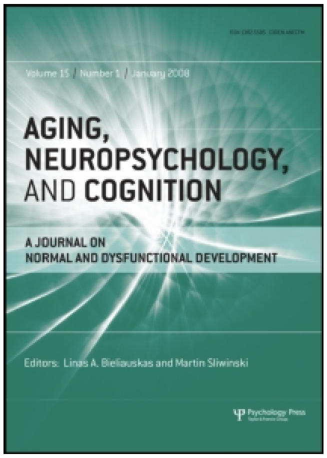

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Adult Age Differences in the Access and Deletion Functions of Inhibition

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Adult Age Differences in the Access and Deletion Functions of Inhibition

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ABSTRACT

This study examined age differences in working memory using a delayed-matching-to-sample (DMTS) task. Based on the inhibitory decline hypothesis, which posits that older adults are more susceptible to interference, age differences were expected to be greater for older adults when irrelevant information was present during encoding. Two experiments tested both the access and deletion functions of inhibition. In both experiments, performance was equated for older and younger participants on a no-interference version of the DMTS task to control for age differences in encoding information into working memory. Results consistently showed equivalent effects of distraction for older and younger adults regardless of the difficulty of the perceptual discrimination of targets and distractors, the degree of processing of the distractors, or the semantic relationship between targets and distractors. These results support theories that propose age differences in encoding to explain age differences in working memory, and are inconsistent with theories that propose that older adults are more susceptible to interference than younger adults.

Keywords: Access; Aging; Deletion; Inhibition; Working memory.

INTRODUCTION

There is strong empirical evidence that working memory, the ability to temporarily hold and manipulate information (Baddeley & Hitch, 1974; Baddeley, 1986), is affected by increased age. Nevertheless, the locus of age differences has not been fully determined. The purpose of this study is to test the hypothesis that age differences in working memory result from an increased susceptibility to interference. Interference control is important

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because working memory tasks typically require the ability to keep relevant information in mind while processing or ignoring other information that is irrelevant to the memory portion of the task.

According to Hasher and Zacks (1988), age differences in interference result from the inability of older adults to effectively inhibit information, and in particular from declines in three major inhibition functions in working memory: control of access, deletion, and restraint of irrelevant information (Hasher, Zacks, & May, 1999). The first two of these, the access and deletion functions, are important determinants of the contents of working memory. The access function keeps recently activated but irrelevant information from entering working memory, and the deletion function serves to remove information that has entered working memory but is no longer relevant. The restraint function, in contrast, is important in keeping prepotent response tendencies from driving further cognition, but has a less direct effect on the contents of working memory. Because of our focus on interference involving the contents of working memory, we consider here only the deletion and access functions.

Inhibition may best be thought of as a function of the central executive portion of working memory. In Cowan's (1988, 1999) model, working memory is conceptualized as the activated portion of long-term memory, which in turn contains information both inside and outside the focus of attention. The focus of attention has a very restricted capacity, limited in some cases to as little as one item (e.g., Garavan, 1998; McElree, 2001; Verhaeghen & Basak, 2005), so that when multiple pieces of information are held in working memory, attentional mechanisms under the control of the central executive move information in and out of focused attention as needed. Outside the focus of attention, passive mechanisms are thought to keep information activated, and information becomes increasingly unavailable over time through decay and over-writing (Cowan, 1988, 1999). It is also possible that active attentional mechanisms operate outside the focus of attention, both to keep information activated (Morey & Cowan, 2004; Oberauer, 2002), as well as to inhibit irrelevant information (Oberauer, 2001; Oberauer & Kliegl, 2001).

In the context of this working memory model, the hypothesis of age-related changes to the access mechanism implies that older adults allow both relevant and irrelevant information to enter into the focus of attention. As to age differences in the deletion function, older adults may fail to selectively remove irrelevant information that has already entered working memory. Overall then, the source of reduced interference control may lie in failures of age-related attentional mechanisms that control the contents of the focus of attention and sustain activation of information outside the focus of attention.

The prior literature provides partial support for age differences in the access function of inhibition. A study using the listening span task, for instance, has reported age-related disruptions of working memory in the presence of background noise (Pichora-Fuller, Schneider, & Daneman, 1995). Much of the remaining evidence comes from studies of selective attention and of sentence comprehension under distraction. Selective attention paradigms engage the access function in that they require the ability to prevent irrelevant information from gaining access to the focus of attention. Evidence for age differences from this type of task includes negative priming tasks, in which older adults show less evidence of inhibiting to-be-ignored non-target stimuli (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). Similarly, on conjunction visual search tasks, older adults are slower to identify targets (Plude & Doussard-Roosevelt, 1989; Plude & Hoyer, 1986; Scialfa, Esau, & Joffe, 1998). Reading with distraction tasks require a combination of selective attention and working memory mechanisms, and they often show more interference from irrelevant text in older than younger adults (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991; Langley, Overmier, Knopman, & Prod'Homme, 1998). In general, age differences in all these tasks are greater when there are more distractors (Hommel, Li, & Li, 2004) or when targets and distractors have high levels of similarity, either perceptual (Scialfa et al., 1998) or semantic (Carlson et al., 1995; Connelly et al., 1991).

Despite these findings in support of the access hypothesis, age differences are not always evident. For instance, age differences are not reliably found on negative priming tasks (Gamboz, Russo, & Fox, 2002; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Langley et al., 1998; Sullivan & Faust, 1993) or on tests of listening comprehension during irrelevant speech and noise, particularly when age differences in hearing are accounted for (Li, Daneman, Qi, & Schneider, 2004; Murphy, McDowd, & Wilcox, 1999; Schneider, Daneman, & Murphy, 2005). Additionally, age differences are generally not found when targets are in predictable locations. This is true both for visual search tasks (Greenwood, Parasuraman, & Haxby, 1993; Plude & Hoyer, 1986) and reading-with-distraction tasks (Carlson et al., 1995; Connelly et al., 1991). Thus, findings regarding the access function are inconsistent, although age differences are most consistently found when irrelevant information is not predictable and thus requires additional processing.

Turning to the deletion function, evidence for age differences is again inconclusive. For instance, one commonly cited source of support involves the reduced performance of older adults on complex span tasks, such as the reading span task (see Verhaeghen, Marcoen, & Goossens, 1993, for a meta-analysis). It is possible that reduced inhibition of no longer relevant information is the source of age differences; however, the task is complex and involves many additional cognitive processes, such as simple storage, coordination of multiple task demands, and sentence comprehension. In support of the deletion hypothesis is the finding of Li (1999) that age differences increase when relevant and irrelevant information are of the same type (e.g., both involving numbers). Nevertheless, McCabe and Hartman (2003) found no evidence for reduced inhibition as an explanation of lowered reading span performance in older adults; instead, simple storage and reduced speed provided the best account of age differences.

