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Long-Term Semantic Representations Moderate the Effect of Attentional Refreshing on Episodic Memory

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In honor of our beloved adviser, collaborator, and friend, David P. McCabe, who passed away January 11, 2011.

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Abstract

The McCabe effect (McCabe, 2008) refers to an advantage in episodic memory (EM) retrieval for memoranda studied in complex span versus simple span tasks, particularly for memoranda presented in earlier serial positions. This finding has been attributed to the necessity to refresh memoranda during complex span tasks that, in turn, promotes content-context binding in working memory (WM). Several frameworks have conceptualized WM as being embedded in long-term memory. Thus, refreshing may be less efficient when memoranda are not well-established in long-term semantic memory (SM). To investigate this, we presented words and non-words on simple and complex span trials in order to manipulate the long-term semantic representations of the memoranda with the requirement to refresh the memoranda during WM. A recognition test was administered that required participants to make a Remember-Know decision for each memorandum recognized as *old*. The results replicated the McCabe effect, but only for words, and the beneficial effect of refreshing opportunities was exclusive to recollection. These results extend previous research by indicating that the predictive relationship between WM refreshing and long-term EM is specific to recollection, and, furthermore, moderated by representations in long-term SM. This supports the predictions of WM frameworks that espouse the importance of refreshing in content-context binding, but also those that view WM as being an activated subset of and, therefore, constrained by the contents of long-term memory.

Keywords: working memory, long-term memory, episodic memory, recollection, Remember-Know Paradigm

Working memory (WM) and long-term memory have typically been considered distinguishable but related constructs (but see Nairne, 2002). WM is the immediate memory system responsible for maintaining and processing information in the service of ongoing cognition and task goals. Long-term memory refers to the retention of information no longer in WM and is commonly divided into distinct sub-systems including semantic memory (SM; e.g., factual knowledge, vocabulary) and episodic memory (EM; e.g., autobiographical memory). Given models suggesting that WM represents an activated subset of long-term memory (e.g., Cowan, 1999), recent research has further explored this relationship by examining long-term memory factors that affect WM functioning (e.g., Loaiza, Rhodes, & Anglin, 2013). The following study examined the influence of long-term semantic representations on WM maintenance and its consequences for attentional refreshing as a predictor of EM retrieval.

WM is often tested using complex span tasks (e.g., operation span) that interleave the presentation of memoranda (e.g., words) with distracting tasks (e.g., solving arithmetic problems). Complex span tasks have been considered distinguishable from other immediate memory tasks, such as simple span tasks (e.g., word span), in that participants must maintain memoranda despite distraction. EM tasks typically test retrieval of studied information after it has left WM using recall, cued recall, or recognition tests. Much research has shown that WM and EM are highly related but distinct constructs across the lifespan (e.g., McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Unsworth and Brewer (2009) showed that this relationship is more specific to recollection-based EM. Recollection and familiarity are two independent processes underlying EM (Yonelinas, 2002). Recollection requires retrieval of the specific details of an event, whereas familiarity refers to retrieval in the absence of specific, contextual details (i.e., recollection). Using a variety of EM tests, Unsworth and Brewer demonstrated that a model with two factors representing recollection and familiarity had a better fit than a model constraining all EM tests onto a single factor. Furthermore, individual differences in WM capacity were related to the recollection but not the familiarity factor. Thus, there is evidence that individual differences in WM predict recollection-based EM.

Researchers have focused on WM mechanisms, articulatory rehearsal and attentional refreshing (Camos, Lagner, & Barrouillet, 2009), that are potentially important to its predictive utility. Rehearsal maintains memoranda through covert and subvocal phonological repetition, whereas refreshing prolongs activation through a more discrete, briefer act of reflective attention that does not necessarily involve phonological representations (Raye, Johnson, Mitchell, Greene, & Johnson, 2007). For example, in the context of a complex span task, presenting a distracting task disrupts maintenance. Maintenance must be resumed by brief, likely intermittent, acts of refreshing the previously presented memoranda that are still partially active. Consequently, earlier-presented items may have more cumulative opportunities to be refreshed than later-presented items in complex span tasks (McCabe, 2008).

