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Perceptual Load and Attentional Boost: A Study of Their Interaction

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Increasing attention to an item typically interferes with the ability to process other concurrent information. The attentional boost effect, however, appears to contradict the ubiquity of dual-task interference. Rather, detecting a target item for one task boosts memory for a currently presented, but unrelated background scene. To account for the apparent discrepancy between dual-task interference and attentional boost, we present and test the dual-task interaction model. This model states that dual-task interference occurs at multiple stages of processing, but the decision that an item is a target triggers a cross-task enhancement to perceptual processing. Consistent with this model, this study shows that targets, but not perceptually similar distractors, trigger the attentional boost effect. In addition, the attentional boost effect is unperturbed when the perceptual load of target detection increases. The effect can also occur for task-irrelevant background images. Consistent with the dual-task interaction model these data clearly tie the attentional boost effect to the decision that an item is a target. They also suggest that this decision can rapidly boost the availability of perceptual resources.

Keywords: attention, temporal selection, dual-task interference, attentional boost effect

One of the earliest findings in cognitive psychology was that attention is a limited capacity system (Broadbent, 1952). Since that time, overwhelming evidence has shown that increasing attention to an item or task can interfere with the ability to process other information (Kinchla, 1992; Pashler, 1998). This bedrock principle of attention is frequently affirmed in modern life as people increasingly use mobile technologies while performing other tasks. However, several recent reports have demonstrated performance boosts rather than performance trade-offs in dual-task processing. In the *attentional boost effect*, items presented for one task (e.g., scenes) are better encoded into memory if they coincide with the detection of a target in another task (e.g., detecting a predefined target tone rather than a distractor tone; Lin, Pype, Boynton, & Murray, 2010; Swallow & Jiang, 2010). These findings present a conundrum. If attention[1] has limited capacity, how can increasing attention to one task boost performance in another?

The attentional boost effect is a robust and replicable phenomenon. It demonstrates that the appearance of a behaviorally relevant, attentionally demanding item is associated with *enhanced* memory for concurrent information. In one study (Swallow & Jiang, 2010), participants were asked to perform two tasks at once. For one task they encoded a series of briefly presented scenes into memory. At the same time they monitored a second stimulus stream for occasional, predefined target items. For example, they were asked to quickly press a button whenever they heard a high-pitched tone rather than a low-pitched tone. Detecting a target exerts greater attentional demands than rejecting a distractor (e.g., the two-target cost and the attentional blink; Duncan, 1980; Dux & Marois, 2009). Moreover, encoding a scene into memory is subject to dual-task interference (Wolfe, Horowitz, & Michod, 2007). Despite the costs associated with target detection, subsequent memory for scenes that coincided with the target tone was enhanced relative to those that coincided with a distractor tone (Lin et al., 2010; Swallow & Jiang, 2010). Thus, increasing attention to a behaviorally relevant item boosts memory for the concurrently presented scene.

The attentional boost effect occurs in a variety of conditions: when targets are defined by the conjunction of two features (e.g., a green-X among red-X's and green-Y's), when targets are as frequent as distractors (Swallow & Jiang, 2010, 2012), when participants report the identity of the target (Lin et al., 2010; Leclercq & Seitz, 2012), and when they count the targets (Swallow & Jiang, 2012). Moreover, the boost to encoding is temporally precise: it does not occur for items that precede or follow the target by 100 ms, when cueing and arousal have their largest effects (Nakayama & Mackeben, 1988; Posner & Boies, 1971; Swallow & Jiang, 2011). These findings indicate that the attentional boost effect is unlikely to be because of oddball processing, distinctiveness, perceptual salience, cueing to the image, arousal, or the motor response to targets.

