

Attending to unrelated targets boosts short-term memory for color arrays

Tal Makovski*, Khen M. Swallow*, Yuhong V. Jiang

Department of Psychology and Center for Cognitive Sciences, University of Minnesota, United States

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ABSTRACT

Detecting a target typically impairs performance in a second, unrelated task. It has been recently reported however, that detecting a target in a stream of distractors can enhance long-term memory of faces and scenes that were presented concurrently with the target (the *attentional boost effect*). In this study we ask whether target detection also enhances performance in a visual short-term memory task, where capacity limits are severe. Participants performed two tasks at once: a one shot, color change detection task and a letter-detection task. In Experiment 1, a central letter appeared at the same time as 3 or 5 color patches (memory display). Participants encoded the colors and pressed the spacebar if the letter was a T (target). After a short retention interval, a probe display of color patches appeared. Performance on the change detection task was enhanced when a target, rather than a distractor, appeared with the memory display. This effect was not modulated by memory load or the frequency of trials in which a target appeared. However, there was no enhancement when the target appeared at the same time as the probe display (Experiment 2a) or during the memory retention interval (Experiment 2b). Together these results suggest that detecting a target facilitates the encoding of unrelated information into visual short-term memory.

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1. Introduction

Many of our everyday activities are goal oriented: we search for a friend at the airport, drive toward a specific place on the map, and look for a piece of fruit in the refrigerator. In the course of such activities, distractors are rejected, targets are detected, and an appropriate action is taken toward the targets. The majority of vision research has used target detection as a means to study visual perception and attention, and often detecting a target is the end of the observer's task. However, there is increasing evidence that target detection itself may have an important yet poorly understood effect on visual perception, attention, and, ultimately, memory (Bowman & Wyble, 2007; Olivers & Meeter, 2008; Seitz & Watanabe, 2005; Swallow & Jiang, 2010, *in press*). The main purpose of the present study is to investigate the impact of target detection in one task on an unrelated visual short-term memory task.

Detecting a target influences the ability to detect other targets that appear at the same time or shortly afterwards. In Duncan's double-detection experiments (1980), the ability to detect a digit target was impaired if it appeared when observers detected a sec-

ond digit target. In the attentional blink, detecting a target in a stream of distractors impairs the ability to detect a second target that appears 200–500 ms afterwards (Chun & Potter, 1995; Dux & Marois, 2009; Raymond, Shapiro, & Arnell, 1992). These results often have been interpreted in terms of a tradeoff in processing multiple sources of input. If visual attention has limited resources then attending to a target should reduce resources for processing a second target (Kinchla, 1992).

However, target detection appears to do more than just interfere with processing other information. In visual search, successful detection of a target promotes learning of the search display: search is faster for displays that are repeated (Chun & Jiang, 1998), but learning is absent when search is interrupted before the target is detected (Shen & Jiang, 2006). These data suggest that detecting targets may facilitate some types of processing. However, only a few studies have directly investigated this possibility. In one notable example, Seitz and Watanabe (2003, 2005) asked participants to report the identity of white letters presented in a stream of black letters. Each letter appeared over a display of dots moving at a sub-threshold level of coherence and the white target letters were always paired with a particular direction of motion (e.g., up). After several sessions of repeated exposure to these stimuli, sensitivity to the motion direction paired with the target letters was enhanced relative to other directions of motion.

Target detection also appears to facilitate explicit memory and does so without extensive repetition. In a series of experiments, Swallow and Jiang (2010) asked participants to perform two tasks at once. For the target-detection task participants monitored a stream

* Corresponding authors at: Department of Psychology, University of Minnesota, N218 Elliott Hall, Minneapolis, MN 55455, United States. Tel.: +1 612 624 9483; fax: +1 612 626 2079.

E-mail addresses: tal.makovski@gmail.com (T. Makovski), swall011@umn.edu (K.M. Swallow).

of serially presented colored letters and pressed a key whenever a target, a red-X, appeared. For the image-encoding task, participants encoded scenes that appeared at the same time as the letters, at a rate of one every 500 ms. In a later scene recognition test, participants better recognized scenes that were presented at the same time as a search target than scenes that were presented at the same time as a distractor. This effect generalized to different target-detection tasks (e.g., white squares among black squares, high beeps among low beeps) and different types of images (faces). Similar findings have also been reported for source memory for familiar scenes (Lin, Pye, Murray, & Boynton, 2010), and for the ability to discriminate the gender of a briefly presented face (Swallow, Makovski, & Jiang, submitted for publication). Swallow and Jiang (2010) termed this enhancement the *attentional boost effect*, because image processing appears to be better for stimuli presented at the same time as attended search targets.

Together these data present compelling evidence that detecting a target influences the way other, unrelated information is processed. However, several important issues need to be addressed. First, it is not known whether detecting a target can facilitate processing in a system that is highly limited in capacity. Under some conditions visual long-term memory appears to be limitless (Brady, Konkle, Alvarez, & Oliva, 2008; Standing, 1973) and scene processing can occur rapidly and in the absence of attention (Li, VanRullen, Koch, & Perona, 2002; Potter, Staub, & O'Connor, 2002). Although encoding images into long-term memory requires attention (Wolfe, Horowitz, & Michod, 2007), image processing and maintenance in long-term memory do not appear to exert strong limitations on attentional demands. In contrast, visual short-term memory (VSTM) is extremely limited in capacity with estimates ranging from one to four items (Cowan, 2001; Jonides et al., 2008; Luck & Vogel, 1997; Olsson & Poom, 2005). Furthermore, attention is critical for encoding and maintaining items in VSTM (Austen & Enns, 2003; Makovski & Jiang, 2007; Makovski, Shim, & Jiang, 2006; Makovski, Sussman, & Jiang, 2008; Postle, 2006; Rensink, 2000; Rensink, O'Regan, & Clark, 1997; Wright, 2005; Yaxley & Zwann, 2005). Thus, it remains to be seen whether any benefit of detecting targets occurs when the memory-encoding task taps into a system with severe capacity limitations.