Other investigations of the efficiency of the deletion mechanism in older adults have produced mixed evidence. In studies of proactive interference, for instance, several studies using complex span tasks have shown smaller and even an elimination of age differences under conditions that lead to lessened proactive interference (Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999). In these studies, older adults benefited more than younger adults when the most difficult trials were presented first. Interpretation was complicated, however, by the additional finding that increasing time between trials, a manipulation also expected to reduce proactive interference, had a positive impact only on younger adults.

Studies of retroactive interference have also provided some support for age-related declines in deletion. For instance, Hedden and Park (2001) have demonstrated an age-related increase in interference in the context of learning short lists of word pairs. The conclusions are ambiguous here too, however, in that the same authors have more recently argued that such age differences are due to impairments in source monitoring (Hedden & Park, 2003).

A number of working memory studies of divided attention have also examined the deletion function of working memory, and again the results are inconsistent. Strongest support for age differences comes from tasks in which the primary and secondary tasks require similar types of processing (e.g., both verbal processing; Foos & Wright, 1992; Li, 1999; Park, Smith, Dudley, & Lafronza, 1989; Salthouse, Rogan, & Prill, 1984). In addition, age differences in deletion increase with increased memory load (Foos, 1995; Foos & Wright, 1992; Morris, Craik, & Gick, 1990; Oberauer, Wendland & Kliegl, 2003, but see Oberauer, 2001, for a conflicting result), and with increases in the number of cognitive operations required (Oberauer, Demmrich, Mayr, & Kliegl, 2001). Nevertheless, age differences are not always found (e.g., Morris, Gick, & Craik, 1988; Morris et al., 1990), and a meta-analysis of studies using simple span measures suggests no age-related increase in interference from secondary tasks (Jenkins, Myerson, Hale, & Fry, 1999).

A final set of studies looking at the deletion function have utilized tasks in which the contents of working memory must be continuously updated (Oberauer, 2001, 2005a,b; Oberauer & Kliegl, 2001). The findings show age equivalence in the ability to move information out of the focus of attention, but residual activation of no longer relevant information produces greater interference for older than younger adults. Formal modeling was consistent with an explanation in terms of reduced interference control in older adults, although increased noise could also account for age differences (Oberauer & Kliegl, 2001). In addition, age differences in interference do not occur for all updating tasks (Oberauer, 2005b, Experiment 2), and reduced recollection due to deficits in content-to-context binding may also explain the effects of age (Oberauer, 2005a, 2005b).

In sum, the literature provides partial support for age differences in inhibitory functions controlling the access and deletion of irrelevant information. Overall, these functions seem most consistently affected by age when relevant and irrelevant information are confusable, either because of similarity at the perceptual or semantic level, or because of the need to actively process irrelevant information. In terms of Cowan's (1988, 1999) model of working memory, it seems unlikely that older adults have difficulty moving the focus of their attention. Instead, age differences appear to involve greater activation of irrelevant information in the focus of attention (access function) and failures to de-activate no longer relevant information from activated long-term memory (deletion function). Nevertheless, there are conflicting findings that current theory cannot yet account for. In addition, there are often multiple possible interpretations of the findings (e.g., reduced source memory, recollection, or increased noise). Given the lack of consensus regarding age differences in the access and deletion functions, additional work is needed. The current study represents a first step in that direction.

OVERVIEW OF THE EXPERIMENTS

The goal of the two experiments presented here was to provide a straightforward and rigorous test of age differences in access and deletion functions in working memory. We focused on inhibition at the time of encoding, varying the presence of irrelevant information and utilizing multiple manipulations in order to test for limits and boundary conditions. Both experiments used a verbal version of the delayed matching to sample (DMTS) task that has previously been shown to be sensitive to age differences in working memory (Hartman, Dumas, & Nielsen, 2001). This task requires participants to first bring a sub-span amount of information (e.g., three words) into working memory and then maintain that information in the activated portion of long-term memory over a filled delay interval. Memory is tested with a single-item recognition memory test. This simple working memory test, which does not require manipulation of information, was chosen in order to be able to isolate the deletion and access processes of inhibition. With the DMTS task, it is possible to manipulate the presence and degree of processing of irrelevant information without simultaneously affecting other components of working memory. In addition, we chose to use sub-span information so that we could focus on the access and deletion processes in a simpler model without the addition of possible capacity differences between older and younger adults.

In order to ensure that any age differences we observed in the presence of distraction were related solely to the access and deletion functions of inhibition, it was important to control for extraneous factors that might differentially affect younger and older adults. The primary way we achieved this was to establish baseline, no-interference conditions, with equivalent performance for the two age groups. We did this in order to control for the possibility that age differences in overall task difficulty, and specifically the reduced availability of information in working memory, might produce an appearance of age effects on interference (Oberauer, 2005a, 2005b). Thus, in each experiment, we used a pretest to determine individually for each participant the amount of study time needed to reach a preset performance criterion under no-interference conditions, and then used that study time for the conditions examining the effects of interference.[1] If age differences in interference are a result of reduced inhibition, older adults should have lower performance when irrelevant information is present even after baseline conditions are equated for older and younger adults.

EXPERIMENT 1

Experiment 1 addressed two hypotheses. The first was that older adults are less able than younger adults to prevent irrelevant information from gaining access to working memory during encoding. To test this hypothesis, one condition, called the distraction-no processing condition, included irrelevant stimuli; some of the stimuli were enclosed in circles, and only circled stimuli needed to be remembered. Identifying the target stimuli was expected to be very easy under these circumstances. To test for age differences in the access function, this condition was compared to a control, no-distraction condition.

The second hypothesis was that older adults are less able than younger adults to delete information in working memory that is no longer relevant. Thus, in another condition of the DMTS task, called the distraction-processing

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[1] We used a baseline task with a 6-s filled delay between study and test because previous research in our laboratory with a similar DMTS task (Dumas & Hartman, 1999) showed that the presence of such a delay did not contribute to age differences. Thus, when older adults were given enough time to eliminate age differences in no-delay conditions, adding a filled delay interval did not produce any additional age differences.

condition, participants first read aloud both target and distractor stimuli, after which a subset of the stimuli were identified as targets for the memory test. Thus, both relevant and irrelevant information were initially attended and entered into the focus of attention; deletion was then required to dampen activation of the irrelevant information. Interference was measured by comparing the distraction-processing condition to two control conditions, the distraction-no processing condition described above, and a similar condition with extended study time. The latter was used to approximate the additional exposure to the stimuli required for the reading of stimuli in the distraction-processing condition.

