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The fate of distractors in working memory: No evidence for their active removal

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ABSTRACT

Not all the information processed in working memory (WM) must be retained. Due to the strict limitations of its capacity, the mechanisms that prevent WM from being cluttered and choked by no longer relevant information are of paramount importance. The present study tested the hypothesis put forward by the SOB-CS model of an active and attention-demanding mechanism that would remove no-longer relevant items from WM. Such a mechanism has been advocated to account for the well-known fact that, in complex span tasks, processing distractors at a slower pace results in better recall of memory items. According to the SOB-CS model, slow pace would free more time for removing distractors, thus alleviating the interference they create on target items. In direct contradiction with this hypothesis, a first experiment demonstrated that distractors are not less, but more accessible at the end of complex span task trials in which they have been processed at a slow rather than a fast pace. Using the repetition priming effect occurring in a lexical decision task inserted as processing component within a complex span task, a second experiment established that distractors processed at a slower pace do not elicit weaker, but stronger repetition priming effects, indicating that they have not been removed. Along with previous findings, the present study not only shows that there is no trace of distractor removal in the long term, in the short term, nor immediately after processing, but demonstrates that memory traces of distractors are stronger in situations assumed to involve a more complete removal by the SOB-CS model. These empirical evidence suggests that distractors are not actively removed from working memory after having been processed.

1. Introduction

Working memory (WM) is a system devoted to the simultaneous maintenance and processing of the information relevant for ongoing cognition (Baddeley, 1986; Shah & Miyake, 1999). Contrary to long-term memory, WM is characterized by a severe limitation in the number of the distinct representations it can hold (Baddeley, 2012; Cowan, 2001). This limitation is made even more constraining by the fact that not all the information processed in WM must be retained. Consider for example a teacher scrolling the list of candidates who succeeded at a competitive examination in order to know whether some pupils of her class have been admitted and how many they are. She has to read each name, adding one to a running count each time she finds one of her pupils. All the names are necessarily encoded in WM for reading and potential recognition while the number of admitted pupils is maintained and updated. However, as soon as they have been read, most of these names prove no longer relevant for the goal at hand as they are those of pupils from other schools. Considering its drastic limitations, what makes that WM is not rapidly cluttered and choked by no-longer relevant information?

Two main hypotheses have been put forward to answer this question. The first assumes that as soon as an item is no longer the object of some processing and has left the focus of attention, it suffers from a temporal decay and eventually disappears from WM. Within this framework, the removal of no-longer relevant content occurs by default, with the undesirable corollary that useful information is also prone to a temporal decay that must be counteracted by maintenance processes. This conception is known as the decay-and-refresh hypothesis (Baddeley, 1986, 2007; Barrouillet, Bernardin, & Camos, 2004; Barrouillet & Camos, 2015; Cowan, 1999; Just & Carpenter, 1992). The second hypothesis assumes that irrelevant content must be actively suppressed from WM by inhibitory processes such as deletion (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). This latter conception has been recently advocated by Oberauer, Lewandowsky, Farrell, Jarrold, and Greaves (2012) in their SOB-CS[1] model, which aims at accounting for the performance in complex span tasks. According to this model, there would be no decay in WM, but an active and attention-demanding process for removing distractors. The present

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[1] SOB-CS stands for serial order in a box – complex span.

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study aimed at testing this distractor removal hypothesis.

1.1. Complex spans tasks and the fate of distractors

Complex span tasks are especially appropriate to study the fate of distractors in WM. Typically, a series of items (letters, words, digits, matrices, spatial locations) is presented for further serial recall. These memory items alternate with a secondary task such as arithmetic problem solving (Turner & Engle, 1989), reading comprehension (Daneman & Carpenter, 1980), or counting dots (Case, Kurland, & Goldberg, 1982). The items processed in these intervening tasks constitute, for the memory task, distractors that have to be set aside as soon as they are processed. The effect of this concurrent processing on memory is a major source of information about WM functioning. For example, Barrouillet et al. (2004) had participants remembering series of letters of increasing length for further recall, each letter being followed by a series of to-be-read digits that appeared successively on screen at a fixed pace. The main result of this study was that WM span, the maximum number of letters participants were able to recall in correct order, was a function of the pace at which digits were presented, with slower paces resulting in higher spans. This phenomenon relating span to the pace at which distractors are processed has been replicated in several studies (e.g., Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, De Paepe, & Langerock, 2012; Barrouillet, Plancher, Guida, & Camos, 2013; Barrouillet, Portrat, & Camos, 2011; Camos, Lagner, & Barrouillet, 2009; Plancher & Barrouillet, 2013; Vergauwe, Barrouillet, & Camos, 2009, 2010; see Barrouillet & Camos, 2015, for a review).