Testing the effect of target detection on an unrelated VSTM task also has important theoretical implications for the attentional boost effect. Specifically, the separation of short-term memory into encoding, retention, and retrieval stages in individual trials provides a crude handle on the timing of the attentional boost effect. One account of the attentional boost effect proposes that it is due to a transient increase in attention to task-relevant information that is present at the time of a target (Swallow & Jiang, 2010, in press). If this account is correct, then the effects of target detection on memory should be limited to those instances when targets appear at the same time that the memory items are encoded. Alternatively, target detection may increase arousal, task engagement, or motivation, in which case target detection should facilitate memory when targets appear at any stage of the short-term memory task. By varying the time that search targets and distractors appear relative to when encoding, retention, and retrieval occurs, this study evaluates whether target detection facilitates encoding processes specifically, or cognitive processing more generally.

2. Experiment 1: target-detection during encoding

The purpose of Experiment 1 was to assess whether increasing attention to a target letter influences VSTM for an unrelated color array. We used a discrete trial design that combined a target-detection task with a one-shot change detection task (Rensink, 2002). On each trial participants were shown a circular array of col-

ors (*memory display*) and were asked to remember the colors. After a short retention interval, a second color array appeared (*probe display*) and participants had to indicate whether the display was the same or different than the memory display. At the same time, participants performed a target detection task on a letter presented at fixation. If the letter was a "T" they pressed the spacebar, if it was not they made no response. The central letter was presented concurrently with the memory array, when the encoding of the colors into VSTM was initiated.

If target detection facilitates cognitive processes associated with encoding, such as perceptual processing and attention, then change detection should be better when the encoding display coincides with a target letter rather than a distractor letter. Alternatively, these enhancements may not be apparent in a severely capacity limited system such as VSTM. If this is the case then change detection performance may be comparable in target and distractor trials. In fact, detecting a target in the search task could draw attention away from the short-term memory task. In this case, change detection may be impaired on target trials relative to distractor trials.

The discrete trial design also allowed us to evaluate another factor that may be important to the attentional boost effect. Previous experiments have used target to distractor ratios (T-D ratio) that were quite low, with one target typically occurring for every ten distractors (Lin et al., 2010; Swallow & Jiang, 2010, in press). It is therefore possible that the distinctive nature of the target in these experiments played a critical role in the associated memory enhancement (Fabiani & Donchin, 1995; Hunt & Lamb, 2001). Two different experiments were run to evaluate the role of target frequency. In Experiment 1a the T-D ratio was 1:4 and in Experiment 1b it was 1:1. If target frequency and distinctiveness play an important role in the enhancement, then the effect should be greater when the T-D ratio is 1:4 than when it is 1:1.

2.1. Method

2.1.1. Participants

Participants in all experiments were students from the University of Minnesota. They were 18–35 years old, had normal color vision, and normal or corrected-to-normal visual acuity. Participants received \$10/h or course credit for their time.

Eighteen participants (mean age 20.3 years) completed Experiment 1a and another twelve participants (mean age 19.7 years) completed Experiment 1b.

2.1.2. Equipment

Participants were tested individually in a normally lit interior room. They sat unrestrained at approximately 55 cm from a 19" CRT monitor. The experiments were programmed with Psychtoolbox (Brainard, 1997; Pelli, 1997) implemented in MATLAB.

2.1.3. Stimuli

The stimulus for the target-detection task was a single white letter (font: Times, 24) presented at the center of the display against a black background. The target was the letter "T" while distractors were randomly selected from four different letters "H", "X", "L" and "V". The memory display contained three or five unique color squares (1.4° × 1.4°), placed equidistantly on an imaginary circle (radius = 2.8°) centered at fixation. The colors were randomly drawn without replacement from eight distinct colors (orange, red, yellow, green, azure, blue, purple and brown).

2.1.4. Procedure

Fig. 1 illustrates the trial sequence. Each trial started with a white fixation circle (0.35°) presented for 800 ms. Afterwards, an array of 3 or 5 colors appeared together with a letter for 200 ms, followed by a blank retention interval of 1500 ms. Participants were instructed to press the spacebar as soon as they could if the letter was "T". This response was always made during the retention interval. A test array of 3 or 5 colors appeared immediately after the retention interval and was either identical to the memory array, or changed in one of the colors. Participants pressed the 's' or 'd' keys to report whether the displays were the same. Accuracy was emphasized for this task and feedback on the memory task was given in the form of a green plus or a red minus sign for 600 ms.

Articulatory suppression minimized verbal recoding of the colors. At the beginning of each 20 trial block a three-letter word was presented to participants. They repeated this word aloud as quickly as they could throughout the block.

