Journal of Experimental Psychology:
Learning, Memory, and Cognition
2018, Vol. 44, No. 5, 722–733

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0278-7393/18/$12.00 http://dx.doi.org/10.1037/xlm0000468

When Shorter Delays Lead to Worse Memories: Task Disruption Makes Visual Working Memory Temporarily Vulnerable to Test Interference

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Evidence shows that visual working memory (VWM) is strongly served by attentional mechanisms, whereas other evidence shows that VWM representations readily survive when attention is being taken away. To reconcile these findings, we tested the hypothesis that directing attention away makes a memory representation vulnerable to interference from the test pattern, but only temporarily so. When given sufficient time, the robustness of VWM can be restored so that it is protected against test interference. In 5 experiments, participants remembered a single grating for a later memory test. In the crucial conditions, participants also performed a letter change detection task in between, during the delay period. Experiments 1–3 demonstrate and replicate the predicted effect: The intervening task had an adverse effect on memory performance, but only when the test display appeared immediately after the secondary task. At longer delays of 3.5 s, memory performance was on a par with conditions in which there was no intervening task. By varying the similarity of the test pattern to the memorized pattern, Experiments 4 and 5 further showed that performance suffered at early test intervals, unless the test item was dissimilar to the memory item. The results provide positive evidence for test interference, and demonstrates that the susceptibility to interference only occurs temporarily, as memory is restored when attention is allowed to return to the memorandum.

Keywords: visual working memory, focus of attention, fragile memory, test interference

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Visual working memory (VWM) stores relevant visual information for ongoing cognitive tasks. Current theories claim that the active maintenance of information in VWM is strongly served by attentional mechanisms (Awh, Vogel, & Oh, 2006; Chun, 2011; Cowan, 1998; Gazzaley & Nobre, 2012; Jonides et al., 2008; Kiyonaga & Egner, 2013; Olivers, 2008; Theeuwes, Belopolsky, & Olivers, 2009). Consistent with this notion, it has been found that attending to mnemonic representations leads to improved performance, while unattended representations become vulnerable (Astle, Summerfield, Griffin, & Nobre, 2012; Griffin & Nobre, 2003; Magen, 2016; Makovski, 2012; Makovski & Pertzov, 2015; Pertzov, Bays, Joseph, & Husain, 2013; van Moorselaar, Gunseli, Theeuwes, & Olivers, 2015; Vogel, Woodman, & Luck, 2006; Zokaei, Heider, & Husain, 2014).

However, the assumed central role of attention in VWM maintenance is at odds with a number of studies that found that VWM representations readily survive even when in the meantime attention is needed elsewhere serving another task in between memory storage and the memory test (Hollingworth & Maxcey-Richard, 2013; Lewis-Peacock, Drysdale, Oberauer, & Postle, 2012; Olivers, Peters, Houtkamp, & Roelfsema, 2011; Rerko, Souza, & Oberauer, 2014). For example, Hollingworth and Maxcey-Richard (2013) asked participants to remember a cued color for a change detection task. In one condition, during the delay, participants performed a visual search task, which would presumably draw attention away from the memory. Memory performance was nevertheless comparable to a condition without intervening visual search task. Similarly, Rerko, Souza, and Oberauer (2014) found that a cued memory did not suffer even when observers were required to do an unrelated color matching task in between. Further evidence that working memory representations readily survive while attention is needed for a different task comes from fMRI and EEG studies using multivoxel pattern analyses (MVPA; LaRocque, Lewis-Peacock, Drysdale, Oberauer, & Postle, 2013; Lewis-Peacock et al., 2012). In these studies participants were asked to remember two items, each of which was linked to a specific task (which could be visual, semantic, or phonological in nature). Participants were then cued as to which item they would need first, while the other item should be stored for the second task. The second task would only be presented after the first task was completed. This resulted in increased pattern classification accuracy for the first needed memory item, consistent with the idea that this was now in the focus of attention. At the same time, classification accuracy for the remaining memory item decreased to the point where it was indistinguishable from chance level performance, indicating that it was not in the current focus of attention. Interestingly though, classification accuracy for this item was fully restored after the first task was completed, showing that its representation had successfully survived the intervening task.

This article was published Online First November 2, 2017.

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This research was supported by a European Research Council (ERC) advanced grant (ERC-2012-AdG-323413) to Jan Theeuwes, an ERC consolidator grant (ERC-CoG-615423) to Christian Olivers, and a China Scholarship Council (CSC) scholarship (201508330313) to Benchi Wang.

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Taken together, these findings appear to go against the claim that attention and working memory are closely related cognitive functions, and specifically the claim that attention is necessary for successful VWM maintenance.

Theories of VWM are thus served by resolving the paradoxical role of attention in memory maintenance. For this it is necessary to specify the specific function(s) that attention could serve in maintaining a representation. One straightforward function is that attention prevents the decay by sustaining or regularly refreshing activity (Baddeley & Hitch, 1974). Another possibility is that, during the delay, attention protects against interference from intervening stimuli or tasks (e.g., Magen, 2016; Makovski, 2012; Makovski & Pertzov, 2015; Souza, Rerko, & Oberauer, 2016; van Moorselaar, Gunseli, et al., 2015; Vogel et al., 2006; Zokaei et al., 2014), or from other items in memory (e.g., Astle et al., 2012; Bays, 2014; Griffin & Nobre, 2003; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Pertzov et al., 2013; Souza, Rerko, & Oberauer, 2014; van Moorselaar, Olivers, Theeuwes, Lamme, & Sligte, 2015; Williams, Hong, Kang, Carlisle, & Woodman, 2013). Thus, under these accounts, attention provides a necessary protection against information loss during the maintenance period, either due to decay or due to interference.

A so far largely unexplored role for attention is to protect against interference from the memory test itself. As Makovski, Sussman, and Jiang (2008) argued, the test pattern, as a task-relevant stimulus, provides a potential cause of interference. The test pattern is often the first stimulus following the memorandum, and like other stimuli, may thus overwrite, or integrate with, vulnerable memory representations, especially because it is often so similar to the memorandum, and thus likely to make use of the same neural representations. Thus, under this account, attention serves to protect the memory not so much during the delay, but at the test, the moment of retrieval. So far there has been little direct evidence for test interference in VWM and the role of attention in preventing it—the main problem being that the test pattern is also used for what it is designed for: To test the memory. Makovski et al. (2008) arrived at their conclusion through the exclusion of a number of alternative hypotheses, rather than on the basis of positive evidence. Another study by Makovski et al. (2010) provides indirect evidence by showing that the type of task at test affected memory retrieval. Specifically, they found that a test that involved a two-alternative forced choice, and thus two patterns, led to worse performance than a same/different task, which involved only one pattern. Although Makovski et al. (2010) explained this result in terms of the additional task demands, it could also be interpreted in terms of interference, in that doubling the number of stimuli at test leads to an increased likelihood of intrusion and thus reduced performance.

