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The Influence of Age-Related Differences in Prior Knowledge and Attentional Refreshing Opportunities on Episodic Memory

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Abstract

Objectives: The assumption that working memory is embedded within long-term memory suggests that the effectiveness of switching information between activated states in working memory (i.e., attentional refreshing) may depend on whether that information is semantically relevant. Given that older adults often have greater general knowledge than younger adults, age-related deficits in episodic memory could be ameliorated by studying information that has existing semantic representations compared to unknown information.

Method: Younger and older adults completed a modified operation span task that varied the number of refreshing opportunities. The memoranda used was equally known to younger and older adults (neutral words; e.g., *father*), better known to older adults than younger adults (dated words; e.g., *mirth*), or unknown to both groups (unknown words; e.g., *cobot*).

Results: Results for immediate and delayed recall indicated an age-related improvement for dated memoranda and no age difference for unknown memoranda. Furthermore, refreshing opportunities predicted delayed recall of neutral memoranda more strongly for younger adults than older adults, whereas older adults' recall advantage for dated memoranda was explained by their prior knowledge and not refreshing opportunities.

Discussion: The results suggest that older adults' episodic memory deficits could potentially be ameliorated by incorporating their superior knowledge to supplement relatively ineffective attentional refreshing in working memory.

Keywords: aging, working memory encoding, episodic memory, semantic memory

Deficits in memory that accompany aging are well documented (see, e.g., Zacks, Hasher, & Li, 2000, for a review). Moreover, older adults' subjective impressions of their own memory correspond to a view of age-related memory decline (e.g., Lachman, 1991). Much research has sought to explain and remedy such age-related deficiencies in memory performance. Deficits in episodic memory (EM) may reflect age-related variation in the immediate and limited mental workspace that supports complex, higher-order cognition (i.e., working memory; WM). Indeed, WM accounts for age-related variability in other, higher-order constructs, such as EM (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Park et al., 1996). Although EM deficits are ubiquitous with age, older adults typically exhibit age-related increases in semantic memory, such as knowledge of vocabulary and facts (McCabe et al., 2010; Verhaeghen, 2003). The current study examined whether prior knowledge enhances older adults' ability to capitalize on opportunities for refreshing or reduces age-related declines in EM independent of the efficiency of refreshing in WM.

A variety of models of WM have been proposed to account for age-related changes in WM and related higher-order cognitive processes (see McCabe & Loaiza, 2012, for a review). Although these models differ regarding underlying mechanisms or processes, most agree that WM is the immediate mental workspace that allows ongoing information to be maintained and manipulated in the service of a task goal. One such model, the *embedded processes model* (Cowan, 1999), regards WM as maintaining information in different hierarchical states of activation within long-term memory. Specifically, immediately maintained information resides in a capacity-limited focus of attention and, depending on the requirements of a task, may be switched out for other information that is not presently maintained but still highly activated. For example, during a complex span task (e.g., operation span; Turner & Engle, 1989), participants study memoranda (e.g., words) before switching to solve a processing component (e.g., an arithmetic problem, 2 + 3 = 6?). Participants' attention is diverted when solving the processing component, requiring memoranda to be temporarily displaced from immediate maintenance. However, in order to keep all memoranda active for recall, participants must refresh previously presented memoranda after solving the processing component. Thus, in order to be successfully recalled from WM, information must flexibly change between higher and lesser states of activation. The mechanism of switching attention back to information in a lesser state of activation for immediate maintenance is sometimes called focus switching (Basak & Verhaeghen, 2011; Verhaeghen & Hoyer, 2007), refreshing (Johnson, Reeder, Raye, & Mitchell, 2002; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000), or attentional refreshing (Camos, Lagner, & Barrouillet, 2009; Loaiza & McCabe, 2012). For purposes of consistency, we use the term refreshing. In sum, refreshing is an attention-based mechanism that operates to prolong the activation of representations in WM (Johnson et al., 2002).

Maintenance in WM has typically been investigated as function of articulatory rehearsal (e.g., Baddeley, 1986). More recent work has examined the role of refreshing in WM (Camos et al., 2009; Hudjetz & Oberauer, 2007) with several lines of evidence indicating that inefficient refreshing underlies age-related differences in WM (e.g., Basak & Verhaeghen, 2011; Verhaeghen & Hoyer, 2007) and EM (Johnson et al., 2002; Loaiza & McCabe, 2013). Consistent with the unique role of refreshing, evidence suggests that rehearsal and refreshing have dissociable effects on WM recall in complex span paradigms. For example, Camos and colleagues (2009; 2011; 2013) manipulated the attentional demand of a task, thereby reducing the ability to use attention-based maintenance (i.e., refreshing) while leaving phonological, rehearsal-based maintenance intact. They reported that phonologically similar memoranda (e.g., *mad*, *man*, *mat*, *cap*, *cad* compared to *cow*, *day*, *bar*, *few*) were more difficult to recall when it was possible to use articulatory rehearsal, but not when such rehearsal was suppressed. Conversely, the phonological similarity effect occurred when the attentional demand was high and was not evident when participants were instructed to use refreshing to maintain information (Camos et al., 2011; 2013). As well, modifying the placement of arithmetic problems in an operation span task (e.g., all problems at the end of the trial versus the typical spaced format) so that memoranda receive varying refreshing opportunities strongly predicts EM recall (Loaiza & McCabe, 2012). These studies suggest that refreshing and rehearsal are dissociable maintenance mechanisms that can be manipulated within a complex span paradigm.