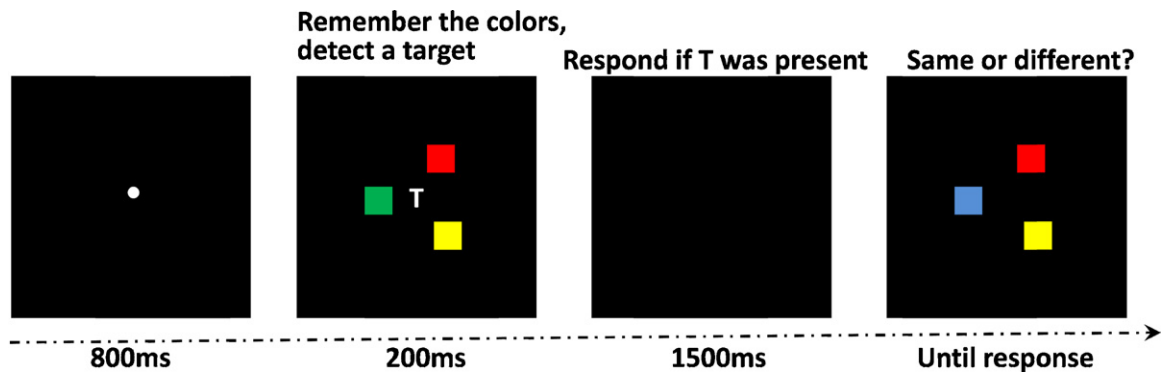


Fig. 1. Schematic illustration of the trial sequence and task requirements in Experiment 1 (target-detection during encoding). Items are not drawn to scale.

2.1.5. Design

After a practice block of 20 trials, participants completed 480 trials in Experiment 1a and 320 trials in Experiment 1b. In both experiments, trials were randomly and evenly divided into two memory loads (3 or 5 colors) and two change-detection types (color change or no change). Target frequency was varied across experiments. The letter in the detection task was a “T” on 20% of trials in Experiment 1a and 50% of trials in Experiment 1b.

2.2. Results

2.2.1. Target-detection task

Participants correctly detected 95.4% (SD=4.2) of the letter “T” targets in Experiment 1a (T–D ratio 1:4), which was comparable to the detection rate of 96.5% (SD=8.4) in Experiment 1b (T–D ratio 1:1), $t < 1$. However, detection RT was faster when the targets were more frequent (Experiment 1b, $M = 498$ ms, $SD = 77$; Experiment 1a, $M = 643$ ms, $SD = 120$), $t(28) = 3.7$, $p < .01$. The false alarm rate was also higher when the targets were more frequent (Experiment 1b, $M = 3.9\%$, $SD = 3.4$; Experiment 1a, $M = 0.4\%$, $SD = 0.6$), $t(28) = 4.22$, $p < .01$, suggesting an overall greater bias toward identifying targets when they were more frequent. In the analyses of the color short-term memory performance, we excluded trials in which an error was made in the target-detection task.

2.2.2. Color short-term memory task

Statistical results were generally the same for percent correct, Cowan’s K (Cowan, 2001) and A' (Grier, 1971). We report A' here and list percent correct and Cowan’s K in Appendix. Fig. 2 shows mean A' in the color short-term memory task separately for Experiment 1a (left) and Experiment 1b (right). Analysis of variance (ANOVA) with memory load (3 vs. 5) and central letter condition (target letter vs. distractor letter) as within-subject factors and T–D ratio (1:4 vs. 1:1) as a between-subjects factor was conducted. Perform-

mance was better when memory load was 3 rather than 5, $F(1, 28) = 116.1$, $p < .01$, $\eta_p^2 = .81$, revealing limited capacity in VSTM. Critically, memory was better for colors presented with target letters than for colors presented with distractor letters, $F(1, 28) = 17.6$, $p < .01$, $\eta_p^2 = .39$, replicating the attentional boost effect in a change detection task. This effect did not interact with memory load, $F < 1$. T–D ratio did not affect performance in the VSTM task, $F < 1$, and did not reliably interact with any of the other factors, all F s < 1 . The attentional boost effect was significant both when the target letters were relatively rare (20% of the trials, Experiment 1a), $F(1, 17) = 6.4$, $p < .05$, $\eta_p^2 = .27$, and when they were as frequent as distractor letters (Experiment 1b), $F(1, 11) = 11.7$, $p < .01$, $\eta_p^2 = .52$. A subsequent analysis that separated hits and correct rejections revealed no significant interaction between the central letter condition and response type (hits or correct rejections), $F(1, 28) = 2.8$, $p > .1$, suggesting the attentional boost effect was not restricted to correctly detecting a color change or correctly confirming a no-change.

