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Storing Verbal Information in Working Memory

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Abstract
Recent reexaminations of the storage of verbal information in working memory have distinguished two mechanisms of maintenance. While a language-based mechanism of rehearsal was long considered the specific means of maintaining verbal information in the short term, another attention-based mechanism of refreshing has been more recently described. New evidence has established that these two mechanisms are affected by different constraints inherent to their respective language-based and attentional natures, have different impacts on recall performance, and are sustained by distinct brain networks. Moreover, adults can use either one or the other mechanism based on strategic choice or instructions. This dissociation presents some similarities with a dichotomy put forward in the '70s between mechanisms permitting short-term versus long-term maintenance, but many questions remain about the functioning of these mechanisms and their interplay.

Keywords
working memory, storage, rehearsal, refreshing

Working memory (WM) is the cognitive system in charge of storing and manipulating information over the short term. Thus, it is conceived of as the hub of human cognition. Accordingly, its capacity is predictive of fluid intelligence, academic achievement, and performance in high-level cognitive activities in adults and children (Conway, Jarrold, Kane, Miyake, & Towse, 2007). Although WM research has been increasingly oriented toward the storage of visual information in the past decade, new evidence has emerged and enlightened our understanding of verbal storage.

Everybody knows that, when trying to remember the two or three things you want to buy at the supermarket, you just repeat them overtly (i.e., aloud) or covertly, using inner speech (i.e., the voice in your head). This mechanism, named *articulatory rehearsal*, has been studied for a long time, and it is often conceived of as the unique and specific way to maintain verbal information in WM (Baddeley, 1986). Initial studies investigating the maintenance of verbal information used immediate-recall tasks in which participants had to recall lists of successively presented verbal items (letters or words) immediately after their presentation. A series of phenomena (effects of phonological similarity, word length, articulatory suppression [described below], and irrelevant speech) was revealed suggesting the existence of a mechanism based on language-production processes. Recently, another maintenance mechanism has been described, often called *attentional refreshing*. Attentional refreshing reactivates memory traces through attentional focusing to maintain them in WM (Barrouillet & Camos, 2012, 2015; Cowan, 1995; Johnson, 1992). Contrary to rehearsal, which is restricted to the maintenance of verbal information, refreshing is assumed to apply to a wide range of material (e.g., verbal, visual, spatial).

Two Mechanisms of Maintenance

Both articulatory rehearsal and attentional refreshing can maintain verbal information in WM. Thus, impeding either of them should reduce recall performance. On the one hand, impeding rehearsal requires asking participants to produce a concurrent overt articulation—for instance, repeating "the" or any other word over and over

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again. Inner speech cannot be used simultaneously with this overt articulation, because both rely on the same language-production system. The production of this concurrent articulation (named *articulatory suppression*) results in reduced recall performance (Baddeley, 1986, 2012). On the other hand, attentional refreshing can be impeded by introducing a concurrent attentional demand during maintenance, which distracts attention away from the reactivation of memory traces. A common method used to test for this effect is the complex span paradigm, in which participants have to memorize items (e.g., words or locations of squares) and process distractors following each memory item. These distractors can be of different natures (verbal, visual, spatial) and be involved in different tasks (e.g., judging the parity of digits or the symmetry of visual patterns). When the attentional demand of this concurrent task is increased (e.g., by increasing the number of distractors or the difficulty of the task), recall performance diminishes as a function of the proportion of time attention is distracted from maintenance activity (Barrouillet & Camos, 2012).

The two mechanisms are thus affected by different constraints inherent to their verbal or attentional nature. Recently, several studies examined how the two mechanisms interplay. Within a complex span paradigm, it is possible to independently vary the articulatory suppression and the attentional demand of the concurrent task. In doing so, it was observed that these two manipulations have additive effects on recall performance (Camos, Lagner, & Barrouillet, 2009; Hudjetz & Oberauer, 2007). The simplest explanation for this pattern of findings is that these manipulations tackle distinct and independent mechanisms of maintenance.