Moreover, the attentional boost effect appears to occur primarily during perceptual encoding. Detecting a target enhances later

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[1] Because both perceptual and control limitations play a role in dual-task interference, we are using the term "attention" broadly here. Later sections refer specifically to perceptual processing or central/control limitations when justified.

perceptual priming for concurrent words (as measured in the lexical decision and word fragment completion tasks), but does not influence performance on a semantic classification task (Spataro, Mulligan, & Rossi-Arnaud, 2013). In addition, detecting a target letter enhances short-term memory (STM) for color arrays if the target is presented during encoding, but not when it occurs during a retention interval or during retrieval (Makovski, Swallow, & Jiang, 2011). Detecting a target letter also increases the magnitude of the visual tilt aftereffect (Pascucci & Turatto, 2013), and facilitates perceptual learning of low-level visual features (Seitz & Watanabe, 2003). Finally, recent neuroimaging data indicate that early visual cortical activity increases in response to auditory target tones, relative to auditory distractor tones (visual target squares produce a similar response in auditory cortex; Swallow, Makovski, & Jiang, 2012).

To account for these data we have recently proposed a "dual-task interaction model" (Swallow & Jiang, 2013). This model states that the attentional boost effect reflects a temporal selection mechanism that exists alongside a basic information processing system (i.e., perceptual processing for two tasks occurs concurrently, information about the detection item is accumulated until the item can be classified as a target or distractor, and central, control processes are used to maintain and accomplish task goals). This model has two key features. First, it assumes that processing limitations are present at multiple stages of processing, including perceptual and central processing stages. In addition, dual-task interference *increases* when a target is presented, because target detection (1) biases perceptual processing away from the concurrently presented images, (2) increases demands on working memory (e.g., from memory updating and the retention of target-related information), and (3) relies on central resources for generating an appropriate response (Pashler, 1994). Thus, although it was developed to account for the attentional boost effect, the dual-task interaction model assumes that target detection produces dual-task interference at central and perceptual processing stages.

A second key feature of the dual-task interaction model is the claim that target detection triggers a boost to perceptual processing that occurs alongside, and sometimes exceeds, dual-task interference. In particular, the model proposes that categorizing an item as a target[2] triggers widespread perceptual enhancements that are selective for moments in time, but not necessarily for task, location, or modality (Swallow & Jiang, 2013; Swallow, Makovski, & Jiang, 2012). This temporal selection mechanism facilitates processing of the target as well as information that coincides with it. Precedent for such a mechanism can be found in the neurophysiological literature, which shows that target recognition coincides with a transient burst of activity in the locus coeruleus norepinephrine (LC-NE) system (Aston-Jones & Cohen, 2005; see also Nieuwenhuis, Aston-Jones, & Cohen, 2005).

The dual-task interaction model claims that interference coexists with a boost in processing that is triggered by the decision that an item is a target. Therefore, a critical test of this model is to determine the conditions under which a boost in dual-task performance is observed. Specifically, the claim that the enhancement results from the *decision* that an item is a target leads to the prediction that the encoding enhancement should occur only when a target is detected. It should not occur when distractor items that are perceptually similar to the target are presented. In addition, the decision that an item is a target should enhance perceptual processing, regardless of (1) the perceptual difficulty of target detection, or (2) the relevance of background image to the current task.

Alternative accounts exist, however. First, it is possible that it is not the decision, but the perceptual similarity of an item to a "target template," that triggers the attentional boost effect. This account is consistent with several well-known phenomena. For example, when searching for a red target, other red stimuli tend to capture attention (Folk, Remington, & Johnston, 1992). In addition, in visual search, distractors that are more similar to the target require greater scrutiny (Duncan & Humphreys, 1989) and hence produce greater contextual cueing (Jiang & Chun, 2001). Previous research has not tested whether the attentional boost effect occurs only when a target is detected (the dual-task interaction model), or whether it may also be triggered by perceptually similar distractors (the feature matching account).

A second issue is whether target detection produces an attentional boost effect under only a very limited set of conditions. In previous studies the attentional boost effect was not observed when the images were task-irrelevant (Swallow & Jiang, 2011; see also Dewald, Sinnett, & Dumas, 2011, 2013) or when participants had to discriminate the color of a target square (red or green; distractors are black), rather than simply report its presence (Swallow & Jiang, 2010). These data raise the possibility that the attentional boost effect occurs only when the detection task is relatively easy and the background images are task-relevant. If this is the case, then asking participants to ignore the images or increasing the perceptual difficulty of target detection should eliminate the boost. However, the dual-task interaction model proposes that the decision that an item is a target produces the boost. Accordingly, increasing task demands that occur after that decision (e.g., response mapping) may interfere with the ability to detect the boost in long-term memory. Increasing task demands before that decision (e.g., accumulating perceptual evidence about the item's identity) should not prevent the boost from happening. The dual-task interaction model therefore predicts that the perceptual encoding enhancement should occur regardless of the perceptual difficulty of target detection and whether the images are task-relevant.