2.3. Discussion

Previous research has shown that detecting a target character impairs the ability to detect a second target character that is presented at the same time or shortly later (Duncan, 1980; Duncan, Ward, & Shapiro, 1994; Moore, Egeth, Berglan, & Luck, 1996; Raymond et al., 1992). Although the exact reasons for this interference are not clear, explanations of the two-target cost typically appeal to limitations in attentional capacity (Duncan, 1980) or to limitations in processes that consolidate items into short-term memory (Chun & Potter, 1995). Other research has shown that VSTM is highly limited in capacity, restricted to one to four objects (Cowan, 2001; Jonides et al., 2008; Luck & Vogel, 1997). Given the preponderance of evidence for limitations in the ability to encode and maintain information in short term memory,

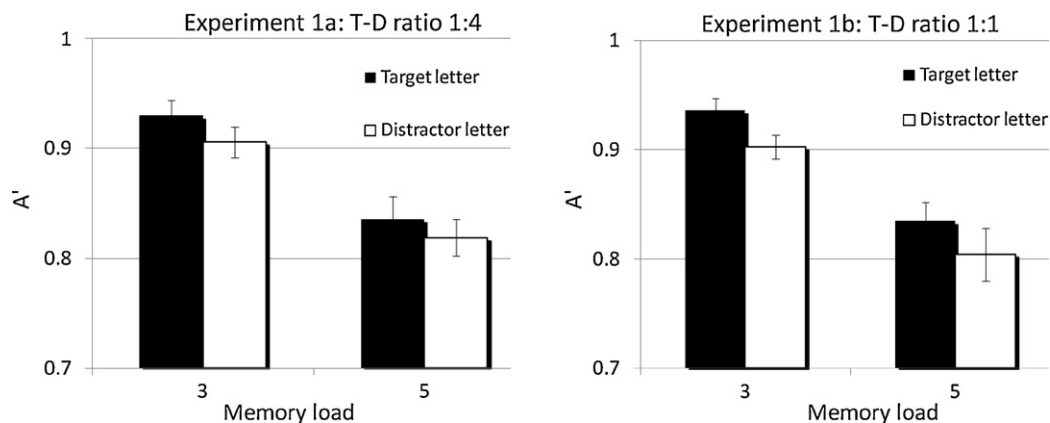


Fig. 2. Change detection performance (in A') in Experiment 1a (left) and 1b (right) as a function of set size and whether the letter appearing during encoding was a target or distractor. Error bars represent ± 1 SE.

it would have been reasonable to expect target detection in one task to interfere with VSTM encoding of another task. In contrast, a VSTM analog of the attentional boost effect was observed: color change detection was better when a target letter, rather than a distractor letter, was present at the same time that the color array was encoded into VSTM. These data are consistent with the hypothesis that the attentional boost effect results from a transient increase in perceptual processing of all task-relevant information in response to the detection of a target (Swallow & Jiang, 2010, *in press*; Swallow et al., submitted for publication).

These results replicate and extend previous demonstrations of the attentional boost effect in several ways. First, they illustrate that the benefit of target-detection is not restricted to long-term memory of scenes and faces (Swallow & Jiang, 2010, *in press*). It also occurs in short-term memory tasks, and for stimuli that are semantically impoverished. Second, the effect is found even though the search target is spatially separated from the VSTM color arrays, suggesting that spatial overlap between the two tasks is not necessary. Third, previous long-term memory tests of the attentional boost effect involved repeating the same scenes with letter targets 10 times (Swallow & Jiang, 2010, *in press*) whereas the current study reveals an enhancement after a single pairing of the memory arrays with the targets. Finally, the current findings also rule out the possibility that the attentional boost effect is a “zero-sum game”, where images presented with targets are better remembered at the expense of images presented with distractors. This criticism is applicable to long-term memory encoding tasks which have intermixed targets and distractors in a rapid serial visual presentation (RSVP) of scenes (Lin et al., 2010; Swallow & Jiang, 2010). Because scenes may compete for memory resources during both encoding and maintenance, encoding and maintaining a scene presented with a target may interfere with processing the other scenes in the series. However, the discrete trial design used here precluded this possibility by independently testing the effects of targets and distractors on the encoding of concurrently presented memory displays. As a result, these data suggest that the boost in memory for items presented with targets does not occur at the expense of memory for items presented with distractors.

These data also suggest that target to distractor ratios probably do not play a critical role in the attentional boost effect. In earlier studies targets occurred less frequently than distractors (Swallow & Jiang, 2010, *in press*), so items that appeared with targets may have been perceived as distinctive. However, the fact that the enhancement was similar when targets were as common as distractors (Experiment 1b) and when they were rare (Experiment 1a) suggests that distinctiveness is not a sufficient explanation of the attentional boost effect. Combined with other evidence that perceptual distinctiveness is not sufficient to produce the attentional boost effect (Swallow & Jiang, 2010), these data provide clear evidence against the notion that the attentional boost effect is an example of the isolation effect in memory.

Although the data presented here are consistent with earlier work examining the effects of target detection on long-term memory, it is notable that the magnitude of the attentional boost effect in Experiment 1 was quite small (~3% advantage for displays with a target relative to displays with a distractor). However, it replicated across two experiments, two set sizes, and was consistent across participants.¹ The small magnitude of the attentional boost effect in VSTM relative to its effect on long-term memory may have several causes. One was also the primary motivation for the study:

the extreme capacity limitations of short-term memory. It has previously been proposed that the attentional boost effect occurs independently of interference that results from the increased attentional demands of the detection task (Swallow & Jiang, 2010). If that is the case, then what is observed behaviorally is the combined effect of interference and enhanced encoding as a result of target detection. Because of the capacity limitations of VSTM, interference may play a larger role in the change detection task than it did in the long-term encoding task used previously. Several other factors also may be important, including the nature of the stimuli that were encoded (scenes/faces versus color patches) and the spatial distance between the target and visual images (overlapping vs. non-overlapping). The role of each of these factors in the magnitude of the attentional boost effect requires further research.