Moreover, these mechanisms also appear to be differentially affected by age. For example, Loaiza and McCabe (2013) manipulated rehearsal by requiring participants performing an operation span task to continuously articulate while reading and solving arithmetic problems (thereby blocking rehearsal; cf. Hudjetz & Oberauer, 2007), or to read aloud and solve arithmetic problems with no articulation constraints. In a second experiment, Loaiza and McCabe varied refreshing opportunities such that zero, one, or two problems preceded each memorandum. Given that the processing component of a span task is presumed to distract attention from maintenance, participants must switch back to maintaining the previously presented memoranda. Accordingly, as the number of processing components increased, the opportunity for distraction and refreshing of memoranda also increased (see Figure 1 for a similar example). In both experiments, participants also recalled memoranda after a delay (i.e., the *delayed recall paradigm*, cf. McCabe, 2008) to examine how manipulating rehearsal and refreshing influence later retrieval from EM. Preventing rehearsal during a WM task impaired recall similarly for younger and older adults but had no effect on EM recall for either age group. However, manipulating opportunities to refresh information during a WM task improved retrieval from EM to a larger degree for younger adults than older adults (Loaiza & McCabe, 2013). These data corroborate other research suggesting an age-related deficit in refreshing in WM (Johnson et al., 2002), apparent in later retrieval of previously studied information.

In contrast to pervasive age-related deficits in WM and EM, semantic memory (e.g., knowledge of vocabulary, facts) appears to be stable or increase with age (McCabe et al., 2010; Verhaeghen, 2003). Indeed, a number of studies have demonstrated that older adults' prior knowledge may facilitate learning (Bäckman, Herlitz, & Karlsson, 1987; Beier & Ackerman, 2005; Castel, McGillivray, & Worden, in press) and even permit them to outperform younger adults (e.g., Biss, Ngo, Hasher, & Campbell, 2013; Castel, 2005; Umanth & Marsh, 2012; Wordon & Sherman-Brown, 1983). For example, Castel (2005) had older adults study grocery products, accompanied by a price that was plausible (schema-consistent) or implausible (schema-inconsistent). When later asked to recall the price when cued by the product, older adults exhibited numerically superior recall of prices consistent with their general knowledge (schema-consistent). However, older adults' recall of schema-inconsistent prices was reliably lower than younger adults. Collectively, these data suggest that older adults' intact general knowledge may attenuate or even reverse age-related declines in EM.

Given older adults' relatively enhanced knowledge, it is plausible that WM, like EM retrieval, may be affected by existing semantic representations. Cowan's (1999) embedded processes model specifically posits that WM is embedded within the wider context of long-term memory, comprising semantic memory. Accordingly, existing knowledge may influence WM maintenance, with unknown information more difficult to maintain than known information. Furthermore, if older adults have a specific refreshing deficit in WM (Johnson et al., 2002;

Loaiza & McCabe, 2012b), yet have intact or superior knowledge relative to younger adults (Verhaeghen, 2003), then (a) existing knowledge may improve the efficiency of older adults' refreshing, or (b) existing knowledge may be less critical for refreshing but still increase recall overall.

One prior study suggests that existing knowledge influences refreshing in younger adults. Specifically, Zhang and Verhaeghen (2009) manipulated semantic meaningfulness by presenting easy and difficult Chinese characters (Experiment 1) and English words (Experiment 2) to Chinese speakers and non-Chinese English speakers in an *n*-back task. Participants were required to switch between different memoranda presented in separate columns and indicated whether each memorandum was the same as the last presented in that column. The results indicated that, relative to Chinese speakers, English speakers' retrieval accuracy was poorer for the unknown Chinese stimuli as *n* increased. In contrast, English speakers' accuracy for English words relative to Chinese characters was much less affected as *n*-back value increased (Zhang & Verhaeghen, 2009). These data suggest that memoranda are more effectively refreshed in WM when they are more semantically meaningful. What remains unclear is whether the impact of prior knowledge would similarly enhance older adults' refreshing or whether such knowledge independently influences EM.

The present study addressed this question by examining differences between younger and older adults' ability to effectively use refreshing opportunities, with particular regard to the semantic meaningfulness of the memoranda between age groups. Previous work has shown that the number of refreshing opportunities in WM increases the likelihood of EM retrieval (Loaiza & McCabe, 2012; McCabe, 2008), but to a lesser extent for older adults (Loaiza & McCabe, 2013). This suggests that older adults make less efficient use of refreshing opportunities during WM encoding than younger adults. However, given age-related increases in semantic memory, coupled with theoretical frameworks (e.g., Cowan, 1999) positing that WM may be embedded within the larger context of long-term memory, prior knowledge of the memoranda may compensate for an age-related refreshing deficit.

