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The influence of aging on attentional refreshing and articulatory rehearsal during working memory on later episodic memory performance

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ABSTRACT

We investigated age-related changes in two proposed mechanisms of maintenance in working memory, articulatory rehearsal, and attentional refreshing, by examining the consequences of manipulating the opportunity for each on delayed recall. Both experiments utilized modified operation span tasks to vary the opportunity for articulatory rehearsal (Experiment 1) and attentional refreshing opportunities (Experiment 2). In both experiments, episodic memory was tested for items that had been initially studied during the respective operation span task. Older adults’ episodic memory benefited less from opportunities for refreshing than younger adults. In contrast, articulatory rehearsal opportunities did not influence episodic memory for either age group. The results suggest that attentional refreshing, and not articulatory rehearsal, is important during working memory in order to bind more accessible traces at later tests, which appears to be more deficient in older adults than younger adults.

Keywords: Working memory; Episodic memory; Aging; Binding; Attentional refreshing.

Working memory is the ability to maintain information online in the service of ongoing processing (Baddeley, 1986). This ability has proven to be instrumental in understanding age-related changes in higher order cognition (Chen & Li, 2007; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2012).
2010; Park et al., 1996; Verhaeghen & Salthouse, 1997), and thus much research has investigated the mechanisms supporting working memory performance. Maintenance in working memory, particularly verbal working memory, was commonly assumed to be due to rehearsal (Baddeley & Hitch, 1974; Baddeley, Thomson, & Buchanan, 1975). However, more recently, an independent attentional refreshing mechanism has been proposed that is also responsible for maintaining information in working memory (Camos, Lagner, & Barrouillet, 2009; Camos, Mora, & Oberauer, 2011; Hudjetz & Oberauer, 2007). The present study investigated age-related deficits in rehearsal and refreshing mechanisms of maintenance in working memory by examining their consequences for retrieval from episodic memory.

A variety of frameworks have attempted to explain working memory retrieval. Cowan’s (1988, 1999) embedded processes model proposes that information is maintained at different levels of activation in working memory within a broader context of long-term memory. The embedded processes model distinguishes between two hierarchical levels of activation. The focus of attention is responsible for maintaining immediately accessible content, whereas the activated portion of long-term memory maintains information that is not immediately available to consciousness (i.e., the focus of attention) but still highly activated and accessible for retrieval to the focus of attention. Although the specific capacity of the focus of attention has been debated (Cowan, 2001; Cowan et al., 2005; Garavan, 1998; Oberauer & Bialkova, 2009; Verhaeghen, Cerella, & Basak, 2004), there is some agreement that it is capacity-limited, and that the reactivation of information within the focus of attention is a domain-general mechanism (e.g., Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Cowan, 1999). This act is sometimes referred to as focus switching (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007), refreshing (Higgins & Johnson, 2009; Johnson, Reeder, Raye, & Mitchell, 2002), or attentional refreshing (Camos et al., 2009, 2011; Hudjetz & Oberauer, 2007). For consistency, we will refer to this process of retrieval of less activated information into the focus of attention as attentional refreshing or refreshing.

Previous research has investigated refreshing given its importance for ongoing maintenance of information (Garavan, 1998), as well as for final retrieval of information from working memory (Vaughan, Basak, Hartman, & Verhaeghen, 2008) and episodic memory (Johnson et al., 2002; Loaiza & McCabe, 2012; McCabe, 2008). With regard to working memory, refreshing is important because information that has left the focus of attention but is still active must be reactivated in order to be effectively maintained and reported during a retrieval attempt. Thus, refreshing is thought to operate by utilizing pauses between processing phases during a working memory task to retrieve displaced information into the focus of attention (Barrouillet, Bernardin, & Camos, 2004; Barrouillet et al., 2007; Hudjetz & Oberauer,
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For example, during an operation span task, to-be-remembered items are interspersed between arithmetic problems (e.g., $7 \times 4 = 27?$) that must be solved. After solving an arithmetic problem, a participant may briefly refresh previously presented to-be-remembered items before viewing another to-be-remembered item in order to maintain the items for retrieval at the end of the trial. Thus, refreshing is accomplished by switching limited attentional resources between the processing phases of a working memory span task and refreshing previously presented to-be-remembered items.

Recently, we have shown that refreshing is particularly important to content-context binding in working memory (Loaiza & McCabe, 2012; McCabe, 2008). Specifically, information studied in the context of a task that affords attentional refreshing opportunities, such as an operation span task, is much more likely to be retrieved during episodic memory tests than information from tasks that do not afford attentional refreshing opportunities. Consistent with this, Loaiza and McCabe (2012) observed that patterns of episodic memory reflected access to the original temporal context from a working memory task trial (e.g., accessing an item from a neighboring serial position within a trial). Furthermore, several experiments have demonstrated that the more refreshing opportunities an item receives, the more likely it is to be recalled from episodic memory (Loaiza & McCabe, 2012; McCabe, 2008). These results collectively suggest that refreshing during working memory serves to promote binding of item-specific information (e.g., to-be-remembered stimuli) to a source context (e.g., the temporal context within the original trial). Such binding is evident in retrieval from episodic memory.