In addition to comparing levels of accuracy across conditions, we also examined the pattern of errors as a further test of the effects of interference on working memory. Thus, in conditions with distraction, the recognition memory test included one studied word, one distractor word that was present at encoding, and one new word. If the distractor words entered working memory more frequently in older than younger adults because of impaired access processes, or remained longer because of impaired deletion processes, then older adults should show a greater tendency to choose the distractor items at test.

METHOD

Participants

Participants were 36 older adults ages 65–89 (*M(SD)* = 74.1(6.5)) and 36 younger adults ages 18–30 (*M(SD)* = 19.3(2.1)). The older adults were recruited through notices and newspaper advertisements and paid $15 for their participation. The younger adults were undergraduate students who participated for credit in an introductory psychology course. Requirements for participation included self-reports of good health, normal or corrected-to-normal vision, and having English as their native language. Exclusion criteria included a history of neurological and psychiatric disorders or other major illnesses that may affect cognitive functioning, current use of psychoactive medications, and consumption of more than three alcoholic drinks per day. All older adults were also screened for dementia with the Mini-Mental State Exam (MMSE, Folstein, Folstein, & McHugh, 1975), using a cutoff score of 27 out of a maximum of 30. All participants were also screened for depression with the Beck Depression Inventory – II (BDI–II; Beck, Steer, & Brown, 1996; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), and for anxiety with the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988; Beck & Steer, 1990). Inclusion in this study required that all participants attain a score lower than 19 out of a maximum of 63 on the BDI–II and a score lower than 15 out of a maximum of 63 on the BAI. Data from two younger adults were replaced for not meeting the criterion on the BDI–II by testing two new younger subjects.

Materials and Design

The stimuli were 520 words selected from the Nelson, McEvoy, and Schreiber (1998) norms. The linguistic frequency of the words ranged from 6 to 150 occurrences per million (Francis & Kucera, 1982), and all words were of medium to high concreteness (e.g., items with a rating of four or greater on a seven point scale, Paivio, Yuille, & Madigan, 1968; Toglia & Battig, 1978). Furthermore, the words were between four and seven letters in length, and consisted of between one and three syllables. For each trial, care was taken to ensure that words were not meaningfully related, and words were matched across condition for concreteness and word frequency. Words were counterbalanced such that they appeared in each of the conditions an equal number of times across participants. Each word was only used one time during the testing session for a particular participant.

The experiment consisted of a 2 (age) × 4 (condition: no distraction, distraction-no processing, distraction-processing, and extended time) design. Age was a between-subjects factor and condition was a within-subjects factor. The order of the four conditions was counterbalanced.

Procedure

Participants were tested individually. Older adults were administered the MMSE at the beginning of the session. To adjust for age differences in the ability to learn the task, older adults were given two practice blocks of eight trials in the no-interference condition, using different stimuli. After this, there were no differences in the procedure for the younger and older adults.

Each participant completed a calibration procedure for the DMTS task in order to determine the amount of study time needed to produce 80% correct performance in the no-distraction condition. In this procedure, participants first saw three plus signs, “+++” in the middle of the screen for 500 ms. Then three circled words appeared, placed in three randomly selected positions out of six possible locations in an imaginary circle approximately 20 cm in diameter. All words and letters appeared in bold type with 18-point Courier New font. After the study period, a 6-s delay period began, during which participants were engaged in an unrelated letter comparison task consisting of 16 pairs of letters arranged in four columns on the computer screen. The participant’s goal was to start at the upper left hand column and proceed down each column from left to right, saying “yes” if the letters in each pair were the same or “no” if they were different. At the end of the delay period, recognition memory for one randomly selected target word was tested. Three words including one studied word and two new words were presented in a column in the center of the computer screen. Participants were instructed to point to the item that was studied previously, and responses were recorded directly on a touch screen monitor. There was no time limit for their responding. After participants chose their answer, they pressed the space bar to proceed to the next trial, which began after a one second inter-trial interval.

The calibration procedure utilized a method developed by Wetherill and Levitt (1965), using a criterion of 80% accuracy. In order to estimate 80% accuracy, this procedure used a starting study time of 1000 ms and proceeded as follows. If a participant made three correct responses in a row, the study time was decreased by 200 ms. If a participant made an error, the time was increased by 200 ms. This procedure continued until each participant completed six runs, with a run defined as a series of trials in which the direction of increasing or decreasing the study time did not change as defined by Wetherill and Levitt (1965). At the end of the procedure, the participant's study times for all trials in the calibration task were averaged. This time was then used as the study time for the rest of the experiment for that participant, except in the extended time condition.

Following the calibration procedure, participants completed the DMTS task. In all conditions, participants first saw three plus signs, "+++", for 500 ms in the middle of the screen, that indicated the trial was about to begin. For the no-distraction condition, the trials were similar to those in the calibration procedure. For the distraction-no processing condition, the study portion of each trial began with the presentation of six words arranged randomly around an imaginary circle. Three of the words were circled, indicating they were to be remembered. A six second delay followed, during which time participants performed the letter comparison task described above. Then recognition memory was tested by presenting one target, one distractor, and one new item.

For the distraction-processing condition, six words appeared on the computer screen, but without circles to indicate which words were to be remembered. Participants were required to read all six words aloud and then touch the computer screen, after which three of the words were circled to indicate they were to be remembered. The study period began at this point, and all words remained on the computer screen for the duration of the calibrated study time. The delay period and the recognition memory test proceeded as in the distraction-no processing condition.

The extended time condition was similar to the distraction-no processing condition except that the study time was longer. This condition was included to control for the additional exposure time that participants had to the targets in the processing condition while they read the words. In this condition, the words remained on the screen for an extended period of time, with the to-be-remembered words encircled and no requirement to read the words aloud.

The study times used were equal to the calibration time plus 2700 ms for older adults and 2200 ms for younger adults. The amount of time to be added was determined by pilot testing 10 older adults and 10 younger adults, and was equal to one-half of the median time each group took to read the six words and touch the screen. We added only one-half of the reading time in order to approximate the amount of extra exposure time the three target words received while participants were reading the words during the processing condition.