In addition to its importance for WM recall, refreshing is important for EM retrieval (Johnson, Reeder, Raye, & Mitchell, 2002; Loaiza & McCabe, 2012). McCabe (2008) demonstrated this relative EM benefit by comparing immediate and delayed recall on complex and simple span tasks. Although immediate recall was greater for simple span relative to complex span, delayed recall was superior for complex span. Furthermore, the advantage was greater for earlier than for later serial positions, whereas delayed recall did not vary with serial position for simple span. We henceforth refer to this relative benefit of complex span over simple span in EM retrieval, especially according to original serial positions, as “the McCabe effect.” McCabe originally accounted for the pattern by proposing that participants engaged in covert retrieval during complex span, but not simple span, in order to maintain the memoranda. Furthermore, McCabe suggested that covert retrieval occurred cumulatively, such that earlier serial positions in a typical complex span received more opportunities for covert retrieval. However, the precise mechanism for covert retrieval was unclear.

Loaiza and McCabe (2012, 2013) further showed that the McCabe effect was a unique consequence of refreshing. Specifically, suppressing the opportunity to rehearse by having participants continuously articulate during a complex span did not impact EM retrieval (Loaiza & McCabe, 2013). However, varying the placement of the distracting task so as to modify refreshing opportunities during a complex span had a strong effect on subsequent EM (Loaiza & McCabe, 2012; 2013). Their results further demonstrated that, as a consequence of its function of maintaining memoranda, refreshing facilitates content-context binding in WM that, in turn, supports EM retrieval. For example, Loaiza and McCabe (2012) examined the likelihood of successful retrieval on the basis of the memoranda's original temporal context (i.e., serial positions) by providing cues that referred back to the memoranda's original serial positions. The results revealed that delayed cued and free recall were more likely to benefit from externally provided and internally generated temporal-contextual cues, respectively, when memoranda were presented in complex span versus simple span (Loaiza & McCabe, 2012). Thus, these studies suggest that refreshing during WM increases the likelihood that EM retrieval utilizes the original temporal context (i.e., serial positions) of the memoranda. Because recollection relies on retrieval of contextual details associated with a study episode, refreshing during WM may help promote recollection of such details during EM (Grillon, Johnson, Krebs, & Huron, 2008). However, prior studies have not specifically examined recollection in the context of the McCabe effect, leaving this possibility untested. Therefore, one goal of the present study was to investigate whether refreshing during WM facilitates recollection. Drawing upon our previous research indicating that serial positions may serve as a proxy for opportunities to refresh memoranda in a complex span task (Loaiza & McCabe, 2012, 2013; McCabe, 2008), we specifically investigated the consequences of refreshing opportunities on EM recollection.

Although refreshing during WM may predict EM, the relationship between WM and EM may be bidirectional such that long-term memory factors may also affect WM maintenance as a consequence of WM being an activated subset of long-term memory (Cowan, 1999). For example, Loaiza and colleagues (2013) demonstrated that prior knowledge strongly benefited WM and EM recall overall, but the effect of refreshing on EM was more prevalent for known versus unknown memoranda. This is consistent with Ricker and Cowan (2010), who reported that the negative impact of blocking refreshing increased across longer retention intervals for English letters, but not for unfamiliar visual stimuli. Such results indicate that memoranda that are difficult to label are less likely to be refreshed in WM, perhaps because they are sparsely represented in long-term SM. However, the impact of semantic representations on the effectiveness of refreshing to facilitate content-context binding in WM remains poorly understood.

The present study thus had two goals. First, we sought to establish that manipulating the opportunity to refresh memoranda during WM predicts recollection-based EM. Second, we examined whether any potential influence of refreshing opportunities on recollection would be attenuated when memoranda were unknown (i.e., was not represented in long-term SM). Such findings would address unresolved issues concerning the relative importance of WM refreshing in EM and demonstrate that refreshing is moderated by long-term semantic representations. Accordingly, we manipulated the lexicality of memoranda (words vs. non-words) across complex and simple span trials. A delayed recognition test for those memoranda was administered, but after each *old* response participants were required to make a Remember-Know decision. The Remember-Know paradigm (Tulving, 1985) is a method of disentangling recollection and familiarity by asking participants to report their subjective experience of recollecting details from the original study episode (Remember) versus "just knowing" the memorandum was presented without any accompanying contextual detail (Know). We anticipated that refreshing opportunities would strongly predict recollection-based EM, evident in relatively higher recollection for earlier serial positions (i.e., items that were refreshed more often during WM) than for later serial positions during complex but not simple span. However, this benefit should be smaller for non-words than for words, such that memoranda lacking well-established representations in long-term SM would be less likely to exhibit the benefit of refreshing for EM recollection.

