resilient to attentional manipulations. This experiment explores how the type of material in a concurrent task affects episodic memory retrieval, and whether aging interacts with these effects.

We first review relevant research reporting effects of division of attention on retrieval, and then discuss general resource and component-process accounts of interference effects. We then test these two accounts by considering whether older adults, with presumed reduced general processing resources, would be more susceptible to interference effects from divided attention (DA) at retrieval than young adults. Literature pertaining to the effect of aging on interference is also discussed.

Myra A. Fernandes, Rotman Research Institute, Baycrest Centre for Geriatric Care, Toronto, Ontario, Canada; Morris Moscovitch, Rotman Research Institute, Baycrest Centre for Geriatric Care, and Department of Psychology, University of Toronto, Toronto, Ontario, Canada.

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Correspondence concerning this article should be addressed to Myra A. Fernandes, Rotman Research Institute, Baycrest Centre for Geriatric Care, 3560 Bathurst Street, Toronto, Ontario M6A 2E1, Canada. E-mail: mfernandes@rotman-baycrest.on.ca

Baddeley, Lewis, Eldridge, and Thomson (1984) used the dual-task technique to examine the role of attention in retrieval of long-term episodic memories. They considered performance on memory tests such as free recall, paired-associate learning, and recognition, while participants concurrently performed a card-sorting task or held a digit load in mind. They concluded that retrieval was automatic because, in all of their experiments, DA produced either no reduction or only a slight reduction in memory performance.

Along the same lines, Craik, Govoni, Naveh-Benjamin, and Anderson (1996) had participants perform free recall, cued recall, or recognition tests of memory simultaneously with a visual continuous reaction time (CRT) task. This concurrent task produced only a small effect on memory, ranging from almost nil on recognition, to a 13% decline from full attention on free recall. They also examined how DA affected performance on the distracting task, as this measure also reflects the resources needed for retrieval. They showed that distracting-task costs varied depending on the amount of environmental support offered by the memory task. Costs were greatest for free recall, less for paired associate, and least for recognition. They concluded that retrieval, despite being immune to disruption, did not proceed automatically and required general attentional resources, as reflected in costs to distracting-task performance.

Other work by Naveh-Benjamin, Craik, Guez, and Dori (1998) examined the resiliency of memory retrieval to various task demands when performed concurrently with a visual CRT task. They considered whether DA at retrieval would affect memory performance in a cued-recall paradigm more when low- versus high-frequency words were to be retrieved. Low-frequency words are harder to recall (Gregg, 1976) and may require more search processes that could be disrupted under DA conditions. They also considered whether different perceptual attributes, using a different versus same voice at retrieval as at study, would increase the effect of DA. Neither of these manipulations altered the resiliency of retrieval to DA conditions. As in previous studies DA had little effect, if any, on retrieval, regardless of whether memory was for low- or high-frequency words, or for items studied in the same or different voice as at study. There were, however, significant costs to the distracting task, which varied depending on the memory task demands. These studies strongly suggest that memory retrieval is immune to disruption, and runs obligatorily, although it does consume general attentional resources as indicated by costs to the distracting tasks.

Although those investigators failed to find substantial interference effects from DA at retrieval, recent work by Fernandes and Moscovitch (2000; see also Fernandes & Moscovitch, 2002) showed that under certain conditions, a strong effect can be found, indicating that retrieval of a list of unrelated words may not occur obligatorily. Specifically, they showed that a *word*-based distracting task produced a large interference effect on memory, whereas a similar *digit*-based, or *picture*-based task did not. They proposed that interference at retrieval arises from competition for a common representational system, activated during recovery of the memory trace, as well as by word-based distracting tasks. They suggested that the material specificity of the distracting task is critical in determining whether interference on the memory retrieval task will be observed. This model of memory is outlined in detail in the following (see also Moscovitch, Fernandes, & Troyer, 2001).

A Model of Memory Retrieval

By examining DA effects created by different concurrent tasks, Fernandes and Moscovitch (2000) extended the component-process model (Moscovitch, 1992, 1994; Moscovitch & Umiltà, 1990, 1991; Moscovitch & Winocur, 1992) of memory. They suggested complementary processes needed for retrieval, mediated by the prefrontal cortex (PFC) and medial temporal lobe/hippocampus (MTL/H). According to this model, some tests of memory rely heavily on strategic resources mediated by the PFC, whereas others do not. On the former types of tests, substantial interference effects are observed at retrieval as long as the concurrent task itself is resource demanding and thus draws resources away from the memory task. Examples of such tasks include recall of categorized word lists (Moscovitch, 1994; Park, Smith, Dudley, & Lafronza, 1989), list discrimination (Dywan & Jacoby, 1990; Jacoby, 1991), and release from proactive inhibition (Moscovitch, 1989, 1994), which are largely disrupted by most distracting tasks.

Other memory tests do not rely as heavily on PFC resources, and are carried out primarily by the MTL/H. In studies in which DA effects at retrieval were small or even nonexistent (Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley et al., 1984; Craik et al., 1996; Naveh-Benjamin et al., 1998), the memory test consisted of free recall, cued recall, or recognition of a list of *unrelated words*. Performance on these tests is often disrupted by MTL/H damage, but rarely by frontal damage (Milner, Petrides, & Smith, 1985; Moscovitch, 1982; Schacter, 1987). As suggested by Moscovitch (1994), if the frontal lobe contribution to the memory test is minimal, then interference effects from DA at retrieval will be small, as retrieval can be performed by the modular MTL/H, which operates relatively automatically and obligatorily. Consequently, competition for general processing resources, drawn on and organized by the PFC, is not a factor that should affect memory performance on these tests. The only resource-demanding aspect of retrieval on these tests lies in establishing and maintaining retrieval mode, as well as monitoring output. These processes are thought to be mediated by the PFC, and under DA conditions, are reflected in costs to the distracting task, regardless of whether material used to divide attention is word based, digit based, or visuospatial (Fernandes & Moscovitch, 2000, 2002).

According to the component-process model, the actual recovery of the memory occurs when the trace interacts with the MTL/H in a process called *ecphory* (Semon, 1924, cited in Schacter, Eich, & Tulving, 1978; Tulving, 1991). The trace is thought to consist of an ensemble of neurons in the neocortex that mediates the conscious experience during encoding, and forms the perceptual and semantic representation responsible for the content of the experience. In the case of memory for words, this likely includes orthographic, phonological, lexical, and semantic representations. During retrieval, an internally generated or externally presented cue activates the MTL/H, which acts as a pointer or index to the neocortical neurons representing the content of the trace. This process is believed to occur automatically. The work by Fernandes and Moscovitch (2000, 2002) suggests that performing a word-based task, concurrently with recall of words, interferes with reactivation of the representation of items in memory in posterior neocortex regions. Competition is created as the memory and distracting tasks compete for the same representational system. Our recent work suggests that the primary locus for competition with retrieval of words is at the phonological level of representation, although competition at other levels (i.e., semantic) was also found (Fernandes, Priselac, & Moscovitch, 2002). Thus, at retrieval, distracting-task costs are unselective, but memory costs are material-specific.