Each condition consisted of 20 test trials divided into two blocks of 10 trials each, separated by a rest break. At the beginning of each condition, participants were presented with a sample trial and three practice items in order to familiarize them with the procedure. After all DMTS tests were administered, participants completed the Shipley–Hartford vocabulary test (Shipley, 1940) and the depression and anxiety screening measures.

RESULTS

In all of the analyses for all experiments, the alpha level was set at .05. The effect size measure η^2 is reported for all significant results. According to standard conventions (Cohen, 1988), an η^2 of .01 is considered a small effect, .06 is a medium effect, and .15 is a large effect.

As a preliminary analysis, age differences in verbal ability were examined. Older adults performed better than the younger adults on the Shipley–Hartford Vocabulary Test, $t(70) = 10.61$, $\eta^2 = .62$, $p < .001$ ($M(SD) =$ 37.1(2.1) for older adults; $M(SD) =$ 30.1(2.8) for the younger adults), but scores on this test were not correlated with performance in any of the DMTS conditions for older or younger adults. Thus, age differences in verbal ability were not related to performance on the verbal working memory tasks.

The calibration procedure revealed that older adults required somewhat longer study times to achieve the same level of performance ($M = 966$ ms, $SD = 192$ for the younger adults and $M = 1127$ ms, $SD = 538$ for the older adults); however, this difference was not statistically reliable, $t(70) = 1.69$, $\eta^2 = .04$, $p > .09$.

Testing the Access Hypothesis

The hypothesis that age differences in working memory arise because older adults have difficulty preventing the access of irrelevant information to working memory was tested by comparing performance in the distraction-no processing and no-distraction conditions (Table 1). Performance on the DMTS task was examined by means of a 2 (age group) × 2 (condition: no-distraction versus distraction-no processing) mixed factorial ANOVA, with the latter as a within subjects factor (see Table 1). The ANOVA revealed two significant effects. First, there was a main effect of age group, $F(1, 70) = 4.77$,

TABLE 1. Mean (standard deviation) proportion of words correctly recognized in Experiment 1

Condition	Older adults	Younger adults
No distraction	0.82 (0.10)	0.85 (0.09)
Distraction-no processing	0.78 (0.11)	0.82 (0.10)
Distraction-processing	0.73 (0.11)	0.72 (0.10)
Extended time	0.94 (0.07)	0.97 (0.05)

$MSE = 0.01$, $\eta^2 = .06$, $p < .05$, indicating that older adults performed worse than the younger adults. Second, there was a main effect of distraction, $F(1, 70) = 4.76$, $MSE = 0.01$, $\eta^2 = .06$, $p < .05$, with worse performance in the distraction-no processing condition. The interaction between age group and distraction did not approach significance, $F(1, 70) = 0.24$, $MSE = 0.01$, $\eta^2 = .003$, $p > .63$.

Errors in the distraction-no processing condition were examined to determine whether they involved choosing an item seen during the study period (i.e., a distractor) more often than choosing a new item (see Table 2). Data were analyzed only for participants who made errors on the distraction-no processing condition; thus, all of the older adults but only 33 of the younger adults were included. A *t*-test comparing older and younger adults on the proportion of errors that were false alarms to the distractor items revealed no age differences, $t(65) = 0.18$, $\eta^2 = .0005$, $p > .86$. In fact, neither older, $t(33) = 0.86$, $p > .40$, nor younger adults, $t(32) = 1.21$, $p > .23$, chose the distractor item more often than chance (.50) when they made errors.

Testing the Deletion Hypothesis

To address the hypothesis that older adults have difficulty deleting no longer relevant information from working memory, performance in the distraction-no processing, distraction-processing, and extended time conditions

TABLE 2. Mean (standard deviation) errors involving distractors as a proportion of total errors for older and younger adults and number of participants making errors in each condition in Experiments 1, 2a, and 2b

Condition	Older adults	Younger adults
Experiment 1		
Distraction-no processing	0.51 (0.30) $n = 36$	0.53 (0.26) $n = 33$
Distraction-processing	0.92 (0.13) $n = 34$	0.91 (0.19) $n = 36$
Extended time	0.47 (0.41) $n = 22$	0.53 (0.46) $n = 13$
Experiment 2a		
Non-redundant distraction	0.57 (0.19) $n = 36$	0.60 (0.15) $n = 36$
Experiment 2b		
Unrelated	0.94 (0.12) $n = 35$	0.97 (0.09) $n = 36$
Related	0.75 (0.16) $n = 36$	0.82 (0.14) $n = 36$

was compared. A 2 (age group) × 3 (condition: distraction-no processing, distraction-processing, and extended time) mixed factorial ANOVA was used with the latter as a within-subjects factor (see Table 1). One significant effect was found, namely a main effect of condition, $F(2, 140) = 124.82$, $MSE = 0.01$, $\eta^2 = .64$, $p < .001$. Tukey's HSD *post-hoc* comparisons (HSD = .05) indicated that all three conditions reliably differed from one another. Performance was best in the extended time condition and worst in the distraction-processing condition, with performance on the distraction-no processing condition in between. Importantly, there were no significant effects involving age, main effect: $F(1, 70) = 2.99$, $MSE = 0.01$, $\eta^2 = .04$, $p > .08$; interaction: $F(1, 70) = 0.21$, $MSE = 0.01$, $\eta^2 = .02$, $p > .64$. As performance in the extended time condition was near ceiling, the data were also analyzed without that condition, using a 2 (age group) × 2 (condition: distraction-no processing and distraction-processing) mixed factorial ANOVA. Again, only the effect of condition was significant, $F(1, 70) = 21.04$, $MSE = 0.01$, $\eta^2 = .23$, $p < .001$, with worse performance in the distraction-processing than the distraction-no processing condition. No effects involving age approached significance, main effect of age: $F(1, 70) = 1.07$, $MSE = 0.01$, $\eta^2 = .02$, $p > .30$; interaction of age and distraction-processing condition, $F(1, 70) = 2.43$, $MSE = 0.01$, $\eta^2 = .03$, $p > .12$.[2]