Method

Participants

Forty-four native English speakers (M_{age} = 20.95, range = 18-29) were recruited for the study. Two participants were dropped due to experimenter error and replaced. Thirty-two were undergraduate students recruited from Colorado State University and 12 were Americans living in Bern, Switzerland. Participants were given course credit or monetary compensation.

Materials and Procedure

The memoranda were 96 high-frequency nouns (Log HAL frequency ratings range = 6.58-12.30, *M* = 9.52) that were three to eight letters and one to two syllables long. To create non-words that matched in letter and syllable length, a letter from each memorandum (e.g., *cup*, *pepper*) was switched to make it a pronounceable non-word (e.g., *cun*, *hepper*). During the study we discovered that one non-word was actually a slang word. This item was excluded from analyses for 17 participants and replaced for the remaining 27 participants. Forty-eight memoranda (24 words and 24 non-words) were presented during the encoding phase and re-presented as *old* items during the recognition test. The other 48 memoranda (24 words and 24 non-words) served as the *new* items during the recognition test. Memoranda were counterbalanced for task, word type, and status as an old/new item on the recognition test.

After 30 practice arithmetic problems, participants completed one block of randomly presented simple and complex span trials of words and non-words before completing a delayed recognition test. Participants practiced one trial of each type before beginning the experiment. There were three trials of each type and four memoranda per trial. The simple span trials presented one memorandum at a time for 1 s (with a 250 ms interstimulus interval) before a cue to recall the memoranda aloud in the original order of presentation. Complex span trials were similar, except that an arithmetic problem to read aloud and solve (e.g., 7 x 4 =28?) preceded each memorandum (see Figure 1). After completing the block, participants completed a demographics questionnaire followed by the delayed recognition test. Each item was randomly presented one-at-a-time and participants were instructed to determine whether it was old or new. After each decision the words "Remember or Know?" appeared on the screen and participants provided a Remember or Know judgment for items deemed *old*. Prior to the test phase, participants were given the source-specific version of the typical Remember-Know judgment instructions developed by McCabe and Geraci (2009) to constrain Remember responses to the encoding phase. Participants made their old/new and Remember-Know judgments aloud, and the experimenter entered each response.

Scoring

For WM recall, we scored for both immediate serial and free recall but focused our analyses on free recall (the results were identical; see Table 1). For EM retrieval, we assessed corrected recognition (hits – false alarms) as well as recollection and familiarity. Consistent with prior work, Remember responses were considered a measure of recollection (e.g., McCabe, Roediger, McDaniel, & Balota, 2009), whereas familiarity was calculated according to the Independence-Remember Know procedure (IRK; Yonelinas & Jacoby, 1995). This correction assumes that Know responses are made on the basis of familiarity in the absence of recollection (F[1 – R]), and thus conditionalizes Know responses on not having recollected an item (i.e., know/[1 – remember]). We also examined recollection and familiarity as a function of serial position for each participant. However, we report Know responses instead of IRK because 7% of the individual IRK estimates had to be dropped due to an undefined result (i.e., a participant provided a Remember response for all of the memoranda of a serial position of one trial type). This caused 25 of the participants to be excluded listwise when analyzing IRK estimates. However, the results of either analysis were largely similar between the two methods of estimating familiarity.

Results

Table 1 reports immediate serial and free recall, and delayed recognition (hits, false alarms, Remember and Know responses) for each trial type. A 2 (task: simple span, complex span) x 2 (word type: word, non-word) repeated-measures ANOVA with the proportion of immediate free recall as the dependent variable showed significant main effects and an interaction (see Table 2). Specifically, the difference between simple and complex span recall with non-words as memoranda was smaller than that for simple and complex span with words. This interaction was likely driven by a ceiling effect for the simple span word trial type.