An alternative account of effects of DA at retrieval is that the large memory costs from similar material in a distracting task is due to competition for general attentional resources, such as those mediated by the frontal lobes. These resources may be needed to coordinate the online processing of dual tasks. In the case of the word-based distracting tasks, retrieval may be disrupted to a relatively greater extent because the similarity in materials makes it more difficult to coordinate the two tasks and overextends a limited pool of general processing resources.

Also consistent with a general resource account of interference, the large material-specific effect of DA at retrieval may arise from competition for input–output channels. That is, processing of incoming words for the distracting task may require a verbal working memory system, while words for the recall task may need the same resources before output. This account fits with Baddeley's (1986, 1992) hypothesis that the ability to coordinate concurrent tasks relies on the central executive (CE), whose operation requires resources mediated by PFC. Coordination of concurrent tasks that require the same slave subsystem, in his model, is more difficult than when tasks require the verbal and visuospatial subsystem respectively, because in the former case they are relying on a common pool of resources. Such an account suggests that words to be recalled are successfully reactivated, but are then disrupted during output.

One way of testing the resource versus component-process account of interference effects is to consider the performance of older individuals under DA conditions. It is well-known that aging is accompanied by a decline in long-term episodic memory. A theoretical account of age-related decline in memory is that general processing resources that are crucial for numerous cognitive operations decline with age (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik, & Ackerman, 1982). These resources have also been conceptualized in terms of reduced working memory capacity (Salthouse, 1996) needed to hold and manipulate information or make computations (Craik & Jennings, 1992). Similarly, Hasher and colleagues (Hamm & Hasher, 1992; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988) suggested that older adults have an impairment in inhibition, leading to a more "cluttered" working memory.

Regardless of how these resources are conceptualized, cognitive aging theorists suggest that changes in brain function, particularly in the frontal lobes, underlie the reduction in resources (e.g., Baddeley & Wilson, 1988; Fuster, 1997; Knight, Grabowecky, & Scabini, 1995; Luria, 1966; Shallice & Burgess, 1991). Evidence of differences in frontal lobe function between young and old have been shown behaviorally (Moscovitch & Winocur, 1992, 1995), and in several neuroimaging studies; when performing a retrieval task, older, adults show a reduction in right PFC (and corresponding increase in left PFC) compared with young adults, who exhibit frontal lobe activation primarily on the right side (Cabeza et al., 1997; Madden et al., 1999). There is also some evidence of age-related reductions in cerebral volume (Coffey et al., 1992), in regional cerebral blood flow (Gur, Gur, Obrist, Skolnick, & Reivich, 1987), and metabolic rates for oxygen and glucose (Leenders et al., 1990; Pantano et al., 1984), particularly in the frontal lobe, although there is some individual variation.

A consideration of DA effects in older adults allows one to determine whether competition for general processing resources, and the frontal lobes, play a role in mediating large interference effects at retrieval. As described in the component-process model, the frontal lobes are central systems that require general resources for their operations. When the frontal lobes deteriorate, they draw on an even greater amount of resources in order to carry out operations effectively. If interference from DA occurs due to a reduction in available processing resources, then performance of those with poor frontal function should show amplified interference because they require more resources to maintain performance, even under full attention.

Previous work comparing the performance of younger and older adults found that various distracting tasks, performed concurrently with retrieval, had little effect on memory in either age group (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park et al., 1989; Whiting & Smith, 1997). Performance on the distracting task, however, was disrupted more in older adults than younger adults (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997). This led Anderson et al. to conclude that older adults have a reduction in resources available to engage in demanding operations, as indexed by higher distracting-task costs, but relatively preserved retrieval operations. That is, in agreement with Salthouse, Rogan, and Prill (1984), older adults can maintain retrieval effectively under DA conditions; however, they do so at a relatively greater cost to attentional resources.

In the experiment here we compare the interference effects from a digit-based distracting task with a word-based one performed concurrently with free recall. In line with the component-process model, we do not expect the size of memory interference to differ between young and old adults. That is, memory performance should suffer when the word-based, but not digit-based distracting task is performed concurrently, to an equal extent in young and older adults. Insofar as interference occurs on the memory task, it is due to competition for a representational system, which is relatively well preserved in older adults (Grady, 2000; Grady & Craik, 2000), and not due to competition for general processing resources in the PFC, which are believed to be compromised in this group.

A general resource account of DA effects, on the other hand, predicts that interference will be greater in older adults. As Craik (1983, 2002) suggested, the ability to retrieve an item from memory can be likened to the ease of pulling out a target from among different backgrounds or distracters in perceptual experiments. That is, one's ability to pick out the target is easier when the background offers a high contrast as opposed to a low contrast. The ability to resolve target items is reduced when it is among other materials that are highly similar. This account suggests that DA between a memory and a distracting task that use similar materials makes greater attentional demands than when the tasks use dissimilar materials. As attentional resources are limited, this results in a breakdown of the retrieval process, accounting for the large interference effect observed from word-based distracting tasks on retrieval in young adults. With respect to older adults, they "may lack the resolving power to distinguish wanted from irrelevant information in an effective manner, especially when the two streams of information are qualitatively similar" (Craik, 2002, p. 276), and thus show amplified interference effects from word-based distracting tasks.

In addition to the effects of DA on memory performance, we examined how costs to the distracting task were affected by DA conditions with retrieval. To do so, we compared the effect of the recall task on distracting-task performance. As predicted by both the component-process and reduced-resource model, older adults are expected to show larger costs on the distracting task than younger adults. Such costs are thought to be incurred in maintaining retrieval mode (Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000), a resource-demanding function ascribed to PFC, which is compromised in older adults.

In this experiment we also manipulated the number of times older adults could hear study lists during encoding. Other research suggests that aging is associated with a decline in episodic memory (Craik & Jennings, 1992; Salthouse 1991) that may stem from difficulties with encoding and/or elaboration at encoding (Craik, 1982, 1983, 1986), and we wanted to examine whether increasing the number of study trials in older adults would produce more robust memory traces that were less susceptible to disruption, and less resource-demanding to retrieve under DA conditions.