This finding has considerable implications for understanding age-related deficits in episodic memory (e.g., McCabe et al., 2010). That is, while refreshing may bear on age-related differences in working memory (Vaughan et al., 2008; Verhaeghen & Hoyer, 2007), refreshing may also be important for age-related changes in episodic memory, particularly due to its importance for content-context binding. For example, Johnson and colleagues (Chalfonte & Johnson, 1996; Johnson et al., 2002; Mitchell, Johnson, Raye, Mather, & D’Esposito, 2000) have shown that older adults derive less benefit to episodic memory than younger adults from refreshing information into the focus of attention, potentially hindering older adults’ ability to bind features of representations. Similarly, Kahana, Howard, Zaromb, and Wingfield (2002) have shown that older adults are less likely than younger adults to exhibit episodic memory retrieval patterns that reflect the original temporal associations between studied items. Thus, manipulating opportunities for refreshing in working memory may differentially impact retrieval from episodic memory for younger and older adults, potentially reducing the likelihood that older adults will retrieve bound information according to its original source context.
Although refreshing has been recognized as an important source of age differences in working memory (Verhaeghen & Hoyer, 2007) and episodic memory (Johnson et al., 2002), other mechanisms are also important for temporary maintenance of information in working memory, such as articulatory rehearsal. Rehearsal is typically construed as a domain-specific mechanism of maintenance involving covert or overt articulation of to-be-remembered information (Baddeley, 1986). In contrast, refreshing is considered a domain-general mechanism that does not necessarily require silent articulation but instead involves focusing attention on particular representations after having devoted attention to another task (Hudjetz & Oberauer, 2007). Indeed, refreshing and rehearsal may independently influence recall from working memory. For example, Camos et al. (2009) showed that increasing the attentional demand of a processing component of a complex span task impaired working memory recall independently from the effect of suppressing rehearsal during the task. This indicates that rehearsal and refreshing are distinguishable mechanisms of maintenance that independently contribute to working memory performance.

Although rehearsal may contribute to working memory performance, it appears to provide little for understanding age-related differences in working memory and episodic memory. For example, age differences are greater for immediate recall tasks that are more cognitively demanding compared to those that rely on rehearsal or passive maintenance (Bopp & Verhaeghen, 2005; Park et al., 2002), perhaps because cognitively demanding tasks vary the ability to engage in attentional refreshing (cf. Camos et al., 2009, 2011). Bailey, Dunlosky, and Hertzog (2009) have further observed that older and younger adults used similar maintenance strategies during working memory tasks (i.e., rehearsal and elaborative strategies), and that such strategies did not interact with the overall impact of age on working memory performance. With regard to episodic memory, rehearsal-based activities are also less likely to benefit episodic memory than other, more elaborative forms of encoding (i.e., levels of processing, Craik & Tulving, 1975; Mazuryk & Lockhart, 1974), a finding evident regardless of age (Grady & Craik, 2000). Taken together, these data suggest that while rehearsal is preserved with increasing age, it has little impact on age-related differences in episodic memory.

Although refreshing and rehearsal may comprise independent mechanisms in working memory, it remains unclear how these mechanisms influence age-related differences in episodic memory. Thus, the goal of the present study was to further elucidate the impact of age on refreshing and rehearsal by manipulating the opportunity for either mechanism during encoding in working memory. Specifically, refreshing information during working memory appears to be an important determinant of episodic memory (Loaiza & McCabe, 2012; McCabe, 2008; Johnson et al., 2002). Given that
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Episodic memory also declines with increasing age (McCabe et al., 2010; Park et al., 1996), it is possible that the efficacy of refreshing, but not rehearsal, during encoding in working memory is important to age-related differences in episodic memory. We addressed this possibility by manipulating a complex span task (i.e., operation span) to vary the opportunities for rehearsal (Experiment 1) and refreshing (Experiment 2) in order to ascertain the influence of each on delayed recall. As noted previously, refreshing is proposed to be a domain-general function (Barrouillet et al., 2007; Raye, Johnson, Mitchell, Greene, & Johnson, 2007; Verhaeghen & Basak, 2005). Because age-related differences appear to be greater for more cognitively demanding tasks compared to less cognitively demanding tasks (Bopp & Verhaeghen, 2005; but see Verhaeghen, 2011, regarding tasks that tax executive functions more specifically), older adults may be impaired relative to younger adults in engaging in attentional refreshing in working memory, potentially contributing to age-related deficits in episodic memory. In contrast, rehearsal-related maintenance may be preserved with age because it is not a domain-general function, yet may have little influence on episodic memory. Thus, opportunities for refreshing should have a larger impact on age-related differences in episodic memory than opportunities for rehearsal.

We tested these predictions in two experiments that utilized modified operation span tasks. In a traditional operation span task, an arithmetic problem to be read and solved aloud (e.g., $7 \times 4 = 27$) precedes each to-be-remembered item. This problem-word sequence alternates within a trial for a given number of items to remember before a recall cue. In Experiment 1 we manipulated the opportunity for rehearsal of information by comparing two conditions. In the continuous reading condition, each segment of the arithmetic problem was presented sequentially on the screen, and thus participants had to continuously articulate during the entire processing phase of the span task. This continuous reading condition was compared to a simultaneous reading condition in which participants were free to read aloud and respond to the arithmetic problem within the same total amount of time that was given during the continuous reading trials (see Figure 1). We used these trial types due to prior evidence that continuous presentation formats of complex span tasks prohibit rehearsal (Hudjetz & Oberauer, 2007). Specifically, Hudjetz and Oberauer (2007) showed that a continuous reading condition precludes the use of rehearsal compared to a simultaneous reading condition, reducing immediate recall performance. We also asked participants to retrospectively report the strategies they had used to maintain information in order to ensure that potential age differences in strategy use did not differentially impact delayed recall between the two reading conditions (cf. Bailey et al., 2009).