The proportion of error responses that were false alarms to the distractor words was also examined (see Table 2), by means of a 2 (age group) × 3 (interference condition: distraction-no processing, distraction-processing, and extended time) mixed factorial ANOVA, with condition as a within-subjects factor. Only those participants who made errors in these conditions were included. Only 22 older adults and 13 younger adults made errors in the extended-time condition, and thus were included in this analysis. The only significant effect from this analysis was a main effect of interference condition, $F(2, 62) = 20.14$, $MSE = 0.08$, $\eta^2 = .39$, $p < .001$. Tukey's HSD *post-hoc* comparisons (HSD = .13) indicated that participants chose the distractor more often in the distraction-processing condition than in either the distraction-no processing or extended time condition. Performance was similar in these latter conditions. Participants chose the distractor words more often than chance (.50) in the distraction-processing condition only—young: $t(35) = 12.68$, $\eta^2 = .82$, $p < .001$; old: $t(34) = 19.37$, $\eta^2 = .92$, $p < .001$. In the distraction-no processing and extended time conditions, participants chose the distractor words no more often than chance. Overall, there were no age differences in the pattern of errors for any of the conditions. Thus, although

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[2] Older adults took longer to perform the distraction-processing task than younger adults, $t(70) = 6.64$, $\eta^2 = .39$, $p < .001$. Pearson-product moment correlations showed that there was no association between processing time and performance on the DMTS task for either age group.

irrelevant information entered working memory and was at times confused with the target words, there were no age differences in this effect.

DISCUSSION

Experiment 1 tested the inhibition hypothesis by examining the ability of older and younger adults to prevent access of irrelevant information to working memory and to delete information that is initially attended and then becomes irrelevant. With respect to the access function, older and younger adults were equally affected by the presence of irrelevant information that did not need to be attended, both with respect to accuracy in recognition of targets and to the pattern of errors. Thus, with older and younger adults' performance equated in the baseline condition, the effect of irrelevant information was similar for older and younger adults.

The lack of age differences in the effects of distraction cannot be explained by the failure of irrelevant information to affect performance. Both older and younger adults showed reduced accuracy in the presence of irrelevant words during encoding. Thus, it appears that irrelevant stimuli gained access to working memory at least sometimes, or else utilized attentional resources that would otherwise be allocated to the encoding of targets. The error analyses for the distraction-no processing condition suggest that the latter is more likely, in that participants chose distractors and new items equally often when they made an error, and distractors were chosen at chance levels. It seems likely then that both older and younger adults were successful in preventing access, but at the cost of reduced memory for target words.

Findings relevant to the deletion function came from a comparison of the distraction-processing condition to the distraction-no processing and the extended time conditions. For both age groups, performance was lowest in the distraction-processing condition, confirming that having to read the words aloud before knowing which were relevant and which were irrelevant had a negative effect on working memory. In addition, the pattern of false alarms in the distraction-processing condition showed higher than chance selection of distractor items. Taken together, these findings indicate that reading words indeed resulted in their entry into working memory, and that they were not always effectively deleted. Nevertheless, the interference effect was similar in size for older and younger adults. Despite the large negative impact of attending to irrelevant information, there was no evidence of differential effects of distraction for older adults. Thus, making demands on the deletion function did not result in age differences in working memory.

Thus far, results do not support the hypotheses of age differences in access and deletion processes in working memory. The following two-part experiment further investigated the inhibitory processes of older and younger adults, providing further tests of the hypotheses by creating conditions where it was more difficult to control access to working memory and delete irrelevant information from working memory.

EXPERIMENTS 2A AND 2B

Experiment 2a further tested the hypothesis of reduced control of access to working memory, using distraction conditions with targets and distractors that were less perceptually discriminable than in Experiment 1. In this experiment, the visual discrimination between the targets and distractors was made more difficult by using only the case of the letters to differentiate them. To further increase the difficulty of locating targets, the number of distractor items was increased to six. If older adults have difficulty with the access function of inhibition, they should show greater effects of distraction than younger adults. A corollary to this hypothesis was also tested, namely that the effects of age differences in inhibition would be lessened if the distracting information were redundant with the target items. As in Experiment 1, we equated performance for older and younger adults in the no-distraction condition through pretesting, in order to control for age-related difficulty in learning the target words. Thus, any age-related effects of interference that we observed could not be attributed to the greater overall difficulty of the memory task for older adults.

Experiment 2a consisted of a no-distraction condition and two conditions with distraction present at encoding: a redundant distraction condition and a non-redundant distraction condition. In all cases, target words appeared in uppercase letters. In the redundant distraction condition, each study phase contained three target words in uppercase letters and six lowercase words that were the same as the targets but since they were presented in lowercase, they were designated as distractors. This condition required participants to locate the targets, but at the same time any attention to the distractors would be expected to boost activation of the targets as well. In contrast, the study phase of the non-redundant distraction condition contained nine words, three target words in uppercase letters and six new and unique distractors in lowercase letters. The reduced access hypothesis predicted that older adults would show greater effects of distraction, but such age effects would be reduced in the redundant compared to the non-redundant distraction condition. If older adults entered more distractor information into working memory, they should show relatively *better* memory of the target items in this condition, and thus smaller effects of distraction.

The second part of this experiment, Experiment 2b, was designed to extend the results of Experiment 1 concerning the deletion function of inhibition. In this experiment, we compared performance under two processing conditions, differing only as to whether the distractor words were semantically unrelated or related to the targets. Carlson et al. (1995) and Connelly et al. (1991) have shown that older adults are more susceptible to interference from semantically related information. The unrelated condition was identical to the distraction-no processing condition in Experiment 1. In the related condition, all words in each trial belonged to the same semantic category. The overlap in semantic features between targets and distractors was expected to increase the difficulty of selectively deleting the distractors. Targets were expected to be remembered less well in the related condition, and participants should choose the distractor items at test more often than new items when they made an error. If older adults have difficulty with the deletion function, older adults should perform more poorly than younger adults, with greater age differences in the related condition.

METHOD

Participants

Two new groups of 36 younger (ages 17–21, *M(SD)* = 18.8(0.9)) and 36 older (ages 63–85, *M(SD)* = 72.4(6.4)) participants participated in both Experiment 2a and 2b. Characteristics of the sample and requirements for participation were the same as in Experiment 1. Data from three younger adults who did not meet criterion on the BAI were replaced.

Materials and Design

For Experiment 2a, stimuli consisted of 340 words selected from the Nelson et al. (1998) norms. Words were selected and used to create stimuli for each trial using the same criteria as in Experiment 1.

Experiment 2b used 175 categorically related words for the related condition and 175 unrelated words for the unrelated condition. For the related condition, the seven most frequent exemplars were chosen from each of 25 semantic categories (Battig & Montague, 1969). For the unrelated condition, words were chosen from the Nelson et al. (1998) norms. In both conditions, words were matched across conditions on frequency of occurrence (between 6 and 500 times per million words, Francis & Kucera, 1982), and concreteness (values higher than four on a seven point scale, Paivio et al., 1968; Toglia & Battig, 1978). All words were between four and nine letters in length, and consisted of between one and three syllables. In the related condition, all of the words in each trial were from the same semantic category, while in the unrelated condition, all words in each trial were semantically unrelated. Each word was only used one time for a particular participant. No words from Experiment 2a were used in this experiment.