Experiment

Method

Participants

Participants were 24[1] undergraduate students at the University of Toronto, who received course credit or monetary compensation for partici-

[1] Data from 3 young adults were excluded because the number of words they recalled in the full-attention condition was four or less. Due to experimenter error, data for 1 other participant were invalid. Additional participants were tested in their place.

pating in the study, and 40 older adults chosen from a pool at Erindale College, recruited by ads in the local newspaper, who received token monetary compensation for participating. The mean age was 19.54 (SD = 1.14) for the young adults and 70.77 (SD = 2.93) for the older adults. The mean number of years of education for the undergraduates was 14.2 (SD = 1.10) and for the older adults was 14.4 (SD = 1.80). All participants were native English speakers, and had normal or corrected-to-normal vision and hearing. The Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) was administered to each older adult, with those obtaining a score of ≤26/30 being replaced. The mean score on the MMSE was 27.7 (SD = 0.77). Older adults were randomly assigned to one of two groups (n = 24 and n = 16) that differed only in terms of number of times study lists were heard at encoding.[2]

Overview of Experiment

In each of three different conditions, participants were asked to try to commit an auditorily presented list of words to memory, and subsequently, a free-recall task was administered. Prior to retrieval in all conditions they began a distracting task, either animacy decisions about words, or odd-digit decisions about two-digit numbers, presented visually on a computer screen. In each of the two DA conditions, participants continued to perform one of the distracting tasks while simultaneously trying to recall out loud the studied word list. Participants also performed a baseline (full-attention) condition, in which the distracting task ended prior to free recall.

For the older adults, the study words were played at a louder volume. The volume was adjusted for each participant during the practice phase to a level at which the older adult could hear the words clearly without straining his or her hearing. Additionally, the study word lists were each played twice at encoding for one of the groups (n = 24) of older adults, and only once for the other group (n = 16) of older adults, as well as for the young adults.

Materials

All word stimuli were medium- to high-frequency words chosen from Francis and Kucera (1982). Word frequencies ranged from 20–100 occurrences per million.

Target-Recall Task

Four word lists were created by randomly choosing 16 words for each list from a pool of 64 unrelated common nouns. Words were recorded in a soundproof booth onto an audio file via a MacIntosh computer using the Sound Designer II (Avid Software, Palo Alto, California) program. Each list was created with 3 s of silence inserted between words. The lists were then recorded onto an audiotape and presented via a cassette player.

Distracting Tasks

For the animacy task, three 50-item word lists, consisting of words representing animals (e.g., kitten) and man-made objects (e.g., hammer), were created from a pool of 220 words. One list was used for practice, one for a single-task measure and the third for the DA condition with recall. A shorter, 20-item word list was also created and used as the filler task for half of the participants in the full-attention (FA) condition prior to recall (see *Procedure*). Another 50-item word list was created for use in the auditory CRT task (see *Procedure*). Each list was created such that half of the words represented animals and half man-made objects.

For the odd-digit task, the same number of lists was created. Stimuli for this task consisted of two-digit numbers chosen from a table of random numbers (Kirk, 1995). Each list was created such that half the numbers were odd and the other half even.

Procedure

Participants were tested individually, and completed the experiment in approximately 1 hr for young adults, and 1.5 hr for older adults. Some of the older adults returned at a later date for the auditory CRT task session (described later). For the memory task, participants heard a tape-recorded female voice reading a list of 16 words at a rate of approximately 1 word every 4 s, and were asked to try to commit the words to memory for a later recall test. For the group of older adults who heard the study list twice at encoding, there was a 4- to 5-s delay between presentations. The encoding phase was followed by an arithmetic task in which participants counted backwards by threes from a number heard at the end of the word list, for 15 s; this was done to eliminate recency (as in Craik et al., 1996).

For the distracting tasks, the words or numbers were presented visually on a computer screen at a rate of one item every 2 s. For the animacy task, participants indicated if the word represented a man-made object, and for the odd-digit task, whether the number was odd, by pressing a key with the dominant writing hand. Although we recorded manual response times in all of our experiments, we did not emphasize to participants the importance of responding quickly on the distracting tasks, either when performed singly or in DA conditions with retrieval.

Participants were given a practice block for the memory task, followed by practice for the animacy and then the odd-digit distracting task, prior to performing all of the experimental conditions. Following the practice blocks, single-task performance for either the animacy or odd-digit distracting task was measured. Single-task performance for the remaining distracting task was measured at the end of the final experimental condition. The order of the single tasks was counterbalanced across participants. Following the first single-task measure, the three experimental conditions (FA plus two DA conditions) were administered (six different orders of presentation were used). Following the study phase (and arithmetic task) in each experimental condition, and prior to recall, participants performed either the animacy or odd-digit distracting task alone for 40 s until the computer emitted a low-pitched tone. The tone signaled that recall of taped words should begin. For the DA conditions, this was done so participants would be engaged in the distracting task prior to beginning recall. In the FA condition, this filler task (the 20-item list for the animacy task for half of the participants, or odd-digit task for the rest) ended once the computer signaled that recall of the taped words should begin. In this way the time lag between study and test, as well as the need to perform another task before recall, were the same in the DA and FA conditions.

In the two DA conditions, the animacy or odd-digit task continued on the computer while participants tried to recall studied words. The distracting and free-recall tasks were performed simultaneously for 60 s, and participants were told to divide their efforts equally between the two tasks. The importance of placing 50% of their effort on the recall task and 50% on the distracting task was emphasized; participants were told that we were logging and evaluating their performance on both tasks, and that they should devote an equal amount of effort to the two tasks. After recall in the DA conditions, the experimenter asked participants if they recalled any additional words from the study list, now that they did not have to do two things simultaneously. Participants' recall responses were tape-recorded. Participants were given a break (4–5 min for young adults, 5–7 min for older adults) before beginning the next experimental condition.

[2] Data were excluded from 3 older adults in the group that heard the study lists twice at encoding: 1 participant misunderstood instructions, and another had difficulty hearing the lists. Due to experimenter error, data from another participant were invalid. In the group that heard study lists once at encoding, data were excluded in one case due to mechanical difficulties with the tape recorder, and in two other cases because the participants scored <26/30 on the MMSE. Additional participants were tested in their place.

Comparing Difficulty of the Distracting Tasks

It is possible that the word and digit-based distracting tasks differ with respect to resource requirements, and that this could contribute to any differences in their effects on retrieval. Thus we assessed the relative resource demands of each task. We examined the effect each task had on a concurrently performed auditory CRT task. For this task, participants had to identify computer-generated tones as either low, medium, or high pitched by pressing the appropriate key using the index, middle, and ring finger of their dominant hand. The tones were played in a random order, and participants were told to respond as quickly and as accurately as possible. A new tone was presented as soon as the participant pressed a key, or after 3 s had elapsed. Participants performed a practice block that ended once they could correctly identify tones on five consecutive trials.