Even though the idea of test interference has been largely unexplored, it can help explain why attention emerges as important for VWM maintenance in some studies, but not in others. More specifically, we propose that the availability of attention interacts with test interference in affecting memory performance. The core hypothesis is that an interrupting task during VWM maintenance makes the memory vulnerable, but only temporarily, until the task is completed and attention is allowed to return to the memorandum. We assume that the secondary task, by taking attention away, temporarily makes the memory vulnerable, or fragile (Sligte, Scholte, & Lamme, 2008; van Moorselaar et al., 2015), and as a result the test pattern has a higher chance of disrupting, biasing, or replacing the original information (Makovski, Sussman, & Jiang, 2008; Makovski, Watson, Koutstaal, & Jiang, 2010). So far, in dual task studies, the task structure typically allowed sufficient time between the intervening task and the subsequent memory test for attention to recover, be directed back to the abandoned working memory representation, and make it robust again, thus allowing little effect from the test. Initial evidence showing that the robustness of a memory can in principle be restored comes from Rerko et al. (2014) and van Moorselaar, Olivers, Theeuwes, Lamme, and Sligte (2015). (see also Murray, Nobre, Clark, Cravo, & Stokes, 2013), although these studies did not specify which type of interference the memory is protected against by restoring attention. Furthermore, in these studies the robustness was restored by explicitly making the observer direct attention to the memorandum, through the use of a retro-cue. This does not explain why VWM has proven so robust in dual task settings, where attention is taken away through an intervening task. For this, we must assume that the recovery occurs endogenously, when observers are given sufficient opportunity to direct attention back to the memorandum.

In the current study, we report evidence (a) for the temporal vulnerability of memory representations under dual task settings, (b) the endogenous restoring of the robustness of the memory when given sufficient time, and (c) for the idea that what the memory becomes vulnerable to is test interference. The temporary vulnerability hypothesis, when combined with the hypothesis of test interference, makes a specific, prominent, and rather counterintuitive prediction: The memory test should not follow too soon after the intervening task. If there is insufficient time for attention to recover from the intervening task, the memory representation remains volatile, susceptible to disruption or replacement by the test item. In other words, the temporary vulnerability hypothesis predicts that the *shorter* the delay between intervening task and the memory test, the *worse* memory performance will be. Longer delays allow for the memory item to become the focus of attention again, making it robust against test interference.

We tested this prediction in a total of five experiments. In all experiments, participants remembered a single visual grating for a later memory test. In the crucial conditions, participants were also required to perform a letter change detection task during the delay period (see Figure 1 for an example). In various replications, Experiments 1–3 demonstrate the predicted effect: The intervening task had an adverse effect on memory performance, but only when the test display appeared immediately after the secondary task. At longer delays of 3.5 s, memory performance recovered, returning to levels when there was no intervening task. Thus, the timing of the test determined whether dual task costs were observed. Experiments 4 and 5 further tested the idea that an intervening task makes the memory vulnerable to interference from the test by varying the similarity of the test pattern to the memorized pattern. On the basis of the evidence that working memory and perception partly share the same neural representations (Kiyonaga & Egner, 2013; Postle, 2006; Serences, Ester, Vogel, & Awh, 2009), and given that short-term memory suffers more from interference the more similar the items (Wickens, Born, & Allen, 1963), we hypothesized that test stimuli that are more similar (but not the same)

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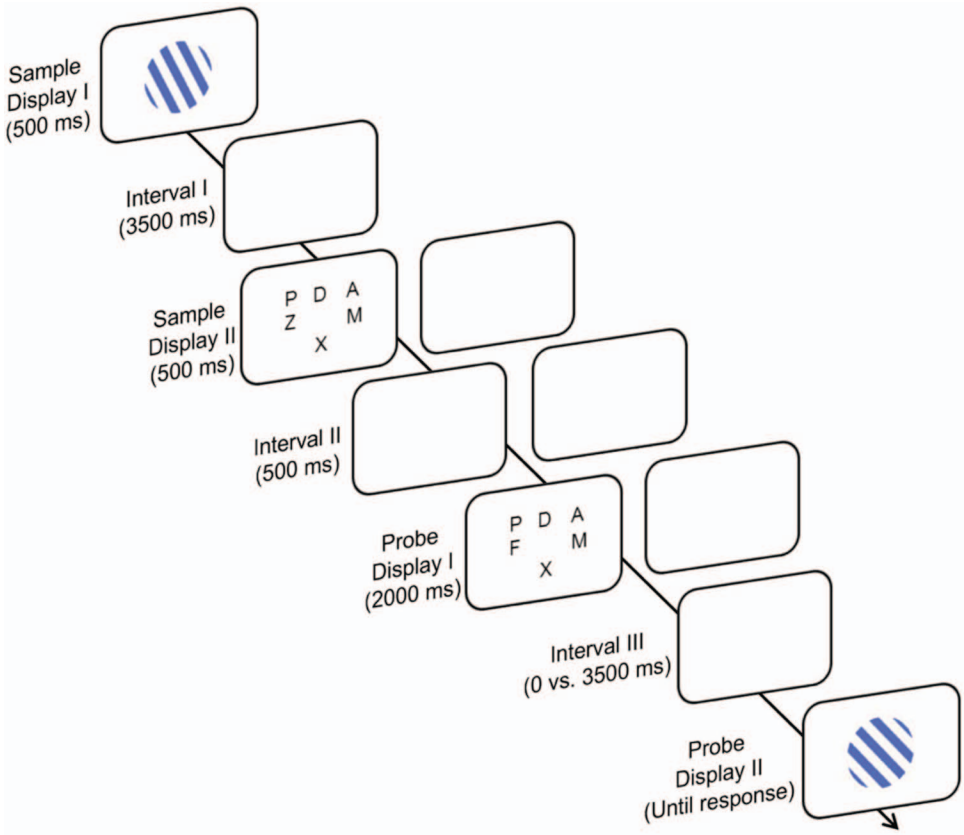


Figure 1. Sequence of events in the *dual task* (with letters present) and *single task* (with letters absent) trials. The interval between the letter and the grating probe displays was fixed at 3,500 ms in Experiment 1, at 0 ms in Experiment 2, and was varied between 0 ms and 3,500 ms in Experiments 3–5. All displays were shown against a gray background. See the online article for the color version of this figure.

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to the memorandum should cause stronger interference than less similar test patterns. Indeed, we again found that performance suffered at early test intervals, unless the test item was dissimilar to the memorized item.

Experiment 1

Experiment 1 served to first test whether in our paradigm, the maintained VWM representation is in principle robust against an intervening task, when tested at long delays. Figure 1 shows the procedure. Participants were required to memorize both the color and the orientation of a grating stimulus for a memory test at the end of the trial. In the *dual task* condition, participants performed another memory task in between, for which they had to remember displays of six letters. In the *single task* condition, no letter displays and task was presented in between.

Method

Participants. Fifteen participants (nine females, mean age = 25.5 years) participated for monetary compensation or course credits. They all provided written informed consent and reported normal color vision, and normal or corrected-to-normal visual acuity. The research protocol was approved by the Scientific and Ethical Review Committee of the Faculty of Behavioral and Movement Sciences of the Vrije Universiteit Amsterdam.

Apparatus. The timing of events was controlled by a HP Compaq 8000 Elite computer, and the stimuli were shown on a 21-in. color monitor. A viewing distance of approximately 71 cm was maintained by a chinrest, and participants were tested in a dimly lit laboratory. Stimulus presentation and response registration was controlled by custom scripts written in Python.

