Long-Term Effects of Working Memory Retrieval from Prioritized and Deprioritized States

Frieda Born (born@mpib-berlin.mpg.de)[1,2,3]

Bernhard Spitzer (spitzer@mpib-berlin.mpg.de)[1]

[1] Group Adaptive Memory and Decision Making, Max Planck Institute for Human Development, Berlin, Germany
[2] Machine Learning Group, Technical University Berlin, Germany
[3] BIFOLD, Berlin Institute for the Foundations of Learning and Data, Berlin, Germany

Abstract:

Which factors determine whether information held in working memory (WM) is transferred to long-term-memory (LTM)? Our present study draws inspiration from the established finding that retrieving ("testing") memories from LTM benefits their future recall. Here, we examined the extent to which such LTM benefit may also occur after retrieval from WM, depending on whether the WM contents were retrieved from a prioritized or deprioritized state. To this end, we combined variants of a novel visual WM paradigm with a subsequent surprise LTM recall test. We found a WM-testing benefit both for prioritized and deprioritized material, which, interestingly, was stronger for temporally deprioritized WM information. This effect replicated across experiments with different priority manipulations. Subsequent LTM benefits generally occurred after free recall, but not after (forced-choice) discrimination of the WM contents. The surprisingly larger LTM benefit for deprioritized WM contents may reflect enhanced encoding of the participants' own WM report into LTM.

Keywords: working memory, long-term memory, attention, prioritization, learning, behavior, fMRI

Introduction

Understanding why some events stick in LTM while others are quickly forgotten is a question of high interest in contemporary WM research. Traditional research into determinants of LTM formation has focused on features pertaining to the encoding of the information such as the depth of encoding (*levels-of-processing*; Craik & Lockhart, 1972). In recent years, researchers in the WM field have increasingly focused on a potential role of WM maintenance for the information transfer to LTM. They found that a longer duration of maintenance was associated with improved subsequent LTM recall (e.g., Souza & Oberauer, 2017). Similarly, rote rehearsal efficacy (Madigan & McCabe, 1971) or benefits determined by the quality of WM information encoding (e.g., attentive encoding, see (Khader et al., 2010; Sundby et al., 2019) or cognitive load (Camos & Portrat, 2015) were found to affect subsequent LTM. A small number of studies (e.g., Jeanneret et al., 2023; LaRocque et al., 2014; Mao Chao et al., 2023; Reaves et al., 2016; Strunk et al., 2019) have also looked into the long-term consequences of selective information (de)prioritization during WM maintenance. Findings have been somewhat mixed (Hartshorne & Makovski, 2019?) with various reports that attentional focusing during WM benefits subsequent LTM, while some work suggests improved LTM when information is moved outside the "focus of attention" (Oberauer, 2002; e.g., Rose et al., 2014).

However, it remains unclear whether beyond encoding and maintenance, the *retrieval* of information from WM might play a role for LTM storage -- just as has been described for retrieval practice from LTM in the "testing-effect" literature (Roediger & Butler, 2011; Rowland, 2014). Therefore, here, we used a novel visual WM paradigm to investigate how active retrieval from WM affects the transfer of information to LTM. Specifically, we examined whether potential benefits may depend on the attentional state (prioritized or deprioritized) of the WM information, and on the way it is being retrieved ("tested") from WM.

Methodology

We performed a series of 3 experiments with in total N = 450 participants recruited via Prolific (https://www.prolific.ac/). Each experiment comprised three stages: a WM task with 60 trials, a brief distractor task (mental arithmetic for about 1 minute), and a surprise LTM test encompassing 100 trials. In the WM task (see Fig. 1; a), participants were presented with one or two WM sample objects with random orientations which were to be maintained over a short delay period. After the delay, the sample(s) reappeared in a random orientation, and participants were asked to rotate them back to their original orientation. In half of the two-sample trials (randomly varied), only one of the two samples (randomly selected) was probed. On the remaining two-sample trials, after the first WM test (Test 1), also the orientation of the other, previously unprobed sample was probed (Test 2). Thus, participants had to maintain the orientation of both WM samples until Test 1, during which the unprobed sample can be assumed to be deprioritized for the remainder of the trial. In the subsequent surprise LTM test, participants were asked to recall the orientations of all WM sample objects again, including those that were not probed in a WM test. Across the three experiments, the basic task structure remained the same, but with the following variations: In Exp. 1, participants were asked to re-rotate the probe via a *continuous* report, whereas Exp. 3 employed a *binary* report (Fig. 1c). In Exp. 2, we operationalized WM deprioritization through a classical retro-cue approach (Fig. 1b). The subsequent LTM free recall testing procedure was identical in all 3 experiments. The LTM data shown for Exp. 2 was pruned to account for differences in average WM performances across conditions.