In Experiment 2 we manipulated the number of arithmetic problems (0, 1, or 2) that preceded each to-be-remembered word in order
to manipulate the number of opportunities available to refresh previously presented information in that trial. This manipulation varies refreshing opportunities by varying the intervals between the to-be-remembered items to switch attention to previously presented information (cf. Barrouillet et al., 2004, 2007; Loaiza & McCabe, 2012; McCabe, 2008). That is, increasing the number of operations between to-be-remembered words will increase the number of opportunities that a person can switch their attention from the operation to the to-be-remembered information to keep it active (Barrouillet et al., 2004, 2007; Loaiza & McCabe, 2012; McCabe, 2008).

For both experiments, we tested immediate and delayed recall in order to determine the influence of rehearsal and refreshing on working memory and episodic memory, respectively. If older adults are less efficient in their ability refresh previously presented representations compared to younger adults, then episodic memory performance should increase more with each refreshing opportunity for younger adults than older adults. However, if rehearsal of those representations is preserved with age, then manipulating rehearsal opportunities should not differentially impact episodic memory between age groups.
EXPERIMENT 1

The primary goal of Experiment 1 was to establish that the impact of rehearsal during working memory is age-invariant, such that opportunities for rehearsal should not differentially impact episodic memory between age groups. We manipulated the opportunity for rehearsal by pacing the arithmetic problem of an operation span task according to a continuous reading presentation of each element of the problem or a simultaneous reading presentation of the entire problem (see Figure 1). Furthermore, we also asked participants to report the strategies used during the task to ensure that strategies did not account for age-related differences in working memory (Bailey et al., 2009) or subsequent episodic memory.

Method

Participants

Participants included 28 younger adults (20 female, age $M = 19.43$, $SD = 1.32$, age range 17–22) and 28 older adults (18 female, age $M = 72.21$, $SD = 5.86$, age range 63–82). Younger adults ($M = 14.11$, $SD = 0.57$) had significantly fewer years of education than older adults ($M = 17.12$, $SD = 2.32$), $t(54) = 6.97$, $d = 2.08$. Participants received either partial course credit or $10/\text{hour for their participation.}$ All older adults were interviewed over the phone before participating and confirmed that they had no medical history of memory or cognitive impairment. They were specifically told that such a history would include seeing a doctor for consistent memory problems, referral to a neurologist or request to monitor the problems after such an appointment, and/or beginning treatment for symptoms of dementia. All participants had normal or corrected-to-normal vision.

Materials and Procedure

Before the operation span task was administered, participants practiced solving multiplication problems that were later used as the processing element of the operation span task (e.g., $8 \times 5 = 40?$, $7 \times 6 = 44?$). Participants were asked to read the problem aloud and respond with the veracity of the presented answer (i.e., true or false).

Afterward, all participants completed two blocks of an operation span task: the simultaneous reading block and the continuous reading block (see Figure 1). There were eight trials of four unrelated, concrete words to remember in each block, and the order of the blocks was counterbalanced. Before beginning each block, participants completed a practice example for each reading condition. During the simultaneous reading block, participants read aloud and responded to a multiplication problem presented in its entirety for 6500 ms, followed by a to-be-remembered word presented for 1000 ms. All
to-be-remembered words were concrete, high-frequency nouns, with an average log HAL frequency (Balota et al., 2007) of 10.49 (range = 8.21–12.31), an average of 5.52 letters (range = 4–8), and an average of 1.59 syllables (range = 1–2). During the continuous reading block, each part of the problem was individually presented for 900 ms, requiring the participant to read each part of the problem as it successively appeared on the screen. The last screen of the problem requiring a true/false response was presented for 2000 ms, and was then followed by the presentation of the to-be-remembered word for 1000 ms. The problem-word sequence for both conditions repeated three more times within the trial and was followed by a cue to recall the four different words of the trial in serial order. An equivalent delay of 2–3 minutes followed each block; participants completed a demographics questionnaire after the first block and a short word search after the second block. The time to complete the demographics questionnaire during the first delay was used as the amount of time to complete the word search during the second delay for each participant. Next, participants were given a surprise free recall test, and asked to freely recall as many of the studied words from the preceding block as possible. In order to separate the two blocks of simultaneous and continuous reading trials, a word search task was completed for 2 minutes between blocks (i.e., after completing the first delayed recall test but before beginning the second block of either simultaneous reading or continuous reading trials, depending on the counterbalance).

After completing the immediate and delayed recall tests of both versions of the operation span task, participants first summarized their overall memory strategies in their own words. Next, participants were asked to indicate, using the options provided, the strategies (i.e., passive reading, rote rehearsal, imagery, sentence generation, meaningful grouping, or other) they had used for each trial during both reading conditions (see Appendix for an example). Dunlosky and Kane (2007) have demonstrated that strategies are reported similarly for retrospective and concurrent reports. Following Dunlosky and Kane, we presented each trial in its entirety on the screen and asked participants to select among the six strategy types they had used to try to remember the words, with no instruction as to whether the strategies were considered effective or ineffective (Bailey et al., 2009; Dunlosky & Kane, 2007). Participant were allowed to indicate only one type of strategy per trial. Finally, participants completed an unrelated task and were thanked for their participation.