Stimuli. Participants were first required to memorize the color and orientation of a grating shown on a gray screen (17 cd/m^2), as illustrated in Figure 1. The grating was cropped by a circular mask (radius: 4°) and its spatial frequency was 0.5 cycles per degree. The foreground color of the grating was randomly selected from one of two color values (either 45° or 135° from one CIE L*a*b* color space centered at L = 70, a = 5, b = 0 with a radius of 60, plus or minus an offset randomly selected from a range of ±10°; luminance: 36–44 cd/m^2), and its orientation was randomly chosen from one of two orientations (either 45° or 135° from vertical, plus or minus an additional offset randomly selected from a range of ±10°). The additional random jitter around the canonical feature value was adopted to discourage verbal recoding. The color and orientation of the test grating were either both the same as the

sample, or there was either a ±10° color change, or a ±15° orientation change (but never both).

Later in the trial in the *dual task* condition, participants were also presented with six black letters (4 cd/m^2, each subtending 1° × 1°). The letters were randomly chosen from the English alphabet, without replacement, and their locations were randomly selected from an invisible 3 × 3 grid, 9° × 9° visual angle located in the center of the display.

Procedure and design. Figure 1 illustrates the *dual task* and *single task* trials. In the *dual task* condition, a trial consisted of two change detection tasks, one embedded within the other. A fixation cross was first shown for 500 ms to signal the beginning of each trial. Then a to-be-memorized grating was shown in the center of the display for 500 ms, followed by a 3,500 ms delay. After that, participants were presented with six letters for 500 ms that they were also instructed to memorize, followed after 500 ms by the same set of letters, but with one potential change. Participants indicated whether any letter had changed or not by pressing the "Z" (no) or "/" (yes) key on a standard "QWERTY" keyboard. After this response or waiting for 2,000 ms, there was another 3,500 ms interval, after which the test grating was presented. Participants judged whether, compared with the original one, the grating has changed in either color or orientation (never both), by pressing the "Z" (no) or "/" (yes) key. After a random intertrial interval (intertribal interval (ITI); range: 500 ms–700 ms), the next trial began. Only accuracy was emphasized in the instructions of the present and the following experiments. In the *single task* condition, no letters were shown; instead the delay period between the to-be-remembered grating and the test grating consisted of a blank display period of 10,000 ms, which is the same length as the interval in the *dual task* condition.

The two main conditions, referred to as task set (*dual task* vs. *single task*) were randomly mixed within blocks. Participants completed 24 practice trials and two blocks of 120 trials each. On the main memory task (for the grating), one third of the trials had no change, one third had a color change, and one third an orientation change. For the intervening (letter) task, there was a change on 50% of trials.

Results and Discussion

Figure 2 shows the mean percent correct for the intervening letter change task. With 75.5% correct responses, the task was doable, but reasonably challenging. Nevertheless, and crucially, performing the letter task in between did not result in any deterioration of performance on the grating task. Figure 3A shows the percent correct for the grating for *single* and *dual task* conditions (68.5% in both conditions). There was no difference, $t < 1$. A pattern that also held when assessing either color, or orientation changes alone, $ts < 1.4$, $ps > 0.2$ (the hit rate for color was 78.3% in the *single task* condition, and 79.5% in the *dual task* condition; the hit rate for orientation was 43.0% in the *single task* condition, and 45.8% in the *dual task* condition). This confirms earlier findings that VWM can be carried across an intervening task, and thus that VWM does not necessarily require attention to be continuously available for maintenance. We also analyzed response times for any speed–accuracy trade-offs, as reported in Appendix A and B. There was no evidence for such trade-offs.

Experiment 2

Experiment 1 confirmed that VWM need not suffer from a demanding intervening task. The question is then what happens to the memorandum when resources are being directed to the secondary task. One possibility is that it does not suffer at all, either because it does not need any attention, or sufficient attentional resources are available to also actively maintain the grating while doing the intervening task. Another possibility is that the representation remains available in principle, but it becomes temporarily vulnerable. To distinguish between these possibilities, Experiment 2 tested the memory for the grating immediately after the intervening letter task. We hypothesized that this way participants had less opportunity to direct their attention back to the primary memory of the grating, making it vulnerable to interference from the test grating. Alternatively, if the grating remained robustly represented even during the secondary task, then we should not observe any decline in performance for early testing.

To exclude the possibility that any observed memory deficit was due to perceptual interference rather than dual task interference, participants were also presented with a *passive-viewing* condition, in which they saw the same letter displays in between, but were not required to memorize them. In addition, to exclude the possibility that any observed interference would be caused by a response bias now participants only responded to the letter task *after* they had responded to the grating task (otherwise participants may have

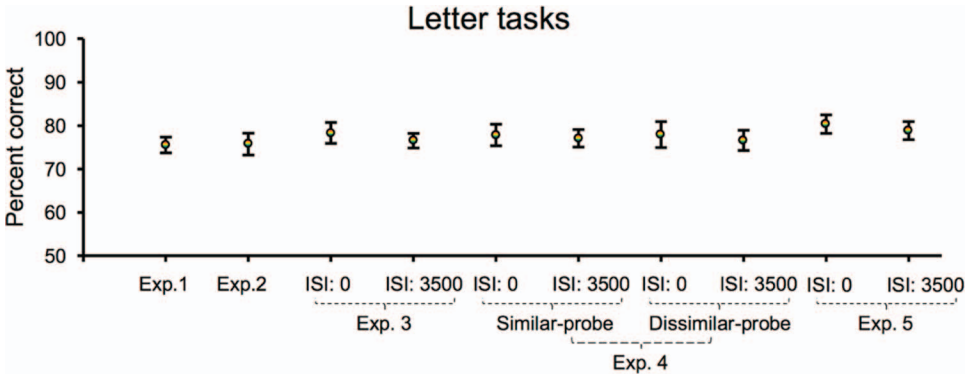


Figure 2. The results of the letter tasks in all experiments. Error bars denote ± 1 SEM. See the online article for the color version of this figure.

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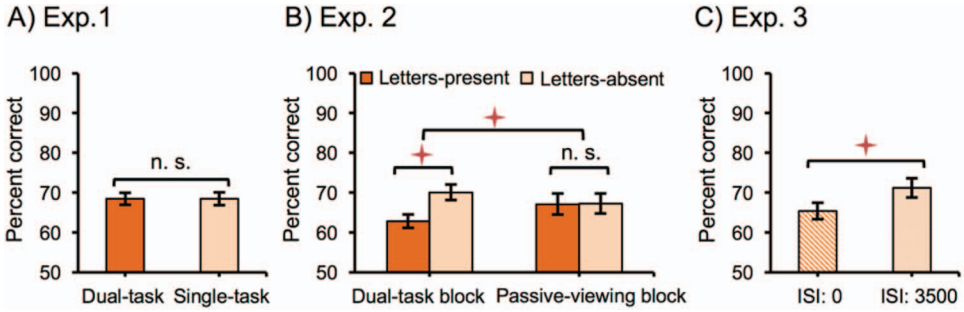


Figure 3. The results of the main task in Experiment 1 (A), Experiment 2 (B), and Experiment 3 (C). Error bars denote ± 1 SEM. See the online article for the color version of this figure.

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pressed a particular key in response to the intervening memory task, and then stuck with that key for the main memory task, resulting in an error).