3. Experiment 2: the effect of target detection following encoding

The data from Experiment 1 are consistent with the suggestion that target detection in one task facilitates VSTM in a second task through a transient increase in attention. However, they are also consistent with the possibility that targets increase participants' arousal and/or engagement in the task. Emotionally arousing images are better remembered than neutral images (Anderson, Wais, & Gabrieli, 2006; Phelps, 2004). If the appearance of a target increases physiological arousal like emotional pictures, then performance on target trials should be better than performance on distractor trials. In addition, participants may find trials with targets more engaging and motivating. To address these concerns the targets and distractors were presented after the memory display in Experiment 2: on the probe display in Experiment 2a and during the retention interval in Experiment 2b. If the attentional boost effect observed in Experiment 1 was due to arousal, task engagement, or motivation differences between target and distractor trials, then it should occur when the target appears during the retention interval and probe displays. In contrast, if the enhancement is due to differences in the way memory displays are encoded when targets appear, then it should not be present when targets appear after the memory display.

3.1. Method

3.1.1. Participants

Ten participants (mean age 19.8 years) completed Experiment 2a. Ten other participants (mean age 22.7 years) completed Experiment 2b.

3.1.2. Equipment, stimuli, and design

The experiment was identical to Experiment 1b (T–D ratio was 1:1) except that the central letter was presented after the memory display was erased. In both cases participants monitored the letter and pressed the space bar if a “T” appeared, and then indicated whether the memory and probe displays matched. In Experiment 2a, a target or distractor letter was presented at the same time as the probe display for 200 ms. The probe display was presented on its own for an additional 1500 ms and participants pressed the spacebar if the central letter was a ‘T’. Then the question, “Same or different?” was presented above the probe display to cue participants to make their change-detection response (Fig. 3, top). In Experiment 2b, after the memory display was removed from the screen and 500 ms into the retention interval a target or distractor letter was presented for 200 ms. The retention interval lasted an additional 800 ms. The entire retention interval between the memory and probe displays was 1500 ms in both experiments (Fig. 3, bottom). All other aspects of the design were the same as in Experiment 1b.

3.2. Results and discussion

3.2.1. Target-detection task

In Experiment 2a, participants correctly detected 99.1% (SD = 0.8) of the “T” targets with a mean RT of 555 ms (SD = 115), and made few false alarms ($M = 5.0\%$, $SD = 5.5$). Participants in Experiment 2b also had a high hit rate ($M = 98.0\%$, $SD = 2.7$) with a mean RT of 450 ms (SD = 71), and a low false alarm rate ($M = 1.75\%$, $SD = 1.8$).

¹ In addition, in an fMRI study testing the neural correlate of change detection, Beck, Rees, Frith, and Lavie (2001) reported that the change detection rate for faces was higher on trials when a central letter was a target rather than a distractor. However, that study did not report inferential statistics for this difference.

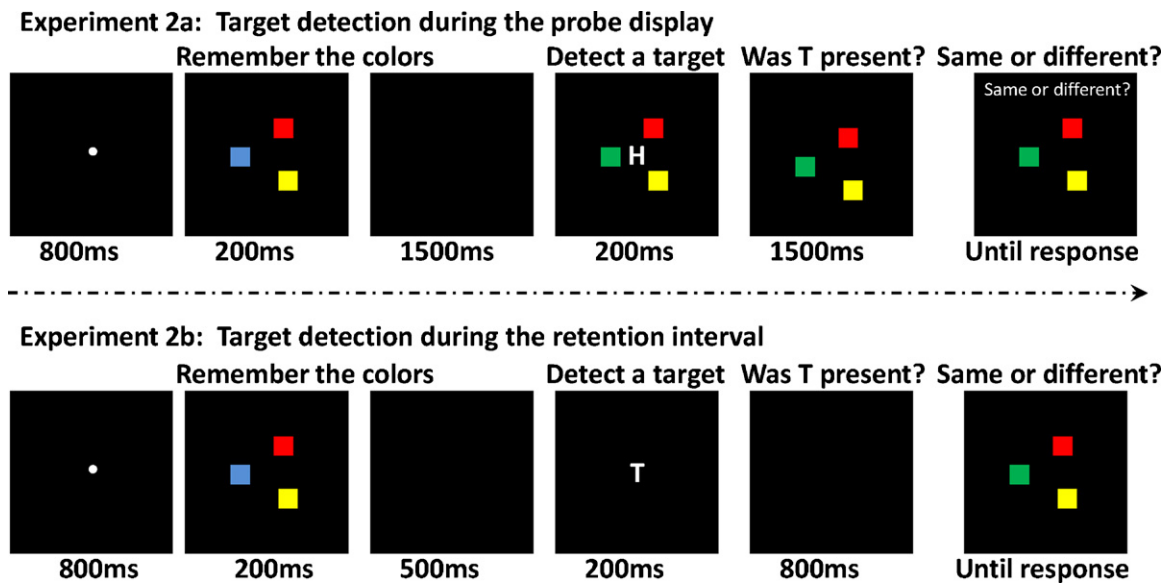


Fig. 3. Schematic illustration of the trial sequence and task requirements in Experiment 2a (top) and Experiment 2b (bottom).

False alarm and miss trials were excluded from the rest of the analyses.