Accordingly, we manipulated the meaningfulness of memoranda in a modified operation span task by including words that both older and younger adults know (neutral words), words that both age groups do *not* know (unknown words), and words that *only* older adults know, but are unknown to younger adults (dated words). Following Loaiza and McCabe (2012; 2013), we manipulated the number of refreshing opportunities via the number of problems following each memorandum (either one or two problems; see Figure 1 for an example). Consistent with prior work (Loaiza & McCabe, 2013), we anticipated that, for neutral words, the number of refreshing opportunities would more strongly predict EM retrieval for younger adults than older adults. For EM retrieval of unknown words, we anticipated that both age groups would generally be unable to refresh memoranda with no existing semantic representations. The critical age comparison, however, is for EM recall of dated words. If prior knowledge facilitates refreshing, then older adults should exhibit an age-related increase in EM recall relative to younger adults as refreshing opportunities for the memoranda increase. Conversely, if prior knowledge simply increases the likelihood of recall, then older adults' EM recall should be greater overall than younger adults', but unrelated to refreshing opportunities. This would suggest that older adults are less able to capitalize on refreshing opportunities than younger adults, but that prior knowledge enhances EM recall overall.

We note that we improved upon Loaiza and McCabe's methods (2013) by equating younger and older adults' response times and accuracy for the processing element (i.e., arithmetic problems) of the operation span task. To do so, we adapted the operation span task so that younger adults read aloud and responded to arithmetic problems in a word format (e.g., six + two = eight?) whereas older adults read aloud and responded to arithmetic problems in the typical, numeric format (e.g., 6 + 2 = 8?; cf. Barrouillet, De Paepe, & Langerock, 2012). Thus, any age-related differences in the experiment reported reflected the efficiency of refreshing and not differences in processing speed (cf. Salthouse, 1996). A pilot study established the timing of the processing task and the characteristics of the memoranda (see Supplementary Material).

Method

Participants

Thirty-two older adults (M_{age} = 69.50, range = 59-78) and 32 younger adults (M_{age} = 21.22, range = 17-29) were recruited who had not participated in the pilot study. All participants were paid ($10/hr) for their participation. Older adults were contacted by telephone and were excluded if they self-reported any medical history with memory or cognitive impairment.

Materials and Procedure

The arithmetic problems and memoranda used in the study were adapted from a pilot study that established the timing of the arithmetic problems and identified memoranda that best matched the age x word type manipulation described previously (see Supplementary Material).

After first completing an unrelated phase of the study, participants practiced 18 experimenter-paced arithmetic problems that would later serve as the processing component of the modified operation span task. Arithmetic problems were in a numeric format (e.g., 6 + 2 = 8?) for older adults and in a word format younger adults (e.g., six + two = eight?). Participants read the problems aloud and responded true or false (half were true).

Following the practice phase, participants began the critical phase of the study. There were three blocks of three randomly presented operation span trials with each trial comprising four memoranda that participants were instructed to remember. Participants completed a practice trial before beginning the first block. The memoranda were separated by either one or two arithmetic problems in order to vary the number of refreshing opportunities within the trial (see Figure 1). Each block contained a trial of each word type (neutral, unknown, and dated), and blocks were randomly presented. At the beginning of each trial, a word was presented for 1 s, followed by a blank ISI for 250 ms. Participants read the word silently and, depending on the trial, either one or two arithmetic problems were presented before another word was presented. The word form of the arithmetic problem was presented (e.g., six + two = eight?) for younger adults and the numeric form was presented for older adults (e.g., 6 + 2 = 8?). Participants were instructed to read and respond to each problem’s veracity aloud (half of the problems were true). Each problem was presented at a fixed rate of 3500 ms and the experimenter recorded the participant’s response. A 500 ms ISI followed each arithmetic problem. After four memoranda were presented, participants were prompted to recall the words in serial order. The experimenter recorded participants’ responses. After each block, participants completed a distracter word search task for 2 min and then engaged in free recall of words from the previous block on a sheet of paper provided.

Participants also completed a post-test vocabulary test for each of the memoranda, rating on a scale of 1 to 5 how familiar they were with the words (i.e., whether they knew the word or had seen it used before). A rating of 5 meant that the participant could provide a brief definition or synonym on a line adjacent to each individual word and rating. A rating of 1 indicated that the participant had never seen the word. Participants were encouraged to guess definitions for other words and to respond as honestly as possible.

Results

All reported significant results met a criterion of $p < .05$ unless otherwise stated. Measures of effect size (Cohen's *d* or partial eta squared, η_p^2) are reported for all significant *t* or *F* values > 1.

Practice Arithmetic and Processing Task Performance

Younger and older adults' reaction times (RTs) and accuracy on the practice arithmetic and processing task were first assessed to ensure there were no overall age group differences. Due to an experimenter error, 5 younger adult participants received 12 extra practice problems. However, results were identical when excluding these participants from the subsequent analyses. Thus, their data were included in the Results.

The practice RTs were trimmed for outliers exceeding 2.5 SDs of each individual's mean. This resulted in 3.2% of RTs removed from the final analysis, with a slightly larger number of older adults' (M = 0.04, SD = 0.03) RTs dropped than younger adults' (M = 0.03, SD = 0.03), $t(61) = 2.07$, $d = 0.49$. However, including all of the practice RTs or the subset of trimmed practice RTs yielded a null age effect, *t*s < 1. Furthermore, older (M = 0.01, SD = 0.02) and younger (M = 0.02, SD = 0.03) adults made a similar number of errors on the practice task, $t < 1$. Thus, younger and older adults performed the respective practice tasks similarly.