Results

All of the reported significant results for both experiments met a criterion of \( p < .05 \), and mean square error (MSE) and partial eta squared (\( \eta^2_p \)) are reported for all \( F \) values > 1.
Recall Performance

Although we asked participants to immediately recall the words in their original order of presentation, the analyses reported reflect immediate free recall, such that items are scored as correct regardless of output order. It should be noted that immediate free recall refers to the scoring method rather than the retrieval instructions, and was used primarily to facilitate comparisons between immediate and delayed recall (see also Loaiza & McCabe, 2012; Loaiza, McCabe, Youngblood, Rose, & Myerson, 2011; McCabe, 2008). We examined recall in a 2 (age: younger, older) × 2 (time of recall: immediate, delayed) × 2 (reading condition: simultaneous, continuous) mixed-factor analysis of variance (ANOVA), the results of which are presented in Figure 2. The analysis revealed that younger adults recalled more, overall, than older adults, $F(1, 54) = 28.41, MSE = 0.80, \eta_p^2 = .35$, immediate recall was superior to delayed recall, $F(1, 54) = 979.53, MSE = 14.68, \eta_p^2 = .95$, and recall was greater in the simultaneous condition than the continuous condition, $F(1, 54) = 25.23, MSE = 0.18, \eta_p^2 = .32$. The interaction between the time of recall and reading condition was significant, $F(1, 26) = 19.90, MSE = 0.15, \eta_p^2 = .27$. In particular, immediate recall was superior for the simultaneous compared with the continuous reading condition, $F(1, 55) = 36.24, MSE = 0.33, \eta_p^2 = .40$, whereas no difference by reading condition was evident for delayed recall, $F < 1$. Importantly, this interaction was not further qualified by a three way interaction with age, $F < 1$. Indeed, age did not interact with any of the variables (reading condition × age, $F < 1$, and time of recall × age, $F(1, 54) = 2.63, MSE = 0.04, \eta_p^2 = .05, p = .11$). Thus, constraining articulatory rehearsal during immediate recall similarly impacted both age groups, but this difference between reading conditions was not evident in delayed recall for either age group.

![Figure 2.](image-url)
Reported Strategy Use

We also assessed age-related differences in reported strategy use during the span tasks and whether strategy use differentially affected successful immediate and delayed recall performance. Table 1 displays the proportions of each strategy reported for both age groups, with significantly different means between ages in bold. Reported strategy use was statistically equivalent for each strategy except for reading and rehearsal in both the simultaneous and continuous reading conditions: older adults were significantly more likely to report reading compared to younger adults (simultaneous: $F(1, 54) = 8.67, MSE = 0.49, \eta_p^2 = .14$; continuous: $F(1, 54) = 7.58, MSE = 0.47, \eta_p^2 = .12$), and younger adults were significantly more likely to report rehearsing than older adults (simultaneous: $F(1, 54) = 3.18, MSE = 0.27, \eta_p^2 = .06, p = .08$; continuous: $F(1, 54) = 6.90, MSE = 0.59, \eta_p^2 = .13$). Older adults also reported “other” more often than younger adults in the simultaneous reading condition, $F(1, 54) = 4.30, MSE = 0.19, \eta_p^2 = .04$. We then classified strategies as either effective (imagery, sentence, group) or ineffective (reading, rehearsal), and submitted the proportion of reported strategies to a 2 (age: younger, older) × 2 (reading condition: simultaneous, continuous) × 2 (strategy type: effective, ineffective) mixed ANOVA, the results of which are presented in Table 2. For the sake of brevity, we only report the significant three-way interaction, $F(1, 54) = 2.47, MSE = 0.13, \eta_p^2 = .12$. This interaction obtained because younger adults reported using effective strategies more often than older adults during the simultaneous reading condition, $F(1, 54) = 4.47, MSE = 0.38, \eta_p^2 = .08$. Otherwise, the impact of age on strategy selection was not significant, $F$ values < 1.

<table>
<thead>
<tr>
<th>Strategy type</th>
<th>Age group</th>
<th>Reading</th>
<th>Rehearsal</th>
<th>Imagery</th>
<th>Sentence</th>
<th>Group</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Younger adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous</td>
<td>0.06 (0.11)</td>
<td>0.41 (0.26)</td>
<td>0.16 (0.23)</td>
<td>0.13 (0.17)</td>
<td>0.21 (0.18)</td>
<td><strong>0.04 (0.14)</strong></td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td><strong>0.10 (0.15)</strong></td>
<td>0.46 (0.25)</td>
<td>0.13 (0.20)</td>
<td>0.10 (0.14)</td>
<td>0.16 (0.18)</td>
<td>0.04 (0.09)</td>
<td></td>
</tr>
<tr>
<td>Older adults</td>
<td>0.25 (0.32)</td>
<td>0.27 (0.32)</td>
<td>0.08 (0.17)</td>
<td>0.10 (0.14)</td>
<td>0.15 (0.17)</td>
<td><strong>0.15 (0.26)</strong></td>
<td></td>
</tr>
<tr>
<td>Simultaneous</td>
<td><strong>0.29 (0.32)</strong></td>
<td>0.25 (0.33)</td>
<td>0.11 (0.17)</td>
<td>0.10 (0.12)</td>
<td>0.14 (0.18)</td>
<td>0.11 (0.26)</td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>0.29 (0.32)</td>
<td>0.25 (0.33)</td>
<td>0.11 (0.17)</td>
<td>0.10 (0.12)</td>
<td>0.14 (0.18)</td>
<td>0.11 (0.26)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Simultaneous, simultaneous reading condition; Continuous, continuous reading condition. Standard deviations are in parentheses. Bold means and standard deviations denote significant age differences in the reported strategy for that particular reading condition.
TABLE 2. Proportions of reported strategies collapsed into effective and ineffective strategies as a function of reading condition and age group in Experiment 1

<table>
<thead>
<tr>
<th>Age group</th>
<th>Effective strategy</th>
<th>Ineffective strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simultaneous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Younger adults</td>
<td>0.50 (0.30)</td>
<td>0.46 (0.29)</td>
</tr>
<tr>
<td></td>
<td>0.39 (0.26)</td>
<td>0.56 (0.26)</td>
</tr>
<tr>
<td>Older adults</td>
<td>0.33 (0.28)</td>
<td>0.51 (0.32)</td>
</tr>
<tr>
<td></td>
<td>0.35 (0.29)</td>
<td>0.54 (0.32)</td>
</tr>
</tbody>
</table>

Note: Standard deviations are in parentheses.