To test the role of target detection in the attentional boost effect, the perceptual similarity between target and distractor items was manipulated in three experiments. The first experiment tests the feature matching account by including distractors that either did, or did not share features with the target. If feature matching produces the attentional boost effect then distractors that share a feature with the target should enhance memory for concurrent images. In contrast, if target detection triggers the enhancement, then only memory for those images that coincide with a target should be facilitated.

Experiments 2 and 3 examine the roles of perceptual detection difficulty and image relevance in the attentional boost effect. In these experiments, a target could either be perceptually easy to distinguish from a distractor (because it was presented in a distinct

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[2] The term "target" is frequently used to refer to items that a person responds to by making a covert or overt response (e.g., they press a button, hold the item's identity in memory, or update a mental count of the number of targets encountered). We use the term more broadly to refer to items that require a change in a planned activity, including those that cancel a planned motor response (see Makovski, Jiang, & Swallow, 2013).

color), or it could be difficult to distinguish from a distractor (because it was visually similar). Increasing the perceptual similarity between targets and distractors reduces the availability of perceptual resources for processing other items on the screen (Lavie, 1995; Roper, Cosman, & Vecera, 2013). However, both the perceptually demanding and the easy targets yield the same decision (i.e., it is a target), and consequently, both types of stimuli should facilitate memory for the background images. Experiment 3 additionally tested whether the attentional boost effect is present in incidental memory. The claim that a broad perceptual encoding enhancement occurs when a target is detected suggests that it could be present even when the images are ignored.

Experiment 1: Feature Matching Versus Target Detection

Experiment 1 provided a critical test of the dual-task interaction model by asking whether items that share features with a target also enhance memory for concurrently presented background objects. Participants encoded a stream of objects to memory and also counted the number of times a target character, defined by the conjunction of shape and color (e.g., a green 2), appeared in a block of trials. The shape and color of the distractor characters varied. A distractor could match the target in color (color match distractor), in shape (shape match distractor), or in neither dimension (no match distractor). The feature matching account predicts that objects that coincide with a distractor that matches the target in one feature should be enhanced relative to those that coincide with a no match distractor. In contrast, the dual-task interaction model predicts that none of the distractors should yield an encoding enhancement for the objects. Moreover, because the perceptual load of the detection task is greater for distractors that match features of the target (Roper et al., 2013), memory for objects that coincide with feature match distractors should be impaired.

Method

Participants. Thirty-two college students (8 males and 24 females; 18–32 years old) completed Experiment 1. Data from six additional participants were collected and replaced because of poor task performance (counting accuracy was below 40%, $n = 3$, or recognition accuracy was at chance, $n = 2$) or computer failure ($n = 1$). Participants had normal or corrected-to-normal visual acuity and passed a color blindness test. All participants were compensated with cash or extra course credit. The University of Minnesota IRB approved all procedures.

Equipment. Stimuli were presented on a 17-inch CRT color monitor (1,024 × 768 pixels, 75 Hz) with an unrestrained viewing distance of approximately 40 cm. Stimulus presentation was controlled using MATLAB and Psychtoolbox (Brainard, 1997; Pelli, 1997).

Materials. A set of 320 color images of everyday objects was obtained from Tim Brady's online database (*http://cvcl.mit.edu/MM/download.html*). The objects were diverse in categories. Objects subtended 12.5° × 12.5° and were presented over a gray background. For each participant the objects were randomly and evenly divided into *old objects*, which were encoded into memory during the first part of the experiment, and *new objects*, which were used as foils in the recognition test. An additional 64 objects were shown during practice. A mask was created for each object by dividing it into 1,024 squares and scrambling the squares' locations.