For the processing task, each participant's RTs were averaged across the three blocks, and errors (e.g., responding *true* when the problem was false) and time outs (i.e., responses exceeding the fixed rate of 3500 ms) were tabulated as a proportion of the total responses. As in the practice arithmetic task, younger (M = 2880, SD = 165) and older (M = 2945, SD = 242) adults responded to the problems at a similar rate, $t(62) = 1.37$, $p = .18$, $d = .31$. Both age groups (younger: $M = 0.18$, $SD = 0.12$; older: $M = 0.21$, $SD = 0.14$) also had a similar proportion of errors, $t(62) = 1.18$, $p = .24$, $d = .23$.

Post-Test Vocabulary Verification Test

Two older adults did not provide definitions during their vocabulary test and one younger adult failed to complete the vocabulary test. In three other instances participants did not rate a word. Whenever relevant, these missing scores were excluded listwise. The definitions were judged independently by two of the authors and assigned a 1 for a correct definition or a 0 for no response or an incorrect definition (inter-rater reliability was .97). The few instances of disagreement were resolved by discussion.

Participants' average ratings and definition accuracies (see Appendix) were submitted to separate 2 (age: younger, older) x 3 (word type: neutral, unknown, dated) mixed ANOVAs. For the sake of brevity, we only examine the age x word type interaction, which was significant for both ratings, $F(2, 122) = 137.14$, $\eta_p^2 = .69$, and definition accuracy, $F(2, 118) = 174.23$, $\eta_p^2 = .75$. Specifically, older adults gave higher ratings to the dated words, $F(1, 61) = 128.08$, $\eta_p^2 = .68$, but younger adults gave higher ratings to the unknown words, $F(1, 61) = 13.12$, $\eta_p^2 = .17$. Older and younger adults' ratings did not differ for neutral words, $F(1, 61) = 2.52$, $p = .12$, $\eta_p^2 = .04$. This pattern was similar for the analysis of definition accuracy: younger and older adults did not differ in neutral word definitions, $F < 1$, but younger adults were more accurate at defining unknown words, $F(1, 59) = 5.43$, $\eta_p^2 = .08$. Older adults were more accurate at defining dated words than younger adults, $F(1, 59) = 217.58$, $\eta_p^2 = .79$.

Working Memory and Episodic Memory Recall

In order to compare immediate and delayed recall (cf. McCabe, 2008), recall was scored at the item level without regard to serial order. We corrected recall for the ratings and definition accuracy of each participant. That is, if participants' ratings either did not match the accuracy of their definitions or did not match the intended manipulation of word type and age, recall for those words was excluded at the item level.[1] This aligned participants' recall with the manipulation of prior knowledge between age groups.

Recall using the corrected scoring was submitted to a 2 (age group: younger, older) x 2 (time of test: immediate, delayed) x 3 (word type: neutral, unknown, dated) mixed-factor ANOVA (see Figure 2). For the sake of brevity, we report only on the significant three-way interaction, $F(2, 118) = 4.24$, $\eta_p^2 = .07$. During immediate recall, younger adults recalled more neutral words than older adults, $F(1, 59) = 6.83$, $\eta_p^2 = .10$, whereas older adults recalled more dated words than younger adults, $F(1, 59) = 3.22$, $\eta_p^2 = .08$ (age x word type interaction, $F(2, 118) = 6.06$, $\eta_p^2 = .09$). Recall of unknown items did not differ by age, $F < 1$. The pattern for delayed recall paralleled immediate recall, but the effect was more pronounced: Younger adults recalled more neutral items than older adults, $F(1, 59) = 19.88$, $\eta_p^2 = .25$, whereas older adults recalled more dated words than younger adults, $F(1, 59) = 8.17$, $\eta_p^2 = .12$. There was no difference in recall for unknown items, $F < 1$ (age x word type interaction, $F(2, 118) = 16.79$, $\eta_p^2 = .22$).

Episodic Memory Recall as a Function of Refreshing Opportunities

[1] Specifically, recall was excluded at the item level if participants rated a word as 5 but provided an inaccurate definition, or rated a word as 1 or 2 but gave an accurate definition. Furthermore, the corrected data also ensured that participants' ratings reflected the intended manipulation of word type between age groups. That is, recall was excluded at the item level if younger participants rated a dated or unknown word as 4 or 5 and correctly knew its definition, or if older participants rated an unknown word as 4 or 5 and correctly knew its definition. Recall was also excluded at the item level if younger participants rated a neutral word as 1 or 2 and did not know its definition, or if older participants rated a dated or neutral word as 1 or 2 and did not know its definition. Ratings of 3 for any word type were excluded from the analysis for all participants. In sum, 14% of the data were excluded in the corrected scoring at the item level.