A Hypothesis of Independence

The hypothesis that rehearsal and refreshing are independent leads to three predictions. First, the use of each mechanism should result in some specific effects on recall. Using rehearsal would favor the emergence of phonological effects, because the to-be-remembered material would be maintained in a phonological format. These phonological effects should disappear under the use of refreshing. Second, one of the two mechanisms could be preferentially used according to instructions or the characteristics of the task. Hence, when the to-be-remembered material could lead to some phonological confusion, refreshing should be preferred to reduce confusion at recall. When an attention-demanding task is concurrently performed with the maintenance of verbal information, rehearsal should be favored because it does not require attention. Third, if rehearsal and refreshing are distinct mechanisms, different brain networks should sustain them.

According to the first prediction, when rehearsal is used for maintenance, recall should be susceptible to well-known phonological effects, such as the phonological-similarity effect and the word-length effect. Thus, lists of phonologically dissimilar words (e.g., *cow, day, bar, few*) should be better recalled than lists of similar words (e.g., *mad, mat, cap, can*) because relying on phonological codes to store information gives rise to more confusion between phonologically similar items. Similarly, lists of short words (e.g., *sum, hate, harm, wit*) should be better recalled than lists of long words (e.g., *association, opportunity, representative, organization*) because more short words can be repeated in a given time period. To test these hypotheses, Camos, Mora, and Barrouillet (2013) and Mora and Camos (2013) manipulated the attentional demand of the concurrent task and the availability of rehearsal. For this purpose, four complex span tasks were compared in which participants maintained lists of phonologically similar or dissimilar words or lists of short or long words. As a manipulation of concurrent attentional demand, participants either performed a concurrent location-judgment task (judging whether a square appeared in the upper or lower part of the screen) or had no additional task. The availability of subvocal rehearsal was manipulated by either allowing participants to remain silent through the concurrent task or asking them to repeat a word at a constant rhythm.

Besides replicating a reduction of recall under articulatory suppression or under an increased concurrent attentional demand, results showed that the phonological characteristics of the memory items (i.e., phonological similarity and word length) impacted recall performance only when rehearsal was available (Figs. 1a and 1b). The emergence of these phonological effects indexes the use of rehearsal. A very different type of effects reveals the use of refreshing: When memory items are maintained through refreshing rather than rehearsal in a complex span task, they are better recalled in a subsequent delayed test (i.e., after performing a distracting task for a few minutes). Moreover, increasing the opportunities to refresh memory items in the complex span task improves long-term retention (Camos & Portrat, 2015; Loaiza & McCabe, 2012).

Concerning the second prediction, regarding the possibility of favoring one mechanism over the other, Camos, Mora, and Oberauer (2011) have shown that adults are able to make adaptive choices. The authors used a complex span paradigm in which participants maintained phonologically similar or dissimilar words while performing either a choice (i.e., deciding if a digit was odd or even) or a simple (i.e., pressing a key when any item appeared onscreen) reaction-time task. Because rehearsal no longer requires attention after a setup period, attention can be allocated to the concurrent task (Naveh-Benjamin &

