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Retroactive Interference in Visual Short-Term Memory

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**ABSTRACT**

Retroactive interference occurs when new information disrupts the retention of an existing representation, but its effects on visual short-term memory remain poorly understood. The present study examined three factors predicted to influence domain-specific retroactive interference, including the type of distractor, its temporal position and the length of the retention interval. Participants compared target and test objects over a brief interval that either was unfilled or contained a similar or dissimilar distractor occurring 200 ms or 1.5 s after the target offset. Retention was influenced by the temporal position of the distractor and its relationship with the to-be-remembered target. Specifically, retroactive interference was only observed following the presentation of a dissimilar distractor that occurred 1.5 s after the target. These results suggest that novel distractors may be particularly interfering.

*Key words:* Retroactive interference, visual short-term memory, forgetting, consolidation.

## Retroactive Interference in Visual Short-Term Memory

Visual short-term memory (VSTM) is responsible for maintaining small quantities of visual information across brief delays. Whilst VSTM plays an important role in cognition and behavior (see Hollingworth, Richard, & Luck, 2008; Sun, Zimmer, & Fu, 2011), it is thought to be highly sensitive to interference from multiple sources (Makovski, Watson, Koutstaal, & Jiang, 2010; Wyble & Swan, 2015). One source of interference occurs when visual information encountered in the recent past disrupts VSTM performance in the present. Makovski and Jiang (2008) found that errors in a change detection task increased when the test item on trial  $n$  was an identical match for an object on trial  $n-1$ . Similarly, the ability to determine whether a single visual probe matches any of the current to-be-remembered targets is damaged when the probe is an item seen on the *previous* trial (McKeown, Holt, Delvenne, Smith, & Griffiths, 2014; Mercer & Duffy, 2015). Concurrently presented visual stimuli can also compete and produce interference over a maintenance period (Pertzov, Manohar, & Husain, 2017).

VSTM can be disrupted by retroactive interference (RI) too. RI occurs when new, incoming information disrupts an existing representation and it is thought to be a major source of forgetting (see Dewar, Cowan, & Della Sala, 2007). Unfortunately, the mechanisms underlying RI and the factors that affect it remain poorly understood, yet interference effects have been documented using various methodologies, including the stimulus suffix paradigm (e.g. Ueno, Mate, Allen, Hitch, & Baddeley, 2011). For example, Ueno, Allen, Baddeley, Hitch, and Saito (2011) presented arrays of to-be-remembered target stimuli that were followed by an irrelevant, to-be-ignored suffix item. Across five experiments, the suffix was shown to disrupt recognition for items in the target array, even though participants were instructed to ignore it.

Other researchers have examined the impact of attention-demanding distractor tasks, and these have been shown to disrupt the retention of visual (e.g. Morey & Bieler, 2013) and visuo-spatial (e.g. Vergauwe, Dewaele, Langerock, & Barrouillet, 2012) material. This suggests the involvement of modality-independent, central mechanisms in managing RI. Makovski, Shim, and Jiang (2006) also argued that central attention is involved in handling interference. They measured change detection performance for colors, spatial locations and natural scenes over brief delays. The delay was either empty or contained visual or auditory distraction. The distractor either had to be ignored (passive condition) or categorized as animate or inanimate (active condition). In all the experiments, change detection performance was damaged by both visual and auditory distractors in the active condition. However, the visual (but not auditory) distractor produced modest interference in the passive condition, indicating some modality-specific effects. Other research suggests RI may exert stronger effects when it is domain- or modality-specific (e.g. Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Klauer & Zhao, 2004). That is, VSTM may be more vulnerable to interfering material that is visual in nature.

Prior studies have found that passive viewing of a visual distractor can disrupt the maintenance of visual representations (e.g. Della Sala et al., 1999; Hecht, Thiemann, Freitag, & Bender, 2016; Logie & Marchetti, 1991) although, crucially, the effect may depend on the type of distractor being employed. Burin, Irrazabal, and Quinn (2007) had participants remember polygons across retention intervals that contained verbal interference (articulatory suppression), dynamic visual noise (DVN; a matrix featuring flickering black and white squares) or no distraction (control). Memory for the polygon was tested using a recognition task, but there was no evidence of interference and performance remained stable across the three conditions. The absence of interference produced by DVN has been reported in several other studies too (e.g. Andrade, Kemps, Werniers, May, & Szmalec, 2002; Avons & Sestieri,

2005; Quinn & McConnell, 2006), but Dent (2010) showed that DVN may damage memory for the color of a dot and Burin et al.'s second experiment found evidence of interference when the distractor was a mobile complex geometric shape. This complex shape was also capable of disrupting recognition performance when it remained static.