Procedure. The experiment occurred in two phases. In the dual-task encoding phase, participants performed two tasks simultaneously in a continuous series of trials (1,000 ms trial duration; 0 ms intertrial interval (ITI); Figure 1a). For the encoding task, an object appeared in the center of the screen for 500 ms, followed by a 500 ms mask (0 ms interstimulus interval, ISI). For the detection task, one of four possible colored characters was presented in a gray square (1.95° × 1.95°) in the center of the object (a red 2, a green 2, a red Z, or a green Z, equally likely; 32 point Arial font) for 100 ms. The character onset at the same time as the object and disappeared after 100 ms. Participants were asked to covertly count the number of times a predefined target character appeared on the screen and to remember all of the objects for a later memory test.

The trials were divided into 15 blocks, each with a mean of 32 trials. Six to 10 targets characters ($M = 8$) occurred in each block. At the end of a block participants were prompted to choose the number of targets (with the options of 6–10) they had counted

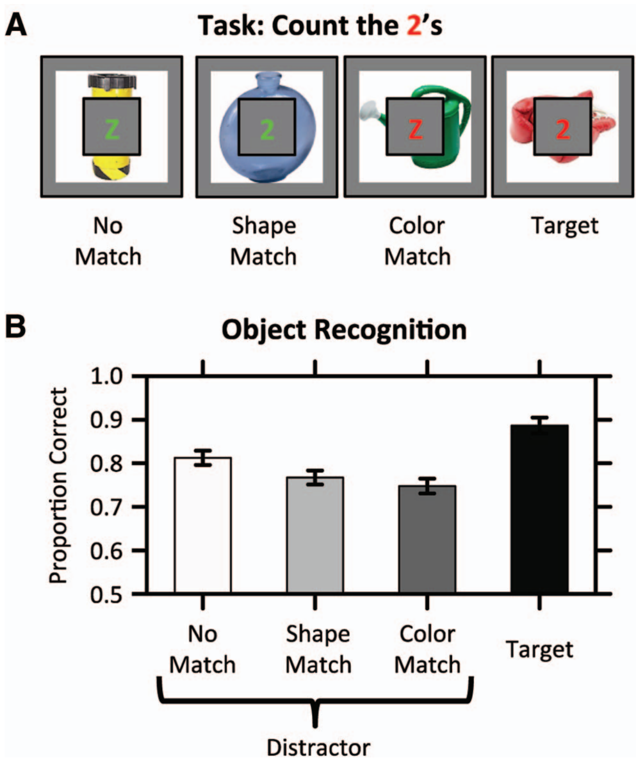

Figure 1. Design and data from Experiment 1. (A) On each trial an object and a green or red character (2 or Z) were presented. Participants counted the number of prespecified target characters in a block of trials. Target characters were defined by the conjunction of color and shape (e.g., a red 2). There were three different types of distractors: Color match distractors were the same color as the target (e.g., a red Z), shape match distractors were the same shape as the target (e.g., a green 2), and no match distractors were a different color and shape than the target (e.g., a green Z). Items are not drawn to scale. (B) Recognition accuracy for objects presented in each of the four conditions. Error bars represent ± 1 SE around the mean.

during the previous block by pressing a key on the keyboard. Accuracy and response times were measured. Feedback was provided immediately.

In the second phase of the experiment participants completed a two alternative forced choice recognition test on the objects. On each trial two objects, one old and one new, appeared on the left and right side of fixation. Participants pressed a button to select the object they believed was shown to them during the encoding task. They then indicated their confidence on a 7-point scale. Accuracy feedback was provided after each trial.

Design. Target characters were defined by the conjunction of color and shape counterbalanced across participants (e.g., red 2). Distractors could match the target in color, in shape, or in neither dimension, resulting in three distractor conditions (Figure 1a). *No match distractors* matched the target in no dimension (e.g., green Z) and therefore required few perceptual resources to distinguish from a target. *Shape match distractors* matched the target in shape, but not in color (e.g., green 2). *Color match distractors* matched the target in color, but not in shape (e.g., red Z). The four types of colored characters appeared with equal frequency (25%). Therefore, a distractor was three times more likely to occur than a target, but equally likely to be in any of the feature matching conditions.