In order to assess the influence of refreshing opportunities and word knowledge on delayed recall between age groups, we submitted recall at the item level (0 for incorrect, 1 for correct) to a binary logistic regression analysis[2] for each word type, using word knowledge (i.e., rating), age and refreshing as predictors (see Table 1). The most important results are the odds ratios (OR) of each predictor: an OR less than 1 suggests a negative effect of the predictor, whereas an OR greater than 1 suggest a positive effect of the predictor on delayed recall; an OR with confidence intervals (CIs) overlapping with 1 is not significant.

The results indicated that controlling for ratings in the first step did not change the effects of age or refreshing opportunities for neutral or unknown memoranda: neutral recall and, to a lesser extent, unknown recall, reliably increased as refreshing opportunities increased whereas age significantly reduced only neutral recall (see Table 1). The most crucial findings concerned recall of dated memoranda. When controlling for ratings, the age advantage shown in the overall analysis for dated memoranda disappeared. This suggests that the age-related benefit for dated memoranda was due solely to older adults' greater word knowledge, so much so that controlling for ratings numerically reversed the effect shown in the overall analysis. Indeed, reversing the order of the variables in the model showed a significant age effect (Wald $\chi^2 = 4.02$, $OR = 1.41$, $CI = 1.01\text{-}1.97$, $p < .05$) that is nullified when adding ratings in the second step (see Table 1).

We further assessed whether the effects of refreshing opportunities shown for the three different word types were equivalent between age groups (see Table 2).[3] The results indicated that both age groups exhibited increased recall of neutral memoranda as a function of refreshing

[2] The flexibility of this analysis allowed us to exclude fewer data points than in the previous overall analysis (Figure 2), such that only missing data and data points where the rating and definition of the word were incongruent (e.g., giving a rating of 5 to a word but an incorrect definition) were excluded (9% of the data).

[3] Including an interaction term between age and refreshing violated the assumption of linear independence between variables (i.e., refreshing and the age x refreshing interaction term were correlated for each word type, rs $\geq$ .40, ps < .001). Therefore, we could not include the interaction term as a predictor in the previous models. Thus, we conducted this analysis given our specific a priori predictions regarding a potential interaction between age, word type and refreshing opportunities.

opportunities, although this effect was stronger for younger adults. In younger adults, refreshing opportunities significantly predicted recall of unknown memoranda and numerically predicted dated recall (p = .14). However, refreshing opportunities did not predict older adults' recall of unknown or dated memoranda.

Discussion

The current study provides the first investigation of the influence of existing knowledge on EM as a function of refreshing opportunities in WM. We showed contrasting age effects for neutral and dated information for WM and EM, both overall and as a function of refreshing opportunities during a WM span task. That is, younger adults recalled more neutral memoranda than older adults, but older adults recalled more dated memoranda than younger adults. Conversely, recall did not vary between age groups when prior knowledge was limited for both age groups (i.e., the unknown memoranda). Further analyses indicated that refreshing opportunities were important for both age groups' recall of neutral memoranda, but to a lesser extent for older adults than younger adults. This suggests that older adults can make use of refreshing opportunities, but do so less efficiently than younger adults (Loaiza & McCabe, 2013). A key question was whether older adults' superior knowledge of dated words would supplement refreshing or whether knowledge was independent of refreshing opportunities. Our results were consistent with the latter possibility, as older adults' greater recall of dated memoranda was unaffected by refreshing opportunities.

Previous research has suggested refreshing as a source of age-related differences in WM (Verhaeghen & Hoyer, 2007) and EM (Johnson et al., 2002; Loaiza & McCabe, 2013). By this account, older adults are less capable of accurately prolonging the activation of previously presented information than younger adults. Our results replicate and extend previous work

(Loaiza & McCabe, 2013) to suggest that, even after controlling for response speed, age-related differences in the effectiveness of utilizing refreshing opportunities for EM remain. However, when younger adults studied information that they did not know, but older adults did know (i.e., the dated memoranda), older adults' WM and EM recall was superior to younger adults. Interestingly, this age-related benefit in EM recall of dated words was not influenced by increasing refreshing opportunities during WM encoding. Thus, older adults' prior knowledge augments WM and EM recall alike, but does not increase the effectiveness of refreshing for EM. Instead, it may supplement encoding or retrieval for older adults independently of their relatively inefficient refreshing.

The results also indicate that prior knowledge is a powerful predictor of WM and EM recall, regardless of age. After accounting for the effect of age, increases in ratings given to words across word type significantly increased the likelihood of WM recall by approximately 58%, and increased the likelihood of EM recall by approximately 68%. Thus, prior knowledge influenced both age groups' retrieval. Indeed, our data demonstrate that older adults' retrieval of dated memoranda from EM reflects intact semantic representations rather than refreshing opportunities during WM encoding. Conversely, refreshing predicted older adults' delayed recall of neutral memoranda, although their recall was lower than younger adults. This may reflect the fact that, despite older adults' similar knowledge of neutral and dated memoranda, the words differed in frequency (see Appendix), thereby rendering refreshing opportunities a less reliable predictor of recall for dated memoranda than neutral memoranda. Thus, further research may disentangle the effects of word knowledge and frequency on the efficiency of refreshing in WM. In contrast, for younger adults, refreshing significantly improved unknown delayed recall and numerically improved dated delayed recall. It is not clear why this was the case for unknown memoranda when dated memoranda were constrained so that prior knowledge was equivalent between both word types for younger adults. The effect suggests that it may be possible for younger adults to refresh information in WM in the absence of prior knowledge. However, further research would need to confirm this pattern.