The findings from Burin et al. (2007, Experiment 2) suggest that RI in VSTM may be particularly detrimental when there is some overlap – or similarity – between the target and distractor items. Evidence consistent with this idea was reported by Borst, Ganis, Thompson, and Kosslyn (2012). They briefly presented unfamiliar characters that had to be remembered and after a 1.5-s delay participants needed to determine whether the character possessed a certain characteristic. The interval contained unstructured DVN, structured DVN (where elements of the pattern were similar to the item being remembered) or no interference (a gray background). Structured DVN was significantly more disruptive than unstructured DVN. Additionally, Blalock (2013) introduced a similar or dissimilar mask after an array of colored squares and a form of similarity-based RI was uncovered – similar masks harmed performance more than dissimilar masks. Other findings are compatible with the notion of similarity-based RI in visual memory (e.g. Clapp, Rubens, & Gazzaley, 2010; Dolcos, Miller, Kragel, Jha, & McCarthy, 2007; Tremblay, Nicholls, Parmentier, & Jones, 2005), so interference may be particularly pronounced when there is a high degree of overlap between the target and distractor representations.

Whilst the concept of similarity-based RI seems plausible, other studies have suggested that the magnitude of RI may be determined by the time separating the to-be-remembered stimuli from the distractor. Experiments using the masked change detection paradigm have often found that a mask has a strong disruptive effect at short stimulus onset asynchronies (SOAs), but this lessens as the interval between the targets and mask increases (e.g. Sun et al., 2011; Vogel, Woodman, & Luck, 2006; see also Jiang, 2004). This has been interpreted

as evidence for consolidation, which converts a transient representation into a more durable memory that is better able to resist interference (Vogel et al., 2006). Yet in the pre-consolidated state, visual representations may be sensitive to all forms of distraction – not just those that are similar to the target stimuli. In support of this view, DVN can damage the retention of visual information when presented very shortly after encoding (Borst et al., 2012; Vasques, Garcia, & Galera, 2016). Nieuwenstein and Wyble (2014, Experiment 2) also documented a general disruptive effect of RI at short SOAs. Participants had to remember a complex, unfamiliar visual object that was sometimes followed by a distractor task involving parity judgements of a digit. The distractor appeared after SOAs lasting 247, 494, 1,000 or 1,494 ms and memory for the target was assessed using a four-alternative forced-choice recognition task. The distractor task had the strongest disruptive effect at the shorter SOAs, suggesting that visual memory is sensitive to interference before it is fully consolidated. In Nieuwenstein and Wyble’s fifth experiment, the visual parity judgement task was replaced with an analogous auditory version. Even the auditory distractor task hindered recognition of complex visual shapes at a short SOA. In summary, a consolidation view of RI may expect any distractor to impair VSTM before consolidation is completed, but extending the interval between encoding and interference should lead to a recovery in performance. Whilst this may seem incompatible with the view of similarity-based RI outlined above, it could be assumed that all distractors – even those of a different modality – impair VSTM prior to consolidation, but only similar distractors damage visual representations once consolidation is complete.

Yet VSTM is also susceptible to time-based forgetting, with numerous studies showing that the ability to retain visual representations declines over short retention intervals (Hesse & Franz, 2010; McKeown et al., 2014; Mercer & Duffy, 2015; Morey & Bieler, 2013; Pertzov et al., 2017; Poom, 2012; Ricker & Cowan, 2010, 2014; Salmela, Mäkelä, & Saarinen, 2010). The loss of VSTM over time is compatible with a decay process, but this also has

implications for RI. Introducing a distractor into the retention interval may be particularly damaging if that interval is long, as interference may exacerbate the decay process already unfolding (a “decay plus interference” effect). The amount of time that a representation must be maintained may therefore play an important role in determining the magnitude of RI.

In summary, RI appears to be a relatively simple forgetting mechanism, but the precise way it operates in VSTM is unclear. It is likely that the impact of RI depends on many different factors and the first experiment aimed to explore three of these variables: the type of distractor, its temporal position within the retention interval, and the overall delay separating encoding and retrieval. Rather than studying variables in isolation, assessing the impact of several factors within the same experiment should allow a better understanding of RI mechanisms. This has important theoretical implications for VSTM and the nature of short-term forgetting more generally.

In the first experiment, participants compared complex target and test objects over retention intervals lasting 2.4 s or 6 s. The task was to determine whether the two objects were the same or different. The retention interval was unfilled in the control condition, but in the experimental conditions a single distractor was presented after a 200 ms or 1.5 s delay. The distractor was either similar or dissimilar to the target. Based on the literature reviewed above, a similar distractor was expected to produce the most RI and lower accuracy on the task. Similarity-based RI was expected to be particularly pronounced at short target-distractor delays, in line with consolidation theory, and following long retention intervals. Unexpectedly, however, the results revealed a very different set of findings.

## **EXPERIMENT 1**

### **Method**



**Participants.** Thirty-one volunteers aged between 18 and 47 completed the experiment. Participants were undergraduate students from the University of Wolverhampton who self-reported normal or corrected-to-normal vision. An additional three participants volunteered for the study but were excluded due to technical problems during data collection. The study was approved by an institute ethics committee and all participants provided written informed consent.

