

Does attending to information in working memory improve long-term memory?

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Conflict of interest

The authors have no conflict of interest to declare.

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Abstract

There is broad agreement among memory researchers that WM processes can influence LTM formation. Prior research has suggested that holding information in WM for longer time may benefit LTM because of mechanisms such as refreshing, elaboration, or consolidation - processes presumed to rely on focused attention. However, studies manipulating free time do not isolate attention effects from other factors. Several studies have used a more direct way to study the effect of attention on LTM performance by using prioritization techniques (such as retro-cuing and rewarding) whereby attention is directed towards specific information in WM during the WM retention interval. Here we review these studies. The results are mixed: Whereas some studies find LTM benefits for prioritized items, others do not. Variability in outcomes could not be explained by differences in memory set size, presentation mode, material type, kind of priority signal, or test format. When a LTM benefit is present, the difference in performance remains modest. Thus, focused attention in WM generates at best a small benefit to LTM. Most of the included studies made use of a surprise LTM test and thus, further research is needed to determine whether the intent to remember information in the long term interacts with attention to promote LTM encoding. Altogether, our review findings suggest that attention to information in WM is insufficient on its own for robust LTM encoding.

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Does attending to information in working memory improve long-term memory?

In many day-to-day situations, we rely on working memory (WM) to keep information temporarily available for use in an ongoing task. In some situations, we might need this information for later recall. In this case, we can rely on long-term memory (LTM). Some theoretical models view WM and LTM as separate *stores* (e.g., Atkinson & Shiffrin, 1968; Baddeley, 2012; Barrouillet & Camos, 2015), whereas others do not make this strict distinction (e.g., Cowan, 1995; Melton, 1963; Nairne, 1990; Oberauer, 2002). While these different theoretical models might not agree on how WM and LTM are related, they do agree that there is a cooperation between these two. In line with this, several studies have demonstrated that processes on information in WM affect how well this information is remembered in the long term (e.g., Bartsch et al., 2018; Bartsch & Oberauer, 2021; Camos & Portrat, 2015; Cotton & Ricker, 2021; Jarjat et al., 2018; Johnson et al., 2002; Loaiza & Lavilla, 2021; Loaiza & McCabe, 2012; McCabe, 2008; Souza & Oberauer, 2017; see also Bartsch et al., 2024). However, it remains unclear what is happening with representations in WM to improve their performance in a delayed test.

Souza and Oberauer (2017) demonstrated that providing more free time for representations to reside in WM is an effective way of creating long-term memories (see also Hartshorne & Makovski, 2019). There are different hypotheses of what might happen during this free time in WM. Some researchers argue that more time to refresh representations in WM results in better LTM performance (e.g., Camos & Portrat, 2015; Jarjat et al., 2018; Loaiza & McCabe, 2012; McCabe, 2008), whereas others suggest that people use this time for elaboration (e.g., Bartsch et al., 2018; Craik & Tulving, 1975; Loaiza & Lavilla, 2021). Another explanation is that this free time enables consolidation of the representation, leading to a more durable representation that can withstand decay and interference (e.g., Cotton & Ricker, 2021;

Labaronne et al., 2023). Despite differing in the specifics, for all three processes researchers assume that they rely on focused attention within WM. This shows broad agreement about the pivotal role of attention in facilitating the transfer of information from WM to LTM.

However, varying free time to enable refreshing, elaboration, or consolidation is not ideal to isolate the effect of focused attention on the formation of LTM. We can only assume that WM representations undergo refreshing, elaboration, or consolidation during free time. There is no way to verify these assumptions independently of the effect of free time on memory.

Studies that use a more direct approach to manipulate focused attention in WM could offer a clearer view of the role of attention in making long-term memories. Such studies employ instructed prioritization techniques to direct attention to specific items during the retention interval by indicating which item is (most likely) to be tested (*retro-cue*) or which item will be worth more points when tested and repended to correctly (*reward*). When memory for this prioritized item is subsequently tested, performance is found to be improved compared to another, not-prioritized item in WM (for reviews, see Allen et al., 2024; Souza & Oberauer, 2016). These methods allow for a more controlled investigation of how focused attention within WM influences subsequent LTM performance.

If LTM performance relies on focused attention during WM retention, improved LTM performance should be observed for prioritized representations in WM compared to unprioritized representations in WM. The evidence on this prediction is mixed. Therefore, in an attempt to get a better understanding of the relationship between WM and LTM, this review serves to evaluate the existing literature on the effect of focused attention in WM on LTM. We will compare all studies with a suitable task set-up including one of the commonly used prioritization strategies, and we will outline similarities as well as differences between these studies.