Recall as a Function of Strategy Use

In addition to assessing recall and reported strategy use, we sought to determine whether effective strategy use qualified the reported effects of general recall performance. In particular, when reanalyzing recall performance on the basis of reported strategies, would the results still indicate the interaction between time and reading condition for each age group? Or would effective strategy use change this pattern, perhaps between age groups? Accordingly, we analyzed recall as a function of the reported strategy for that trial and conducted a 2 (age: younger, older) × 2 (time of test: immediate, delayed) × 2 (reading condition: simultaneous, continuous) × 2 (strategy type: effective, ineffective) mixed ANOVA with recall as the dependent variable (see Table 3). Note that some participants (10 younger adults, 9 older adults) were excluded listwise from this analysis if they did not use effective and ineffective strategies between the two tasks (e.g., a participant who only reported using rehearsal throughout a task could not be represented in the effective strategy condition). This left 18 younger adults and 19 older adults to be included for the analysis. The analysis revealed the same significant effects described in the general recall performance subsection, as well as

TABLE 3. Experiment 1 recall performance as a function of strategy type

<table>
<thead>
<tr>
<th></th>
<th>Simultaneous reading condition</th>
<th>Continuous reading condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effective strategy</td>
<td>Ineffective strategy</td>
</tr>
<tr>
<td>Younger adults</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate test</td>
<td>0.86 (0.16)</td>
<td>0.82 (0.12)</td>
</tr>
<tr>
<td>Delayed test</td>
<td>0.31 (0.18)</td>
<td>0.18 (0.17)</td>
</tr>
<tr>
<td>Older adults</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous</td>
<td>0.74 (0.22)</td>
<td>0.62 (0.19)</td>
</tr>
<tr>
<td>Continuous</td>
<td>0.21 (0.18)</td>
<td>0.12 (0.10)</td>
</tr>
</tbody>
</table>

Note: Standard deviations are in parentheses.
that effective strategies were more beneficial for performance than ineffective strategies, $F(1, 35) = 22.03$, $MSE = 0.75$, $\eta^2_p = .39$. These main effects were qualified by a significant age $\times$ time of recall interaction, $F(1, 35) = 4.89$, $MSE = 0.16$, $\eta^2_p = .12$. In particular, the impact of age on immediate recall, $F(1, 35) = 14.34$, $MSE = 0.25$, $\eta^2_p = .29$, was greater than the impact of age on delayed recall, $F(1, 35) = 5.77$, $MSE = 0.04$, $\eta^2_p = .14$. There was also a significant interaction between time of recall and reading condition, $F(1, 35) = 8.93$, $MSE = 0.18$, $\eta^2_p = .20$, such that the effect of reading condition was only evident in immediate recall, $F(1, 36) = 26.70$, $MSE = 0.28$, $\eta^2_p = .43$, and not in delayed recall, $F(1, 36) = 1.97$, $MSE = 0.01$, $\eta^2_p = .05$, $p = .17$. Importantly, however, all other interactions were not significant ($F$ values $\leq 2.88$), consistent with the previously reported recall performance results. Thus, any age differences in strategy use did not differentially impact working memory or episodic memory.

**Discussion**

The results of Experiment 1 indicate that the opportunity for rehearsal was important for successful immediate retrieval of information from working memory (i.e., a complex span task), but it was not important for retrieval from episodic memory (i.e., delayed recall). Furthermore, this obtained for both age groups, suggesting that age-related deficits in working memory and episodic memory were not exacerbated by constraining articulatory rehearsal during working memory. Thus, affording rehearsal during working memory does not account for age-related changes in subsequent episodic memory.

The retrospective strategy reports also indicated that these results were not attributable to age-related differences in strategy use. Although younger adults reported using effective strategies more often than older adults during the simultaneous reading condition, younger and older adults showed similar benefits to recall when using effective strategies. Furthermore, the age-related deficit in delayed recall was not exacerbated by ineffective strategies. This indicates that age differences in immediate and delayed recall were not due to differential use of effective strategies (Bailey et al., 2009). However, excluding participants listwise who did not indicate effective or ineffective strategy use in both reading conditions minimized the power of this analysis, and thus these results should be interpreted with some caution. Although older adults reported using rehearsal less frequently than younger adults in both trial types, delayed recall was similarly unaffected by rehearsal constraints during working memory encoding. Thus, instead of an age-related impairment in rehearsal in working memory, older adults may be selectively deficient in refreshing information into the focus of attention compared to younger adults. However, it is not clear from Experiment 1 that this is the case given that we only manipulated rehearsal opportunities.
Therefore, in Experiment 2, we examined the extent to which aging affects attentional refreshing during working memory, especially with regard to how that information is retrieved after a delay. We did this by manipulating opportunities to refresh information during a modified operation span task. In particular, we varied the number of refreshing opportunities by including trials with 0, 1, or 2 operations prior to each to-be-remembered word, such that the completion of an operation presented an opportunity to briefly refresh previously presented words back into the focus of attention (Loaiza & McCabe, 2012; McCabe, 2008). We have previously shown that manipulating refreshing opportunities by changing the placement of the arithmetic problems in an operation span task directly predicts episodic memory (Loaiza & McCabe, 2012). We expected that episodic memory would benefit from increasing refreshing opportunities to a greater extent for younger adults than older adults.