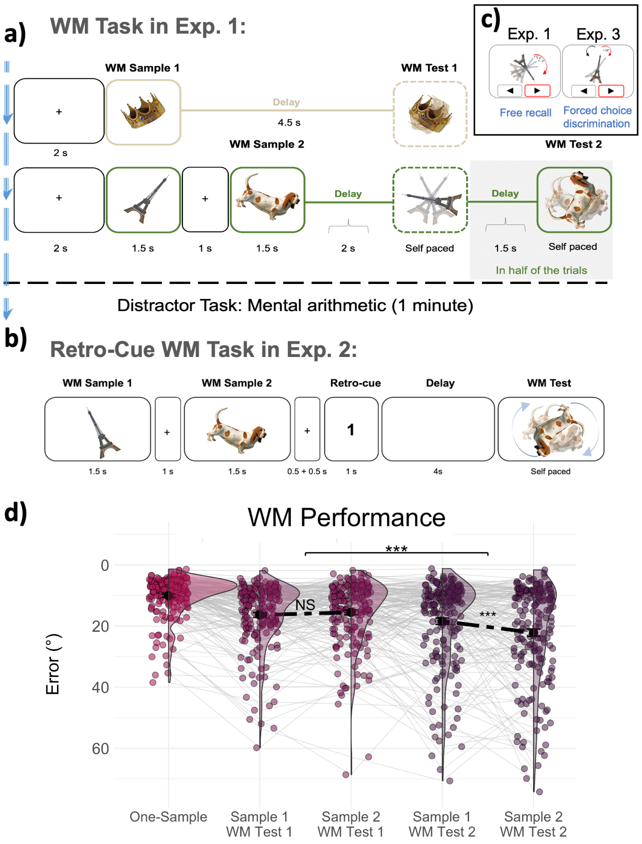
Results and Conclusions

Figure 1d show the error (absolute angular difference from the sample orientation; note inverted y-axis) of participants' reports in the WM task. As expected, WM accuracy was significantly higher (i.e. smaller errors) for prioritized WM contents compared to temporarily deprioritized material [t(186) = -6.50, $p < 0.001$].

Also as expected, participants' LTM reports (Fig. 1e) (M = 53.961°, SE = 1.137°) were overall considerably less accurate than their previous WM reports [t(186) = 37.28, $p < 0.001$]. However, contrary to the WM results, LTM accuracy was significantly higher for samples that had been probed second (i.e. after deprioritization) in the WM task [WM Test 2, M = 49.000°, SE = 1.475°], compared to samples that had been probed first [WM Test 1; t(186)=4.319, $p < 0.001$]. Thus, whereas the WM accuracy for deprioritized samples was expectedly reduced, their subsequent LTM recall was surprisingly improved.

In Exp. 2 we examined the robustness of these findings using a retro-cueing paradigm, which holds the WM maintenance duration constant for prioritized and deprioritized information. After pruning for equivalent WM performance we found a significant interaction of WM Testing and Cueing [F(1,88) = 5.826, p = 0.01, η2 = 0.006; which indicates a greater LTM benefit of WM testing for uncued than for cued samples. Thus, in terms of LTM memorability, also in the retro-cuing paradigm, deprioritized samples again benefited more from WM retrieval than prioritized samples (Fig. 1f). In Exp. 3 we asked whether the findings of Exp. 1 would also be observed when using a different WM-testing procedure (forced-choice discrimination of a small rotation change; see Fig. 1b), which we hypothesized to involve less active retrieval/recall processing. Unlike in Exp.1, we found no significant LTM benefit for samples probed in WM Test 2 (M = 70.951°, SE = 1.881°) compared to WM Test 1 [t(106) = 1.492, p =0.139]. Compared to Exp. 1, the overall LTM accuracy in Exp. 3 was significantly lower (M = 72.137°, SE = 1.137, t(236.6) = -10.168, $p < 0.001$), indicating that less active recall had weaker (or no) benefits for subsequent LTM.

In sum, our work complements research from the LTM-"testing" literature by demonstrating a "WM-testing" effect which appeared to be particularly strong for material that was temporarily deprioritized in WM. This slightly counterintuitive finding could be explained by enhanced memorability of information generated by the participants themselves, at the time of WM-recall. Building on these results, we are preparing an fMRI study to pinpoint the neural signatures of WM encoding and -retrieval in our task, with a specific focus on activity patterns that may predict subsequent LTM ("subsequent memory effects").



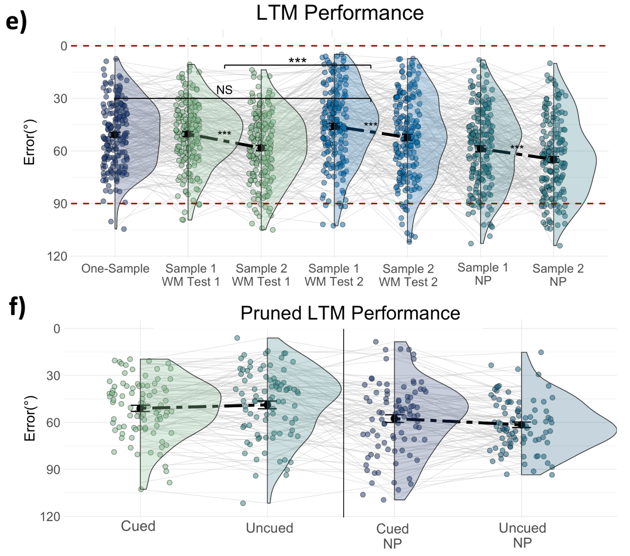


Figure 1: Behavioral paradigm overview and WM results in Exp. 1. **a)** WM task in Exps. 1. **b)** Retro-cue WM task in Exp. 3 **c)** Test procedures used in WM task, free recall in Exp. 1 (left), and forced-choice discrimination in Exp. 3 (right) **d)** WM performance in Exp. 1. **e)** LTM performance in Exp. 1. **f)** Pruned LTM performance in Exp. 2**.**

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