Experiment 2a consisted of a 2 (age) × 3 (condition: no distraction, non-redundant distraction, redundant distraction) design. Age was a between-subjects factor and the type of condition was a within-subjects factor. Experiment 2b consisted of a 2 (age) × 2 (semantic relatedness: related and unrelated) design. Age was a between-subjects factor and semantic relatedness was a within-subjects factor. The order in which conditions were administered was counterbalanced.

Procedure

Participants performed the tasks for Experiments 2a and 2b in the same testing session, with the order of the two experiments counterbalanced across participants. Participants were tested individually. Older adults were administered the Mini-Mental State Exam at the beginning of the session. After this, there were no differences in the procedure for the younger and older adults. Both younger and older adults performed two blocks of practice trials.

All participants performed a calibration task similar to that used in Experiment 1, except that in this experiment the criterion was set to an accuracy level of 70%. They began with a study time of 825 ms and the time change interval was 200 ms. Using the Wetherhill and Levitt (1965) procedure for this level of criterion accuracy, study time was decreased after two correct trials in a row, and increased after one error. As in Experiment 1, this procedure was terminated after six runs, and the average time for all trials was used as the study time in the rest of the experiment.

In all conditions of Experiment 2a, participants first saw three plus signs in the middle of the screen for 500 ms, that indicated the trial was about to begin. In the no-distraction condition, three to-be-remembered words appeared on the computer screen in uppercase letters and in bold 18-point Courier New font. They were randomly placed in a three by three grid that was 20 cm wide and 8 cm high. The words remained on the screen for the time determined by the calibration procedure. After a 6-s delay, during which time participants completed the same letter comparison task used in Experiment 1, recognition memory was tested by presenting one studied word and two new words, all in uppercase letters. Participants were instructed to point to the studied word on the touch screen monitor.

The procedure for the non-redundant distraction condition was identical, with the following exceptions. Participants studied nine different words, with the three target words in uppercase letters, and the six irrelevant words in lowercase letters. The recognition memory test included one target, one distractor, and one new item, all in uppercase letters.

The redundant distraction condition was similar to the non-redundant distraction condition in the layout of the words for study. The only difference was that the six distractor words consisted of two copies of each of the target words, and the recognition memory test included one target word with two new items, all in uppercase letters.

The procedure for DMTS trials in Experiment 2b was the same as for the processing condition from Experiment 1, with participants reading all words aloud before three of the words were circled to indicate they were the ones to be remembered. The only difference from the earlier experiment involved the recognition memory test for the related condition in that on each trial participants saw one target, one distractor, and one new item from the same semantic category. As before, the memory test for the unrelated condition included one target, one distractor, and one unrelated new word.

In both Experiment 2a and 2b, each condition consisted of 20 test trials divided into two blocks of 10 trials separated by a rest break. A sample and three practice trials were given to participants to familiarize them with the procedure before each condition.

RESULTS

As in Experiment 1, older adults performed better than the younger adults on the vocabulary test, $t(70) = 6.51$, $\eta^2 = .38$, $p < .001$ ($M(SD) = 37.1(2.8)$ for older adults; $M(SD) = 32.3(3.3)$), but performance on this test was not correlated with accuracy on any of the DMTS conditions for older or younger adults in either phase of Experiment 2.

The mean study times determined by the calibration procedure were 858 ms ($SD = 258$) for the older adults and 658 ms ($SD = 118$) for the younger adults. Younger adults had reliably shorter calibration times than the older adults, $t(70) = 3.84$, $\eta^2 = .17$, $p < .001$.

Experiment 2a: Testing the Access Hypothesis

The next analysis compared older and younger adults' performance on the three DMTS conditions in Experiment 2a (see Table 3). The proportion of words correctly recognized on the DMTS task was examined by means of a 2 (age group) × 3 (condition: no-distraction, non-redundant distraction, redundant distraction) mixed factorial ANOVA, with the latter as a within subjects factor. Results revealed a main effect of condition, $F(2, 140) = 71.88$, $MSE = 0.01$, $\eta^2 = .51$, $p < .001$. Tukey's HSD *post-hoc* comparisons

TABLE 3. Mean (standard deviation) proportion of the words correctly recognized in the no distraction, non-redundant distraction, and redundant distraction DMTS conditions in Experiment 2a

Condition	Older adults	Younger adults
No-distraction	0.80 (0.12)	0.78 (0.13)
Non-redundant distraction	0.58 (0.13)	0.56 (0.11)
Redundant distraction	0.67 (0.14)	0.71 (0.14)

(HSD = .06) indicated that all three conditions were significantly different from one another, with best performance in the no-distraction condition and worst performance in the non-redundant distractor condition. There was neither a main effect of age group, $F(1, 70) = 0.002$, $MSE = 0.02$, $\eta^2 < .001$, $p > .97$, nor an interaction between age and type of distraction, $F(2, 140) = 1.91$, $MSE = 0.01$, $\eta^2 = .03$, $p > .15$.

The types of errors in the non-redundant distraction condition were also examined (see Table 2). All participants made errors in this condition; thus the proportion of errors that were false alarms to the distractor items was computed. A *t*-test showed no age differences, $t(70) = 0.89$, $\eta^2 = .01$, $p > .38$. Both age groups, however, were likely to select the distractors more often than predicted by chance (.50), $t(35) = 2.04$, $\eta^2 = .11$, $p < .001$, for the older adults and $t(35) = 3.85$, $\eta^2 = .30$, $p < .001$, for the younger adults.