Method

Fifteen participants (11 females, mean age = 22.1 years) took part. Two participants were excluded because of chance level performance when the letters were absent in the *dual-task* block. The procedure was the same as in Experiment 1 except for the followings: First, the response to the letter task was given *after* the response to the grating task. After the test display of the grating task, participants saw a sentence "For letters, change or not?", and then responded to the letter task by pressing the "Z" (no) or "/" (yes) key. Second, there was now no interval between the test display of the letter task (shown for 2,000 ms) and the test display of the grating task (shown until response). Participants also completed a *passive-viewing* condition, in which the intermediate letter displays were presented, but observers did not need to memorize or respond to them. Thus, a 2 (Block Type: *passive-viewing* vs. *dual-task*) × 2 (Intermediate Letter Displays: *present* vs. *absent*) within-subject design was adopted. For efficiency purposes, the number of trials in the *letter display absent* condition (60) was half that in the *letter display present* condition (120) in both *passive-viewing* and *dual-task* blocks. Each participant first completed the *passive-viewing* block, then completed the *dual-task* block to avoid inadvertent memorizing of the letters. Within each block, trial type (*letter display present* or *letter display absent*) was randomly mixed. Of course, on trials when no letters were present in the dual task block, there was no secondary task.

Results and Discussion

Figure 2 shows the mean percent correct for the intervening letter change task, which, at 75.7% was again comparable to the previous experiments. The main results of Experiment 2 are presented in Figure 3B. For the *passive-viewing* block the mean percent correct on the grating memory task was 67.2% when the letters were shown, and 67.3% when no letters were shown. In the *dual-task* block, it was 62.9% when the letters were to be remembered too, and 70.1% when no letters were shown. The memory performance of the grating task was entered in a repeated measures ANOVA, with variables *intermediate letter display* (present vs. absent) and *block type* (passive-viewing vs. dual-task). A significant main effect was observed for intermediate letter display, $F(1, 12) = 6.77$, $p = .023$, partial $\eta^2 = .36$, but not for block type, $F(1, 12) = 0.27$, $p = .61$, partial $\eta^2 = .02$. Importantly, the two-way interaction between intermediate letter display and block type was reliable, $F(1, 12) = 5.81$, $p = .033$, partial $\eta^2 = .33$. Planned pairwise comparisons revealed that memory performance suffered in the *dual-task* block, when participants had to perform the intermediate task versus when there were no letters present, $t(12) = 3.42$, $p = .005$. This effect was reliable for orientation (the hit rate was 42.7% when participants had to perform the intermediate task, vs. 60.8% when there were no letters present), $t(12) = 5.66$, $p < .001$, but not for color, although the pattern went in the same direction (74.6% when participants had to perform the intermediate task, vs. 80.8% when there were no letters present), $t(12) = 1.52$, $p = .154$. In contrast, in the *passive-viewing* block, the presence of intermediate letter displays did not matter, $t(12) = 0.07$, $p = .949$ (neither for orientation, $t < 1.25$, nor color, $t < 1$).[1] We also analyzed response times for any speed–accuracy trade-offs, as reported in Appendix A and B. There was no evidence for such trade-offs.

As a further check that people did not accidentally respond to the wrong task, we analyzed the trials on which participants responded incorrectly on the grating task, to see if there was a tendency toward the response associated with the intervening task. This was not the case. The proportion responses on incorrect trials in the grating task that was the same as the intervening task was 44%, which did not reliably differ from the proportion identical responses on correct trials, 48%, $t(12) = 1.63$, $p = .126$.

These results support the idea that at short test intervals after an intervening task, the memory is vulnerable to the presentation of the test pattern. Moreover, this vulnerability was caused by the active, attention-demanding aspect of the intervening task, and not by the intervening stimuli per se. Thus, when the test was imme-

[1] We successfully replicated the results of this experiment with an experiment in which participants responded to the letter task first, before responding to the grating. In brief, the two-way interaction between *intermediate letter display* and *block type* was again reliable, $F(1, 14) = 7.43$, $p = .016$, partial $\eta^2 = .35$. Planned pairwise comparisons revealed that memory performance suffered in the *dual-task* block, when participants had to perform the intermediate task versus when there were no letters present, $t(14) = 3.34$, $p = .005$. In contrast, in the *passive-viewing* block, the presence of intermediate letter displays did not matter, $t(14) = 0.22$, $p = .826$.

diate, memory performance decreased when observers conducted a secondary task, suggesting that the grating, when not in the current focus of attention, was temporarily vulnerable to interference from the test pattern.

Experiment 3

Experiments 1 and 2 demonstrated that an intervening task results in memory deterioration (relative to passive viewing or single tasks), unless participants are provided with additional time between the intervening task and the main memory probe. However, the crucial comparison—that is, whether participants are tested immediately subsequent to an intervening task, or after some delay—was between experiments, and thus between different groups of participants. Experiment 3 therefore sought to replicate this effect, but now within the same group of participants. Participants always performed the main memory task for the grating plus the intervening letter memory task. The main manipulation was now the interstimulus interval (ISI) between the test display of the letter task and that of the grating task, which was varied between 0 ms and 3,500 ms. We predicted that at 0 ms ISI, memory for the grating is still vulnerable and would suffer from the early test (replicating Experiments 2). An ISI of 3,500 ms, however, allows attention to be directed back from the intermediate task to the primary task, and thus memory is given the opportunity to regain its robustness against test interference. Thus, memory should be better for the longer delay (replicating Experiment 1).

Method

Fifteen participants (nine females, mean age = 21.9 years) took part. The procedure was the same as in the Experiment 2 except that the letter displays were always present and both memory tasks (letter and grating) had to be performed. Instead, the interval between the test display of the letter task and that of the grating task was varied, between 0 ms and 3,500 ms. The different ISIs were mixed within blocks, with 108 trials in total each. Each participant completed two blocks of 108 trials.

Results and Discussion

Figure 2 shows the mean percent correct for the intervening letter change task, which, at 78.3% (for ISI = 0 ms) and 76.5% (for ISI = 3,500 ms; no difference, $t < 1$) was again similar to the previous experiments. The main results of Experiment 3 are shown in Figure 3C. Memory performance for the grating task was significantly worse for ISI = 0 ms than for ISI = 3500 ms, $t(14) = 5.4$, $p < .001$ (65.4% vs. 71.23% for 0 ms and 3,500 ms, respectively). This pattern held for color (67.6% for ISI = 0 ms, vs. 74.4% for ISI = 3,500 ms), $t(14) = 3.27$, $p < .001$, as well as orientation (50.2% for ISI = 0 ms, vs. 63.7% for ISI = 3,500 ms), $t(14) = 6.99$, $p < .001$, confirming that when tested immediately the grating was more vulnerable to test interference than when tested late.

Experiment 4

Experiments 1–3 demonstrated that when participants have to perform an intermediate memory task, memory for the primary task suffers when tested immediately after the intermediate task. When the memory test is delayed, memory performance recovers to levels similar to conditions without the intervening task. Thus, the effect of the test on memory performance was demonstrated through timing. To further assess the role of the test item, Experiment 4 manipulated the *similarity* of the test pattern to the memorandum. Assuming that similar test patterns are more likely to make use of the same neural circuitries as the memorandum we predicted that test similar patterns would cause relatively more interference under conditions of temporary vulnerability as induced by short intervals than dissimilar test patterns. To test this prediction, in the *similar probe* condition the test pattern was the same type of grating as the memorandum, with either the same or a deviating orientation—as was the case in the previous experiments (see Figure 4A, top panel). In the *dissimilar probe* condition, the test pattern consisted of just a single black dot positioned on the rim of a virtual circle. Here the location of the dot on the circle indicated the orientation (see Figure 4A, bottom panel). We reasoned that because the dot probe pattern did not look like the original memorandum, it should not interfere as much as the grating, and thus a reduced time-to-test should not affect performance as much.

