Journal of Memory and Language 96 (2017) 155–167

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Time to process information in working memory improves episodic memory ☆

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ARTICLE INFO

Article history:
Received 16 December 2016
Revision received 19 June 2017

Keywords:
Complex span
Simple span
Working memory
Presentation rate
Focus of attention

ABSTRACT

In simple-span tasks, participants encode items sequentially for immediate serial recall. Complex-span tasks are similar, except that items are interleaved with a distraction task. Whereas immediate memory is higher in simple than complex span, in tests of episodic long-term memory, better recall for words studied in complex than simple span has been observed (McCabe, 2008). This *McCabe effect* has been explained by assuming that distraction displace items from working memory, forcing people to covertly retrieve items after each distraction, thereby generating better episodic retrieval-cues than during simple span. Our experiments support an alternative hypothesis: individual words are attended to and processed longer in working memory in complex-span than in simple-span trials. We reduced the presentation rate of words in simple span, creating a *"slow span"* condition. Across four experiments, slow span improved episodic memory compared to simple span, and this benefit was larger than the McCabe effect.

We often need to maintain information readily accessible in mind to perform ongoing cognitive tasks – e.g., remember a list of assignments for your boss that you received over the phone. The same information may become relevant again minutes or hours later. For instance, your boss may ask you later to pass the list to another colleague. The memory systems supporting performance in these two scenarios are working memory (WM) and episodic long-term memory, respectively.

WM is a limited capacity system which retains only a handful of representations available for ongoing processing (see Oberauer, Farrell, Jarrold, & Lewandowsky, 2016 for a recent review). This limited capacity constrains how well one can retain information to perform quotidian, yet complex tasks. Taking the example above, a very long list, or the occurrence of distractions (e.g., other phone calls), severely increases the chance of list items getting lost or being corrupted in memory.

Episodic long-term memory, in contrast, is not limited in capacity. We are constantly storing new events, and we can retrieve them over periods that vary between hours, days, or even years. This is not to say that episodic long-term memory does not fail us: retrieval from this system is slow and error-prone, and it is assumed to strongly depend on the ability of so-called *retrieval cues* to activate the appropriate memory trace (Craik & Tulving, 1975; Rugg & Wilding, 2000; Tulving, 1985). One question of interest in research on episodic memory is therefore which processes foster creation of effective retrieval cues.

In the present paper, our focus is on understanding how processing of information in WM (i.e., for an immediate task goal) affects the creation of episodic retrieval cues for recall over the long-term. One approach to investigating this question has been to compare episodic memory performance for information studied in the context of different WM tasks, such as simple span and complex span (Loaiza, Duperreault, Rhodes, & McCabe, 2014; Loaiza & McCabe, 2012a, 2012b; Loaiza, Rhodes, & Anglin, 2013; McCabe, 2008). In a typical simple-span task (aka word span), words are presented sequentially for study, and participants have to retain these words in their correct order of presentation for an immediate recall test. Complex-span tasks also require memory of a list in serial order, and in addition, in between presentation of the words participants have to complete a distractor task (e.g., judge the correctness of a multiplication equation; aka operation span) (Turner & Engle, 1989). It is well known that immediate recall is better for simple span than for complex span.

McCabe (2008) was the first to assess how the study opportunities offered in simple and complex span affected episodic memory. In his experiments, participants initially studied words in simple-span and complex-span trials for immediate recall. As typical, immediate recall was higher for simple span than complex span.

☆ The data and analysis scripts for all the experiments are available at the Open Science Framework at: https://osf.io/ctgr3/.

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http://dx.doi.org/10.1016/j.jml.2017.07.002
0749-596X/

When participants were however confronted with a delayed memory test for all words they had encountered during the immediate-memory tests, the opposite pattern emerged: recall was higher for words studied in complex span than simple span. This finding was observed regardless of the delayed test being a surprise or fully anticipated. Hereafter, we will refer to this observation as the *McCabe effect*.

McCabe explained his findings with a covert retrieval model in which the distractor task is assumed to displace items from WM[1]. During the distraction period, the learned words are maintained only in episodic long-term memory. After each distraction, participants try to covertly retrieve the words back into WM. McCabe assumed that these covert retrieval attempts strengthen the retrieval cues associated with the item, and more so the more often those items were retrieved. He also argued that items in early list positions are retrieved more often because after each distraction participants retrieve items in forward serial order. Accordingly, serial position curves for the delayed recall showed a primacy gradient in complex span, but not in simple span.

Loaiza and McCabe (2012a) extended these findings by showing that complex span yields better episodic memory compared to simple-span trials of different lengths (4 or 8 words). Lists with 8 words (aka supra-span lists) exceed the presumed capacity of WM, hence immediate recall of these lists may also require the formation of effective retrieval cues. If participants could form these cues during the study phase, and they did so whenever the memory demand exceeded WM capacity, then supra-span lists, just like complex-span lists, should yield better delayed recall than short simple-span lists. This was however not the case: Only complex span yielded better delayed recall. This finding suggests that the distraction period taking place during the time in-between words in complex span is critical to yield better episodic memory.