We note that our method of addressing differences in response speed, as well as implementing measures of individual vocabulary words between age groups, may benefit future research seeking to account for these effects. Processing speed generally slows with advancing age and accounts for substantial age-related variance in other measures of higher-order cognition (Salthouse, 1996). By equating for response speed between age groups during a WM task, researchers may better isolate the mechanisms that support WM maintenance independently of processing speed.

Despite this methodological improvement, we note that the complex span paradigm does not allow a direct measure of refreshing, but rather an indirect examination by varying refreshing opportunities in WM. Accordingly, our design cannot directly measure or precisely define the locus of the refreshing deficit with advancing age (e.g., whether the deficit is due to access or availability of memoranda between age groups; cf. Vaughan, Basak, Hartman, & Verhaeghen, 2008). However, prior work has established that varying refreshing opportunities can highlight the impact of refreshing on WM (Camos et al., 2009; 2011; 2013) and EM (Loaiza & McCabe, 2012; 2013) recall. Indeed, by varying refreshing opportunities, the current study demonstrates that older adults are not as capable of utilizing refreshing opportunities as younger adults, but this relative deficiency may be supplemented by prior knowledge.

In sum, the results of the present study add to a growing literature concerning the importance of refreshing in WM across the lifespan, particularly as it predicts retrieval from EM.

Although the nature of the refreshing deficit still requires further research, this study establishes that existing knowledge can independently compensate for age-related differences in refreshing, so much as to reverse age-related differences in recall. This in turn allows a better understanding of the mechanisms that support WM maintenance and later EM retrieval. We hope that such research, emphasizing older adults' intact abilities, serves as a fruitful method of improving memory ability in older age.

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Table 1. Binary logistic regression at the item level (1 recalled, 0 not recalled) using age and refreshing as predictors of delayed recall for each word type. Age was dummy-coded, with younger adults as the reference group.

Word Type	Step	Variable	*B*	*SE*	Wald χ^2	OR	95% CI
Neutral	1	Rating	-0.22	0.54	0.17	0.80	[0.28, 2.29]
	2	Rating	0.03	0.51	0.00	1.03	[0.38, 2.80]
		Age	-1.10	0.16	46.39**	0.33	[0.24, 0.46]
		Refreshing	0.20	0.05	17.83**	1.22	[1.11, 1.34]
Unknown	1	Rating	0.42	0.12	11.98*	1.52	[1.20, 1.94]
	2	Rating	0.37	0.13	8.57*	1.45	[1.13, 1.85]
		Age	-0.16	0.21	0.54	0.86	[0.56, 1.30]
		Refreshing	0.13	0.06	4.61*	1.14	[1.01, 1.29]
Dated	1	Rating	0.25	0.06	19.77**	1.29	[1.15, 1.44]
	2	Rating	0.31	0.07	19.29**	1.37	[1.19, 1.58]
		Age	-0.25	0.22	1.39	0.78	[0.51, 1.18]
		Refreshing	0.10	0.05	3.69†	1.10	[1.00, 1.22]

* $p < .05$, ** $p < .001$, † $p < .06$

Table 2. Binary logistic regression analysis of the effect of refreshing on delayed recall at the item level for younger and older adults for each word type. Note that there was no effect to report for ratings when predicting neutral recall because older adults' ratings were all 5.

Word Type	Age Group	Step	Variable	*B*	*SE*	Wald χ^2	OR	95% CI
Neutral	Younger	1	Rating	-0.01	0.51	0.00	0.99	[0.36, 2.69]
		2	Rating	0.04	0.51	0.01	1.04	[0.38, 2.82]
			Refreshing	0.24	0.07	11.08***	1.26	[1.10, 1.45]
	Older	1	Rating	-	-	-	-	-
		2	Rating	-	-	-	-	-
			Refreshing	0.17	0.06	7.11**	1.19	[1.05, 1.35]
Unknown	Younger	1	Rating	0.47	0.14	11.17***	1.60	[1.21, 2.10]
		2	Rating	0.41	0.14	8.33**	1.51	[1.14, 2.00]
			Refreshing	0.19	0.09	4.73*	1.21	[1.02, 1.43]
	Older	1	Rating	0.11	0.33	0.12	1.21	[0.59, 2.12]
		2	Rating	0.12	0.33	0.13	1.12	[0.59, 2.13]
			Refreshing	0.06	0.09	0.49	1.07	[0.89, 1.28]
Dated	Younger	1	Rating	0.26	0.08	11.01***	1.30	[1.11, 1.52]
		2	Rating	0.29	0.08	12.45***	1.33	[1.14, 1.56]
			Refreshing	0.11	0.08	2.19	1.12	[0.97, 1.29]
	Older	1	Rating	0.42	0.17	6.14**	1.52	[1.09, 2.13]
		2	Rating	0.43	0.17	6.53**	1.54	[1.11, 2.15]
			Refreshing	0.09	0.07	1.47	1.09	[0.95, 1.26]

* $p < .05$, ** $p = .01$, *** $p < .001$

Figure 1. Example of a modified operation span trial used in the critical study that varied refreshing opportunities while controlling for response time differences between age groups. The left-hand example is a trial that younger adults completed (i.e., arithmetic problems written in word format) while the right-hand example is a trial that older adults completed (i.e., arithmetic problems written in typical format) to equate response speed to the arithmetic problems in the operation span.