In addition, Experiment 4 provides a control for an alternative hypothesis with regards to the results of the previous experiments. One could argue that the costs associated with short ISIs were not due to test interference, but due to task switch costs, because observers had to switch from the intermediate task to the memory test. Note that observers could use as much time as they needed at test, so we regard such task switch costs as rather unlikely. Indeed, the reaction times (RTs) suggest that participants also took more time at short ISIs (see Appendix). However, Experiment 4 controls for task switching, as such task switch costs should be alike regardless of the similarity of the test pattern.

Method

Sixteen participants (eight females, mean age = 23.8 years) were tested. The procedure was the same as in Experiment 3 except for the followings: First, where in previous experiments both color and orientation had to be remembered, here we opted for orientation only, as this more easily allowed for the differential testing conditions (grating vs. dot). Thus, the foreground color of the grating was always black (4 cd/m^2, see Figure 4A top panel). Because now color was not tested, the test pattern carried a change in orientation on 50% of the trials, and no change on the other 50%. Second, we introduced a new factor, *probe similarity*. In the *similar probe* condition, we used the same type of grating as in the previous experiments (see Figure 4A, top panel), and which was thus exactly the same type of pattern as the memorandum. In the *dissimilar probe* condition, we used a black dot instead, and its position on the rim of a virtual circle indicated the orientation (see Figure 4A, bottom panel). This way there was no grating-like pattern presented at test. Thus, a 2 (Similarity: *similar probe* vs. *dissimilar probe*) × 2 (Interval: 0 ms vs. 3,500 ms) within-subject design was adopted. The total number of blocks was two, containing 160 trials each. The two different intervals were mixed within blocks, and two levels of probe similarity were blocked, with block order counterbalanced across participants.

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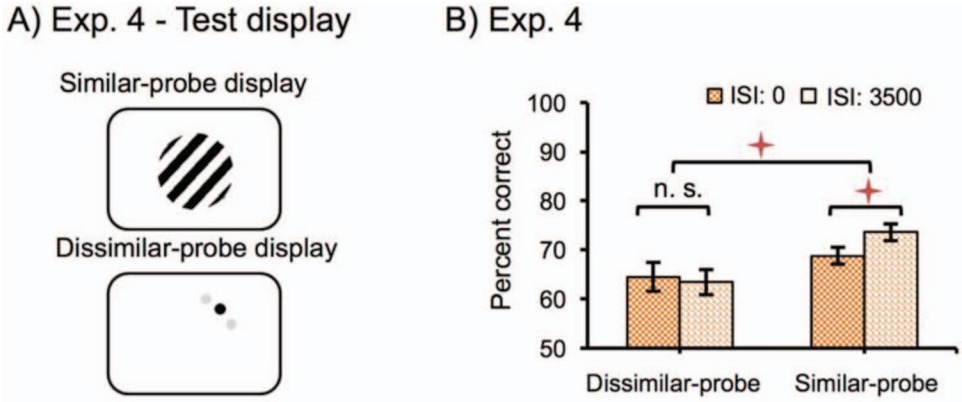


Figure 4. An example of the test display in Experiment 4 (A), and the results of the main task in Experiment 4 (B). In the *similar probe* condition, we adopted the same grating (but was black) as in Experiment 3 (A, top panel); in the *dissimilar probe* condition, a small black disk shown along an invisible circle was adopted (A, bottom panel). The corresponding location of each disk on this virtual circle of each disk denoted one orientation value. Error bars denote ± 1 SEM. See the online article for the color version of this figure.

Results and Discussion

Figure 2 shows the mean percent correct for the intervening letter change task. For the *similar probe* condition this was 77.8% when ISI was 0 ms, and 77.1% when ISI was 3,500 ms. In the *dissimilar probe* condition, scores were 77.9% when ISI was 0 ms, and 76.6% when ISI was 3,500 ms. A repeated measures ANOVA on the mean percent correct, with variables *probe similarity* (similar probe vs. dissimilar probe) and *interval* (0 ms vs. 3,500 ms), showed no significant main effects nor interaction, all $Fs < 1$.

The main results of Experiment 4 are presented in Figure 4B. In the *similar probe* condition, the mean percent correct was 68.8% when ISI was 0 ms, and 73.6% when ISI was 3500 ms. In the *dissimilar probe* condition, it was 64.5% when ISI was 0 ms, and 63.4% when ISI was 3,500 ms. The percent correct scores for the main task were entered in a repeated measures ANOVA, with variables *probe similarity* (similar probe vs. dissimilar probe) and *interval* (0 ms vs. 3,500 ms). Significant main effects were observed for interval, $F(1, 15) = 5.87$, $p = .029$, partial $\eta^2 = .28$, and for probe similarity, $F(1, 15) = 15.89$, $p = .001$, partial $\eta^2 = .51$. Performance was overall better in the *similar probe* condition, and for the 3,50- ms interval. Importantly, the two-way interaction between *similarity* and *interval* was statistically reliable, $F(1, 15) = 12.69$, $p = .003$, partial $\eta^2 = .46$. Planned follow-up comparisons revealed that the memory performance suffered for the 0-ms interval relative to the 3,500-ms interval in the *similar probe* condition, $t(15) = 4.98$, $p < .001$, while in the *dissimilar probe* condition there was no such difference, $t(15) = 0.87$, $p = .399$.

Thus, as predicted, the short time-to-test led to a performance drop relative to delayed testing, but only when the test pattern was similar to the memorandum. For the dissimilar test pattern (i.e., a dot instead of a grating), there was no detrimental effect of early testing after the intervening task, relative to delayed testing.[2] These results confirm that the intervening memory task causes the memory for the grating to become temporarily vulnerable, and therefore to suffer from test interference. Furthermore, they exclude general task switch costs as the cause of the decline in performance.

One caveat is that overall performance was somewhat worse in the *dissimilar probe* condition than in the *similar probe* condition. This may have been expected given that the dot probe carried less rich orientation information (which, after all, was part of the point, as that made it less similar to the memorandum). We used the same levels of change for the dot probe as for the grating probe. However, it may have made the test less sensitive to interference, since performance was not that good in the first place, leading to potential floor effects. However, it deserves pointing out that performance in Experiments 2 and 3 was at a very similar level, yet there we found clear effects of secondary task requirements, and ISI, suggesting that overall level of performance is not the limiting factor here. Nevertheless, since the current result relies on a null finding, we thought it prudent to confirm it with a more sensitive measure, as presented in Experiment 5.

Experiment 5

Experiment 5 replicated the dissimilar probe condition of Experiment 4 (where we failed to find an effect), but used a continuous recall task instead of a binary, forced choice change detection task. Here too, we asked participants to remember a grating, but did not use a grating at test. Instead, we used a small pointer, which participants moved along the rim of a faint ring around the original pattern, with the use of the mouse (see Figure 5A). This way observers could indicate the orientation that they remembered, rather than imposing a changed orientation of fixed magnitude upon them.

Method

Fifteen participants (13 females, mean age = 20.5 years) participated. The procedure was the same as in Experiment 4 except

[2] Note that this does not mean that there is no interference at all, even for dissimilar probes. We show that this interference is no stronger at short intervals than at long intervals. There may still be some interference from dissimilar tests especially at short intervals, while longer intervals may in turn suffer from relatively more decay.