Loaiza and McCabe (2012a) also provided evidence to support the covert retrieval model of the McCabe effect over an alternative temporal distinctiveness explanation (Brown, Neath, & Chater, 2007). In complex span, the words are presented in a temporally distributed fashion (i.e., separated from one another by the intervening distractor episodes). This may render the individual list words more temporally distinctive, thereby facilitating episodic retrieval. In contrast, the covert retrieval model assumed that the covert retrieval opportunities after the distraction task were the cause of the improved episodic memory. To test for these possibilities, Loaiza and McCabe (2012a) compared trials in which they varied the position of the distractor task (arithmetic problems): 4 problems followed by 4 memoranda, which is essentially a simple span task; 4 memoranda followed by 4 problems (i.e., a Brown-Peterson task); or memoranda and problems in alternation (complex-span trials). The latter two tasks require participants to retain information in mind over a period of distraction, which arguably requires the covert retrieval of the memoranda back into WM. At the same time, they differ in the temporal distribution of the memoranda: In the complex-span condition the memory items were temporally more separated than in the simple-span condition, but in the Brown-Peterson task they were not. Delayed recall was higher for both complex span and the Brown-Peterson task compared to simple span. These results favored the covert retrieval interpretation (see also Camos & Portrat, 2015; Loaiza & McCabe, 2012b; Loaiza et al., 2013 for further data consistent with this interpretation).

One question that has not been addressed in these studies concerns the role of the distractor task in yielding better episodic memory. In the original model, McCabe (2008) assumed that it was the displacement from, and subsequent retrieval of information back into WM that yielded better episodic cues. An alternative explanation starts from the assumption that list items are not displaced from WM during distractor processing – although they are likely to suffer interference from the concurrent processing of distractor material (Oberauer et al., 2016) or they may suffer from time-based forgetting (Barrouillet & Camos, 2012). In this alternative view, the memoranda remain in WM throughout the trial. Given that complex-span trials take longer to complete than simple-span trials, the memoranda – in particular the words early in the list – are maintained in WM for a longer period of time in complex span than in simple span. If longer maintenance of information in WM is beneficial for episodic memory, then there would be more opportunities for encoding of information into episodic memory in complex span than simple span. If it is the amount of time words remain in WM that matters for the creation of strong episodic retrieval cues, then replacing the distractor processing interval by an equally long unfilled time interval after each word in simple span should also have a beneficial effect on episodic memory. Because this condition is effectively a simple-span task with reduced rate of presentation of the words, we refer to it as *slow span*.

We may distinguish between two possible ways in which maintenance time may be relevant. First, it may be that the total time words remain in WM is relevant irrespectively of whether there is distraction or not. If this is the case, complex-span trials and slow-span trials should yield comparable performance in a delayed memory test. Alternatively, it may be that what is important is the total amount of free time (i.e., time in which attention is not engaged in distracting activities) that matters. According to this hypothesis, focusing attention on information held in WM promotes the creation of strong episodic retrieval cues. There are several ways in which free time may improve episodic memory. One possibility is that participants use this free time to cycle their attention sequentially through all items stored in WM, thereby refreshing them (Barrouillet, Portrat, & Camos, 2011; Johnson, 2012; Souza, Rerko, & Oberauer, 2015; Vergauwe & Cowan, 2014). Refreshing is assumed to be a domain-general mechanism used for maintenance of all types of information in WM, which depends on the availability of central attention capacity (Barrouillet & Camos, 2012; Souza & Oberauer, 2017; Vergauwe, Barrouillet, & Camos, 2010). Loaiza and McCabe have suggested that the McCabe effect may reflect the use of attentional refreshing to strengthen episodic retrieval cues (Loaiza, Duperreault, Rhodes, & McCabe, 2015; Loaiza & McCabe, 2012a, 2012b; Loaiza et al., 2013).

An alternative possibility is that free time is used to consolidate only the just encoded item into WM (Bayliss, Bogdanovs, & Jarrold, 2015; Ricker, 2015; Ricker & Cowan, 2014; Schrijver & Barrouillet, 2017). According to this view, free time is used to strengthen only the last presented item. This stands in contrast with the refreshing hypothesis, which assumes that free time is used to cycle attention over all items in memory. A last possibility is that participants elaborate on the memoranda, thereby improving their episodic memory. If participants have free time, they might focus on "deep" aspects of the memoranda (e.g., the semantics of the words) which have been found to be beneficial to long-term memory (Craik, 2002; Craik & Tulving, 1975) and, to a smaller extent, WM (Loaiza, McCabe, Youngblood, Rose, & Myerson, 2011; Rose, Buchsbaum, & Craik, 2014). In sum, if free time is important for creating helpful episodic retrieval cues, then complex-span trials should yield better delayed recall than simple span, but still worse recall than a slow simple-span condition.

[1] McCabe (2008) framed his theory in terms of Cowan's embedded-processing theory of WM, and assumed that the distractor task displaced items from the "focus of attention" in that theory, referring to a capacity-limited device for holding up to about four items. Because the term "focus of attention" refers to different constructs in different theories, we use the more generic term "working memory".