EXPERIMENT 2

Method

Participants

Forty-two older adults (31 female; age $M = 70.93$, $SD = 5.68$, age range 62–81) and 42 younger adults (32 female; age $M = 18.30$, $SD = 0.70$, age range 18–21) were recruited for the study. Younger adults ($M = 14.31$, $SD = 0.52$) had fewer years of education than older adults ($M = 17.24$, $SD = 2.07$), $t(82) = 8.90$, $d = 2.26$. Participants received either partial course credit or $10/hour for their participation. As in Experiment 1, all older adults were interviewed before participating to ensure no history of pathological memory impairments. All participants had normal or corrected-to-normal vision.

Materials and Procedure

For the first half hour, participants completed an unrelated series of tasks before completing the relevant portion of the experiment. Before completing the modified operation span task, participants performed the initial arithmetic practice task described in Experiment 1, in which they solved only the multiplication problems that would later be used as the processing element of the operation span task.

After the practice task, participants completed a modified operation span task. A typical operation span task was modified so as to include 0, 1, or 2 operations preceding each word to remember. A trial with 0 operations preceding each word is considered akin to a word span trial (i.e., an alternative, simple span test of immediate memory), a trial with 1 operation preceding each word is a typical operation span trial, and a trial with 2 operations preceding each word was the modified trial type that was included in order to
increase the number of refreshing opportunities during the trial. There were three trials of each type, and each trial had four unrelated, concrete words to remember, with the same characteristics as the items used in Experiment 1. The presentation of trials was random within the same block, but participants were warned before each trial regarding the number of operations that would precede each word. For trials with operations, participants had to read aloud and respond to each multiplication problem within 5250 ms. After 1 or 2 operations (depending on the trial type), a word was presented on-screen for 1000 ms. After four words had been presented, participants were prompted to recall the items they had seen in the order that they were presented. Afterward, participants completed a demographics questionnaire for 2–3 minutes in order to serve as an interval-filled delay. Next, participants were given a surprise delayed free recall test with instructions to recall of any of the items from the modified operation span task that could be remembered in any order.

Results

As in Experiment 1, we used immediate free recall in the following analyses in order to allow for a better comparison between immediate and delayed recall. We first conducted a 2 (age group: younger, older) × 2 (time of test: immediate, delayed) × 3 (number of operations: 0, 1, 2) mixed-factor ANOVA on recall (see Figure 3). The analysis revealed that younger adults recalled more overall than older adults, $F(1, 82) = 8.79, MSE = 0.41, \eta^2_p = .10$, and immediate recall was superior to delayed recall, $F(1, 82) = 2416.73, MSE = 44.75, \eta^2_p = .97$. In addition, a significant main effect of the number of operations preceding each word to remember was evident, $F(2, 164) = 4.49, MSE = 0.10, \eta^2_p = .05$. The interaction between age group and time of test was not significant, $F(1, 82) = 1.30, MSE = 0.02, \eta^2_p = .02, p = .26$, but

Figure 3. Experiment 2 recall performance. Error bars denote one standard error around the mean.
the interaction between age group and the number of operations was significant, \( F(2, 164) = 3.18, \text{MSE} = 0.07, \eta_p^2 = .04 \). In particular, age differences in recall were larger with each increase in the number of operations preceding each to-be-remembered word. The interaction between time of test and number of operations was significant, \( F(2, 164) = 121.72, \text{MSE} = 1.96, \eta_p^2 = .60 \). Specifically, increasing the number of operations diminished immediate recall, \( F(2, 166) = 56.17, \text{MSE} = 0.89, \eta_p^2 = .40 \), whereas delayed recall performance increased with each operation, \( F(2, 166) = 51.76, \text{MSE} = 1.16, \eta_p^2 = .38 \). For immediate recall, the source of the overall effect of operations was the difference of increasing from zero to one operation preceding each word to remember, \( F(1, 83) = 105.40, \text{MSE} = 0.02, \eta_p^2 = .56 \), but there was no difference in immediate recall between one and two operations, \( F(1, 83) = 2.57, \text{MSE} = 0.02, p = .11, \eta_p^2 = .03 \). In contrast, delayed recall significantly increased with each successive operation condition (zero versus one: \( F(1, 83) = 78.78, \text{MSE} = 0.02, \eta_p^2 = .49 \); one versus two: \( F(1, 83) = 5.60, \text{MSE} = 0.03, \eta_p^2 = .06 \)). The three-way interaction was marginally significant, \( F(2, 164) = 2.45, \text{MSE} = 0.04, \eta_p^2 = .03, p = .09 \). However, given the nature of the hypotheses, we conducted planned comparisons in order to determine whether the number of operations differentially affected younger and older adults’ recall. For immediate recall, the number of operations preceding each word to be remembered similarly diminished recall for both age groups, \( F(2, 164) = 55.83, \text{MSE} = 0.89, \eta_p^2 = .41 \) (age × number of operations interaction, \( F < 1 \)). However, the number of operations preceding each word to remember improved delayed recall to a larger extent for younger adults, \( F(2, 82) = 42.08, \text{MSE} = 0.96, \eta_p^2 = .51 \), than older adults, \( F(2, 82) = 14.81, \text{MSE} = 0.30, \eta_p^2 = .27 \) (age × number of operations interaction, \( F(2, 164) = 4.64, \text{MSE} = 0.10, \eta_p^2 = .05 \)).