**Materials.** The stimulus set used in the present experiment are known as Fribbles (see [www.tarrlab.org](http://www.tarrlab.org); stimulus images courtesy of Michael J. Tarr, Center for the Neural Basis of Cognition, Carnegie Mellon University). Each Fribble is an unusual, three-dimensional object featuring a central body and four appendages. They are arranged into three families (A, B and C), each of which possesses four different species. This results in 12 distinct Fribble types, of which there are 81 exemplars. The different Fribble families share no resemblance, whereas the species within a family all possess the same central body, but have different appendages. These stimuli therefore allow systematic control over similarity. They also have other advantages, such as their structure and complexity (which mimics real-world items) and their unfamiliarity (which may make maintenance strategies such as rehearsal difficult).

For the present experiment, 546 Fribbles were used (520 on the experimental trials and 26 on the practice trials). Each experimental condition contained 10 “Same” trials and 10 “Different” trials, with participants comparing target and test Fribbles drawn from the same family and the same species. On “Same” trials the target and test were identical, whereas on “Different” trials they differed on two of their four appendages. There were six possible combinations involved in changing the appendages (e.g. items differ on appendages 1 and 2, or 2 and 4, etc.), and within each condition every change to the appendage combinations

occurred at least once and no more than twice. The arrangements for the task have previously been shown to be challenging, whilst avoiding floor and ceiling effects (Mercer, 2014).

The distractor stimulus was either a Fribble drawn from the same family as the target and test, but represented a different species, or was from a completely different family and species. The former Fribbles were used as similar distractors, whereas the latter were classed as dissimilar distractors. Similar distractors therefore shared the same body as the target, but had different appendages, whereas dissimilar distractors had no resemblance to the target. Example trials can be seen in Figure 1. Specific Fribbles were presented on no more than one trial throughout the course of the experiment, so repetition of stimuli was eliminated.

The experiment was designed and run using SuperLab 4.5 and a PC. A HannsG HP191 19-in. LCD monitor was used to display the stimuli, which were presented in the middle of the screen. Participants were seated approximately 60 cm from the screen and used a keyboard to make their responses.

*“Figure 1 about here”*

**Design and Procedure.** The present experiment employed a 2 (consolidation interval: 200 ms vs. 1.5 s) x 2 (retention interval: 2.4 s vs. 6 s) x 3 (distractor: similar vs. dissimilar vs. no distractor) repeated measures design. This created 12 conditions in total. Each trial began with a fixation cross, for 100 ms, followed by the target stimulus. The target remained on screen for 700 ms and was succeeded by the test stimulus after 2.4 s or 6 s. On “No distractor” trials the retention interval was unfilled, whereas on the “similar” and “dissimilar” distractor trials another Fribble was presented after the consolidation interval. Distractors were also displayed for 700 ms. The test stimulus remained on the screen until participants responded by pressing either “S” (to denote a match with the target) or “D” (to denote that

the two stimuli differed). Participants were not given a time limit in which to respond, but they were encouraged to answer as quickly as possible without sacrificing accuracy. After making their response, the next trial began after an inter-trial interval (ITI) of either 3.4 s when the retention interval was short or 7 s when the retention interval was long. As such, the ITI was 1 s longer than the retention interval, which was designed to reduce carryover effects and proactive interference from the previous trial (see Mercer, 2014).

At the beginning of the task, participants completed 12 practice trials, including one example from each condition. The main experiment was completed in six blocks of 20 trials (10 “Same” and 10 “Different”), with instructions being briefly presented at the beginning of each block. Instructions clarified the length of the retention interval and stated whether a distractor would be present (if so, participants were also told when it would occur). The retention interval and consolidation interval variables were arranged into independent blocks, as were conditions removing the distractor. Similar and dissimilar distractors were intermixed within blocks, but the order of the trials and the blocks was randomized. Participants could take a break after every three blocks and the experiment lasted approximately 60 min.

## Results and Discussion

**Preliminary analyses.** Preliminary screening examined the number of invalid responses (i.e. participants pressing a button other than “S” or “D” to respond) and trials where responses were very long ( $\geq 8$  s) or very short ( $\leq 150$ ms). In the latter two cases, there was concern that participants were not responding based on memory. Fortunately, these cases were rare: invalid ( $M = .65$ ,  $SD = 1.2$ ), long ( $M = 2.9$ ,  $SD = 4.16$ ) and short ( $M = .03$ ,  $SD = .18$ ). Affected trials were removed from the analysis, but these constituted less than 1.5% of collected data, on average.

**Accuracy analysis.** Data were converted to  $A'$  scores using the procedure outlined by Snodgrass, Levy-Berger, and Haydon (1985). Hits were defined as trials on which the participant correctly stated that the test object matched the target, whereas false alarms occurred when participants incorrectly responded “Same” when the two stimuli differed.  $A'$  was considered appropriate due to the relatively small number of trials in each condition, which may prevent a reliable  $d'$  from being calculated (Miller, 1996), whilst still controlling response bias. Chance performance would be denoted by  $A'$  of 0.5 and perfect performance by 1.