3.2.2. Color short-term memory task

Mean A' in the color short-term memory task for Experiments 2a and 2b are presented in Fig. 4. Percent correct and K estimates are listed in Appendix. In Experiment 2a where the target letter appeared on the VSTM probe display, we found significantly better performance when memory load was 3 than 5, $F(1, 9) = 52.7$, $p < .01$, $\eta_p^2 = .85$. Unlike Experiment 1, however, there was no difference between target letter and distractor letter trials, $F < 1$. That is, detecting an unrelated target that was presented at the same time as the probe display did not benefit or impair memory performance relative to rejecting a distractor, and this did not change across memory loads, $F < 1$. A direct comparison between Experiment 2a and Experiment 1b, when the letter appeared during encoding, confirmed that while there was no overall difference between the experiments, $F < 1$, the interaction between experiment and target condition was significant, $F(1, 20) = 4.7$, $p < .05$, $\eta_p^2 = .19$.

Similarly, in Experiment 2b where the target letter appeared during the memory retention interval, a repeated-measures ANOVA with memory load (3, 5) and central letter condition (target, distractor), revealed a significant memory load effect, $F(1, 9) = 34.1$, $p < .01$, $\eta_p^2 = .79$. However, there was no difference in

color memory between target letter and distractor letter trials, $F = 1$. There was also no interaction between central letter condition and memory load, $F < 1$. A between-experiment analysis with Experiment 1b, 2b) and central letter condition (target, distractor), $F(1, 20) = 8.3$, $p < .01$, $\eta_p^2 = .29$, with no overall main effect of experiment, $F < 1$.

These findings confirm that the attentional boost effect observed in Experiment 1 was not due to a general increase in arousal, motivation, or task engagement as a result of detecting a target. They also rule out the possibility that the attentional boost effect originates from making a motor response (Buttaccio & Hahn, 2010). The temporal specificity found here is consistent with data from studies in the attentional boost effect in long-term memory. Images that appear 100–3000 ms after the target, the period of time when the effect of alerting on performance increases and peaks (Posner & Boies, 1971), are not better remembered than images presented with distractors (Swallow & Jiang, 2010, in press).

4. General discussion

The appearance of a target in a stream of distractors influences both the ability to detect other targets and the way other

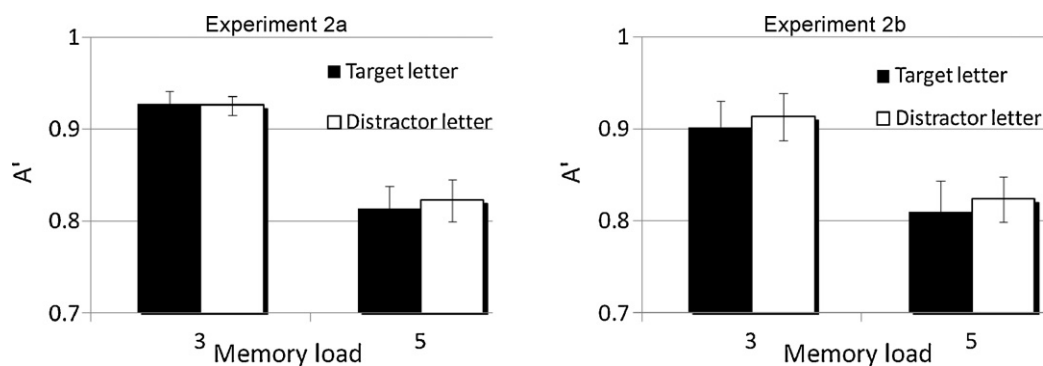


Fig. 4. Change detection performance (in A') as a function of set size and whether a target or a distractor letter appeared with the probe display (left) or during the retention interval (right). Error bars represent ± 1 SE.

concurrent information is processed. When a target is presented at the same time as another visual stimulus, processing of that stimulus is facilitated. When stimuli are paired with targets, sensitivity to perceptual features of those stimuli such as motion (Seitz & Watanabe, 2003) and gender (Swallow et al., submitted for publication) increases, and visual long-term memory and source memory is enhanced (Lin et al., 2010; Swallow & Jiang, 2010, *in press*). This study investigated whether target detection has similar effects on encoding into a limited-capacity system – VSTM. Given the limited capacity of short term memory (Cowan, 2001; Luck & Vogel, 1997; Olsson & Poom, 2005) and given the close connection between attention and VSTM (e.g., Jonides et al., 2008; Postle, 2006), one might expect that target detection would interfere with encoding into short-term memory as it does with detecting other targets presented around the same time (Duncan, 1980; Pohlmann & Sorkin, 1976). However, we found that VSTM for colors presented with a target letter was better than for colors presented with a distractor letter. This effect was found both when targets were infrequent (Experiment 1a) and frequent (Experiment 1b), and regardless of memory load. Importantly, this benefit was absent when the target appeared at the same time as the probe display (Experiment 2a) or during the retention interval (Experiment 2b) of the VSTM task. Taken together these findings support the proposal that detecting a target increases transient attention and facilitates early processing of unrelated visual input (Swallow & Jiang, 2010, *in press*; Swallow et al., submitted for publication).