There were 480 total trials in the dual-task encoding phase. They were evenly divided across the four character conditions and randomly ordered for each participant. For each participant, the 160 old object images were randomly assigned to each encoding condition (40 objects per condition) and presented three times, always in the same condition.

Results and Discussion

Target detection. Participants correctly reported the number of target letters in the block 81.5% of the time ($SE = 1.72\%$). Overall, reported counts deviated from the actual number of targets by a mean of 0.21 ($SE = 0.02$).

Object recognition. If the attentional boost effect is triggered by feature matching, then distractor characters that match a target character on one dimension should enhance memory for concurrent images. Our data did not support this feature matching account. A one way analysis of variance (ANOVA) on the accuracy data (the proportion of correctly recognized objects) with encoding condition as a factor produced a significant main effect, $F(3, 93) = 22.03$, $p < .001$, $\eta_p^2 = .415$. This effect reflected better memory for objects presented at the same time as a target character than for objects presented with any kind of distractor characters, smallest $t(31) = 3.72$, $p = .001$, $d = 0.76$. Moreover, increasing the perceptual similarity between the distractor character and the target interfered with, rather than boosted, the ability to encode the background objects into memory: Object recognition was worse for objects presented with color match distractors than for those presented with no match distractors, $t(31) = 3.02$, $p = .005$, $d = 0.68$. Similarly, recognition was worse for objects presented with the shape match distractors than for those presented with the no match distractors, $t(31) = 3.58$, $p = .001$, $d = 0.49$. Recognition did not reliably differ for objects presented with the shape match and color match distractors, $t(31) = 1.08$, $p = .287$. All reliable tests survived a Bonferonni corrected alpha threshold of $p < .008$.

Analysis of the confidence ratings for correctly recognized objects produced a similar pattern of data. Confidence ratings were significantly influenced by encoding condition, $F(3, 93) = 32$, $p < .001$, $\eta_p^2 = .508$. Follow up *t* tests indicated that confidence ratings for objects in the no match distractor condition (M = 5.28, $SE = 0.14$) reliably differed from those in the target condition (M = 6.14, $SE = 0.14$), $t(31) = 6.14$, $p < .001$, $d = 1.06$, and those in the color match distractor condition (M = 4.94, $SE = 0.19$), $t(31) = -3.17$, $p = .003$, $d = 0.36$. The difference between the no match distractor and the shape match distractor (M = 5.34, $SE = 0.15$) conditions was not significant, $t(31) = 0.6$, $p = .55$. All reliable effects exceed the Bonferonni correct alpha threshold ($p < .008$).

The data supported the claim that target detection produces the encoding enhancement underlying the attentional boost effect. There was no evidence that distractors that share features with a target character produce a memory advantage for concurrently presented objects. If anything, distractors that required more perceptual resources to reject impaired the ability to encode concurrently presented information. These data are consistent with the claim that perceptual resources are limited (Desimone & Duncan, 1995; Lavie, 1995). They also provide critical support for the dual-task interaction model's claim that the decision that an item is a target triggers the attentional boost effect.

Experiment 2: Perceptual Detection Difficulty

Experiment 2 tested a second prediction of the dual-task interaction model: the attentional boost effect should occur even when targets are perceptually difficult to detect. In contrast to previous experiments in which the difficulty of the response to a target was manipulated (Swallow & Jiang, 2010), Experiment 2 varied the difficulty of distinguishing a target from a distractor at the perceptual level. As in Experiment 1, participants encoded a series of objects into memory for a later memory test. In addition, they monitored a second unrelated stream of colored characters (2 and Z) for a predefined target character (e.g., a 2). In this experiment, however, targets were defined by their shape, and their color (green or red) was irrelevant. In addition, distractors were presented in only one color (e.g., red). Some targets therefore matched the distractors in color and were more difficult to detect. Other targets were unique in color and were easier to detect (Duncan & Humphreys, 1989).