The  $A'$  scores were then subjected to a 2 (consolidation interval: 200 ms vs. 1.5 s) x 2 (retention interval: 2.4 s vs. 6 s) x 3 (distractor: similar vs. dissimilar vs. no distractor) repeated measures ANOVA. Violations to the sphericity assumption were corrected using the Greenhouse-Geisser adjustment. There was a modest decrease in accuracy as the retention interval was lengthened (2.4-s:  $M = .78$ ; 6-s:  $M = .75$ ), but this was non-significant,  $F(1, 30) = 3.07$ ,  $MSE = .03$ ,  $p = .09$ ,  $\eta_p^2 = .09$ . To assess whether there was a genuinely null retention interval effect, a Bayesian analysis was performed based on Dienes (2014) and assuming a uniform distribution. Mean  $A'$  at the 2.4-s interval was considered the upper limit of performance (.78) and .5 was set as the lower limit (complete loss of the target memory would be expected to yield chance performance). The actual decline over the interval was .03 and the resulting Bayes factor ( $B$ ) was 1.98. Based on Dienes' (2014) parameters,  $B$  values exceeding 3 denote substantial support for the alternative hypothesis and those less than .33 denote substantial support for the null hypothesis. Here, data are considered insensitive (offering support for neither hypothesis). There was no reliable interaction between retention interval and distractor (see Table 1),  $F(2, 60) = 2.49$ ,  $MSE = .02$ ,  $p = .09$ ,  $\eta_p^2 = .08$ , but a subsequent Bayesian analysis suggested there was time-based forgetting in the no distractor condition ( $B = 3.35$ ). This effect was not found in the similar distractor condition ( $B = .06$ ),

but there was a modest time-based decline in the dissimilar distractor condition (although the resulting  $B$  slightly exceeded the threshold denoting support for the null hypothesis,  $B = .35$ ).

Whilst the influence of the retention interval was unclear, there was a reliable effect of the distractor, indicating the presence of RI,  $F(2, 60) = 4.31$ ,  $MSE = .02$ ,  $p = .018$ ,  $\eta_p^2 = .13$ . Subsequent post-hoc tests adjusted with the Šidák correction showed that this was due to worse performance following a dissimilar distractor ( $M = .74$ ), in comparison with a similar distractor ( $M = .78$ ,  $p = .038$ ). Neither the similar or dissimilar distractor reliably differed from the no distractor control ( $M = .79$ ,  $p = .156$  and  $.986$ , respectively). There was no main effect ( $F = 0$ ) of consolidation interval, as mean accuracy for both gaps was identical ( $M = .77$ ). However, there was an interaction between the distractor type and consolidation interval,  $F(2, 60) = 5.65$ ,  $MSE = .01$ ,  $p = .006$ ,  $\eta_p^2 = .16$  (see Figure 2). To further explore the interaction, simple effects analysis was used to compare the three distractor conditions at each consolidation interval. When the gap separating the target from the distractor was just 200 ms, there was no difference in recognition performance,  $F(2, 60) = .07$ ,  $MSE = .01$ ,  $p = .94$ ,  $\eta_p^2 = .002$ . Conversely, different distractor effects were uncovered at the 1.5 s consolidation interval,  $F(2, 60) = 8.64$ ,  $MSE = .01$ ,  $p = .001$ ,  $\eta_p^2 = .22$ . Subsequent paired  $t$ -tests (corrected using the Holm-Šidák adjustment) showed that accuracy dropped when a dissimilar distractor was present in comparison with both the similar distractor,  $t(30) = -3.82$ ,  $p = .003$ ,  $r = .57$ , and the no distractor control,  $t(30) = -2.72$ ,  $p = .022$ ,  $r = .45$ . The latter two conditions did not differ,  $t(30) = .83$ ,  $p = .414$ ,  $r = .15$ , and no other interactions were significant.

*“Figure 2 about here”*

In summary, RI was only detected when a dissimilar distractor was presented after a 1.5 s delay. This effect is surprising and appears problematic for both similarity-based RI and consolidation explanations of interference.

## EXPERIMENT 2

Given the unexpected nature of the Experiment 1 results, a second experiment was conducted that attempted to replicate the interaction reported above. One limitation with Experiment 1 was the relatively low number of trials (20) in each condition, and the present study rectified this issue. To do so, the retention interval variable was removed, as this was not relevant to the interaction of interest, and the number of trials was increased to 30 in each condition. This created a two-way design, with consolidation interval and distractor type being manipulated.

### Method

**Participants.** To determine the sample size needed to find the interaction between consolidation interval and distractor type, an a priori power analysis was conducted and based on the interaction effect size from Experiment 1. This analysis suggested that a minimum of 28 participants would be needed to find the interaction, based on 80% power and an  $\alpha$  of 0.05. In total, 33 participants were recruited during a four-week period. Data from one participant was lost due to technical problems, but the remaining 32 individuals were psychology students from the University of Wolverhampton. All participants reported normal or corrected-to-normal vision and none had taken part in Experiment 1. The study was approved by an institute ethics committee and all volunteers provided written informed consent prior to undertaking the procedure.