4.1. *New insights into processing enhancements associated with target detection*

Not only do these data demonstrate that the attentional boost effect can occur in a capacity limited system, they also address several questions raised by the design of earlier experiments (Lin et al., 2010; Swallow & Jiang, 2010, *in press*). First, they demonstrate that the boost can occur when targets are as equally likely as distractors as well as when they are rare (Experiment 1). This suggests that the effect is not due to distinctiveness of the target events. The discrete trial nature of the design used in these experiments also precluded the possibility that any target detection related advantage is due to a trade-off between encoding items presented with targets and encoding items presented with distractors. Because the color arrays were encoded and retrieved within a single trial, there is no reason to suspect that resources were devoted to encoding arrays presented with targets at the expense of encoding arrays presented with distractors. These findings also provide new evidence that the attentional boost effect is limited to processes involved in encoding items into memory. In Experiment 2, no memory advantage was observed when the target appeared after encoding. This suggests that the enhancement is not due to arousal, motivation, or task engagement and is instead restricted to processes involved in encoding.

These data are consistent with recent findings that suggest that in order to facilitate memory, targets must overlap in time, but not necessarily in space, with the item that is being encoded (Swallow & Jiang, *in press*; Swallow et al., submitted for publication). Swallow and Jiang (*in press*) showed that long-term memory for images presented 100 ms after or 100 ms before a target is not facilitated. However, because that study measured long-term memory and only examined a particular target-to-image interval (100 ms), there is still some ambiguity as to how precise the temporal relationship between the detection target and encoding items needs to be for facilitation to occur in short-term memory. Although Experiment 2 showed that VSTM is not enhanced when targets appear more than 500 ms after the encoding display, it is still possible that the attentional boost can be found if the target appears shortly after (e.g., 50 ms) the encoding display. It is therefore not

yet clear whether temporal overlap is necessary for target detection to enhance encoding into VSTM. In addition, unlike previous studies (Lin et al., 2010; Swallow & Jiang, 2010) where target-detection stimuli spatially overlapped with the items to be encoded, here, the targets and color patches appeared in separate locations. The presence of an attentional boost effect under these conditions implies that spatial overlap is not necessary for target detection to facilitate the encoding of concurrent stimuli. It is still possible, however, that the spatial distance between targets and the encoding items modulates the attentional boost effect, with a stronger effect for spatially near items than far items. Future studies should characterize the fine spatial and temporal properties of the attentional boost effect.

Taken together, the data are consistent with the suggestion that detecting targets leads to a transient increase in attention to task-relevant information that is present when the target appears (Swallow & Jiang, 2010, *in press*). According to this transient attention hypothesis, the detection of a target increases attention to task-relevant information that coincides with the target. A prime candidate mechanism for this attentional enhancement is the locus-coeruleus norepinephrine system (LC-NE system). In nonhuman primates, the detection of a target leads to a transient release of norepinephrine from neurons in the locus coeruleus (Aston-Jones & Cohen, 2005). Norepinephrine has the effect of driving neurons toward a more extreme state of firing (Aston-Jones & Cohen, 2005; Robbins, 1997) and may thereby speed the rate at which neural networks settle into a representational state. Because the locus coeruleus projects broadly throughout the cortex (Aston-Jones & Cohen, 2005), a transient increase in norepinephrine in response to a target could facilitate processing of other concurrently presented stimuli. The effect of the LC-NE system is most likely detectable during memory encoding when the neural networks representing the memory display are still working toward a stable representational state (cf., Lamme, 2003). This representation should be relatively stable 500 ms into the retention interval (Experiment 2b) or at the probe stage (Experiment 2a), and may not be facilitated further by the LC-NE firing.

In addition to the LC-NE system, other neural systems may play an important role in the encoding enhancements observed in the attentional boost effect. For example, the processes by which the hippocampus forms stable, long-term as well as short-term memory traces (Henke, 2010) may be facilitated by target detection. In addition, enhanced encoding in response to targets may be associated with increased neural activity in regions of the brain initially involved in processing the display, such as primary visual cortex. Research using EEG and fMRI methodologies will need to be conducted in order to determine the role of these systems in the attentional boost effect.

4.2. *The relationship between attention and short-term memory*

While the finding that targets enhance encoding of items into VSTM has important implications for the attentional boost effect, they are also relevant to our understanding of the relationship between attention and VSTM. Previous research on this topic has revealed two general patterns. First, spatial attention can facilitate VSTM encoding and maintenance processes. For example, when cues are used to direct people's attention to a subset of information during encoding (e.g., Makovski & Jiang, 2007; Schmidt, Vogel, Woodman, & Luck, 2002) or during the retention interval (e.g., Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Makovski et al., 2008), the cued subset is remembered better than the uncued subset. On the flip side, information held in VSTM biases spatial attention to similar information in visual search (e.g., Soto, Heinke, Humphreys, & Blanco, 2005; Vickery, King, & Jiang, 2005). Second, in divided attention paradigms, performing a secondary task usually interferes with memory. Directing

attentional resources away from a VSTM task during encoding (Dell'Acqua & Jolicoeur, 2000; Jolicoeur & Dell'Acqua, 1999), retention (e.g., Fougne & Marois, 2006; Makovski et al., 2006), or retrieval (Makovski et al., 2010) disrupts VSTM performance.

The current findings are exceptional in that they demonstrate that increasing attention to one task enhances performance in an unrelated VSTM task. In these experiments, the target-detection and VSTM tasks operate on different sources of information: detection on central letters and VSTM on an array of colors. Because detecting a target increases attention to the central letter task (Duncan, 1980; Duncan et al., 1994; Moore et al., 1996) one should expect interference in the VSTM task. The data from Experiment 1 show the opposite. Even if the letter task and the color short-term memory task produce weak competition, this would not explain why detecting targets in the letter task *enhances* VSTM relative to rejecting a distractor, as opposed to leaving it *unaffected*. These results indicate that detecting relevant information in one task can briefly enhance concurrent processing in another task, even when the two tasks are usually found to interfere with each other.