In order to demonstrate the influence of the number of refreshing opportunities on delayed recall, we examined the relationship between delayed recall and refreshing opportunities for both age groups (cf. McCabe, 2008). As noted previously, the number of operations following each word to remember is thought to influence the number of attentional refreshing opportunities, such that an item presented in the first serial position of a two-operation trial will receive six refreshing opportunities, whereas the same serial position in a one-operation trial will only receive three refreshing opportunities (see McCabe, 2008, for more details on the logic of this analysis). Figure 4 displays the aggregate delayed recall performance as a function of an item’s number of opportunities to be refreshed. Both younger and older adults showed strong positive correlations of +.97 and +.85, respectively, but the correlation was significantly stronger for younger adults compared with older adults, \( Z = 3.85, p < .01 \). Thus, refreshing opportunities were more strongly predictive of delayed recall for younger adults than older adults.
Discussion

The results of Experiment 2 indicated that varying the number of attentional refreshing opportunities by varying the number of operations between to-be-remembered items influenced both immediate and delayed recall. During immediate recall, increasing the number of operations presented prior to to-be-remembered stimuli similarly reduced recall for both age groups. It should be noted that this confirms predictions from the time-based resource sharing model of working memory, such that older adults, like children and younger adults (Barrouillet et al., 2004, 2007; Barrouillet, Gavens, Vergauwe, Gaillard, & Camos, 2009), exhibited effects of cognitive load on working memory recall. That is, increasing the cognitive load of a task (i.e., increasing from zero to one operation prior to each word) similarly impaired memory performance in both age groups. However, holding the ratio of attentional capture and time to complete the arithmetic problem constant (i.e., increasing from one to two operations to solve prior to each word presentation, but also increasing the time to solve both operations) did not affect immediate recall for either age group.

Most germane to this study, however, is retrieval from episodic memory, which showed the opposite pattern: increasing the number of operations increased the likelihood of subsequently recalling items from those respective trial types, but to a greater extent for younger adults than older adults. This finding converges with other studies distinguishing working memory and episodic memory (e.g., Rose et al., 2010). As well, these data have implications for theories of forgetting from working memory versus episodic memory, suggesting that decay of memory traces occurs despite refreshing.
may impact working memory (e.g., Barrouillet et al., 2004), while refreshing, but not decay, predicts later retrieval from episodic memory. Future research should further investigate the interaction of forgetting mechanisms and refreshing on working memory and episodic memory. Of greatest importance to the scope of the current study, however, is that opportunities to refresh previously presented information once it has left the focus of attention in working memory improves the likelihood of retrieving that information from episodic memory (Johnson et al., 2002; Loaiza & McCabe, 2012; McCabe, 2008), but to a greater extent for younger adults than older adults (Johnson et al., 2002).

GENERAL DISCUSSION

The current study examined the extent to which age-related deficits in articulatory rehearsal and attentional refreshing during working memory contributed to subsequent retrieval from long-term episodic memory. Thus, it is important to note that despite the use of complex span tasks, the primary goal of the study was not to examine working memory per se, but instead to investigate long-term retrieval of information once maintained in working memory.

The results are consistent with previous research demonstrating that rehearsal and refreshing are independent mechanisms of maintenance (Camos et al., 2009, 2011) by further expanding the scope of this conclusion to include age-related differences in episodic memory (i.e., delayed recall). In particular, age differentially influenced delayed recall only as a function of opportunities for refreshing and not opportunities for rehearsal. Indeed, Experiment 1 showed that the opportunity for rehearsal during working memory encoding did not differentially impact delayed recall for either age group, suggesting that rehearsal is unimportant to age differences in episodic memory. This finding extends previous research demonstrating that rehearsal and related strategies during working memory encoding are age-invariant with respect to retrieval from working memory (Bailey et al., 2009) to include retrieval from episodic memory as well. In contrast, Experiment 2 showed that the more cognitively demanding ability to refresh information is important to retrieval from episodic memory, such that older adults benefitted less than younger adults from having more opportunities to refresh an item. These data comport with a growing corpus of research demonstrating age-related deficits in episodic memory as the consequence of deficiencies in refreshing information in working memory (Chalfonte & Johnson, 1996; Johnson et al., 2002). Such deficits may reflect poorer content-context binding with increased age, thereby leading to a relative inability to access the original context of items studied during working memory (Loaiza & McCabe, 2012; McCabe, 2008; Mitchell et al., 2000; Oberauer, 2005).
It should also be noted that using ineffective or effective strategies did not differentially impact older and younger adults’ recall in Experiment 1. However, it is important to interpret the strategy reports with caution. First, older adults reported using rehearsal less frequently than younger adults, despite the similar impact of constraining rehearsal between age groups on working memory and episodic memory. Furthermore, while effective and ineffective strategy use had no impact on the overall results, strategy reports may not perfectly reflect maintenance operations in working memory. Future research would benefit from additional investigation into the correspondence between strategy reports and strategies in working memory. Despite such limitations, these data do indicate that the age deficit in delayed recall, in particular, was not accounted for by ineffective strategy use or by constrained rehearsal. This result converges with previous findings that differences in strategy use do not substantially account for age-related differences in working memory (Bailey et al., 2009), and extends this to episodic memory (see also Dunlosky & Hertzog, 1998).