The most crucial results regard the delayed recognition test. We first considered corrected recognition for each item type using the previous 2 x 2 analysis (see Figure 2A). There was a main effect of task as well as an interaction, such that the benefit of complex span relative to simple span was significant for words, $F(1, 43) = 14.14$, $\eta_p^2 = .25$, but not for non-words, $F < 1$. This replicates the McCabe effect in delayed recognition (McCabe, 2008) but also shows that the effect disappears when memoranda are not well-established in long-term SM. When assessing recollection, there were significant main effects of task and word type, but the interaction failed to reach significance (see Figure 2B). Finally, there was only a marginally non-significant effect of word type on familiarity, with non-words showing a slightly higher overall level of familiarity than words (see Figure 2C).

The critical analysis considered recollection and familiarity as a function of serial position using a 2 (task: simple span, complex span) x 2 (word type: word, non-word) x 4 (serial position: 1, 2, 3, 4) repeated-measures ANOVA (see Table 3). In the interest of brevity, we focus on the significant interactions. For recollection (Figures 3A and B), the task x serial position interaction indicated a larger effect of serial position on complex span ($F(3, 129) = 9.15$, $\eta_p^2 = .18$) than on simple span ($F < 1$) tasks. This supports and extends previous research, such that tasks that afford refreshing opportunities (i.e., complex span) predict EM retrieval, especially recollection-based EM. The word type x serial position interaction was significant, such that the effect of serial position was larger for words, $F(3, 129) = 8.18$, $\eta_p^2 = .16$, than for non-words, $F < 1$. Interestingly, the three-way interaction was not significant. However, this likely reflects a slightly positive slope for simple span/non-word, $Y = 0.02x + 0.17$, thereby yielding a difference between simple span/word and non-word trial types in the first serial position. Indeed, the most negative slope was for complex span/word trial type, $Y = -0.10x + 0.71$, whereas the simple span/word, Y = -0.03x + 0.42, and complex span/non-word trial types, Y = -0.03x + 0.35, had predictably identical slopes (cf. Loaiza & McCabe, 2012). For familiarity (Figures 3C and D), only the main effect of word type was significant, indicating that more Know responses were given to non-words than to words, overall.

Discussion

The results largely supported our prediction that long-term semantic representations moderate the facilitatory effect of refreshing on recollection-based EM. Specifically, we replicated the McCabe effect, demonstrating a benefit of complex span over simple span memoranda on a delayed recognition test. However, this advantage was larger for words than for non-words in both corrected recognition (Cohen's d = 0.61 and 0.12, respectively) and recollection (Cohen's d = 0.60 and 0.32, respectively). Furthermore, the McCabe effect was especially evident in recollection-based EM retrieval across serial positions, such that participants were more likely to report recollective experiences for memoranda originally presented earlier in complex span trials, relative to simple span trials. Conversely, the benefit to recollection for earlier serial positions was attenuated for non-words, and there was no effect of serial position on familiarity-based retrieval for any of the trial types. Because serial positions in complex span trials reflect the opportunity for refreshing (cf. Loaiza & McCabe, 2012), these data indicate that refreshing during WM was optimal when memoranda are well-established in long-term SM. Thus, the beneficial effect of refreshing on EM retrieval is strongly influenced by the status of the representations in SM.

These results bear on the bi-directionality of the relationship between WM and long-term memory. Specifically, the mechanisms supporting WM may facilitate recollection that occurs during later EM retrieval and are sensitive to established knowledge in long-term memory. WM refreshing has been previously tied to content-context binding during WM encoding (Loaiza & McCabe, 2012), such that memoranda are more likely to be bound to their original source context after having been refreshed during WM. Content-context binding has been an important aspect of explaining recollection-based EM (e.g., Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000) in that binding increases the likelihood of recollecting specific contextual details during EM retrieval. The present study suggests that refreshing, at least in part, facilitates content-context binding during WM, yielding significantly greater subjective experiences of recollection as the opportunities to refresh information increase. Conversely, familiarity does not require content-context binding, because it reflects memory in the absence of contextual detail. The results of the study thus provide divergent validity: Non-words were more likely to be regarded as familiar (i.e., elicited more Know responses) than words, but this was unrelated to the opportunity to refresh information in WM. Accordingly, the results suggest that refreshing during WM plays a strong role in the likelihood that memoranda are bound to their source contexts (in this study, serial positions in complex span), thereby yielding changes in recollection and not familiarity-based EM (Grillon et al., 2008).