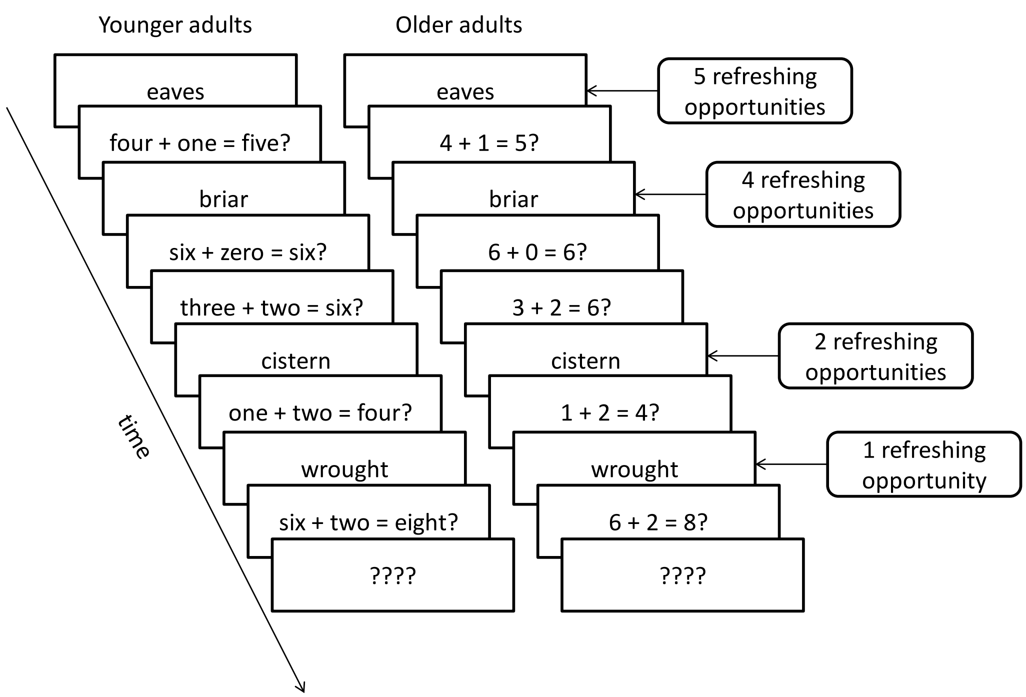
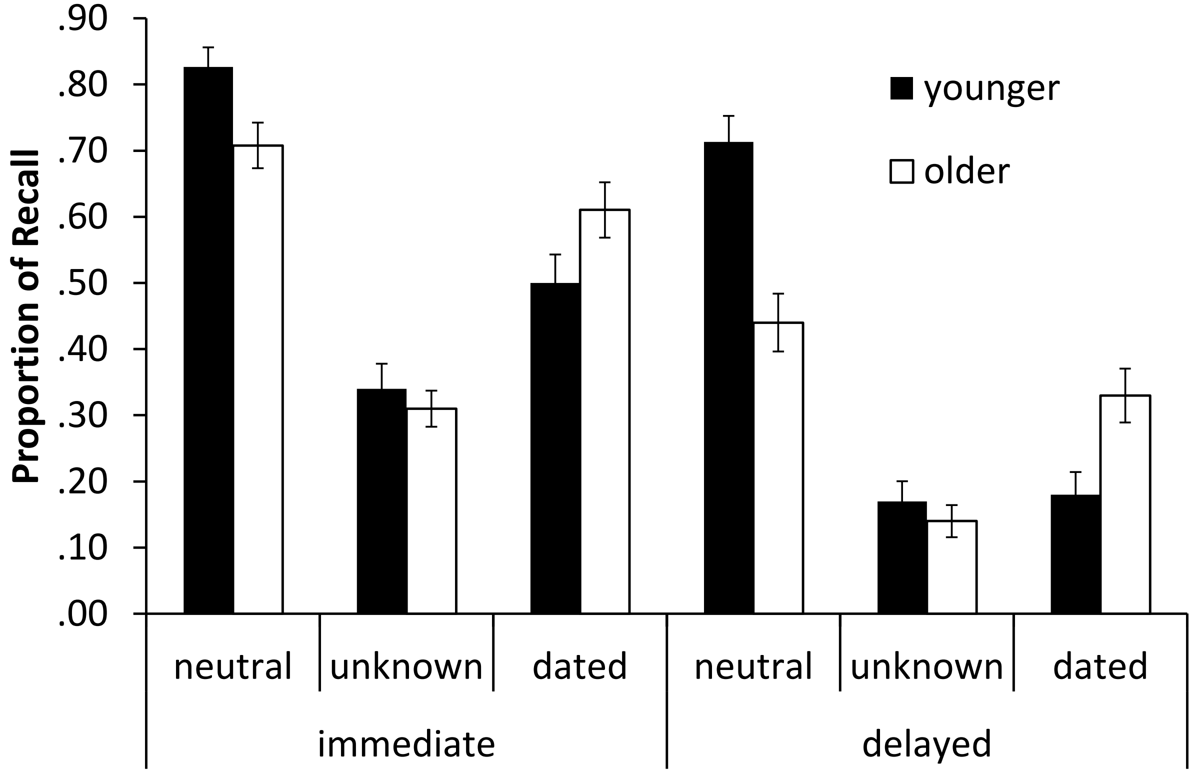


Figure 2. Proportion of recall as a function of age group, time of test, and word type of recall (corrected scoring). Error bars reflect one standard error of the mean.