**Attentional Refreshing as a Mechanism Supporting Binding in Working Memory**

The number of refreshing opportunities afforded by a trial systematically improved delayed recall to a greater extent for younger adults than older adults. This result has substantial implications for understanding age differences in working memory and subsequent episodic memory. Namely, these data support the more general prediction that attentional refreshing is important to both working memory (Barrouillet et al., 2004, 2007; Camos et al., 2009, 2011; Hudjetz & Oberauer, 2007) and episodic memory (Loaiza & McCabe, 2012; McCabe, 2008; Johnson et al., 2002). Younger and older adults’ immediate recall was similarly impaired when increasing from one to zero operations, a finding that is inconsistent with previous research documenting age-related deficits in refreshing for working memory recall (e.g., Vaughan et al., 2008; Verhaeghen & Hoyer, 2007). It is not clear why this was the case, but the operation span task may have been less sensitive to refreshing differences in working memory accuracy than other tasks, such as n-back. In fact, the n-back and similar tasks have been exclusively used in research documenting age differences in refreshing during immediate recall. Thus, the null effect of age on refreshing in immediate recall in this study could be due to differences in tasks between this study and others. However, more relevant to the goals of the current study, the results indicated age-related deficits in attentional refreshing manifested in episodic memory (Chalfonte & Johnson, 1996; Johnson et al., 2002). This may be due to less efficient binding of item-specific information to particular contexts during working memory encoding (Oberauer, 2005).
Oberauer and colleagues (Oberauer, 2005, 2010; Oberauer et al., 2007) have argued that successful working memory performance requires flexibly binding representations or events to contexts, which could be temporal-contextual in nature. That is, an item presented during an operation span trial, for example, could be bound to its serial position within its respective trial. It has already been shown that an item’s serial position is significantly related to its likelihood of being retrieved from episodic memory (Kahana et al., 2002; Loaiza & McCabe, 2012; McCabe, 2008; Sederberg, Miller, Howard, & Kahana, 2010). Similarly, the data we report suggest that an item’s likelihood of retrieval during delayed recall is significantly related to the number of opportunities for an item to be refreshed within a trial, which is intrinsically related to an item’s serial position (i.e., an earlier presented item has more opportunities to be refreshed; see McCabe, 2008). Loaiza and McCabe (2012) report data consistent with this conclusion. In particular, we showed that episodic memory was largely determined by whether information was originally studied during working memory tasks that afforded attentional refreshing opportunities. Opportunities to attentionally refresh information during working memory increased the likelihood that these items were recalled during a delay by accessing the original temporal-context of the item (Loaiza & McCabe, 2012). Furthermore, attentional refreshing opportunities strongly predicted retrieval from episodic memory, regardless of other potential factors that are known to influence episodic memory, such as spacing or primacy. Thus, successful recall from episodic memory is partially contingent on the ability to access the original temporal context in which an item was studied and potentially bound during working memory (Kahana et al., 2002; Loaiza & McCabe, 2012; Sederberg et al., 2010).

With regard to age-related deficits in episodic memory, because older adults’ ability to refresh information during encoding in working memory is relatively impaired compared to younger adults (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007), they may be less able to bind information to a source context. Consequently, the source context is less likely to be utilized as a cue to access information compared to younger adults. Indeed, Kahana et al. (2002) have reported that older adults are less likely to utilize temporal-contextual cues to guide retrieval from episodic memory relative to younger adults. These data, in sum, suggest that older adults are less likely to bind information to a temporal source context in working memory due to a relatively deficient refreshing mechanism. This in turn reduces the likelihood that the original temporal context may be accessed as a cue for retrieval during episodic memory.

The notion that refreshing is a method of maintenance in working memory also suggests the possibility that, like rehearsal, people may adaptively select refreshing to maintain information in working memory (Camos et al., 2011). As mentioned previously, the data we report are consistent
with previous research indicating that strategy selection does not differentially impact recall with age (Bailey et al., 2009). However, no studies have investigated whether younger and older adults differ in self-reported use of refreshing to maintain information. Thus, future research on age-related differences in strategy selection during working memory should include refreshing as an option in order to determine whether there are differences in how younger and older adults adaptively select refreshing during working memory encoding. In addition, it is possible that strategy selection might differ if an episodic memory test was expected (cf. Balota & Neely, 1980). Thus, future research may also differentiate between intentional and incidental encoding in working memory (but see McCabe 2008). Furthermore, such adaptive strategy use could potentially lead to interventions aimed at improving episodic memory for older adults.

SUMMARY AND CONCLUSIONS

The current study demonstrated the influence of age on independent mechanisms of articulatory rehearsal and attentional refreshing during working memory with particular regard to age-related differences in episodic memory. Specifically, age-related deficits in the ability to refresh once-active information in working memory have greater consequences for episodic memory than the relatively age-invariant act of articulatory rehearsal. This is likely due to the importance of refreshing as a mechanism to help bind information in working memory to source contexts (Chalfonte & Johnson, 1996; McCabe, 2008; Mitchell et al., 2000; Oberauer, 2005), which may later be accessed during retrieval from episodic memory (Loaiza & McCabe, 2011). Although strategy use and rehearsal are important to working memory, they do not substantially contribute to age differences in episodic memory. Instead, the ability to reactivate previously presented information through an attentional refreshing mechanism appears to be the most compromised with age.

REFERENCES


**APPENDIX**

Example of a retrospective strategy report for a single complex span trial in Experiment 1

\[7 \times 9 = 63?\]

DISTANCE

\[5 \times 4 = 18?\]

DETAIL

\[4 \times 7 = 30?\]

TRADE

\[5 \times 8 = 40?\]

CHECK

How did you originally try to remember the words from the series above? State the number corresponding to the most appropriate response:

1. read each word as it appeared
2. repeated the words as much as possible
3. used a sentence to link the words together
4. developed mental images of the words
5. grouped the words in a meaningful way
6. did something else