However, the likelihood that refreshing facilitates content-context binding in WM appears subject to whether the memoranda are represented in long-term SM. Thus, refreshing may be optimal when information in WM is more semantically meaningful, perhaps because WM is an activated subset of long-term memory (Cowan, 1999). This is consistent with other results indicating that WM functioning is moderated by the level of semantic support from long-term memory (e.g., Loaiza et al., 2013; Ricker & Cowan, 2010; Zhang & Verhaeghen, 2009). The present results support and extend this literature regarding the influence of semantic representations on refreshing in WM to include the effect of refreshing on EM retrieval.

Specifically, representations established in long-term SM may moderate the degree to which refreshing facilitates content-context binding, thereby yielding less recollective experience but higher familiarity-based EM overall. There are several interesting implications of these findings. First, potential differences between WM tasks (e.g., visual vs. verbal) may be more or less discriminable on the basis of long-term semantic support provided by either type of task. Second, these data predict that as novel information becomes well-learned (e.g., when learning another language), the ability to refresh that information is progressively altered. Furthermore, the relationship between WM capacity and other higher order cognitive variables such as long-term EM (e.g., McCabe et al., 2010; Unsworth & Brewer, 2009) could partially reflect the ability to engage in refreshing that is affected by both WM factors (e.g., increasing attentional demand; Camos et al., 2009) and long-term memory factors (e.g., SM).

We note that there remains some controversy as to whether Remember-Know judgments map on to the recollection-familiarity distinction. Alternative perspectives might posit that these judgments reflect a unitary memory strength dimension (e.g., Dunn, 2008) or that the Remember-Know paradigm does not directly test recollection and familiarity (e.g., Wais, Mickes, & Wixted, 2008). In order to ensure that the dissociation is not exclusive to the Remember-Know paradigm, future research will be necessary to replicate this pattern using alternative methods of disentangling recollection and familiarity. Furthermore, it is also probable that other factors besides refreshing in WM contribute to recollection-based EM. For example, the rate of forgetting in WM could differ between words and non-words, and could, consequently, render refreshing less effective for non-words. Future research should investigate the extent to which these mechanisms interact to promote recollection.

Summary and Conclusions

The advantage of complex span over simple span in EM (McCabe, 2008) was originally labeled “the delayed recall effect.” However, this effect has been replicated in delayed cued recall (Loaiza & McCabe, 2012) and now delayed recognition, all three tests being the typical methods of testing EM. As such, the effect clearly supersedes the type of test, likely because all EM tests involve some degree of recollection (cf. Yonelinas, 2002). Our results converge with a growing literature showing that the advantage of refreshing during WM is specific to recollection-based EM (Grillon et al., 2008) due to enhanced content-context binding as a consequence of refreshing (Loaiza & McCabe, 2012; Mitchell et al., 2000). Furthermore, the advantage is limited not to a particular type of EM test, but instead by the memoranda’s current status in long-term SM. Accordingly, the well-documented relationship between WM and long-term memory may not just be predictive on the part of WM, but may be reciprocal, such that factors underlying long-term memory may likewise moderate the efficiency of WM functioning.

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Table 1. Summary of results for immediate recall and delayed recognition for all four trial types (standard deviations are in parentheses).

		Word		Non-Word	
Time of Test	Measure	Simple Span	Complex Span	Simple Span	Complex Span
Immediate	Free Recall	0.98 (0.05)	0.67 (0.18)	0.56 (0.23)	0.38 (0.16)
	Serial Recall	0.95 (0.11)	0.45 (0.26)	0.48 (0.26)	0.17 (0.20)
Delayed Recognition	Hits	0.63 (0.20)	0.74 (0.16)	0.65 (0.21)	0.68 (0.22)
	False Alarms	0.13 (0.11)		0.14 (0.13)	
	R Hits	0.35 (0.22)	0.47 (0.16)	0.23 (0.18)	0.29 (0.21)
	R False Alarms	0.02 (0.04)		0.02 (0.04)	
	K Hits	0.28 (0.18)	0.27 (0.16)	0.42 (0.20)	0.39 (0.19)
	K False Alarms	0.11 (0.09)		0.12 (0.12)	

Note. R = remember, K = know. Note that *new* items in the recognition test were never presented in simple or complex span trials, and, thus, are represented only as words vs. non-words.