**Materials.** Except where noted, arrangements were identical to Experiment 1. In total, 386 Fribbles were used (360 on the experimental trials and 26 on the practice trials). Each experimental condition included 15 “Same” and 15 “Different” trials, and on the latter trials the different changes to the Fribble appendages occurred either two or three times within each condition. The experiment was designed and run using SuperLab 5 and a PC, and stimuli were presented on a Lenovo ThinkVision 24” LCD monitor.

**Design and Procedure.** A 2 (consolidation interval: 200 ms vs. 1.5 s) x 3 (distractor: similar vs. dissimilar vs. no distractor) repeated measures design was used. The retention interval separating the target and test stimuli was always 6 s and participants were given a maximum of 3 s to respond. The main experiment was completed in three blocks of 60 trials – two blocks included a distractor (but with consolidation interval arranged into independent blocks, to minimize confusion with the stimulus sequence) and the final block removed the distractor. The order of the trials and blocks was randomized and the experiment lasted approximately 60 min. Other procedural arrangements replicated Experiment 1.

## Results and Discussion

**Preliminary analyses.** As in Experiment 1, data were screened to assess the number of invalid responses, but also omissions (i.e. occasions where a response was not provided within the 3-s limit). Two participants were removed – one had 23 invalid responses and five missing responses (15.56% of all trials) and another had 55 invalid responses (30.56% of all trials). For the remaining participants, responses classed as missing ( $M = 2.8$ ,  $SD = 2.82$ ) or invalid ( $M = .13$ ,  $SD = .43$ ) were rare. Affected trials were removed from the analysis, but these constituted less than 1.7% of collected data, on average.

“Figure 3 about here”

**Accuracy analysis.** Data were again converted to  $A'$  scores and subjected to a 2 (consolidation interval: 200 ms vs. 1.5 s) x 3 (distractor: similar vs. dissimilar vs. no distractor) repeated measures ANOVA. There was no effect of the consolidation interval,  $F(1, 29) = .68$ ,  $MSE = .01$ ,  $p = .42$ ,  $\eta_p^2 = .02$ , with very similar performance at the 200 ms ( $M = .81$ ) and 1.5 s ( $M = .80$ ) delays. However, the effect of distractor was significant,  $F(2, 58) = 7.43$ ,  $MSE = .004$ ,  $p = .001$ ,  $\eta_p^2 = .20$ , with Šidák-corrected post-hoc tests showing worse performance in the dissimilar distractor condition ( $M = .78$ ) in comparison to the similar distractor ( $M = .82$ ,  $p = .002$ ) and the no distractor control ( $M = .82$ ,  $p = .047$ ). The latter two conditions did not differ ( $p = .902$ ). Finally, the interaction between consolidation interval and distractor was also significant and depicted in Figure 3,  $F(2, 58) = 4.17$ ,  $MSE = .01$ ,  $p = .02$ ,  $\eta_p^2 = .13$ . Simple effects analysis was again used to compare the three distractor conditions at each consolidation interval, showing no effect of distractor type at 200 ms,  $F(2, 58) = .82$ ,  $MSE = .01$ ,  $p = .45$ ,  $\eta_p^2 = .03$ , but a significant difference in performance at 1.5 s,  $F(2, 58) = 10.64$ ,  $MSE = .01$ ,  $p < .001$ ,  $\eta_p^2 = .27$ . Paired  $t$ -tests (corrected using the Holm-Šidák adjustment) in the 1.5 s condition showed that accuracy dropped when a dissimilar distractor was present in comparison with both the similar distractor,  $t(29) = -5.31$ ,  $p < .001$ ,  $r = 0.70$ , and the no distractor control,  $t(29) = -2.43$ ,  $p = .043$ ,  $r = .39$ . There was no significant difference in performance between the similar distractor and no distractor conditions,  $t(29) = 1.85$ ,  $p = .075$ ,  $r = .33$ , but there was a trend towards better performance *with* the distractor.

**Hits and false alarms.** To better understand the interference effect reported above, separate 2x3 ANOVAs were conducted on the hit rate (correctly responding “Same” on Same trials) and false alarm rate (incorrectly responding “Same” on Different trials). These data can