4.3. Relation to other findings

How do we reconcile the apparent discrepancy between the two-target cost found in previous studies and the attentional boost effect observed here? Duncan (1980) noted that the two-target cost is probably not due to interference at the encoding stage; presumably, determining that something is a target requires the same perceptual processing as determining that something is a distractor. Instead, Duncan proposed that interference occurs after participants have categorized an item as a target, at later stages of processing such as response selection. Therefore, provided that one assumes that the enhancement occurs at an early stage (e.g., perceptual processing), and the cost of target detection occurs at a later stage (e.g., elaborative processing, response selection), the attentional boost effect is not inconsistent with the two-target cost. Data collected so far are consistent with this hypothesis. In the VSTM task, the attentional boost effect is observed only when the letter targets are presented during memory encoding. In the long-term memory task for scenes, the attentional boost effect is observed when the target detection task involves a simple detection response (e.g., press the spacebar for a red or green square), but not when it involves a discrimination response that requires response mapping and selection (e.g., press "R" for red or "G" for green squares; Swallow & Jiang, 2010). Together these results suggest that the consequences of target detection are more complex than previously believed: it appears to enhance early perceptual processes but disrupt later response related processes.

The attentional boost effect highlights the influence of target-detection on concurrent task processing. It resonates with task-irrelevant perceptual learning (Seitz & Watanabe, 2003), where target detection in a letter RSVP task facilitates perceptual learning of background sub-threshold motion stimuli. Our results extend task-irrelevant perceptual learning to tasks that do not require extensive training and to tasks where the background stimuli are supra-threshold. The attentional boost effect also resembles lag-1 sparing in the attentional blink. People are usually impaired at detecting a second target (T2) when it appears within 200–500 ms of the first target (T1) in RSVP presentations (Chun & Potter, 1995; Dux & Marois, 2009; Raymond et al., 1992). However, if T2 immediately follows T1 without intermediate distractors, its processing is "spared" from the attentional blink (Jefferies & Di Lollo, 2009; Visser, Bischof, & Di Lollo, 1999). Theories that account for lag-1 sparing have proposed that target detection transiently facilitates processing (Bowman & Wyble, 2007; Olivers & Meeter, 2008). Although it is not yet clear whether lag-1 sparing and the attentional boost effect are due to the same mechanism, there is some

evidence to suggest that they are not. Lag-1 sparing is strongest when T2 trails T1 by a short SOA (Potter et al., 2002), whereas the attentional boost effect requires temporal overlap between the two sources of stimuli (Swallow & Jiang, *in press*). However, all of these effects, lag-1 sparing, the attentional boost effect, and task-irrelevant perceptual learning have one thing in common: they all illustrate that cognitive processing changes as a result of detecting goal-relevant information.

5. Conclusions

Whether it is finding an ally in a battle or a vegetable on the ground, the moments in time when goal-relevant events are detected may be critical for an individual's ability to successfully navigate and function in their world. These moments in time call for extra attention and deeper perceptual processing and often demand that these enhancements occur rapidly. As a result, the enhancement may occur globally, for all task-relevant information. The attentional boost effect is consistent with this possibility, suggesting that processing of all task-relevant information present during these critical periods of time is enhanced (Swallow & Jiang, *in press*). The experiments presented in this study demonstrate that target detection can facilitate encoding into VSTM despite the markedly limited capacity of that system and the increased demands involved in detecting and responding to a target. The data also suggest that this phenomenon is limited to encoding processes, does not depend on memory load or target frequency, and occurs for items that do not spatially overlap with the target. This benefit is absent when the target appears at the same time as the probe display or during the retention interval, differentiating it from a general arousal effect (Anderson et al., 2006). Thus, attending to one source of input can enhance the encoding of concurrent, unrelated information into VSTM.

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Appendix A.

Average percent correct and K 's (where $K = \text{memory load} \times (\text{hit} + \text{correct rejection} - 1)$) measurements in the color short-term memory task in all experiments. Standard errors of the mean are presented in parentheses.

Percent correct	Memory load: 3		Memory load: 5	
	Distractor	Target	Distractor	Target
Experiment 1a	84.3 (2.1)	87.9 (2.2)	72.8 (1.9)	74.5 (2.3)
Experiment 1b	83.3 (1.7)	88.7 (1.7)	71.4 (2.4)	74.0 (2.1)
Experiment 2a	86.5 (1.7)	85.9 (2.4)	73.9 (1.8)	71.8 (2.8)
Experiment 2b	86.3 (3.3)	84.6 (4.0)	72.7 (2.6)	72.4 (3.6)
K				
Experiment 1a	2.1 (0.1)	2.3 (0.1)	2.3 (0.2)	2.4 (0.2)
Experiment 1b	2.0 (0.1)	2.3 (0.1)	2.1 (0.2)	2.4 (0.2)
Experiment 2a	2.2 (0.1)	2.2 (0.1)	2.4 (0.2)	2.2 (0.3)
Experiment 2b	2.2 (0.2)	2.1 (0.2)	2.3 (0.3)	2.2 (0.4)

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