The consequences of focused attention on long-term memory performance

In the search of articles that (1) used one of the commonly used prioritization strategies and (2) studied the effects of attention in WM on LTM performance, we identified 15 articles (Atkinson et al., 2024; Born & Spitzer, 2024; Fan & Turk-Browne, 2013; Hartshorne & Makovski, 2019; Higgins et al., 2020; Jeanneret et al., 2023; M. K. Johnson et al., 2002; M. R. Johnson et al., 2013; LaRocque et al., 2015; Lintz & Johnson, 2021; Mao Chao et al., 2024; Reaves et al., 2016; Sandry et al., 2020; Strunk et al., 2019; Wang & van Ede, 2024). We excluded studies that did not observe a performance benefit for the prioritized item in the WM test (Higgins et al., 2020; M. K. Johnson et al., 2002; M. R. Johnson et al., 2013) and studies in which the set-up did not allow to measure the benefits of prioritization in the WM test (Fan & Turk-Browne, 2013) because in these studies it is not clear whether the prioritization manipulation worked. After excluding these articles, 11 relevant studies remained. For some of these studies, we excluded experiments which were not suitable for comparison for the purpose of the current review (see Supplementary Materials for more details).

Table 1 presents an overview of the potentially theoretically relevant methodological differences and similarities between the included studies. All these studies followed the same sequence of phases: WM task – filler task – LTM task. In the WM task, one of the to-be-memorized items was prioritized and thus, assumed to be in the focus of attention during the retention interval of the WM task. In the LTM task, memory for this prioritized item is then compared to other, unprioritized items from the WM task. An important confound that should be taken into account in this type of task set-up is whether or not the memory item was tested in the WM task (for a review on testing effects, see Rowland, 2014). Specifically, to measure the effect of WM prioritization on LTM performance, over and above potential effects of testing, we can consider two comparisons. First, we can compare LTM performance for the prioritized and unprioritized items that were both tested in the WM task. In this comparison,

LTM of both items would be similarly affected by being tested, but one was attended during the retention interval of the WM task whereas the other one was not. Second, the testing effect can be eliminated by including trials in which the memory test is omitted. In this way, one can compare LTM performance for the prioritized-untested items with that of the unprioritized-untested items. In this case, both items were not tested in WM, but one was attended during the retention interval of the WM task whereas the other one was not. As it remains unclear whether testing in WM has a similar effect on the unprioritized item as on the prioritized item, the second approach is the most ideal to examine the isolated effect of attention in WM on LTM performance. Still, we will use both approaches to review the findings in the literature. In Table 1, we included the results of both approaches (if applicable). As some of the relevant experiments or studies did not control for the testing effect, we also included a column in Table 1 to report these results. When the results within one study contradict each other when taking in account testing effects or not, we will only focus on the results where testing has been taken into account. We will discuss each of the included variables in the sections below.

Table 1

Overview of the relevant studies and results in terms of LTM benefit of attentional prioritization (with or without taking into account the testing effect in WM).