be seen in Table 2. For hits, neither consolidation interval,  $F(1, 29) = 2.01$ ,  $MSE = .013$ ,  $p = .17$ ,  $\eta_p^2 = .07$ , or the interaction,  $F(2, 58) = 2.21$ ,  $MSE = .01$ ,  $p = .13$ ,  $\eta_p^2 = .07$ , were significant. However, there was an effect of distractor type,  $F(2, 58) = 4.20$ ,  $MSE = .01$ ,  $p = .02$ ,  $\eta_p^2 = .13$ . Šidák-corrected post-hoc tests showed that the hit rate following a dissimilar distractor ( $M = .80$ ) was lower than that following a similar distractor ( $M = .85$ ,  $p = .01$ ). No other comparisons were significant. For false alarms, distractor type was non-significant,  $F(2, 58) = .90$ ,  $MSE = .02$ ,  $p = .41$ ,  $\eta_p^2 = .03$ , but consolidation interval was reliable,  $F(1, 29) = 5.54$ ,  $MSE = .02$ ,  $p = .03$ ,  $\eta_p^2 = .16$ . The false alarm rate increased following a 1.5 s delay ( $M = .42$ ) in comparison with 200 ms ( $M = .37$ ), but this effect was qualified by a significant interaction,  $F(2, 58) = 9.83$ ,  $MSE = .02$ ,  $p < .001$ ,  $\eta_p^2 = .25$ . Simple effects analysis found no differences in the false alarm rate at the 200 ms consolidation interval,  $F(2, 58) = 1.87$ ,  $MSE = .02$ ,  $p = .16$ ,  $\eta_p^2 = .06$ , but there was a much stronger effect at 1.5 s,  $F(2, 58) = 12.67$ ,  $MSE = .01$ ,  $p < .001$ ,  $\eta_p^2 = .30$ . Holm-Šidák corrected paired  $t$ -tests found a higher false alarm rate in the dissimilar distraction condition ( $M = .50$ ) in comparison to both the similar distractor ( $M = .37$ ,  $t[29] = 4.53$ ,  $p < .001$ ,  $d = .85$ ) and the no distractor control ( $M = .40$ ,  $t[29] = 4.35$ ,  $p < .001$ ,  $d = .78$ ). The latter two conditions did not differ,  $t(29) = -.91$ ,  $p = .372$ ,  $d = -.19$ .

*“Table 2 about here”*

In summary, the interaction observed in Experiment 1 was replicated, with RI only exerting a significant effect when a dissimilar distractor was presented 1.5 s after the offset of the target.

## GENERAL DISCUSSION

The present study aimed to examine the role of different variables thought to affect RI in visual memory. The main result, emerging from two experiments, was an interaction between the length of the consolidation interval and the distractor type. When the gap separating the target and the distractor was short, there was no evidence of RI. When this gap was lengthened to 1.5 s, the dissimilar distractor significantly disrupted recognition performance in relation to both the no distractor control and the similar distractor. This was found in both experiments, with the second study reporting an increase in false alarms – participants found it increasingly difficult to spot differences between the target and test when the dissimilar distractor occurred 1.5 s after the target. The RI reported here therefore appeared to be novelty-based, rather than similarity-based, and occurred even though the distractor did not have to be attended to (see Makovski et al., 2006).

The absence of similarity-based interference appears to contradict some previous studies of VSTM (e.g. Blalock, 2013; Borst et al., 2012), although additional research has found that similarity can sometimes be beneficial. Lin and Luck (2009), for example, used a color change detection task and found that performance improved when the objects in an array were similar (e.g. all red), in comparison to when they were dissimilar. Other evidence is consistent with this finding (e.g. Makovski et al., 2010; Sanocki & Sulman, 2012), but these previous studies explored *concurrent* interference, in which interactions amongst stimuli in an array are examined, rather than RI.

Whilst the novelty-based RI reported here was unexpected, prior studies have shown that there need not be an overlap between target stimuli and distractors to uncover interference. For example, Ueno et al. (2011) found that a visual suffix with minimal overlap with to-be-remembered target stimuli had a small, but significant, interfering effect. Furthermore, novelty-based RI is potentially reconcilable with some theoretical accounts. For example, Johnson, Spencer, and Schöner (2009) proposed a model of visual working memory

based on dynamic field theory. This model consists of an excitatory perceptual field, an excitatory working memory field and a connecting inhibitory layer. Visual stimuli that are sufficiently strong activate an excitatory response (the “peak”) in the perceptual field. After the stimulus offset, the peak in the perceptual field decays, but it can persist in working memory. This allows a visual representation to be maintained even when the original stimulus is no longer present. Importantly, however, there is an inhibitory response centred around the representations that are being maintained. New visual input very similar to the current contents of memory will be inhibited, but visual stimuli that are sufficiently different from currently maintained representations will produce an excitatory response in the perceptual field and be incorporated into working memory. This model also allows new stimuli to delete existing memories, providing a mechanism that can explain RI. In relation to the present findings, it could be assumed that similar distractors only produce an inhibitory response and consequently do not disrupt existing memories. Dissimilar distractors produce an excitatory response that leads to an updating of the memory buffer and a decrease in task performance. Whilst plausible, the model does assume that new inputs either delete the current contents of memory or exist alongside it. The precise effect depends on the novelty of the stimulus, as objects that are very dissimilar to the original input do not produce a disruptive effect because they occupy a different location within the excitatory field. Only objects sharing some similarity with the original input causes deletion of existing memories. The model therefore seems to predict similarity-based RI in relation to the present experiment, as the similar distractor was sufficiently different from the target to avoid an inhibitory response, but simultaneously contained enough overlap to require memory updating.