Experiment 2b: Testing the Deletion Hypothesis

The primary test of the deletion hypothesis examined the proportion of words correctly recognized on the DMTS task by means of a 2 (age group) × 2 (semantic relatedness: related and unrelated) mixed factorial ANOVA, with the latter as a within-subjects factor (see Table 4). The only significant effect was an interaction of age and semantic relatedness, $F(1, 70) = 4.84$, $MSE = 0.01$, $\eta^2 = .07$, $p < .05$. Unexpectedly, older adults performed worse on the unrelated condition compared to the related condition, $t(35) = 2.11$, $\eta^2 = .11$, $p < .05$, whereas younger adults performed at the same level in both conditions. More importantly, and contrary to the deletion hypothesis of age differences in working memory, there were no age differences in the related condition, $t(70) = 0.55$, $\eta^2 = .004$, $p > .59$, and only a non-significant trend towards worse performance by older adults in the unrelated condition, $t(70) = 1.80$, $\eta^2 = .04$, $p > .07$.[3]

The pattern of errors was also examined (see Table 2). For those participants who made errors (all participants except one older adult), the proportion of errors that were false alarms to the distractor items was subjected to a 2 (age group) × 2 (semantic relatedness: related and unrelated) mixed factorial ANOVA, with the latter factor as a within subjects variable. The ANOVA revealed two significant effects. First, there was a main effect of semantic relatedness, $F(1, 69) = 58.02$, $MSE = 0.02$, $\eta^2 = .46$, $p < .001$. Contrary to expectation, participants were more likely to select a distractor in the

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[3] A 2 (age group) × 2 (semantic relatedness: related and unrelated) mixed factorial ANOVA was used to examine median processing times, with semantic relatedness as a within-subjects factor. Results revealed one significant effect, namely a main effect of age, $F(1, 70) = 22.74$, $MSE = 1.32 \times 10^7$, $\eta^2 = .25$, $p < .001$, indicating that older adults spent more time on the processing task than younger adults. Correlations between DMTS performance and the median processing times, however, showed no significant relationships for either age group in either the related and unrelated condition.

TABLE 4. Mean (standard deviation) proportion of the words correctly recognized in the related and unrelated DMTS conditions in Experiment 2b

Condition	Older adults	Younger adults
Unrelated	0.67 (0.12)	0.72 (0.12)
Related	0.71 (0.12)	0.70 (0.12)

unrelated condition than in the related condition. There was also a main effect of age, $F(1, 69) = 6.53$, $MSE = 0.02$, $\eta^2 = .09$, $p < .05$. Contrary to the deletion hypothesis, older adults were *less* likely to choose the distractor item over the new item compared to younger adults. Furthermore, no interaction was found between age and semantic relatedness, $F(1, 69) = 1.18$. Overall, in both conditions and in both age groups, participants selected the distractor item more often than chance: unrelated condition – young: $t(35) = 69.36$, $\eta^2 = .99$, $p < .001$, old: $t(34) = 45.78$, $\eta^2 = .98$, $p < .001$; related condition – young: $t(35) = 35.35$, $\eta^2 = .97$, $p < .001$, old: $t(35) = 29.20$, $\eta^2 = .96$, $p < .001$.

DISCUSSION

The access function of inhibition was tested in Experiment 2a by presenting perceptually similar targets and distractors at study in the DMTS task. Although the distractors did not have to be explicitly attended, their presence was clearly detrimental to working memory performance. This conclusion is supported by the finding that both distraction conditions produced lower performance than the no-distraction condition. Informal comparison to the results of Experiment 1 also suggest that the attempt to increase the difficulty of discriminating targets and distractors was successful, in that accuracy in the non-redundant distraction condition in this experiment was substantially lower than in the similar distraction condition in Experiment 1. Furthermore, the cost of the distraction condition, that is the reduction in performance relative to the no-distraction condition, was much greater in Experiment 2a (.22 for both older and younger adults) than in Experiment 1 (.04 and .03, for older and younger adults, respectively). An additional result of Experiment 2a was the demonstration that redundancy between the targets and distractors lessened the impact of irrelevant information, with performance levels falling between those of the non-redundant distraction and no-distraction conditions. As expected, the redundant information, when entered inadvertently into working memory, boosted the activation of target stimuli and increased accuracy on the memory test.

With respect to comparisons of older and younger adults, there was no evidence of age differences in the ability to prevent access of irrelevant information to working memory, even under difficult conditions. Previous research from the selective attention literature had suggested that age differences would be found under conditions where targets and distractors were difficult to discriminate and where the targets appeared in random locations on each trial (Plude & Doussard-Roosevelt, 1989; Plude & Hoyer, 1986; Scialfa et al., 1998). The findings from search tasks, however, were not observed on the working memory test used in this experiment. With performance in the no-distraction condition equated, there were no age differences in conditions with irrelevant information.

Turning to Experiment 2b, which tested for age differences in the ability to delete irrelevant information from working memory, the results replicated findings from Experiment 1, with no significant age differences when distraction consisted of words unrelated to the targets. They also extended the previous results by showing that even when targets and distractors are semantically related, older adults do not show greater effects of distraction. This pattern of results is inconsistent with previous findings of greater age differences on both selective attention and working memory tests when target and distractor items are related relative to when they are unrelated (Carlson et al., 1995; Connelly et al., 1991; Li, 1999). In addition to using different tasks, however, the earlier research did not control for the reduced ability of older adults to encode the material. It is possible that the differential effects of semantic relatedness occur only when older adults are also at a disadvantage under no-distraction conditions, or more generally, that interference effects are greater for more difficult baseline tasks.

In addition to the lack of age differences in deletion, the pattern of performance with related versus unrelated stimuli showed an unexpected set of findings. Younger adults showed equivalent accuracy regardless of the relationship of distractors to targets, and older adults performed better in the condition with semantically related targets and distractors than they did in the unrelated condition. Although contrary to expectation, the pattern can perhaps best be explained by considering the possible benefits and costs of semantic relatedness. On the one hand, we expected semantic relatedness to entail a cost, that is, the difficulty of discriminating targets in distractors should be increased in this condition compared to the unrelated condition. This cost was the basis for our prediction of lower performance and greater age differences in the related condition. What we did not consider, however, was the benefit of having the target words share semantic features. Semantic relatedness among targets would in fact be expected to boost performance. Our results suggest that for younger adults, the benefit was equivalent to the cost; they showed no difference in performance for the two conditions in overall accuracy. The older adults, however, appear to have experienced a greater benefit than cost, leading to better performance for the related condition. This interpretation is speculative, of course, but the main conclusion remains, that there is no evidence of reduced ability in older adults to engage the deletion function.

Experiment 2 did show age differences in the amount of study time needed to equate performance of older and younger adults on the calibration task, with older adults needing significantly more time to perform at the same level as younger adults. This finding is consistent with findings from Experiment 1, except that the age difference in that first experiment approached but did not reach a statistically reliable level. Overall, there is some evidence that older adults have difficulty encoding information in the DMTS task, even under no-distraction conditions. We discuss the significance of this finding for understanding age differences in interference in the General Discussion.