The CRT task was then performed alone for a baseline measure (for 115 s), and in dual-task conditions with the animacy and odd-digit tasks (counterbalanced across participants). In order to avoid having participants make two different manual keypress responses (one for the CRT task and another for the distracting task) in the dual-task conditions, participants made verbal responses to distracting-task targets that were recorded by the experimenter using a separate keyboard. In the dual-task conditions, the tone task was performed alone for 15 s, followed by one of the distracting tasks that lasted 100 s. As in the DA conditions described previously, participants were told that we were logging and evaluating their performance on both tasks (the CRT and the distracting tasks, in this case), and that they should devote an equal amount of effort to the two tasks. The RT and number of correct responses in the auditory CRT task were recorded and analyzed as a means of gauging how demanding each distracting task was, with longer RTs indicating greater resource demands. Young adult participants performed the auditory CRT task at the end of the main experiment. Data were collected for older adults in a separate session on a different day.

Results and Discussion

Memory Task

The means for each condition and group are presented in Table 1. The following results were significant at $p < .01$ unless otherwise noted.

Number of words recalled. Because we were interested mainly in the effects of aging on memory performance, we first examined performance of the two groups of older adults separately, then collapsed the groups for a comparison with the young adult group. There was a main effect of encoding group, with older adults recalling fewer words overall when the word list was heard once compared to twice at encoding for each condition, $F(1, 28) = 8.58$, $MSE = 3.06$, $\eta^2 = .24$. There was also an effect of attentional manipulation (FA, DA animacy, DA odd-digits), $F(2, 56) = 27.52$, $MSE = 2.23$. Importantly, however, there was no interaction between encoding group and attentional manipulation, $F(2, 56) = 1.33$, $\eta^2 = .05$. Thus the encoding condition in older adults did not change the pattern of effects from our attentional manipulations at retrieval. As such we considered the effect of age group on memory performance by collapsing the two groups of older adults for comparison with the young adult group.

Data were analyzed in a 3 (attentional manipulation) × 2 (age group) × 6 (order of attentional manipulation) analysis of variance (ANOVA), with the first variable being within-subjects and the other variables between-subjects manipulations. There was a main effect of age group, $F(1, 52) = 11.75$, $MSE = 49.05$, $\eta^2 = .18$, with older adults recalling fewer words overall than young adults ($M = 22.13$ for young adults, and $M = 16.68$ for old adults). It should be noted that this main effect is driven by the group of older adults who heard word lists only once during encoding. When this group was removed from the analysis, there was no main effect of age group, $t(46) = 1.86$, $p > .05$ ($M = 22.13$ for young adults, and $M = 18.88$ for old adults who heard study lists twice at encoding). Thus, when older adults are given additional study opportunity during encoding, subsequent recall performance improves to a level similar to young adults, compared to when only one encoding opportunity is allowed.

There was a main effect of attentional manipulation, $F(2, 104) = 43.09$, $MSE = 2.23$, $\eta^2 = .45$. Importantly, there was no Attentional Manipulation × Age Group interaction, $F(2, 104) = 0.91$, $\eta^2 = .02$, suggesting that older adults were not affected more by the DA conditions than young adults. Simple effect analysis showed that the overall number of words recalled in the FA condition ($M = 7.12$) differed significantly from that in the animacy DA condition ($M = 4.80$), $F(1, 52) = 62.10$, $MSE = 5.34$, $\eta^2 = .54$, but not from that in the odd-digit DA condition ($M = 6.81$), $F(1, 52) = 1.75$, $\eta^2 = .03$. The number of words recalled was significantly lower in the animacy compared to odd-digit DA condition, $F(1, 52) = 66.53$, $MSE = 4.48$, $\eta^2 = .56$.

Table 1
Number of Words Recalled and Percentage of Decline in Recall From Full- to Divided-Attention Conditions for Each Group

	Young adults ($n = 24$)		Older adults[a] ($n = 24$)		Older adults[b] ($n = 16$)		All older adults ($n = 40$)	
Measure and condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Words recalled								
Full attention	8.42	2.32	7.17	2.75	5.06	1.77	6.33	2.59
DA odd-digit	7.71	2.40	7.21	2.43	4.88	2.16	6.28	2.57
DA animacy	6.00	2.36	4.50	2.54	3.44	1.36	4.08	2.19
% decline in words recalled								
DA odd-digit	6.52	25.24	−11.72	44.05	−1.55	46.33	−7.65	44.67
DA animacy	27.22	24.85	30.16	43.84	28.61	23.72	29.54	36.75

Note. DA = divided attention.
[a] Older adults given two encoding opportunities/condition. [b] Older adults given one encoding opportunity/condition.

Percentage decline in memory under DA conditions. In the following analyses we considered the percentage decline in words recalled for each participant as the dependent variable. This was calculated by subtracting the number of words recalled in each of the DA conditions from that in the FA condition, and then dividing by the number of words recalled under FA. In this way we could examine directly the interference effects from DA, relative to each participant's own FA level of recall (see Table 1).

We examined data from the two groups of older adults first. There was a main effect of DA condition, with greater interference in the animacy than odd-digit DA condition, $F(1, 28) = 34.28$, $MSE = 0.08$, $\eta^2 = .55$. The effect of encoding group on interference from the two DA conditions was nonsignificant, $F(1, 28) = 0.18$, $\eta^2 = .01$. Furthermore, the DA Condition × Encoding Group interaction was also nonsignificant, $F(1, 28) = 0.50$, $\eta^2 = .02$, indicating that hearing the word list once or twice at encoding, in the older adult groups, did not alter the pattern or size of interference from DA.

To investigate the effect of age on interference, we then collapsed the two groups of older adults, for comparison with the young adults. Data were analyzed in a 2 (DA condition) × 2 (age group) × 6 (order of DA condition) ANOVA. There was a main effect of DA condition, $F(1, 52) = 49.96$, $MSE = 0.05$, $\eta^2 = .49$, with overall greater interference in the animacy ($M = 28.67$) than odd-digit DA condition ($M = -2.33$), but no main effect of age group, $F(1, 52) = 0.58$, $\eta^2 = .01$. The Age × DA Condition interaction was significant,[3] $F(1, 52) = 4.36$, $MSE = 0.05$, $\eta^2 = .08$. Simple effects analysis showed that the size of interference did not differ for young and old adults in the DA animacy condition, $F(1, 62) = 0.08$, $p > .05$, or in the DA odd-digit condition, $F(1, 62) = 2.02$, $p = .16$. Surprisingly, the older adults performed better in the DA odd-digit condition than in the FA condition, accounting for the interaction.