Nonetheless, Johnson et al.’s (2009) ideas about memory updating may be a useful way of conceptualizing RI and another model of nonverbal memory incorporates similar ideas to

Johnson et al.'s (2009) theory. The model, known as TMM (Timbre Memory Model; Mercer & McKeown, 2010a, 2010b; McKeown, Mills, & Mercer, 2011; McKeown & Wellsted, 2009), has previously been applied to auditory short-term memory but it explains RI through two processes (updating and feature overwriting). The theory states that representations of the recent past are held over the short-term and new, incoming information is compared against the current contents of memory. When novel events are detected, the model is updated, making it harder to access prior representations. Events similar to those experienced before do not require updating and instead produce adaptation (unless the components of a newly encountered object are very similar to the contents of the memory buffer and cause feature overwriting). The dissimilar RI reported here is compatible with the ideas concerning novelty-based memory updating. Whilst TMM does not anticipate RI effects to become stronger over time, it could be modified to assume that novel distractors become more salient at longer consolidation intervals. This is theoretically plausible, as over time it becomes less important to retain previous memories and the detection of new changes in the environment might be prioritized. This would account for the RI effect uncovered here.

Whilst there are ways of explaining the RI documented in the present experiment, it is necessary to consider why prior studies have demonstrated similarity-based RI in VSTM. The crucial factor may be the degree of similarity between the target and distractor. In the present study, the similar distractor was still noticeably different from the target, due to the appendages (see Figure 1). In cases of "extreme" similarity (e.g. where visual objects overlap in important properties or where the target and distractor are the same type of stimulus), RI may be particularly pronounced. This is compatible with the overwriting process in TMM. Additionally, similarity-based RI may be influenced by variables not manipulated in the current design, such as encoding time and the size of the array. Strategy may also be important – for example, participants may have used the similar distractor as an "anchor" to

help remember the target. This could explain the modest facilitation seen in the similar distractor condition at the 1.5 s consolidation interval in both experiments.

The present experiment raises other theoretical implications relevant to our understanding of forgetting. For instance, these findings are difficult to reconcile with consolidation theory, which expects a distractor to have a stronger effect when occurring shortly after the target. It is possible that consolidation of the target had taken place before the distractor was presented, even when there was just 200 ms separating the target from the distractor. Prior research has indicated that consolidation in VSTM may be very rapid (e.g. Vogel et al., 2006) and most studies present stimuli for much shorter intervals than the 700 ms used here. Even so, Nieuwenstein and Wyble (2014) have suggested consolidation may continue for delays up to 1 s after the offset of the to-be-remembered stimuli, and their stimuli were closer to those used here (i.e. single, complex objects). Furthermore, assuming consolidation had taken place, the present results show that a fully consolidated visual memory cannot resist RI in all circumstances.

Experiment 1 also has implications for the notion of memory decay, as the retention interval separating the target and test objects was manipulated. Whilst the effect of the delay was non-significant, a Bayesian analysis found that the results were insensitive and therefore do not offer support for either the alternative or null hypotheses. There was a modest decline in task accuracy from 2.4-s to 6-s intervals, but the strongest time-dependent forgetting occurred in the absence of a distractor (performance in the no distractor control at the 2.4 s interval was high, but such performance could not be sustained after 6 s and the effect in the no distractor condition offered substantial support for the alternative hypothesis). When a distractor was already present, there was less convincing evidence for additional time-based forgetting, particularly in the similar distractor condition. These data therefore do not offer strong support for a “decay plus interference” account, where distractors might accelerate

time-dependent forgetting, but there may be evidence of decay across a silent delay. Such a finding is in line with prior studies, which have reported a loss in visual memory accuracy over time (e.g. Hesse & Franz, 2010; McKeown et al., 2014; Morey & Bieler, 2013; Poom, 2012; Ricker & Cowan, 2010, 2014; Salmela et al., 2010). Nonetheless, the overall impact of the retention interval remains uncertain and future studies may benefit from employing a range of delays – stronger effects of time with Fribble stimuli have been found after 10 s gaps (Mercer, 2014).

In conclusion, RI is often cited as a key source of forgetting in memory yet in VSTM this process remains poorly understood. In two experiments, the present study found that the temporal position of the distractor and its relationship with the to-be-remembered target affects performance, with RI only being uncovered when a distractor that was dissimilar to the target was presented 1.5 s into the retention interval.

Word count: 5,914.

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## TABLES

Table 1

*Mean (and Standard Deviation) A' According to Retention Interval and Distractor Type in Experiment 1*

	2.4 s	6 s
Dissimilar distractor	.75 (.14)	.73 (.13)
Similar distractor	.78 (.11)	.79 (.10)
No distractor control	.82 (.10)	.75 (.17)

Table 2

*Mean (and Standard Deviation) Hits and False Alarms According to Consolidation Interval and Distractor Type in Experiment 2*

Distractor	Consolidation Interval			
	200 ms		1.5 s	
	Hits	False alarms	Hits	False alarms
Dissimilar distractor	.78 (.14)	.33 (.17)	.82 (.12)	.50 (.16)
Similar distractor	.82 (.10)	.40 (.21)	.87 (.11)	.37 (.19)
No distractor control	.84 (.11)	.38 (.17)	.82 (.13)	.40 (.17)

**FIGURE CAPTIONS**

*Figure 1.* Example trials used in the experiment. The top row shows a trial with a similar distractor and identical target and test objects. The bottom row shows a trial with a dissimilar distractor and different target and test objects. The consolidation interval separating the target and distractor either was 200 ms or 1.5 s, and the retention interval separating the target and test either was 2.4 s or 6 s. In the control condition, the distractor was removed.