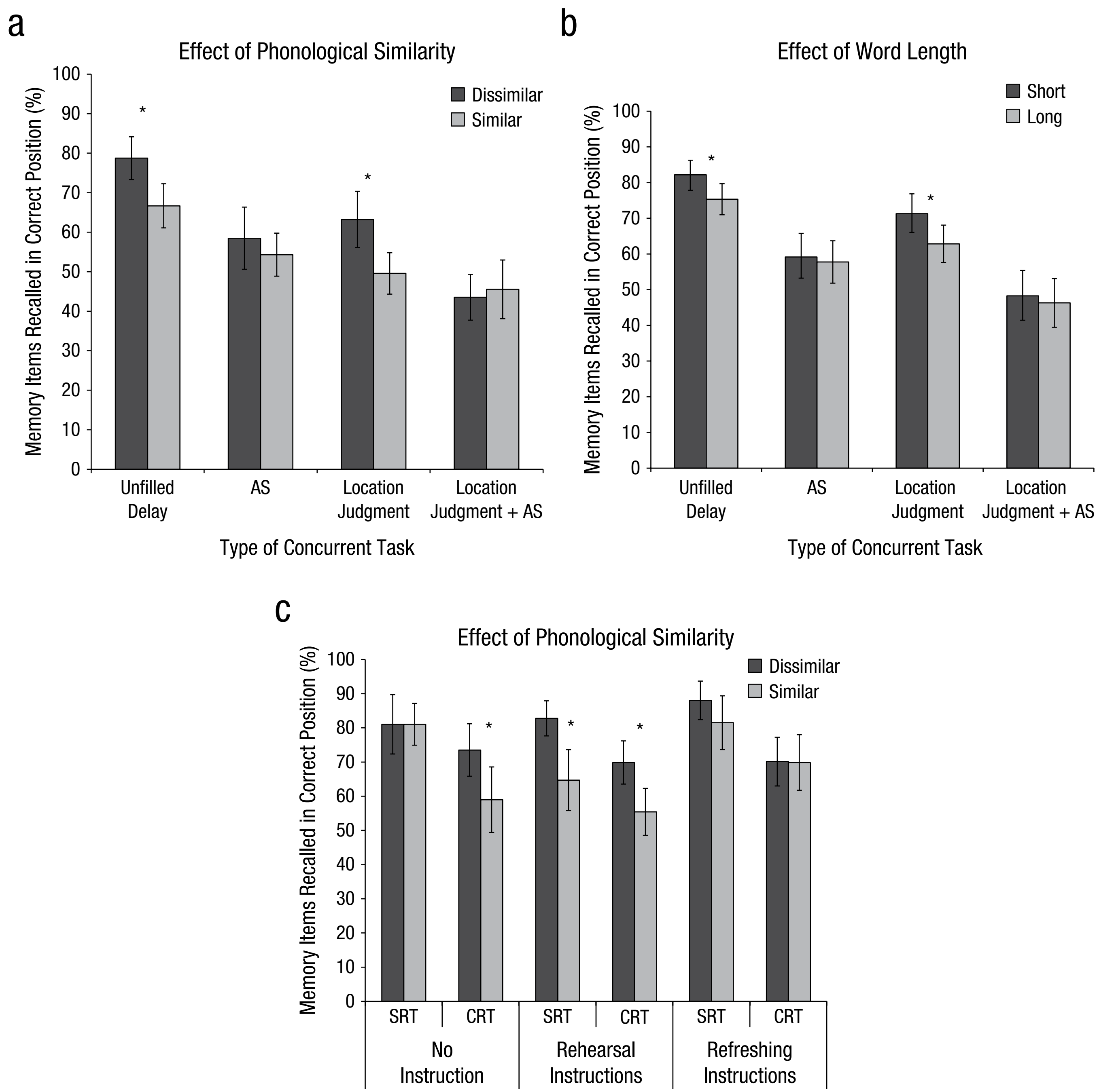

Fig. 1. Findings illustrating how variations of rehearsal and refreshing impact the recall of verbal information. Panels (a) and (b) show the phonological-similarity effect (a) and the word-length effect (b) in four experimental conditions of a complex span paradigm, in which each memory word was followed by an unfilled delay (i.e., no concurrent task), articulatory suppression (AS; i.e., producing an overt articulation while maintaining memory items), a location-judgment task, or the combination of the location-judgment task and AS. Panel (c) shows the phonological-similarity effect as a function of the processing component of the complex span task—whether participants had to press a key whenever an item appeared on-screen in a simple reaction-time task (SRT) versus whether they had to decide if a digit was odd or even in a choice reaction-time task (CRT)—and the type of maintenance strategy induced by instructions. Error bars show confidence intervals. Asterisks indicate significant effects ($p < .05$). Panel (a) is adapted from "Phonological Similarity Effect in Complex Span Task" by V. Camos, G. Mora, and P. Barrouillet, 2013, *Quarterly Journal of Experimental Psychology, 66*, p. 1938. Copyright 2013 by the Experimental Psychology Society. Adapted with permission of Taylor & Francis Ltd, on behalf of the Experimental Psychology Society. Panel (b) is adapted from "Two Systems of Maintenance in Verbal Working Memory: Evidence From the Word Length Effect" by G. Mora and V. Camos, 2013, *PLoS One, 8*(7), Article e70026. Copyright 2013 by the authors. Adapted with permission. Panel (c) is adapted from "Adaptive Choice Between Articulatory Rehearsal and Attentional Refreshing in Verbal Working Memory" by V. Camos, G. Mora, and K. Oberauer, 2011, *Memory & Cognition, 39*, p. 238. Copyright 2011 by Elsevier. Adapted with permission.

Jonides, 1984). Thus, if adults can adapt their maintenance mechanism, they should favor rehearsal while performing the choice task that requires attention to make a decision before each response. Alternatively, adults should favor refreshing when the concurrent task is less demanding (as in the case of the simple reaction-time task) because this would reduce phonological confusion between phonologically similar memory traces. As explained previously, the emergence of the phonological-similarity effect was used as an index of maintenance through rehearsal. In line with these predictions, the phonological-similarity effect occurred only when the concurrent task involved a sizable attentional demand, inducing the strategic use of rehearsal (Fig. 1c). In two follow-up experiments, the same authors instructed participants to use either rehearsal (by covertly repeating the to-be-remembered words) or refreshing (by thinking about them). As shown in Figure 1c, the phonological-similarity effect appeared under rehearsal instructions and disappeared under refreshing instructions. Thus, the type of mechanism used to maintain information in WM is modulated depending on task characteristics or specific instructions.