This pace effect has, by now, received two competing explanations. The first, pertaining to the decay-and-refresh hypothesis, is provided by the time-based resource-sharing (TBRS) model (Barrouillet & Camos, 2015; Barrouillet et al., 2011). This theory assumes that spans depend on the balance between the duration of the attentional capture brought about by processing each distractor, during which memory traces suffer from temporal decay and interference, and the time available in-between two successive distractors, during which decayed memory traces can be refreshed. More precisely, span would correspond to the number of memory items that can be sufficiently refreshed during free time to survive decay and interference during the next processing episode. Shorter durations of processing, which result in smaller decay, and longer free times, which allow for more items refreshed, lead to higher spans (Barrouillet & Camos, 2014, 2015). Processing distractors at a slower pace frees more time in-between successive distractors for refreshing decayed memory traces, hence their better recall.

The second explanation has been put forward by Oberauer et al. (2012) in their SOB-CS model. Denying any temporal decay, this model accounts for the detrimental effect on memory of concurrent processing by the interference created by encoding distractors in WM. It is assumed that representations of the memory items and distractors are superimposed into a common matrix in such a way that encoding distractors distorts memory items representations. The resulting interference could be alleviated by a process of distractor removal that takes the form of a Hebbian antilearning. This process would disconnect each distractor from the serial position marker of the preceding target item with which it has been associated at encoding. Distractor removal is assumed to play the same role as temporal decay in the decay-and-refresh hypothesis and is presented as a “control process that can clear working memory for unwanted contents” (Oberauer et al., 2012, p. 782). Importantly, this removal is assumed to occupy the central bottleneck, thus taking place only when attention is free. Moreover, the removal process is gradual, progressing relatively slowly, in such a way that, depending on the time available, the removal of a given distractor can be more or less complete. Consequently, the longer the free pauses in-between distractors, as it is the case when distractors are processed at a slow pace, the more complete their removal, the lower the level of resulting interference, and the better the recall performance.

1.2. In search for evidence for the process of distractor removal

In a previous study (Dagry, Vergauwe, & Barrouillet, 2017), we aimed at testing the hypothesis of an active inhibition of distractors in complex span tasks through a delayed recall procedure. In four experiments, participants performed a complex span task with either letters or words as memory items while distractors were words presented either at a slow or fast pace. After having performed eight trials of the WM span task in which they immediately recalled memory items at the end of each trial, participants were asked to perform an intervening arithmetic task for two minutes followed by a surprise delayed recall or recognition of the words previously studied. This delayed retrieval task involved distractors, but also memory items when they were words, whereas only distractors were concerned when memory items were letters. We reasoned that if distractors are removed, inhibited during free time, this inhibition would leave in long-term memory what Healey, Campbell, Hasher, and Ossher (2010) called *fingerprints* in the form of a reduced accessibility of the suppressed items. Moreover, if this inhibition is stronger with longer free time (i.e., in the slow pace condition), the subsequent accessibility of inhibited distractors should be lower after having performed the WM span task in the slow than the fast pace condition. Contrary to this prediction, recall and recognition rates of distractors were never lower, but even slightly higher in the slow than the fast pace condition. This finding lent little support to the hypothesis that the better immediate serial recall of memory items in the slow pace condition of the WM span task was due to a better deletion of the distractors. However, the question of the removal of distractors was addressed in this study using delayed recall and recognition tasks, and it remains possible that a genuine removal process occurred that did not leave any trace in long-term memory, all the memory traces, removed or not, having resumed their base level of activation at the moment of test.

In a recent study, Oberauer and Lewandowsky (2016) addressed the same question using an immediate recall (reconstruction) task. They presented participants with five memory items (nouns) appearing successively on screen. Each of these nouns was followed by a single distractor noun in such a way that 10 nouns were presented (five targets and five distractors) that differed by their color (red for targets, black for distractors). Participants had to decide whether each noun (targets and distractors) referred or not to an object smaller than a soccer ball while remembering the red nouns only. At the end of the series, 15 nouns were displayed on screen in a 3 × 5 grid (the five memory items, the five distractors, and five non-presented lures). Participants were asked to reproduce the memory list by clicking on the five memory items in their order of presentation. The critical manipulation consisted in varying the free time available after each distractor, which was either short (0.2 s) or long (1.5 s). The authors reasoned that if free time is used for removing distractors, then the tendency to recall distractors should diminish with longer free time. Accordingly, the results revealed that more memory items and less distractors were selected in the long free time condition, whereas the rate of non-presented lures selected remained unaffected by the duration of free time. From the fact that distractors were more often erroneously selected than non-presented lures, Oberauer and Lewandowsky (2016) concluded that distractors are encoded in WM, and their less frequent selection in the long free time condition was interpreted as evidence for the removal process.

Although these results seem to support the distractor removal hypothesis, their significance is strongly limited by a flaw of the experimental design adopted by Oberauer and Lewandowsky (2016). Because, at the end of each trial, participants had to reproduce a memory list of five nouns by selecting five out of the 15 nouns presented, the number of memory items (correctly) selected and the number of distractors (erroneously) selected were not allowed to vary independently of each other. Any increase in the number of memory items recognized was necessarily accompanied by a decrease in the number of lures selected. Moreover, it does not come as a surprise that the selected lures

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