Table 2. Summary of main effects and interaction of task (complex span, simple span) and word type (word, non-word) on each dependent variable (see Figure 2).

	Immediate Free Recall		Corrected Recognition		Recollection		Familiarity	
Source	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2
Task	131.61***	0.75	12.31**	0.22	18.75***	0.30	1.92	0.04
Word Type	209.71***	0.83	1.08	0.02	21.79***	0.34	3.21†	0.07
Task x Word Type	10.69**	0.20	4.34*	0.09	2.11	0.05	1.10	0.03

† $p < .09$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 3. Summary of main effects and interactions of task (complex span, simple span), word type (word, non-word), and serial position (1-4) on each dependent variable (see Figure 3).

	Recollection		Know Responses	
Source	*F*	η_p^2	*F*	η_p^2
Task	19.36***	0.31	1.46	0.03
Word Type	23.13***	0.35	12.64**	0.23
Serial Position	5.02**	0.11	1.32	0.03
Task x Word Type	2.05	0.05	0.39	0.01
Task x Serial Position	3.66*	0.08	2.29	0.05
Word Type x Serial Position	4.90**	0.10	1.52	0.03
Task x Word Type x Serial Position	0.15	0.00	0.78	0.02

† $p < .06$, * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 1. Examples of simple and complex span trials with words and non-words. There were three trials of each type, and four memoranda per trial.

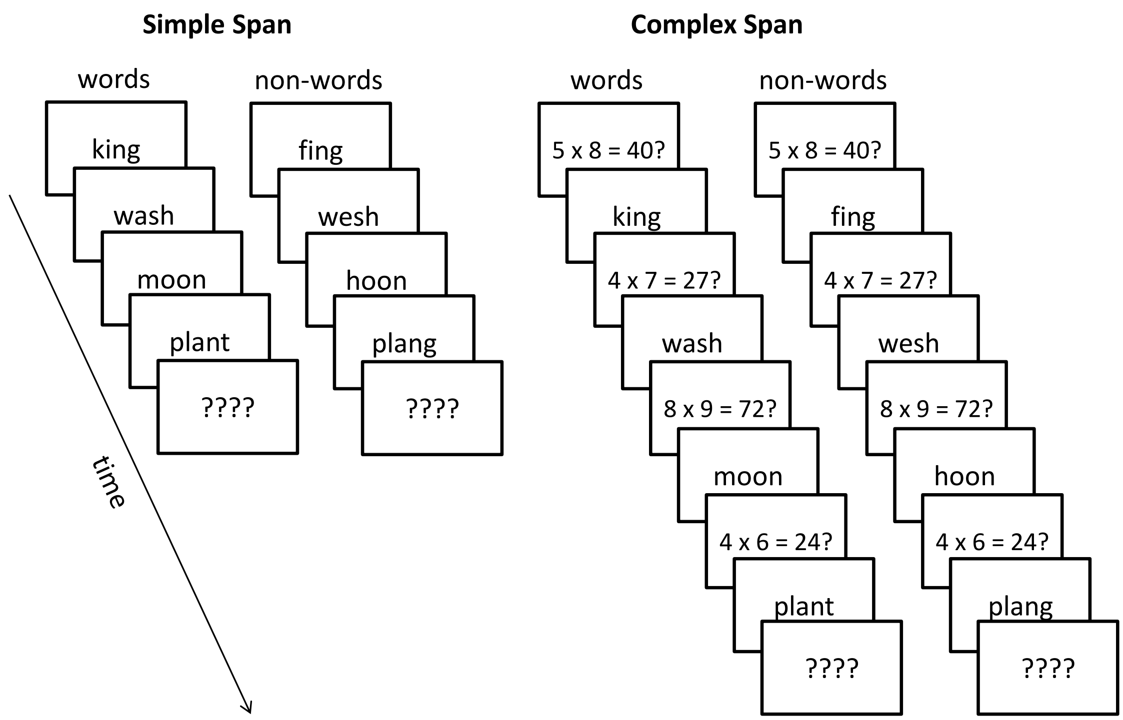

Figure 2. Proportion of retrieval from episodic memory: (A) corrected recognition (hits – false alarms), (B) Recollection, and (C) Familiarity.