Finally, the existence of two distinct mechanisms should be revealed in the involvement of different brain networks. In accordance with this prediction, brain-imaging studies have revealed interesting dissociations. Gruber (2001) observed that the brain network sustaining verbal storage in WM is not uniquely localized but depends on whether or not one is able to rely on rehearsal. In this study, Broca's area, the left premotor cortex, the cortex along the left intraparietal sulcus, and the right cerebellum were activated when rehearsal could be used. However, under articulatory suppression, which prevents rehearsal, the activation of another network comprising the anterior prefrontal cortex and the inferior parietal cortex was enhanced. Congruently with these results, two patients with circumscribed brain lesions to Broca's area and to the anterior middle frontal gyrus, respectively, demonstrated a double dissociation (Trost & Gruber, 2012). The patient with the lesion to Broca's area had reduced recall performance under articulatory rehearsal but unimpaired non-articulatory maintenance (i.e., refreshing). Conversely, the patient with the bifrontopolar brain lesion demonstrated impaired refreshing, whereas that patient's performance under articulatory rehearsal was unaffected. Other studies in which participants were instructed to manipulate their use of rehearsal or refreshing (e.g., Raye, Johnson, Mitchell, Greene, & Johnson, 2007) also evidenced distinct brain networks sustaining each mechanism.

An Echo From the Past

Although the dissociation of these two mechanisms of maintenance is recent in the WM literature, it echoes another dichotomy put forward in the '70s. This occurred before Baddeley's work on WM (Baddeley, 1986), when multistore models of memory distinguished stores in terms of duration of retention (short- vs. long-term retention) and aimed at accounting for the transfer of information from one store to the other. Craik and Lockhart (1972) proposed that this transfer depends on the level of processing of information, such that deeper (vs. shallower) processing leads to long-term (vs. short-term) retention. A distinction between two types of maintenance was derived from this framework, contrasting "Type I" and "Type II" processing, also named "maintenance" and "coding rehearsal."