Study & Experiment		WM Items				Priority Information			Memory Tests		LTM Comparison (prioritized vs. ...)	LTM Benefit		
		Set size	Presentation	Duration (per item, in ms)	Type	Type	Timing (relative to encoding)	Duration + post delay (in ms)	WM	LTM (E = expected, U = unexpected)		Regardless of testing in WM	Both tested in WM	Neither tested in WM
<i>LaRocque et al. (2015)</i>	2	2	Simultaneous	1000	Visual	Retro-cue	After	500 + 2000	Recognition	Recognition (U)	Uncued	-	✓	(✓)
	3	2	Simultaneous	1000	Visual	Retro-cue	After	500 + 2000	Recognition	Recognition (U)		-	✓	(✓)
<i>Reaves et al. (2016)</i>	-	2	Simultaneous	100	Visual	Retro-cue	After	200 + 700-1100	Recognition	Recognition (E)	Neutral-cued	-	✓	-
<i>Strunk et al. (2019)</i>	-	2	Simultaneous	100	Visual	Retro-cue	After	200 + 700-1100	Recognition	Recognition (E)	Neutral-cued	-	✓	-
<i>Hartshorne and Makovski (2019)</i>	12	3	Simultaneous	770	Verbal	Retro-cue	After	4000 + 0	Recognition	Recognition (U)	Neutral-cued, Uncued	-	-	✓*
	13	4	Simultaneous	770	Visual	Retro-cue	After	4000 + 0	Recognition	Recognition (U)		-	-	✓*
<i>Sandry et al. (2020)</i>	1	3	Sequential	500	Verbal	Reward	During	500 + 500	Recognition	Free recall (U)	Uncued and Neutral-cued	-	✗	✓
<i>Lintz and Johnson (2021)</i>	2	3	Simultaneous	750	Verbal	Retro-cue	After	1500 + 100	LDT	Recognition (U)	Uncued	-	-	✓
<i>Mao Chao et al. (2023)</i>	1	2	Simultaneous	1000	Visual	Retro-cue	After	1000 + 2000	Recognition	Recognition (E)	Uncued	-	✗	-
	3	2	Simultaneous	1000	Visual	Retro-cue	After	1000 + 2000	Recognition	Recognition (U)		-	✗	-
<i>Jeanneret et al. (2023)</i>	1	4	Simultaneous	250	Visual	Retro-cue	After	500 + 500	Recognition	Recognition (U)	Neutral-cued, Uncued	✓	-	✗
	2	4	Simultaneous	250	Visual	Retro-cue	After	500 + 500	Recognition	Recognition (U)		✓	-	✗
		4	Simultaneous	250	Visual	Reward	After	500 + 500	Recognition	Recognition (U)	Low reward	✗	-	-
<i>Atkinson et al. (2024)</i>	1	4	Sequential	250	Visual	Reward	During	250 + 250	Recognition	Recognition (U)	Low reward, Equal reward	✗	✗	✗
	2	4	Sequential	500	Visual	Reward	During	500 + 250	Recognition	Recognition (U)		✗	✗	✗
<i>Wang and van Ede (2024)</i>	2	2	Simultaneous	250	Visual	Retro-cue	After	500 + 1500	Recognition	Recognition (U)	Uncued and Neutral-cued	-	✗	✓*
<i>Born and Spitzer (2024)</i>	2	2	Sequential	1500	Visual	Retro-cue	After	1000 + 4000	Reproduction	Reproduction (U)	Uncued	✗	-	-

Note. WM = working memory, LTM = long-term memory, LDT = lexical decision task. A checkmark ‘✓’ means statistical evidence for a LTM benefit, ‘✗’ means no statistical evidence, and ‘(✓)’ refers to a descriptive benefit. *These studies include items that were tested but there was no re-exposure of the items on screen (no-match trials).

Variations in the Presentation of Working Memory Items

The studies included in Table 1 made use of different WM set sizes, ranging from two to four items. While there is no clear pattern in the results, it seems that studies using smaller set sizes are more likely to detect a LTM benefit. Thus, the differences in results displayed in Table 1 might be due to a difference in WM set size, with lower set sizes being more likely to detect a LTM benefit of attentional prioritization in WM.

The studies included in Table 1 made use of different item presentation modes, such that some studies presented the memory items simultaneously whereas others presented them sequentially. Additionally, the encoding durations range from 100 ms – 1500 ms per item. There does not seem to be a relation between the presentation mode or encoding duration and the obtained results for LTM performance, and thus these task parameters are unlikely to explain why some studies observed a LTM benefit of WM prioritization whereas others did not.

Whereas most studies included in Table 1 used visual memory materials, there are three experiments included in which verbal materials were used. For all three of these experiments, a LTM benefit was obtained. Thus, it is possible that using verbal memory materials is more likely to result in a LTM benefit of attentional prioritization in WM. However, given the limited number of studies using verbal materials, it would be premature to draw any conclusions here. In addition, even if using verbal materials is more likely to result in a LTM benefit, this does not explain the inconsistency in the obtained results when visual materials were used.

Variations of the Priority Signal

The studies included in Table 1 mostly used a retro-cue, which is typically a spatial cue presented during the retention interval of a WM task (after encoding) that indicates which item is most likely to-be-tested at the end of the trial (for a review, see Souza & Oberauer, 2016). In

most of the included studies, the retro-cue even indicated the to-be-tested item with 100% validity (Born and Spitzer made use of a 75 or 83.33%-valid cue and Lintz and Johnson made use of a 40%-valid cue). In four experiments, reward values were used to prioritize an item in WM (A. L. Atkinson et al., 2024; Jeanneret et al., 2023; Sandry et al., 2020). In these studies, one of the memory items was assigned a higher reward value when tested and responded to correctly compared to the other items (for a review, see Allen et al., 2024). In the included studies, the reward values could be assigned through a location cue after encoding (similar to the retro-cue) or could be linked to the serial position of the item. Given that the studies that observed a LTM benefit of WM-prioritization did not consistently use a retro-cue or reward values, the type of priority signal and its timing in the WM task can most likely not explain the differences in obtained results.