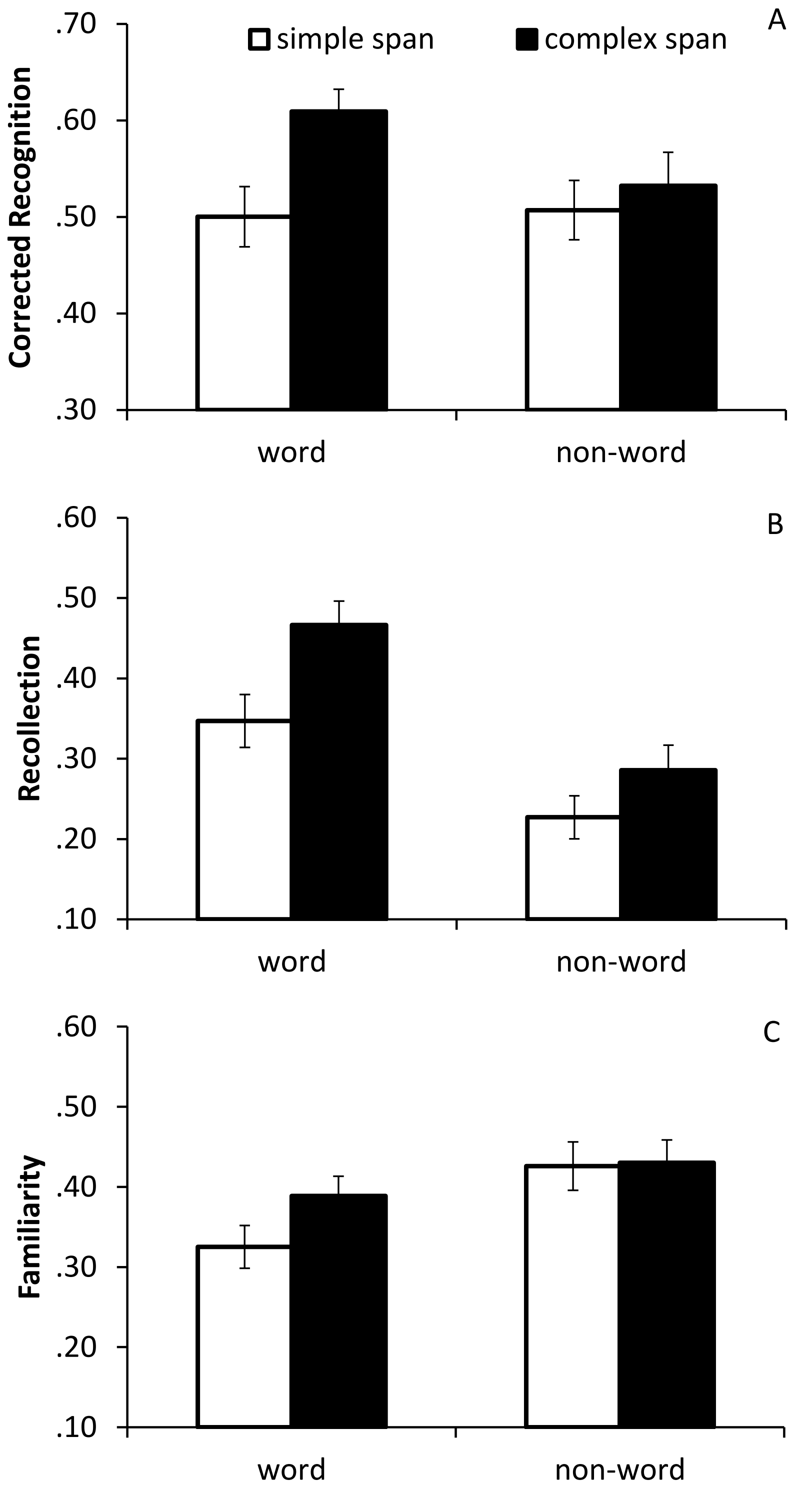

Figure 3. Proportions of recollection and know responses for complex and simple span as a function of word type and serial position. (A) Recollection of words studied during complex and simple span; (B) Recollection of non-words studied during complex and simple span; (C) Know responses for words studied during complex and simple span; (D) Know responses for non-words studied during complex and simple span.