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# Cleaning working memory: The fate of distractors

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ABSTRACT

As a capacity-limited system, working memory (WM) is at risk to be cluttered by no-longer-relevant items and distractors, which makes it necessary for WM to have some cleaning mechanism. A prominent approach in WM assumes that active inhibition by deletion of distractors fulfills this function, more efficient inhibition resulting in better WM performance. This hypothesis was tested here in the context of WM span tasks in which distractors have to be processed while maintaining target items for further recall, taking advantage of the fact that processing distractors at a slow pace results in better recall performance (pace effect). The question is whether this better recall result from a more efficient inhibition of distractors, as it has been assumed? Previous studies on inhibitory processes have shown that the deletion function leaves fingerprints in the form of a subsequent reduced accessibility of the suppressed material. Accordingly, in four experiments, we tested this inhibitory hypothesis by assessing in delayed recall and recognition tasks the accessibility of distractors that had been previously processed either at a slow or a fast pace in WM span tasks. Contrary to the inhibitory hypothesis, the pace of the WM span task had no effect on the subsequent accessibility of distractors whereas it affected delayed recall and recognition of memory targets. We discuss the implications of these findings for inhibitory and decay-and-refresh approaches of WM.



## Introduction

Working memory (WM) is usually conceived of as a system devoted to the temporary storage of information during ongoing cognitive processes (Baddeley, 2007). One of the most striking characteristics of this system is its limited capacity, estimated at seven items or chunks by Miller (1956), a number that has been subsequently reduced to four (Cowan, 2001). A challenge for such a limited system in the service of on-line cognition is to remain efficient while cognitive operations succeed each other. Indeed, as its content has to be continuously and rapidly updated, WM is at risk to be cluttered and choked by no-longer relevant information and proactive interference. However, as Hasher, Lustig, and Zacks (2007) stressed, the ideal processing system is a narrowly focused and uncluttered WM, maximizing the speed and accuracy of on-line processing by preventing attention to switch to goal-irrelevant representations. Thus, some mechanism devoted to WM cleaning is needed, for which two hypotheses have been put forward, which are not necessarily mutually exclusive. The first assumes that any WM content naturally decays with time. According to this view, the removal of no-longer relevant contents occurs by default, whereas relevant information has to be actively maintained by refreshing mechanisms to avoid forgetting, resulting in the decay-and-refreshing hypothesis (Baddeley, 1986, 2007; Barrouillet, Bernardin, & Camos, 2004; Barrouillet & Camos, 2015; Cowan, 1999; Just & Carpenter, 1992). By contrast, the second view emphasizes the role of inhibitory

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rather than activatory processes by assuming that no-longer relevant contents are actively suppressed from WM (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012). In keeping with this latter hypothesis, Healey, Campbell, Hasher, and Ossher (2010, p. 1468) suggested that "the logic of looking for the fingerprints of inhibition" in what happens to no-longer relevant contents, instead to target information, holds great promise for behavioral investigations. Following this logic, the aim of the present study was to examine the fate of no-longer relevant information in the context of WM span tasks in which distractors have to be processed, but not remembered, looking for the fingerprints of their inhibition.

### *The fate of target items in WM span tasks*[1]

The question of what happens to information that has been, at some point in time, present in WM was recently addressed by several studies in the context of complex span tasks, but these studies focused on the fate of target information rather than distractors. This line of research was launched by McCabe (2008) who observed that, whereas immediate serial recall is better in simple than in complex span tasks, performance in a delayed recall test administered at the end of the experimental session was better for memory items previously studied in the complex than in the simple span tasks. McCabe explained this effect by suggesting that participants actively maintain memory items in complex span tasks by covertly retrieving them in between processing episodes. These frequent covert retrievals that do not occur during simple span tasks would then create retrieval cues that can be used for delayed recall. Loaiza and McCabe (2012) subsequently tested this hypothesis by increasing the number of processing episodes presented after each memory item in complex span tasks. They reasoned that more processing episodes provide more opportunities for covert retrieval after each processing episode and should result in better delayed recall of memory targets. Analysis of delayed recall performance confirmed this prediction. Commenting on this result, Loaiza and McCabe suggested that attentional refreshing is the mechanism that underlies the delayed recall effect predicted by the covert retrieval hypothesis. According to the authors, refreshing would strengthen the associations between memory items and their context of encoding, these associations constituting retrieval cues for further delayed recall.

Camos and Portrat (2015) subsequently went further by pointing out that, according to the TBRS model, refreshing of memory traces in complex span tasks depends on the cognitive load (*CL*) of concurrent processing. The TBRS model assumes that processing and storage in WM compete for a unique and limited resource which is attention. Due to a central bottleneck that constrains cognitive operations to take place one at a time, when attention is occupied by processing, it would no longer be available for the maintenance of WM traces that would suffer from temporal decay and interference. However, these decayed memory traces could be restored through a process of attentional refreshing when attention is available anew. This interplay between decay during processing and restoration during free time is expressed in the TBRS model by the notion of *CL*, conceived of as the proportion of time during which processing occupies attention, preventing the refreshing of memory traces to take place. In a complex span task in which each memory item (e.g., letters) is followed by a series of distractors to be processed (e.g., digits for parity judgment), increasing the number of distractors to be processed in an unchanged temporal interval, or reducing this interval while keeping the number of distractors constant, results in a higher *CL* because the proportion of time available for refreshing the decaying memory traces is reduced (Fig. 1). Accordingly, this should result in more forgetting of the memory items and their poorer immediate recall, something that has been verified in several experiments (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, Portrat, & Camos, 2011; Barrouillet et al., 2004; see Barrouillet & Camos, 2012, 2015 for reviews). From this theoretical framework, Camos and Portrat (2015) reasoned that if the effect on delayed recall discovered by McCabe (2008) is due to the refreshing of memory items during the complex span task, then varying the *CL* of its processing component should not only affect immediate, but also delayed recall.

They tested this hypothesis by presenting participants with words for immediate recall, each word being followed by a series of digits for a parity judgment task the *CL* of which was manipulated by varying the pace at which digits were displayed on screen. In line with the TBRS predictions and previous studies, processing the digits at a fast pace involved lower immediate recall of the words, but also their poorer delayed recall, confirming that *CL* mediates the effect of covert retrieval opportunities observed by Loaiza and McCabe (2012). It is interesting to note that not all the factors that affect immediate recall have an effect on delayed recall. Camos and Portrat (2015) predicted and observed that hindering verbal rehearsal by asking people to give their responses aloud in the parity task had a detrimental effect on immediate recall of the words, but left their delayed recall unaffected (see also Loaiza & McCabe, 2013), suggesting that attentional refreshing is the mechanism by which WM items leave prints in LTM that can be subsequently retrieved for delayed recall.

### *The fate of distractors*

The studies reported so far focused on the fate of items that have left WM, but that were at some point in time target information encoded for memorization purpose. The question addressed in the present study was what happens

[1] Working memory span or complex span tasks are tasks in which participants are presented with series of memory items for further recall (e.g., digits, words, visual patterns), each of these items being followed by distractors to be processed (e.g., digits for additions or parity judgments, words for semantic judgment, sentences for reading comprehension). These tasks are especially important and widely used as they are deemed to assess WM capacity (Case, Kurland, & Goldberg, 1982; Daneman & Carpenter, 1980; Turner & Engle, 1989) and are highly correlated with fluid intelligence (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Kyllonen & Christal, 1990).