One could argue that the duration of the priority signal and/or the time after it could be critical, as more time for the item to reside in the focus of attention could result in improved LTM performance (e.g., Hartshorne & Makovski, 2019; Souza & Oberauer, 2017). Indeed, the studies that did observe a LTM benefit from WM prioritization presented the priority signal for a longer period and/or combined this with a longer post-priority signal delay, ranging from 1000 ms to 4000 ms. In some of the studies that did not observe a LTM benefit, this duration was much shorter, ranging from 500 ms to 1000 ms. Still, there are two studies included in Table 1 that did not observe a LTM benefit for WM prioritization and used similar time ranges as the ones that did, i.e., 3000 and 4000 ms (Mao Chao et al., 2023, and Born and Spitzer, 2024, respectively). Therefore, the presentation rate of the priority signal as well as the duration of the post-priority signal delay can most likely not explain the different results.

Variations in the Memory Tests

Another task parameter that could potentially explain the differences in results for the LTM benefit of WM prioritization is the type of WM and LTM test. For example, a more precise measure of memory performance (such as recall error of a reproduction test) might be more sensitive to detect a LTM benefit of WM prioritization than more blunt measures (such as accuracy from a recognition test). However, almost all studies made use of a recognition test for the WM task (Lintz and Johnson, 2021, used a lexical decision task, and Born and Spitzer, 2024, used a reproduction test). Thus, the type of WM task is unlikely to explain the obtained difference in LTM results. Almost all studies also used a recognition test for the LTM task (Sandry et al., 2020, used free recall, and Born and Spitzer, 2024, used a reproduction test). Thus, the type of LTM test is unlikely to explain the differences in results.

Furthermore, the intent to remember could potentially make a difference in whether or not a WM prioritization benefit can be observed in LTM performance. From the studies included in Table 1, the LTM test was announced beforehand, and thus expected, in only three experiments (Experiment 1, Mao Chao et al., 2024; Reaves et al., 2016; Strunk et al., 2019). Whereas Reaves et al. (2016) and Strunk et al. (2019) did observe a LTM benefit of WM prioritization, Mao Chao et al. (2024) did not. Mao Chao et al. (2024) even compared between two experiments in which participants were either aware (Experiment 1) or unaware (Experiment 3) of the upcoming LTM test, but neither of the experiments resulted in a LTM benefit of WM prioritization. Thus, based on these studies, the intent to remember is not a compelling explanation of the difference in results. Still, it seems plausible that people might be more efficient in using attention in WM to benefit LTM when they are aware of the upcoming LTM test compared to when they are unaware (see also Popov & Dames, 2023). This possibility will be further addressed in the General Discussion.

Variations in the Long-Term Memory Comparison

A final variable that could be critical to explain the differences in obtained LTM results, is the comparison that is made to measure the potential LTM benefit. Specifically, in the WM literature, the performance difference is often calculated by comparing performance for the prioritized items to performance for the neutral or baseline items, that is, items from a trial in which no priority signal was present. This comparison reflects the true performance benefit of prioritization. In contrast, one can also calculate the performance difference between the prioritized items and the unprioritized items from the same trials. This comparison reflects the combination of the performance benefit of prioritization as well as the performance cost for unprioritized items in trials with a priority signal. In the WM literature, some studies have already demonstrated that these costs and benefits are not equally large and that, on some occasions, one can be present without the other (e.g., Hautekiet et al., 2025; Vergauwe et al., 2025). Thus, it is possible that some of the LTM benefits observed in the studies included in Table 1 are actually a combination of the cost and the benefit, rather than reflecting a pure benefit.

When comparing the studies included in Table 1, it seems that most studies that did observe a LTM benefit did indeed compare the prioritized item to an unprioritized item from the same type of trials and thus, the observed benefit might actually be a combination of the costs and benefits of prioritization rather than a pure benefit. However, some of the studies that did not obtain a LTM benefit also made use of the same comparison. Therefore, based on this, it seems that the differences in results cannot be explained by the prioritization comparison made to measure the LTM benefit.

Discussion

The question asked in this review is whether focused attention in WM is beneficial for LTM performance. We compared experiments from 11 articles that used a similar task-set up to review the evidence in the literature. Overall, the results in the literature are mixed. When taking into account testing effects in WM (for a review, see Rowland, 2014), about half of the experiments detected a LTM benefit for WM prioritization. When comparing studies that did vs. did not observe LTM benefits of WM prioritization, no clear pattern emerged. None of the identified task parameters seems to explain the differences in obtained results, except that there might be a slight tendency to observe a LTM benefit with smaller WM set sizes. Future studies will need to determine whether this is a reliable predictor for observing a LTM benefit or not. The inconsistencies in the results as well as the fact that there is no clear pattern to explain these differences raises the question as to whether attention in WM is actually beneficial for LTM performance or not.