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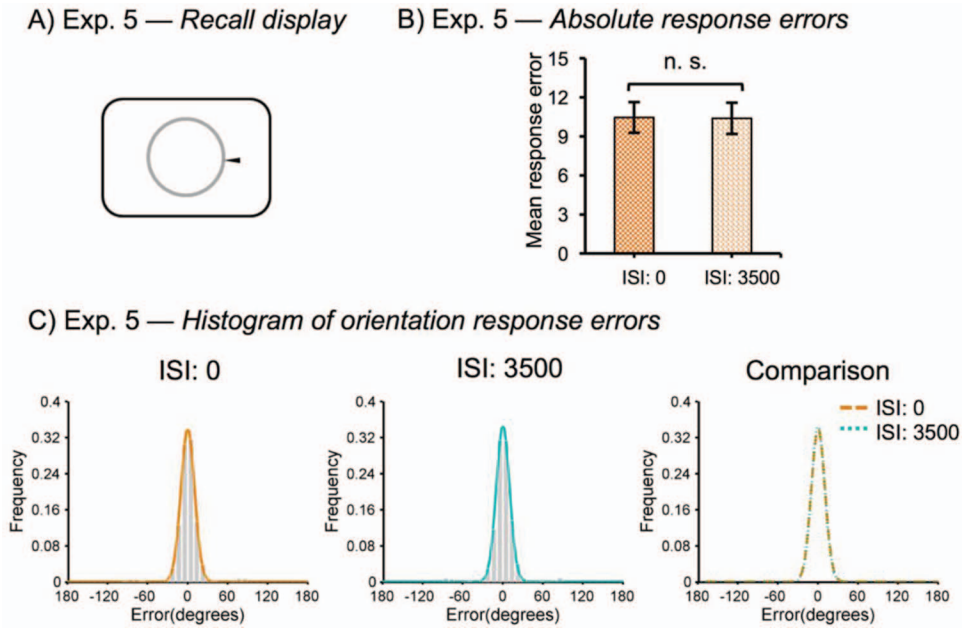


Figure 5. Example of the test display (A), absolute response error (B), and response error histograms across all participants (C) in the main task in Experiment 5. Lines with different colors indicate the best fitting curve for each distribution. Error bars denote ± 1 SEM. See the online article for the color version of this figure.

that we only ran a condition with a dissimilar probe, to see if the absence of an effect in the dissimilar condition could be replicated using a more sensitive memory test. The test display consisted of a light gray wheel (radius: 4°; luminance: 23 cd/m^2) plus a mouse-driven pointer that was always initially located at the most rightward point on the circle (see Figure 5A for an example). Participants chose the remembered orientation by moving the mouse with their right hand, and clicking the mouse button upon the chosen orientation. Afterward, participants indicated whether there had been a change to the intervening letter display, as before, by pressing "S" (no, same) or "D" (yes, different), but here with the left hand.

Results and Discussion

Figure 2 shows the mean percent correct for the intervening letter change task, which was 80.3% when ISI was 0 ms, and 78.8% when ISI was 3,500 ms, there was no difference, $t < 1$. The mean absolute response error for each condition is presented in Figure 5B, and the histogram of response errors are presented in Figure 5C. The results are clear. The distributions for the short- and long-interval conditions overlapped almost completely, and there was no difference on mean response error (10.45 vs. 10.39 for 0 ms and 3,500 ms, respectively), $t < 1$. The results thus confirm those of the dissimilar probe condition of Experiment 4: Here too the probe was different from the memorandum, and there was again no evidence for reduced memory performance at early tests relative to late tests. Combined with the continuous measurement and the overall low response error, this shows that the visual patterns are stored in a relatively high quality, and that early testing does not result in additional interference (relative to late testing) from a dissimilar test pattern.

General Discussion

Our study investigated how attention interacts with the test pattern in shaping VWM performance. Classically, it has been found that working memory performance deteriorates the longer the delay period, as information decays, suffers from proactive interference, or otherwise disappears (Baddeley, 1976, 2007; Keppel & Underwood, 1962; Zhang & Luck, 2009). Here we reveal that under particular circumstances, the opposite holds, and testing too soon leads to decreased memory performance. In particular, we argue that when attention is being directed away from a memory representation, as was done here by directing attention to a different task, the memory becomes vulnerable to interference from the test. Time is then an important asset, as it allows attention to restore the robustness of the memory, and protect it against test interference. We report several important findings:

1. VWM for a grating pattern can survive a considerably straining letter memory task presented during the delay period, to the extent that performance was indistinguishable to when there was no such intermediate task (i.e., either blank displays or passive viewing; Experiment 1 and 2). Thus, the grating did not need to be continuously in the focus of attention for effective maintenance.

2. However, performance did suffer from the intermediate task when the memory test followed the secondary task closely in time (Experiments 2, 3, and 4). With immediate testing, performance was worse than when tested after an additional 3,500-ms delay. This novel and counterintuitive finding supports the hypothesis that the test pattern interferes with memory retrieval, but especially so

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when attention has not yet been allowed to return to the primary task.

3. In further support of the idea that test interference drives the early testing deficit, we demonstrate that immediate testing is only detrimental when the test pattern was similar to the memorandum, not when it was dissimilar (Experiments 4 and 5).

The finding that VWM can readily survive an intermediate task (as long as testing is delayed) may appear to contradict earlier findings showing that VWM suffers from an intermediate task. Fougnie and Marois (2006) as well as Makovski, Shim, and Jiang (2006) found that performance on a color change detection task suffered from an intermediate visual attention task. However, in those studies, the memory test either followed immediately (as in Fougnie & Marois, 2006) or within a relatively short time-period (500 ms, as in Makovski et al., 2006) after the intermediate task, and thus their findings may be regarded as consistent with the results from our early test conditions. Other studies using longer test delays have shown that working memory representations can survive intermediate tasks largely unharmed (Hollingworth & Maxcey-Richard, 2013; Lewis-Peacock et al., 2012; Oberauer, 2002; Olivers et al., 2011; Stokes, 2015). However, until the exact time course of test interference has been determined, it remains an open question whether these previous timing parameters played a role. Some differences in stimuli and task may also have contributed. For example, our primary VWM task only involved a single pattern, whereas these previous studies used larger set sizes.

The characteristic of surviving an intervening stimulus or task is in fact seen as a defining characteristic of working memory (Engle, Tuholski, Laughlin, & Conway, 1999; Miller, Erickson, & Desimone, 1996). Working memory not only serves to maintain the current task goal, but also prospective goals for future tasks (Lewis-Peacock et al., 2012; Olivers et al., 2011). If, and how the current goal, and thus the associated item in the current focus of attention, differs from prospective goals in terms of representation or mechanisms remains an open question. One possibility is that the perceptual representation necessary for the current task is actively maintained through increased firing rate driven by recurrent processes (Funahashi, Bruce, & Goldman-Rakic, 1989; Fuster & Alexander, 1971). Such active maintenance would make the representation more robust against interfering input. In contrast, prospective memories may be stored more passively. One possibility is that recurrent processes are temporarily switched off, leaving the memory to slowly decay and become vulnerable to overwriting by stimulus-induced activity from the test pattern, similar to what has been referred to as fragile memory (Sligte et al., 2008; van Moorselaar, et al., 2015). Another possibility is that the prospective memory is stored through temporary synaptic weight changes rather than active firing (Erickson, Maramara, & Lisman, 2010; O'Reilly, Braver, & Cohen, 1999; Sandberg, Tegnér, & Lansner, 2003). This way they do not affect the current task, but can be readily reactivated after the current task is completed. However, such synaptic weights may also be susceptible to changes from new perceptual input.