GENERAL DISCUSSION

The present study investigated the ability of older and younger adults to inhibit irrelevant information in working memory through access and deletion processes. The access function was evaluated in conditions in which irrelevant stimuli were intermixed with relevant stimuli but did not need to be attended. Conditions used to evaluate the deletion function required participants to initially attend to all stimuli and then dampen activation of irrelevant stimuli after learning which stimuli were relevant. All participants were sensitive to the interference manipulations, in that performance was consistently worse when interference was present, and greater declines in performance occurred for more difficult discriminations between targets and distractors. Nevertheless, across both experiments, older adults showed no differential susceptibility to interference during encoding, either in preventing access of irrelevant information into the focus of attention (Experiments 1 and 2a) or in deleting previously relevant information from the activated long-term memory portion of working memory (Experiments 1 and 2b).

The most important innovation in the current study was the use of a baseline, no-interference condition as a foundation for examining the effects of irrelevant information. In both experiments, each participant was calibrated to the same level of performance in the baseline condition by adjusting the amount of study time to meet a preset accuracy criterion. In Experiment 2, older adults needed more time to encode the words during study to perform at the same level as the younger adults. A similar pattern was observed in Experiment 1, although the age difference did not reach statistical significance. Thus, our findings imply that older adults may be slower than younger adults to encode information into working memory, but controlling for this deficit eliminates age differences in access and deletion functions under the task conditions examined in the current studies.

It should be noted that one explanation for the lack of finding age differences in interference is that the interference manipulations used in these studies did not produce large effects. Basing interpretations on null effects, of course, raises questions about statistical power. In this regard, an examination of the effect sizes of the non-significant interactions showed that these critical interactions had very small effect sizes (Experiment 1 age × distraction condition interaction, $\eta^2 = .003$, age × processing condition, $\eta^2 = .02$, Experiment 2a age × interference condition, $\eta^2 = .03$). This study was underpowered to detect such small effects. Given the sample size of 72 participants in each experiment, the effect size would need to be medium to large to detect age differences at an alpha level of .05, with power of .80. Nevertheless, an examination of the data patterns for the two experiments is inconsistent with experimental power being the reason for the failure to observe age differences. In Experiment 1, the comparison between the distraction-no processing and no-distraction conditions was only .01 in favor of older adults having more difficulty in the distraction condition relative to younger adults, and the difference between the distraction-processing and the distraction-no processing actually showed a numerically greater cost for younger adults (.09 for older adults versus .13 for younger adults). In Experiment 2a, the difference between the no-distraction and non-redundant distraction conditions showed no age difference (.22 for both older and younger adults); in Experiment 2b, the interaction of age and relatedness condition was significant, but the pattern of means were in the opposite direction to what was predicted and did not support an account of age differences in deletion of irrelevant information from working memory. Thus, it seems unlikely that the lack of age differences in inhibition results from insufficient experimental power. In sum, the results point consistently to a lack of support for age-related reductions in the functions of access and deletion mechanisms in working memory, across a range of experimental manipulations.

Implications for the Measurement of Age Differences in Working Memory

The absence of age differences in the effects of irrelevant information on working memory has important implications for understanding prior studies that have found age differences in interference. Studies that have not considered differences in performance on a baseline task have been inconsistent in their conclusions, whereas in studies that have, age differences in interference control are generally not observed. For instance, in two divided attention studies that equated performance for older and younger adults on the primary memory task, no age differences in interference were found (Baddeley, Logie, Bressi, Della Salla, & Spinnler, 1986; Wickens, Braune, & Stokes, 1987). Similarly, language comprehension with distraction shows no effects of age when adjustments were made to control for individual differences in hearing (Murphy et al., 1998). Of particular relevance is the finding that on the reading span task, the most widely used measure of working memory, age differences were eliminated when the task was adjusted to account for age differences in simple word span (McCabe & Hartman, 2003). This pattern of findings, in conjunction with the current study, raises the possibility that variations among studies in the extent of age-related declines in non-interference conditions may contribute to the lack of consistent results in the literature.

The conclusion that controlling age differences in baseline tasks may be sufficient to eliminate performance differences between younger and older adults under interference conditions also raises an additional question. It implies that in general, and regardless of age, interference effects may increase with lower levels of performance. If this is the case, it will be important in the future to better understand the functional relationship between performance level and interference effects. At present, we do not know the generality of the current findings, and further work in this area is warranted.

Given the suggestion that reduced working memory under non-interference conditions is key to understanding age differences in complex working memory tasks, it still remains to determine the cause of such reduced performance. Although much of the research literature focuses on executive or controlled attentional processes necessary for manipulating and updating information, there is a growing support for the importance of more basic working memory processes. For instance, older adults perform more poorly than younger adults on simple span measures, and effects of age on simple word and letter span tend to be as large as age effects on complex span measures (Verhaeghen et al., 1993). In addition, a number of studies have ruled out interference from stimuli presented after encoding as the source of age differences. For example, age differences in the DMTS and the related Brown–Peterson task are absent in long delay conditions when performance is calibrated at short delays (Dumas & Hartman, 1999; Parkinson et al., 1985; Puckett & Lawson, 1989; Puckett & Stockburger, 1988). Thus, simple storage is reduced in older adults, and effects of age on working memory do not appear to result from interference either at encoding (e.g., current results) or after encoding.

As to the cause of reduced working memory under non-interference conditions in a task with substantial support at retrieval (a recognition task), the current study only demonstrates that older adults need more study time. Generalized slowing is one possible explanation for this finding (Byrne, 1998; Salthouse, 1996). The slowing hypothesis, however, also predicts greater age effects in more difficult conditions (i.e., the complexity effect), and thus would predict an increase in effects of age when distracting information is present. This was not observed in the current study. Furthermore, statistically controlling for performance on low level speeded tests does not always remove the effects of age on tests of working memory (e.g., McCabe & Hartman, 2003).

Other explanations of reduced working memory in older adults include deficits in binding content to context (Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Oberauer, 2005a) and in creating associations (Naveh-Benjamin, 2000). More generally, these speak to the hypothesis that older adults are less able to encode components of context that support memory (Braver et al., 2001). The current results are consistent with this hypothesis; although no contextual information was explicitly presented, younger adults may have generated contextual cues or created stronger associations among stimuli than older adults. Additional work will be needed to determine which explanation or explanations produce the best account of age differences in working memory. At present, however, it appears that although additional work may be needed to determine the best account of age differences in working memory, the present findings suggest that age differences in access and deletion functions are unlikely to be part of that account.

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