A formal meta-analysis could be helpful to obtain an overall estimate of the effect of WM prioritization on LTM performance. However, of the 17 experiments discussed in Table 1, effect sizes are reported for less than half of the experiments. Based on a closer examination of the studies that *did* observe a LTM benefit of WM prioritization, it seems that when a LTM benefit is observed this effect reflects a rather modest difference in performance. For example, Hartshorne and Makovski (2019) observed a difference of about 8% (Experiment 12) and 3% (Experiment 13) accuracy between the cued and uncued items¹. Sandry et al. (2020) observed a difference of about 0.004 in proportion of items retained between high and low reward items (Cohen's $d = 0.33$). Although supported by a non-negligible Bayes factor ($BF = 4.05$), it is a small difference in performance. Lintz and Johnson (2021) observed a difference of 0.2 in

¹ No effect size reported.

confidence rating between cued and uncued items (Cohen's $d = 0.755$). Similarly, Wang and van Ede (2024) observed a difference of about 6% in accuracy between the cued and uncued/neutral cued items on the LTM test¹. Thus, while these studies did observe a LTM benefit for WM prioritization, the difference in performance in LTM for prioritized and unprioritized items remains rather modest. If the LTM benefit that can be obtained from WM prioritization is indeed a small effect, this could explain why it cannot consistently be observed in the literature.

Does this mean that attention is not needed to create long-term memories? This conclusion would be premature. Both prioritized and unprioritized items (from cue trials and no-cue trials) have been encoded into WM, and presumably that involved some degree of attention to them when they have been presented. What the findings from our review suggest is that directing additional focused attention to items once they already are in WM has at best a small additional effect on long-term retention of these items.

Perhaps an initial brief moment of attention to a stimulus is enough to establish it in LTM, and further attention to it does not yield any further benefit? That does not seem to be the case, because both extension of study time and repeated presentation of stimuli for study are well-established experimental techniques for strengthening individual items in LTM. However, in these cases the person has the intention to encode the stimulus for a subsequent test of LTM. This was not the case in most of the studies reviewed here: When a prioritization signal directed attention to one item in WM, participants usually did not anticipate that this item will be relevant beyond the duration of the WM-task trial. In the present review we found only three studies in which participants were expecting the LTM test, and in two of them prioritization had a beneficial effect on LTM. Therefore, we should consider the following possibility: Initial attention to a stimulus for about 200 to 1000 ms – the typical presentation duration of stimuli in a WM test – generates a trace in LTM independently of the person's

intention to remember it. This is the basis of incidental memory for attended events. Attending to the same stimulus again – either in the perceived environment or in WM – does not add much to its strength or accessibility in LTM. However, when such a second period of attention to the stimulus is accompanied by processes suited for generating strong LTM representations – such as elaboration – then the second attention period is likely to yield a more substantial benefit in LTM. Participants are more likely to employ such processes when they are aware of an upcoming LTM test and therefore try to establish good LTM representations. This could explain why repeated presentation as well as longer presentation time are effective means to strengthen memory in intentional-memory studies, while they are less effective in incidental-memory studies (e.g., Helbing et al., 2020; Tatler & Tatler, 2013).

While not the main focus of our review, the studies included in Table 1 also demonstrated mixed findings in terms of the effect of testing in WM on LTM performance. While some studies did observe an effect of testing on LTM performance (e.g., A. L. Atkinson et al., 2024; Jeanneret et al., 2023), others did not (e.g., Hartshorne & Makovski, 2019; Sandry et al., 2020). In our comparison of Table 1, we followed authors' descriptions of tested vs. not tested WM items, but some of the studies eliminated re-exposure rather than actually removing the memory test (A. L. Atkinson et al., 2024; Hartshorne & Makovski, 2019; Wang & van Ede, 2024). Thus, in these experiments, participants still had to compare the target item in mind to the probes on screen, even if the actual target was not represented on screen. It is possible that some of the processes involved with testing are still present when comparing the target item to the items on screen. If we would – for that reason – take out these studies from our comparison, even less evidence is remaining for a benefit of focused attention in WM on LTM performance.

In summary, our review of the literature demonstrates that – when participants are unaware of the upcoming LTM test – there is little evidence that focused attention in WM benefits LTM. This means that attention might be a necessary but not sufficient condition for

LTM learning. Additional processes that depend on the intention to learn might contribute. To better understand the role of attention in creating long-term memories, future studies should further examine whether focused attention in WM benefits LTM when there is an intent to remember and what the difference is between intentional and incidental memorization.

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