The findings are consistent with recent studies showing that the robustness of a memory can be restored by cueing attention back toward it, after it has first been cued away (Murray et al., 2013; Rerko et al., 2014; van Moorselaar, Olivers et al., 2015), In these studies the robustness was restored by explicitly making the observer direct attention to the memorandum, through the use of a retro-cue. Here we show that this shift in attentional status can also occur endogenously, driven by the task structure rather than an explicit cue.

We believe that the present findings cannot be explained by scenarios under which the secondary task simply causes speeded decay, or increased interference during the delay period itself, which is then measured using the test pattern. Note that both these mechanisms would result in information loss, but what our data shows is that information is not lost: If one waits a little longer, the information is still there. Thus, at least under the circumstances of the present experiments, the secondary task may have weakened the memory, but only to the extent that it became vulnerable to test interference, and only temporarily so.

More generally, the fact that directing attention to an intermediate task makes a memory vulnerable to test interference has important implications for theories of the role of the focus of attention within VWM. Several competing hypotheses have been raised (see Makovski et al., 2008 for an overview). First, attending to an item in working memory may prevent it from decaying, while unattended items do decay. Note that our results are largely inconsistent with this proposal, since unattended items did not suffer at all after longer delays. Second, attention may prevent interitem interference when multiple items are being maintained (Pertzov, Manohar, & Husain, 2017). We cannot exclude this possibility, but note that it does not apply here, because the main memory task required participants to remember only a single grating. Third, directing and refocusing attention may protect an item against test interference. We believe our study is the first to provide positive evidence for this. Effects of the test item in VWM have been shown before, but these have been demonstrations of *proactive* interference stemming from previous trials (Hartshorne, 2008; Makovski, 2016), rather than *retroactive* interference from the test item onto the current memory, as shown here. The idea of retroactive test interference itself is not new, but so far had only met with circumstantial evidence, through the exclusion of a number of alternative hypotheses (Makovski et al., 2008, 2010). Here we provide direct evidence for test interference by showing that memory performance suffers from (a) too early, and (b) too similar tests.

In conclusion, we provide further evidence that VWM storage involves multiple types of representation, with unattended memories being more susceptible to interference than others. Moreover, this fragility is only temporary. When given enough time, the memory can be reactivated and made robust against the test item.

References

Astle, D. E., Summerfield, J., Griffin, I., & Nobre, A. C. (2012). Orienting attention to locations in mental representations. *Attention, Perception & Psychophysics, 74,* 146–162. http://dx.doi.org/10.3758/s13414-011-0218-3

Awh, E., Vogel, E. K., & Oh, S.-H. (2006). Interactions between attention and working memory. *Neuroscience, 139,* 201–208. http://dx.doi.org/10.1016/j.neuroscience.2005.08.023

Baddeley, A. D. (1976). *The psychology of memory*. New York, NY: Basic Books.

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This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Baddeley, A. (2007). *Working memory, thought, and action*. Oxford, UK: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780198528012.001.0001

Baddeley, A. D., & Hitch, G. (1974). Working memory. In Gordon H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). New York, NY: Academic Press. Retrieved from http://www.sciencedirect.com/science/article/pii/S0079742108604521 http://dx.doi.org/10.1016/S0079-7421(08)60452-1

Bays, P. M. (2014). Noise in neural populations accounts for errors in working memory. *The Journal of Neuroscience, 34,* 3632–3645. http://dx.doi.org/10.1523/JNEUROSCI.3204-13.2014

Chun, M. M. (2011). Visual working memory as visual attention sustained internally over time. *Neuropsychologia, 49,* 1407–1409. http://dx.doi.org/10.1016/j.neuropsychologia.2011.01.029

Cowan, N. (1998). *Attention and memory: An integrated framework*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195119107.001.0001

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128,* 309–331. http://dx.doi.org/10.1037/0096-3445.128.3.309

Erickson, M. A., Maramara, L. A., & Lisman, J. (2010). A single brief burst induces GluR1-dependent associative short-term potentiation: A potential mechanism for short-term memory. *Journal of Cognitive Neuroscience, 22,* 2530–2540. http://dx.doi.org/10.1162/jocn.2009.21375

Fougnie, D., & Marois, R. (2006). Distinct capacity limits for attention and working memory: Evidence from attentive tracking and visual working memory paradigms. *Psychological Science, 17,* 526–534. http://dx.doi.org/10.1111/j.1467-9280.2006.01739.x

Funahashi, S., Bruce, C. J., & Goldman-Rakic, P. S. (1989). Mnemonic coding of visual space in the monkey's dorsolateral prefrontal cortex. *Journal of Neurophysiology, 61,* 331–349.

Fuster, J. M., & Alexander, G. E. (1971). Neuron activity related to short-term memory. *Science, 173,* 652–654. http://dx.doi.org/10.1126/science.173.3997.652

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences, 16,* 129–135. http://dx.doi.org/10.1016/j.tics.2011.11.014

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience, 15,* 1176–1194. http://dx.doi.org/10.1162/089892903322598139

Gunseli, E., van Moorselaar, D., Meeter, M., & Olivers, C. N. (2015). The reliability of retro-cues determines the fate of noncued visual working memory representations. *Psychonomic Bulletin & Review, 22,* 1334–1341.

Hartshorne, J. K. (2008). Visual working memory capacity and proactive interference. *PLoS One, 3,* e2716. http://dx.doi.org/10.1371/journal.pone.0002716

Hollingworth, A., & Maxcey-Richard, A. M. (2013). Selective maintenance in visual working memory does not require sustained visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 39,* 1047–1058. http://dx.doi.org/10.1037/a0030238

Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G., & Moore, K. S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology, 59,* 193–224. http://dx.doi.org/10.1146/annurev.psych.59.103006.093615

Keppel, G., & Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behavior, 1,* 153–161. http://dx.doi.org/10.1016/S0022-5371(62)80023-1

Kiyonaga, A., & Egner, T. (2013). Working memory as internal attention: Toward an integrative account of internal and external selection processes. *Psychonomic Bulletin & Review, 20,* 228–242. http://dx.doi.org/10.3758/s13423-012-0359-y

LaRocque, J. J., Lewis-Peacock, J. A., Drysdale, A. T., Oberauer, K., & Postle, B. R. (2013). Decoding attended information in short-term memory: An EEG study. *Journal of Cognitive Neuroscience, 25,* 127–142. http://dx.doi.org/10.1162/jocn_a_00305

Lewis-Peacock, J. A., Drysdale, A. T., Oberauer, K., & Postle, B. R. (2012). Neural evidence for a distinction between short-term memory and the focus of attention. *Journal of Cognitive Neuroscience, 24,* 61–79. http://dx.doi.org/10.1162/jocn_a_00140

Magen, H. (2016). The role of central attention in retrieval from visual short-term memory. *Psychonomic Bulletin & Review, 24,* 423–430.