Other measures of memory. Following each DA condition, participants were given a chance to recall words from the studied list under FA, but few recalled any additional words. Young adults recalled only 0.38 ($SD = 0.65$) words following the DA animacy condition, and 0.25 ($SD = 0.44$) words following the DA odd-digit condition. Older adults recalled only 0.73 ($SD = 1.04$) and 0.43 ($SD = 0.76$) words following the animacy and odd-digit DA conditions, respectively.

We also examined errors in recall. We found that the number of intrusions from previously studied word lists, as well as from distracting-task words, was small (<1 intrusion/condition) for young and older adults (see Table 2). The number of intrusions was not significantly different for young and older adults, $F(1, 62) = 2.03$, $p > .05$, $\eta^2 = .03$, which argues against a source memory account of DA effects. There was no effect of attentional manipulation, $F(2, 124) = 2.52$, $p > .05$, and the interaction with age was nonsignificant.

Table 2
Number of Intrusions From Previously Studied Word Lists and From Words in the Animacy Distracting Task, for Each Condition and Group

Age group and condition	Intrusions	
	M	*SD*
Young adults ($n = 24$)		
Full attention	0.66	0.92
DA odd-digit	0.33	0.64
DA animacy	0.29	0.46
Older adults[a] ($n = 24$)		
Full attention	0.71	0.99
DA odd-digit	0.58	0.83
DA animacy	0.38	0.58
Older adults[b] ($n = 16$)		
Full attention	0.81	1.11
DA odd-digit	0.69	0.79
DA animacy	0.88	1.15
All older adults ($n = 40$)		
Full attention	0.75	0.92
DA odd-digit	0.63	0.81
DA animacy	0.58	0.87

Note. DA = divided attention.
[a] Older adults given two encoding opportunities/condition. [b] Older adults given one encoding opportunity/condition.

Distracting Tasks

Accuracy rate. Accuracy rates (calculated as hit rate minus false alarm rate) on the animacy and odd-digit distracting task are presented in Table 3 for each age group and condition. We examined data from the two groups of older adults first, and found that the effect of encoding condition in older adults on accuracy rates for distracting tasks was nonsignificant, $F(1, 28) = 2.75$, $\eta^2 = .09$. We therefore collapsed these groups for a comparison with the young adult group, and report only this analysis. Data were analyzed in a 2 (task) × 2 (attention) × 2 (age group) × 6 (order of attentional manipulation) ANOVA. There was a main effect of attention, $F(1, 52) = 69.60$, $MSE = 0.02$, $\eta^2 = .57$, with poorer performance under DA ($M = 0.76$) than single-task conditions ($M = 0.92$). There was also a main effect of task, $F(1, 52) = 30.52$, $MSE = 0.01$, $\eta^2 = 37$, with poorer accuracy on the animacy ($M = 0.80$) than odd-digit task (M = 0.87). The Attention × Task interaction was also significant, $F(1, 52) = 16.63$, $MSE = 0.01$, $\eta^2 = .24$. Planned comparisons showed that accuracy rate on each distracting task did not differ under single-task, but only under DA conditions. Performance was poorer in the animacy ($M = 0.70$) compared to odd-digit DA condition ($M = 0.81$), $t(63) = -5.90$. The main effect of age group was nonsignificant, $F(1, 52) = 0.92$, $p > .05$, $\eta^2 = .02$, as were the Attention × Age, and Task × Age interactions, $F(1, 52) = 1.52$, $\eta^2 = .03$, and $F(1, 52) = 0.23$, $\eta^2 = .01$, $ps > .05$, respectively. All three-way interactions and the four-way interaction with task, attention, and order were nonsignificant.

Analysis of percentage decline in accuracy rate showed a main effect of DA condition, $F(1, 52) = 1972$, $MSE = 0.02$, $\eta^2 = .28$, indicating that there were greater costs to performance in the DA

[3] The power of our experiment to detect a significant Age × DA Condition interaction is .54. Nevertheless, we did find a significant interaction. Older adults performed *better* in the odd-digit DA than FA condition, whereas young adults did not show this benefit. In order to achieve a power of .80, we would require a sample of over 1,300, thus we believe that any differences in effect size between age groups, in a direction that would support the general resource account, are so small that we consider them to be functionally nil.

Table 3
Accuracy Rate (Hit Rate − False Alarm Rate) on Distracting Tasks and Percentage of Decline From Single-Task to Divided-Attention Conditions for Each Group

	Young adults (n = 24)		Older adults[a] (n = 24)		Older adults[b] (n = 16)		All older adults (n = 40)	
Measure and condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Accuracy rate								
Single-task odd-digit	0.92	0.06	0.92	0.06	0.94	0.06	0.93	0.06
DA odd-digit	0.85	0.10	0.78	0.17	0.81	0.18	0.79	0.18
Single-task animacy	0.91	0.07	0.90	0.08	0.93	0.05	0.91	0.07
DA animacy	0.72	0.14	0.66	0.19	0.74	0.17	0.69	0.19
% decline in accuracy								
DA odd-digit	7.50	13.85	15.13	19.52	13.24	20.94	14.37	19.86
DA animacy	20.10	16.56	26.95	21.29	20.17	19.90	24.24	20.40

Note. DA = divided attention.
[a] Older adults given two encoding opportunities/condition. [b] Older adults given one encoding opportunity/condition.

animacy (M = 22.69) than DA odd-digit condition (M = 11.80). The effect of age group was nonsignificant, $F(1, 52) = 1.69$, $\eta^2 = .03$, as were all interactions. The correlation between accuracy rate on each distracting task under the DA conditions, and memory interference for that condition, was nonsignificant for both age groups. Thus, trade-offs between the memory and distracting task do not appear to be variables influencing performance levels.

Reaction time. The mean RT to make a response to target items for each distracting task, in the single-task and DA conditions, is noted in Table 4 for each group. We examined data from the two groups of older adults first, and found that the effect of encoding condition in older adults was nonsignificant, $F(1, 28) = 2.94$, $p > .05$, $\eta^2 = .09$. We therefore collapsed these groups for a comparison with the young adult group, and report only this analysis. Data were analyzed in a 2 (task) × 2 (attention) × 2 (age group) × 6 (order of attentional manipulation) ANOVA. There was a main effect of attention, $F(1, 52) = 210.79$, $MSE = 10{,}083.81$, $\eta^2 = .80$, with slower RTs under DA (M = 917.94) compared to single-task conditions (M = 729.53). The main effect of task, $F(1, 52) = 276.74$, $MSE = 9{,}391.62$, $\eta^2 = .84$ was also significant, with slower RTs on the animacy task (M = 927.90) compared to the odd-digit task (M = 719.57). The Attention × Task interaction was also significant, $F(1, 52) = 6.13$, $MSE = 15{,}018.38$, $\eta^2 = .11$. The difference in RT between single and DA conditions was greater for the animacy than odd-digit task (but see analysis of relative percentage change in RT, reported in the following).