Like articulatory rehearsal, maintenance rehearsal was described as a rote repetition or a recirculation of information at a phonemic level and was assumed to have only transitory, not long-term, effects. Although some benefit was observed on recognition tests, increasing its duration of use did not lead to consistent improvement in delayed recall (Greene, 1987), something any student could confirm: The mere repetition of information does not allow a lasting acquisition of knowledge. In contrast, coding rehearsal was assumed to involve a deeper and more elaborative processing of information, which influences long-term retention. Increasing the total study time improves delayed recall when the added time is used for coding rehearsal. Thus, while the modern concept of articulatory rehearsal is clearly the same construct as maintenance rehearsal, it remains to be determined if refreshing is akin to coding rehearsal or if the two concepts refer to distinct cognitive mechanisms.

Alternative Accounts and Remaining Questions

Despite the empirical evidence that establishes the dissociation between rehearsal and refreshing, alternative accounts have been proposed to explain these findings. Concerning rehearsal, authors favoring interference as the only source of forgetting in memory have suggested that introducing a concurrent articulation does not impede rehearsal but rather creates verbal interference, which degrades memory traces and results in reduced recall performance. Within this alternative conception, the phenomenological experience of hearing the memory words in our head would be a mere by-product of their maintenance instead of a process contributing to this maintenance (Lewandowsky & Oberauer, 2015). Though such a proposal still needs support (cf. Lucidi et al., 2015), our inner speech is more than just a way to maintain information; it is also involved in the control of our mental activity. For example, repeating to ourselves some instructions permits us to better switch between activities in a multitasking environment. These different conceptions of how inner speech is related to our mental life can be traced back to Piaget and Vygotsky, questioning the link between language and thought.

An even more striking challenge is to understand what refreshing is and how it works. Originally, refreshing was conceived of as the minimal executive function: focusing attention on memory traces to keep them active (Cowan, 1995; Johnson, 1992). Among the alternative theoretical proposals, many relate refreshing to search or retrieval in long-term memory (McCabe, 2008; Unsworth & Engle, 2007). It can also be conceived of as an elaboration or enrichment of memory traces by long-term memory knowledge. Alternatively, refreshing could be seen as reconstructing memory traces in a WM considered as distinct from long-term memory (Barrouillet & Camos, 2015). Ultimately, the existence of refreshing was also denied, and the attentional effect reported in many studies interpreted as reflecting the reduction of interference by the removal of distractors (Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012). Other authors have proposed that refreshing is based on selective visual attention, specifying the nature of the attentional resources involved (Awh & Jonides, 2001).

Finally, the joint use of two mechanisms for the same maintenance purpose raises the question of their coordination. Does each mechanism work on different representations of the same memory items? Does this imply the existence of two distinct memory buffers for storing these different representations? Although redundancy in stored information is a safe solution for an information-processing system like our cognitive system (just think of how many backup files you have of your work), this explanation lacks parsimony. It can be put forward that the existence of rehearsal does not imply the need for a phonological store. Refreshing would process memory representations stored in WM, while rehearsal would reinstall sensory inputs through output planning processes (Jones, Hughes, & Macken, 2007). This could provide an adequate solution for understanding the coordination of the two mechanisms. In any case, the question of how different representations or sources of information are integrated at recall remains to be examined.

Conclusion

Despite the challenges in understanding how rehearsal and refreshing work, the existence of these two independent mechanisms in the maintenance of verbal information constitutes the latest advance in WM research. Much evidence has been collected supporting this dissociation, and differences in the mechanisms' nature and effects on recall are well established. Given the central role of WM in cognitive development, an important avenue for future research is to examine how these mechanisms evolve with age and, more importantly, how they affect WM development (Jarrold & Hall, 2013).

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Declaration of Conflicting Interests

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