*Figure 2.* Interaction between consolidation interval and distractor type in Experiment 1. Graph shows mean  $A'$  values and error bars denote 95% CIs calculated according to Jarmasz and Hollands' (2009) equation for a repeated measures interaction.

*Figure 3.* Interaction between consolidation interval and distractor type in Experiment 2. Graph shows mean  $A'$  values and error bars denote 95% CIs calculated according to Jarmasz and Hollands' (2009) equation for a repeated measures interaction.

Figure 1

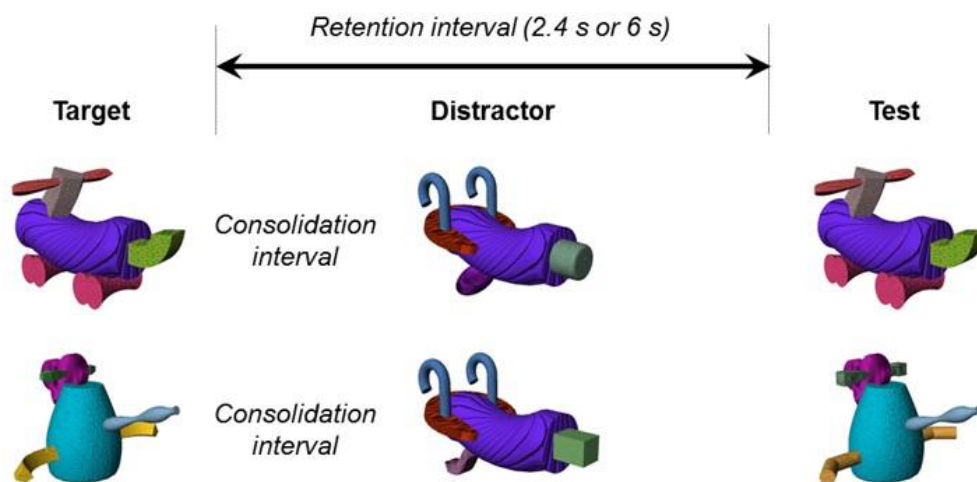




Figure 2

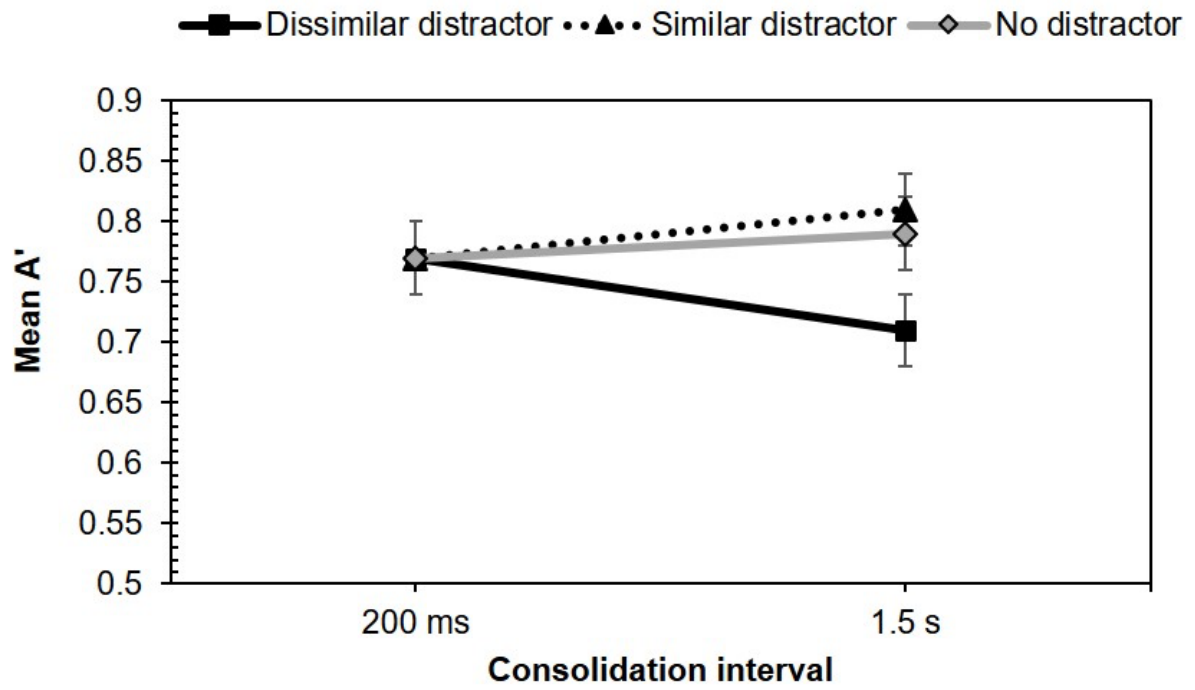


Figure 3