Appendix

					Ratings				Definitions			
					younger adults		older adults		younger adults		older adults	
Word Type	Word	Length	Syllables	LogHal	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
neutral	*M*	5.25	1.50	11.57	4.98	0.06	5.00	0.00	0.97	0.05	0.96	0.15
	book	4	1	12.16	5.00	0.00	5.00	0.00	0.94	0.25	0.97	0.18
	country	7	2	11.58	5.00	0.00	5.00	0.00	0.94	0.25	1.00	0.00
	course	6	1	12.19	5.00	0.00	5.00	0.00	0.90	0.30	0.97	0.19
	father	6	2	10.55	5.00	0.00	5.00	0.00	1.00	0.00	0.97	0.18
	game	4	1	12.19	4.84	0.73	5.00	0.00	0.97	0.18	0.97	0.18
	hand	4	1	11.74	5.00	0.00	5.00	0.00	1.00	0.00	0.97	0.19
	house	5	1	11.55	5.00	0.00	5.00	0.00	1.00	0.00	0.93	0.25
	music	5	2	11.81	5.00	0.00	5.00	0.00	1.00	0.00	0.97	0.18
	nature	6	2	10.85	4.97	0.18	5.00	0.00	0.94	0.25	0.97	0.18
	phone	5	1	11.86	5.00	0.00	5.00	0.00	1.00	0.00	0.93	0.26
	police	6	2	10.78	4.97	0.18	5.00	0.00	0.97	0.18	0.93	0.25
	water	5	2	11.57	5.00	0.00	5.00	0.00	1.00	0.00	0.97	0.19
unknown	*M*	5.42	1.83	-	1.31	0.39	1.06	0.11	0.02	0.04	0.00	0.02
	cobot	5	2	-	1.29	0.64	1.09	0.53	0.00	0.00	0.00	0.00
	ladette	7	2	-	1.19	0.65	1.00	0.00	0.00	0.00	0.00	0.00
	misper	3	2	-	1.10	0.30	1.00	0.00	0.00	0.00	0.00	0.00
	mobe	4	1	-	1.68	1.05	1.06	0.25	0.00	0.00	0.00	0.00
	otaku	5	3	-	1.45	1.21	1.00	0.00	0.06	0.25	0.00	0.00
	racino	6	3	-	1.26	0.68	1.00	0.00	0.00	0.00	0.00	0.00
	sadcore	7	2	-	1.13	0.57	1.00	0.00	0.03	0.18	0.00	0.00
	skeeve	6	1	-	1.90	1.30	1.19	0.78	0.10	0.30	0.03	0.18
	sleb	4	1	-	1.26	0.77	1.00	0.00	0.03	0.18	0.00	0.00
	traceur	7	2	-	1.19	0.54	1.22	0.87	0.00	0.00	0.00	0.00
	twocker	7	2	-	1.06	0.36	1.09	0.39	0.00	0.00	0.00	0.00
	wazz	4	1	-	1.27	0.59	1.00	0.00	0.00	0.00	0.00	0.00

dated	*M*	5.92	1.50	5.20	2.57	0.91	4.61	0.46	0.17	0.15	0.77	0.17
	billow	6	2	3.18	3.19	1.60	4.75	0.51	0.29	0.46	0.83	0.38
	bower	5	1	5.96	1.61	0.92	3.53	1.72	0.00	0.00	0.31	0.47
	bramble	7	2	5.59	2.60	1.67	4.69	0.59	0.26	0.44	0.87	0.35
	briar	5	1	5.30	2.52	1.39	4.72	0.63	0.06	0.25	0.97	0.18
	cherub	6	2	5.17	3.39	1.75	4.72	0.68	0.45	0.51	0.87	0.35
	cistern	7	2	4.09	2.77	1.71	4.88	0.55	0.16	0.37	0.97	0.18
	dearth	6	1	5.93	1.77	1.02	4.22	1.21	0.06	0.25	0.50	0.51
	eaves	5	1	-	2.84	1.53	4.81	0.40	0.13	0.34	0.97	0.18
	mirth	5	1	5.93	1.90	1.19	4.81	0.64	0.03	0.18	0.86	0.35
	parson	6	2	5.63	2.55	1.55	4.84	0.72	0.13	0.34	0.90	0.31
	russet	6	2	4.14	2.74	1.48	4.75	0.67	0.35	0.49	0.90	0.31
	wrought	7	1	6.30	2.87	1.36	4.63	0.75	0.03	0.18	0.34	0.48