The main effect of age group was not significant, $F(1, 52) = 2.06$, $\eta^2 = .04$, $p > .05$, but the Task × Age group interaction was, $F(1, 52) = 4.21$, $MSE = 4{,}695.81$, $\eta^2 = .08$. There was an effect of age on RT for the animacy task, $t(62) = -2.15$, $p = .04$, with older adults showing slower RTs than young adults. There was no effect of age on RT for the odd-digit task, $t(62) = -.45$, $p > .05$. The Attention × Age group interaction was nonsignificant, $F(1, 52) = 0.12$, $\eta^2 = .00$, $p > .05$. All other two-way and three-way interactions and the four-way interaction with task, attention, and order were nonsignificant.

Percentage increase in RT under DA conditions. In the following analyses we considered the percentage increase in RT under DA conditions as the dependent variable. Planned comparisons showed that the single-task RTs for the distracting tasks differed significantly, $t(63) = 14.49$, thus making comparisons of

Table 4
Reaction Time (in Milliseconds) on Distracting Tasks and Percentage of Increase From Single-Task to Divided-Attention Conditions for Each Group

	Young adults (n = 24)		Older adults[a] (n = 24)		Older adults[b] (n = 16)		All older adults (n = 40)	
Measure and condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Reaction time								
Single-task odd-digit	638.08	88.57	655.13	110.19	624.13	121.72	642.73	114.43
DA odd-digit	792.17	126.82	834.25	139.78	775.81	108.05	810.88	129.82
Single-task animacy	790.86	100.99	857.79	140.82	843.81	110.60	852.20	128.25
DA animacy	1,004.67	148.53	1,092.25	129.84	1,031.63	161.99	1,068.00	144.71
% increase in reaction time								
DA odd-digit	18.34	11.60	20.11	14.25	19.22	11.72	19.75	13.15
DA animacy	20.49	10.15	20.85	13.84	16.91	13.16	19.28	13.54

Note. DA = divided attention.
[a] Older adults given two encoding opportunities/condition. [b] Older adults given one encoding opportunity/condition.

relative interference effects on distracting tasks problematic. As such we calculated the percentage change in RT from single to DA conditions, and then compared interference effects. This was calculated by subtracting the RT in each of the single-task conditions from that in the DA condition, and then dividing by the RT in the DA condition.

The effect of DA condition was nonsignificant, $F(1, 52) = 0.21$, therefore interference effects on distracting-task RTs were similar for the animacy and odd-digit tasks. The effect of age group was nonsignificant, $F(1, 52) = 0.01$, $\eta^2 = .00$, as were all interactions. As such, older and younger adults did not differ in terms of RT interference, even though older adults did show longer response RTs, at least on the animacy task. The correlation between RT for each distracting task under the DA conditions, and memory interference, was nonsignificant for both age groups. Thus, trade-offs between the memory and distracting task do not appear to be variables influencing performance levels.

Distracting Tasks Performed Concurrently With the Auditory CRT Task

Data from the auditory CRT task for 22 of the 24 young participants were available for analysis; due to experimenter error, data for 2 participants were lost. Data were collected from 20 of the 24 older adults in the group that studied lists twice at encoding; 4 participants in that group declined participating in the CRT task session for reasons relating to poor general health or stroke (in 1 participant) since the initial testing session.

Distracting tasks. Data were analyzed in a 2 (DA condition) × 2 (age group) × 2 (order of DA condition) ANOVA, using accuracy rate on distracting tasks as the dependent variable. The main effect of age group was significant, $F(1, 38) = 9.04$, $MSE = 0.02$, $\eta^2 = .19$, with older adults showing poorer accuracy rates on distracting tasks (see Table 5). The main effect of DA condition was nonsignificant, $F(1, 38) = 0.55$, thus accuracy rates on the distracting tasks under dual-task conditions did not differ from each other. The Age × DA Condition interaction was also nonsignificant.

Table 5
Accuracy Rate on Distracting Tasks, Correct Responses, and Reaction Time (in Milliseconds) on the Auditory Continuous Reaction-Time (CRT) Task

	Young adults (n = 22)		Older adults (n = 20)	
Measure and condition	*M*	*SD*	*M*	*SD*
Accuracy rate on distracting tasks				
DA odd-digit	0.71	0.14	0.57	0.18
DA animacy	0.69	0.14	0.56	0.21
Correct responses on CRT task				
Baseline	97.82	22.41	75.95	24.95
DA odd-digit	77.23	20.48	46.60	21.29
DA animacy	72.09	17.49	44.90	22.09
Reaction time on CRT task				
Baseline	793.90	177.19	1,099.04	320.57
DA odd-digit	908.35	199.46	1,424.18	261.50
DA animacy	956.26	174.01	1,407.51	245.99

Note. DA = divided attention.

CRT task. Data were analyzed in a 3 (attentional condition) × 2 (age group) × 2 (order of DA condition) ANOVA, using number of tones correctly identified (on the auditory CRT task) as the dependent variable. The main effect of age group was significant, $F(1, 38) = 16.43$, $MSE = 449.97$, $\eta^2 = .30$, with older adults identifying fewer tones than young adults (see Table 5). The main effect of attentional condition was significant, $F(2, 76) = 214.31$, $MSE = 46.96$, $\eta^2 = .85$. More tones were identified under single-task compared with the odd-digit and animacy DA conditions, $F(1, 38) = 290.06$, $MSE = 90.08$, $\eta^2 = .89$, and $F(1, 38) = 259.39$, $MSE = 130.20$, $\eta^2 = .87$, respectively. Significantly fewer tones were identified in the animacy compared to odd-digit dual-task condition, $F(1, 38) = 7.96$, $MSE = 61.51$, $\eta^2 = .17$. There was also an interaction of Age × Attentional Condition, $F(2, 76) = 4.35$, $MSE = 46.96$, $\eta^2 = .10$. Planned comparisons showed that the number of tones identified under each dual-task condition did not differ for older adults, $t(19) = -0.77$, although for young adults, significantly fewer tones were identified in the animacy than odd-digit dual-task condition, $t(21) = -3.03$, $p < .05$.