Makovski, T. (2012). Are multiple visual short-term memory storages necessary to explain the retro-cue effect? *Psychonomic Bulletin & Review, 19,* 470–476. http://dx.doi.org/10.3758/s13423-012-0235-9

Makovski, T. (2016). Does proactive interference play a significant role in visual working memory tasks? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42,* 1664–1672. http://dx.doi.org/10.1037/xlm0000262

Makovski, T., & Pertzov, Y. (2015). Attention and memory protection: Interactions between retrospective attention cueing and interference. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 68,* 1735–1743. http://dx.doi.org/10.1080/17470218.2015.1049623

Makovski, T., Shim, W. M., & Jiang, Y. V. (2006). Interference from filled delays on visual change detection. *Journal of Vision, 6,* 1459–1470. http://dx.doi.org/10.1167/6.12.11

Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 369–380. http://dx.doi.org/10.1037/0278-7393.34.2.369

Makovski, T., Watson, L. M., Koutstaal, W., & Jiang, Y. V. (2010). Method matters: Systematic effects of testing procedure on visual working memory sensitivity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 1466–1479. http://dx.doi.org/10.1037/a0020851

Miller, E. K., Erickson, C. A., & Desimone, R. (1996). Neural mechanisms of visual working memory in prefrontal cortex of the macaque. *The Journal of Neuroscience, 16,* 5154–5167.

Murray, A. M., Nobre, A. C., Clark, I. A., Cravo, A. M., & Stokes, M. G. (2013). Attention restores discrete items to visual short-term memory. *Psychological Science, 24,* 550–556. http://dx.doi.org/10.1177/0956797612457782

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 411–421. http://dx.doi.org/10.1037/0278-7393.28.3.411

Olivers, C. N. L. (2008). Interactions between visual working memory and visual attention. *Frontiers in Bioscience, 13,* 1182–1191. http://dx.doi.org/10.2741/2754

Olivers, C. N. L., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences, 15,* 327–334.

O'Reilly, R. C., Braver, T. S., & Cohen, J. D. (1999). A biologically based computational model of working memory. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 375–411). New York, NY: Cambridge University Press. http://dx.doi.org/10.1017/CBO9781139174909.014

Pertzov, Y., Bays, P. M., Joseph, S., & Husain, M. (2013). Rapid forgetting prevented by retrospective attention cues. *Journal of Experimental Psychology: Human Perception and Performance, 39,* 1224–1231. http://dx.doi.org/10.1037/a0030947

Pertzov, Y., Manohar, S., & Husain, M. (2017). Rapid forgetting results from competition over time between items in visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43,* 528–536. http://dx.doi.org/10.1037/xlm0000328

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Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience, 139,* 23–38. http://dx.doi.org/10.1016/j.neuroscience.2005.06.005

Rerko, L., Souza, A. S., & Oberauer, K. (2014). Retro-cue benefits in working memory without sustained focal attention. *Memory & Cognition, 42,* 712–728. http://dx.doi.org/10.3758/s13421-013-0392-8

Sandberg, A., Tegnér, J., & Lansner, A. (2003). A working memory model based on fast Hebbian learning. *Network, 14,* 789–802. http://dx.doi.org/10.1088/0954-898X_14_4_309

Serences, J. T., Ester, E. F., Vogel, E. K., & Awh, E. (2009). Stimulus-specific delay activity in human primary visual cortex. *Psychological Science, 20,* 207–214. http://dx.doi.org/10.1111/j.1467-9280.2009.02276.x

Sligte, I. G., Scholte, H. S., & Lamme, V. A. F. (2008). Are there multiple visual short-term memory stores? *PLoS One, 3,* e1699. http://dx.doi.org/10.1371/journal.pone.0001699

Souza, A. S., Rerko, L., & Oberauer, K. (2014). Unloading and reloading working memory: Attending to one item frees capacity. *Journal of Experimental Psychology: Human Perception and Performance, 40,* 1237–1256. http://dx.doi.org/10.1037/a0036331

Souza, A. S., Rerko, L., & Oberauer, K. (2016). Getting more from visual working memory: Retro-cues enhance retrieval and protect from visual interference. *Journal of Experimental Psychology: Human Perception and Performance, 42,* 890–910. http://dx.doi.org/10.1037/xhp0000192

Stokes, M. G. (2015). "Activity-silent" working memory in prefrontal cortex: A dynamic coding framework. *Trends in Cognitive Sciences, 19,* 394–405. http://dx.doi.org/10.1016/j.tics.2015.05.004

Theeuwes, J., Belopolsky, A., & Olivers, C. N. L. (2009). Interactions between working memory, attention and eye movements. *Acta Psychologica, 132,* 106–114.

van Moorselaar, D., Gunseli, E., Theeuwes, J., & Olivers, C. N. L. (2015). The time course of protecting a visual memory representation from perceptual interference. *Frontiers in Human Neuroscience, 8,* 1053. http://dx.doi.org/10.3389/fnhum.2014.01053

van Moorselaar, D., Olivers, C. N. L., Theeuwes, J., Lamme, V. A., & Sligte, I. G. (2015). Forgotten but not gone: Retro-cue costs and benefits in a double-cueing paradigm suggest multiple states in visual short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41,* 1755–1763. http://dx.doi.org/10.1037/xlm0000124

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 1436–1451. http://dx.doi.org/10.1037/0096-1523.32.6.1436

Wickens, D. D., Born, D. G., & Allen, C. K. (1963). Proactive inhibition and item similarity in short-term memory. *Journal of Verbal Learning and Verbal Behavior, 2,* 440–445. http://dx.doi.org/10.1016/S0022-5371(63)80045-6

Williams, M., Hong, S. W., Kang, M.-S., Carlisle, N. B., & Woodman, G. F. (2013). The benefit of forgetting. *Psychonomic Bulletin & Review, 20,* 348–355. http://dx.doi.org/10.3758/s13423-012-0354-3

Zhang, W., & Luck, S. J. (2009). Sudden death and gradual decay in visual working memory. *Psychological Science, 20,* 423–428. http://dx.doi.org/10.1111/j.1467-9280.2009.02322.x

Zokaei, N., Heider, M., & Husain, M. (2014). Attention is required for maintenance of feature binding in visual working memory. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 67,* 1191–1213. http://dx.doi.org/10.1080/17470218.2013.852232

Appendix A

Average RTs (in ms) for the Secondary (Letter) Task

					Exp. 4				Exp. 5	
			Exp. 3		Similar probe		Dissimilar probe		Dissimilar probe	
Condition	Exp. 1	Exp. 2	ISI: 0	ISI: 3,500	ISI: 0	ISI: 3,500	ISI: 0	ISI: 3,500	ISI: 0	ISI: 3,500
Mean RTs	888	645	410	573	446	588	498	600	633	854

Note. There were only significant effects of ISI (0 ms vs. 3,500 ms), all Fs > 5.95, $p < .029$.

(*Appendices continue*)

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Appendix B

Average RTs (in ms) for the Primary (Grating) Task

	Exp. 1		Exp. 2				Exp. 3		Exp. 4			
			Passive viewing		Dual task				Similar probe		Dissimilar probe	
Condition	Dual task	Single task	Letter present	Letter absent	Letter present	Letter absent	ISI: 0	ISI: 3500	ISI: 0	ISI: 3500	ISI: 0	ISI: 3500
Mean RTs	1,257	1,374	1,039	1,094	1,126	1,119	1,177	1,067	1,503	1,439	1,527	1,404

Note. In Experiments 3 and 4, there were significant main effects of ISI (0 ms vs. 3,500 ms), Fs > 6.64, $p < .021$. No other effects were significant.

Received March 16, 2017
Revision received July 7, 2017
Accepted July 7, 2017 ■

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