The mean RT to identify tones on the CRT task is shown for correct responses only, in each condition (see Table 5). An outlier analysis eliminated RTs greater or less than two standard deviations from the mean for each participant in each condition. Data were analyzed in a 3 (attentional condition) × 2 (age group) × 2 (order of DA condition) ANOVA, using RT to correctly identified tones as the dependent variable.

The main effect of age group was significant, $F(1, 38) = 40.54$, $MSE = 46{,}469.19$, $\eta^2 = .97$, with older adults showing longer RTs in all attentional conditions. The main effect of attentional condition was also significant, $F(2, 76) = 49.38$, $MSE = 14{,}706.48$. RTs were significantly slower in the odd-digit and animacy DA conditions compared to the single-task condition, $F(1, 38) = 58.88$, $MSE = 34{,}385.11$, $\eta^2 = .61$, and $F(1, 38) = 83.85$, $MSE = 27{,}696.47$, $\eta^2 = .69$, respectively. However, there was no significant difference between RTs in the odd-digit compared to animacy DA conditions, $F(1, 38) = 0.39$, $p > .05$, $\eta^2 = .01$.

There was an interaction of Age × Attentional Condition, $F(2, 76) = 8.29$, $MSE = 14{,}706.48$. Planned comparisons showed that the RT, under each dual-task condition, did not differ for older adults, $t(19) = -0.37$, although for young adults it approached significance, $t(21) = 1.93$, $p = .07$. Interestingly, older adults tended to have longer RTs to identify tones in the odd-digit compared to animacy DA condition, but the reverse was true in young adults.

General Discussion

This experiment was conducted to determine whether competition for general processing resources or for a common representational system best accounts for interference effects on memory for a list of unrelated words under DA at retrieval. To distinguish between these hypotheses, we compared the performance of older and younger adults.

Memory Costs

The major finding from this experiment is that young and old adults were similarly affected by the DA conditions. In line with the component-process model, the animacy distracting task interfered substantially with free recall, whereas the odd-digit task had a smaller effect on memory, and these effects were similar in magnitude in young and old adults. These results do not support a single resource account of retrieval interference effects. A reduced attentional resource view of aging (Craik, 1983; Craik & Byrd, 1982; Rabinowitz et al., 1982) suggests that an age-related loss of available resources impairs the ability to engage in resource-demanding cognitive operations, such as encoding or retrieval. If interference effects occur because DA demands significant processing resources, to the point of overextending a limited pool of general resources, then older adults should have even greater difficulty under DA conditions, as they have fewer resources available for the tasks, and/or must recruit additional resources to carry out the tasks compared with young adults. In either case they would show amplified interference effects.

One could also interpret our results in terms of a multiple-resource model (Allport, Antonis, & Reynolds, 1972; Brooks, 1968; Wickens, 1980) of attention, which suggests that there are separate pools of attentional resources for the processing of different types of materials. Numerous studies of dual-task performance of short-term or working memory tasks have shown that interference effects are larger when two verbal tasks are combined, compared to when tasks requiring verbal and spatial processing are combined. Applied to the work here, the processing of word and number material may require relatively distinct control centers, thus can be processed independently, leading to little interference under dual-task conditions. We favor the component-process model account of material-specific effects because, like the general (single) resource model, a multiple-resource model still places the locus of the large material-specific interference effect at the level of attentional resources. Thus, older adults, characterized as having diminished resources, should have shown amplified interference.

Yet another alternative to the component-process model, for the large material-specific DA effect, is that competition is created at the level of input–output channels in working memory. According to Salthouse's (1996) view, aging is associated with a cognitive slowing that reduces the amount and quality of information simultaneously available in working memory, or the "dynamic capacity" (p. 406) of working memory. Along the same lines, age-related differences in memory and other cognitive functions can be attributed to a decline in attentional inhibitory control over the contents of working memory. As suggested by Hasher and Zacks (1988), older adults are more distracted by irrelevant information, and this reduced inhibitory control allows more "nongoal" information to enter working memory, thereby producing difficulty with memory. Given these accounts of the state of working memory, older adults in our study should have been affected to a greater degree in the animacy DA condition than they were, if competition for a verbal working memory buffer underlies the large effect.[4] Our results suggest that the ability to retrieve words from memory while attending to competing irrelevant material is not affected by aging. Surprisingly, both groups of older adults performed better in the odd-digit DA condition than FA condition during retrieval. We have no explanation for this finding, except that perhaps adding a distracting task raises arousal, which improves performance (see Kahneman, 1973).

Furthermore, both young and older participants recalled few, if any, additional words after the DA conditions ended. That is, the effect of DA from the word-based distracting task persisted in both age groups. Such results are consistent with the notion that word-based distracting tasks interfere by corrupting the memory trace (Fernandes & Moscovitch, 2000, 2002) prior to its being reported, rather than competing for input–output channels in working memory, in which case memories should recover once the distracting task ends.

The lack of a large interference effect on memory from the digit-based distracting task may also indicate that digits are represented independently from words or word forms. Consistent with this claim, Allison, McCarthy, Nobre, Puce, and Belger (1994), using electrophysiological recordings, showed a negative potential, N200, in discrete regions of the fusiform and inferior temporal gyri that were in different locations for face, letter-string, and number stimuli. This led them to conclude that different "modules" exist for the processing of numbers, in addition to the previous suggestion that there are separate processing streams for faces and words (Farah, 1990; Farah, Wilson, Drain, & Tanaka, 1998).

Distracting-Task Costs

According to the component-process model described in the Introduction, the resource-demanding aspect of retrieval lies in establishing and maintaining retrieval mode, as well as in monitoring output. These processes are thought to be mediated by the PFC. Insofar as the memory task makes use of these processes, the resource demands should be reflected in costs to distracting-task performance. Indeed, such costs were noted in both age groups. That we did not find larger distracting-task costs in older adults, however, was unexpected. If such costs reflect the resource-demanding aspect of retrieval and are mediated by the PFC, then older adults should have been affected more than our results indicate.

Previous work that examined performance on the distracting tasks (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997) showed a larger decline in performance from single- to dual-task conditions. In these studies, however, the dependent measure was latency. Had we emphasized the importance of making responses quickly (we emphasized to participants the importance of accuracy rather than RT), an effect of age might have emerged. Nevertheless, one should keep in mind that the costs to the distracting task were always significant, thereby illustrating that retrieval does make resource demands, although these experiments do not allow us to ascribe these demands to the needs of the frontal lobe.

It could be that our distracting tasks were much easier than those used in other studies where there were age differences in distracting-task costs incurred by the DA condition (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997). If, however, our tasks were easier, then the effect of the animacy task on memory should also have been

[4] Contrary to these views, recent work by Hale and Myerson (1996), and Jenkins, Myerson, Joerding, and Hale (2000) suggests that older adults have had extensive practice with verbal information over the course of a lifetime, and as such, are likely to show little age-related slowing on working memory tasks involving verbal processing. It is unclear, however, whether such practice could account for the lack of an age difference in interference effects in this study. Further research is needed to test whether their hypothesis applies to long-term memory of verbal information.

smaller than that found in other studies. Instead, its effect on memory was quite substantial. The only age difference that emerged was in RT to make a response to words in the animacy task; it was longer in older adults. However, the overall percentage increase in RT from single- to dual-task conditions did not differ with age. Thus older adults may have a deficit in processing speed, but this did not have an impact on susceptibility to interference under DA conditions.

It may also be that our measures of distracting-task performance are not sensitive enough to differentiate young and average, from older and high-functioning, adults. For example, in recent work, Fernandes, Davidson, Glisky, and Moscovitch (2002) examined directly how different levels of frontal lobe (FL) function affected performance under DA conditions. They examined interference effects in a group of community-dwelling older adults in the same experiment as the one presented here (study lists were heard twice at encoding). These older adults were divided preexperimentally into four groups, determined by their scores on measures of FL and medial temporal lobe (MTL) function, derived from neuropsychological testing. We found that the level of FL and MTL function did not change the magnitude or pattern of interference on memory performance. Costs to distracting-task performance, on the other hand, were somewhat elevated in those with low compared to high levels of FL function. Thus the effect of DA, on the distracting task itself, is likely related to the level of FL function and available processing resources, although the present experiment does not allow us to determine the extent.

Difference in Level of Distracting-Task Difficulty

Single-task performance of the animacy and odd-digit task, as measured by accuracy, did not differ from each other, suggesting that the tasks had similar levels of difficulty. In contrast to this measure, RTs were longer for the animacy than odd-digit distracting task. However, because we did not emphasize to our participants the importance of responding quickly to distracting-task items, conclusions about the level of difficulty of each task based on differences in RT must be made cautiously.

We can also consider performance on the auditory CRT task, performed concurrently with each of the distracting tasks, as a measure of the level of difficulty of each task. The CRT task had similar effects on accuracy rates for each of the distracting tasks. For young adults, the number of tones identified on the CRT task was lower when the animacy, rather than odd-digit, task was performed concurrently, although there was no significant difference in older adults. (In fact, older adults identified more tones in the animacy than odd-digit dual-task condition!) Thus there were no consistent measures showing that one task was more difficult or resource demanding than the other. Furthermore, RTs to identify tones were similar, regardless of whether the CRT task was performed concurrently with the animacy or odd-digit task, suggesting that the distracting tasks require similar amounts of resources.

What Can These Results Tell Us About Memory in Older Adults?

Large age differences are usually found in tests of free recall, but these are smaller when the memory test is cued recall, and there often are no age differences on tests of recognition (Craik & McDowd, 1987; Rabinowitz, 1984). Thus, age differences in memory performance diminish when retrieval is aided in older adults by cuing or, in more general terms, by environmental support. If recall is more effortful than recognition and requires a large amount of resources, and aging is associated with a decline in available resources, then this decline will be reflected in poorer performance on tests such as free recall that make heavy resource demands.

However, as suggested in previous work (Nyberg et al., 1997), the finding of interference effects from DA at *retrieval* that are similar in magnitude in young and older adults, does not support the hypothesis that age-related deficits in episodic memory retrieval are due to reduced attentional capacity. Likewise, this experiment showed that performing a concurrent, resource-demanding, distracting task during free recall did not disrupt memory more in older adults than in younger adults. Our results suggest that in older and younger adults, associative, cue-dependent retrieval (ecphory) is relatively unaffected by the amount of available resources, although maintaining retrieval mode and monitoring the products of retrieval (see the following) may require resources.

A review of the literature on effects of DA at *encoding* provides mixed support for the reduced-resource view of aging. In both young and old adults, performing a concurrent task during encoding has a large interference effect on subsequent memory performance (Anderson et al., 1998; Nyberg et al., 1997; Park et al., 1989), thereby supporting the claim that encoding operations consume attentional resources (Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000). However, it remains an open question whether older adults show greater interference than young adults, as predicted by a reduced-resource view of aging. Anderson et al. and Nyberg et al. found no effect of age on the size of interference on memory from DA at encoding. In contrast, Park et al. did find a larger effect in older adults, although the memory test used in their study consisted of free or cued recall of a list of categorized words that may draw more heavily on resources mediated by the frontal lobe (Moscovitch, 1994), which is believed to be compromised in this group (Moscovitch & Winocur, 1995).

In addition to the effects of DA at encoding on memory, one can also consider its effects on the distracting task. Anderson et al. (1998) found larger RT costs on their distracting task, in older adults compared with younger adults, which may reflect inefficient functioning of the frontal lobes. However, this increased slowing on the distracting task does not make them more susceptible than young adults to memory interference from DA at encoding. Thus, whether a reduction in available resources at encoding, associated with aging, can account for the poorer episodic memory characteristic in aging remains to be shown conclusively.

These results can also be brought to bear on the issue of age differences in recall, but not recognition performance (Craik & McDowd, 1987; Rabinowitz, 1984). That older adults benefit more from cuing during recognition than recall does not necessarily indicate that they do so because of a lack of processing resources needed to implement strategies and guide retrieval. It may simply reflect poor strategy use and/or storage (or lack thereof) in older adults during encoding, which results in formation of a trace that can be recovered only with extensive cuing or environmental support. The results here certainly support this possibility because manipulations of available resources during retrieval did not produce age differences in memory performance, although differences in encoding conditions in older adults did alter absolute levels of recall performance. This idea applies primarily to tests of recall and recognition that are associative and/or cue dependent. When retrieval tests are strategic and more reliant on FL processes, availability of cognitive resources may be a crucial factor. On these tests, older adults should show greater memory interference under DA than younger adults.

Conclusion

These data, together with other information showing no age-related increase in the effects of DA at retrieval, suggest that free recall of a list of unrelated words proceeds obligatorily, and is relatively immune to disruption. It is only when the memory task shares the same representational system as the distracting task that large effects on memory are seen. Results support the hypothesis derived from the component-process model, that interference from DA at retrieval arises from competition in brain regions representing the content of the memory trace (the posterior neocortex), rather than in regions mediating control processes responsible for coordinating dual tasks (the frontal lobes). Because the former regions are relatively preserved with aging, and access to these representations occurs relatively automatically (i.e., it requires few cognitive resources), older adults show a pattern of interference effects on memory that are similar to that of young adults.

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