In Experiment 1 distractors that matched the target in color interfered with object encoding, suggesting that categorization of the character as a target (e.g., a 2) or distractor (e.g., a Z) based on shape alone requires more perceptual resources than when that decision can be based on multiple feature dimensions. In addition, search slope on target-present trials was flat in a pilot visual search task when participants searched for a target that was a different color than the distractors (e.g., a red 2 among green 2s or green Zs; 1 ms/item), but steep when they searched for a target that was the same color as the distractors (e.g., a red 2 among red Zs; 21 ms/item). These data verified that targets that were perceptually similar to distractors exerted greater perceptual load than those that were perceptually distinct (Roper et al., 2013).

If the decision that an item is a target produces the attentional boost effect (dual-task interaction model), then the effect should be present for both the perceptually demanding target and the easily discriminable target. Alternatively, the attentional boost effect may be limited to situations in which the target detection task is relatively easy (perceptual difficulty account). If this is the case, increasing the difficulty of the detection task may eliminate the attentional boost effect for objects presented with the perceptually demanding target.

Method

Participants. Twenty college students (4 males and 16 females; 18–25 years old) completed Experiment 2. This sample size allows one to detect an interference effect as big as that observed in Experiment 1 (distractor no match-distractor color match, $M_D = .065$, $SD = .102$) with a power of .77 for a two-sided test and .86 for a one-sided test. Though one-sided tests were reasonable given the hypotheses, we performed two-sided tests to allow for the possibility that findings that directly contradict our hypotheses would emerge. Three participants were replaced because of high false alarm rates in the detection task (they responded to more than 10% of the distractor characters).

Materials. This experiment used the same set of 320 object images as Experiment 1.

Design and procedure. This experiment was identical to Experiment 1 with the following exceptions. First, participants were instructed to press a button as quickly as possible whenever a target character (2 for half the participants and Z for the remaining participants) was presented. They were told to respond to the target character regardless of its color (red or green). Both red and green targets resulted in a button press that allowed us to measure the effect of perceptual load on target detection. The task paused after blocks of 40 trials to provide a break and feedback on the detection task.

The dual-task encoding phase consisted of three conditions. In the *distractor* condition, the distractor character appeared in the center of the object (e.g., a red Z). Distractor characters were presented in one color throughout the experiment (red or green, counterbalanced across participants). In the *color match target* condition a target character appeared in the center of the object in the same color assigned to the distractor character (e.g., a red 2). In the *no match target* condition, a target character appeared in a different color than that assigned to the distractor character (e.g., a green 2). Whereas color match targets could be distinguished from distractors only by their shape (that was similar to that of the distractor), no match target characters could be distinguished from distractors by both color and shape. As a result, perceptual discrimination was difficult for the color match targets and easy for the no match targets.

The no match target to color match target to distractor ratio was 1:1:2. Targets and distractors were equally likely to occur. Targets were also equally likely to be a color match (high load) or no match (low load) target. For each participant the 160 old objects were randomly assigned to the three conditions (40 in each of the two target conditions and 80 in the distractor condition). Each object was presented three times, always in the same condition. This resulted in a total of 480 trials in the dual-task encoding phase. Participants were asked to encode all of the objects into memory. A recognition test on the objects followed the encoding phase.

Results and Discussion

Target detection. The perceptual load of the target influenced participant's detection performance. Participants responded to significantly fewer color match targets (hit rate = .971; SE = .003) than no match targets (hit rate = .99; SE = .006), $t(19) = -4.26$, $p < .001$, $d = -0.93$. Responses to color match targets (mean reaction time (RT) = 408; SE = 6.8) were also significantly slower than those to no match targets (mean RT = 389; SE = 4.8), $t(19) = 4.71$, $p < .001$, $d = 0.73$. Thus, targets that matched the distractors in color were more difficult to detect than those that did not. This difference, along with the data from Experiment 1 and the pilot visual search data, supports the claim that the perceptual load manipulation was effective.

Object recognition. If the attentional boost effect occurs whenever a target is detected, then it should be present in both the color match and no match target conditions. Alternatively, if increasing the perceptual difficulty of the detection task prevents the enhancement from occurring, then there should be no advantage for objects presented at the same time as color match targets.

As can be seen in Figure 2b, objects that were presented at the same time as a target were later better recognized than those that were presented at the same time as a distractor. Thus, an atten-

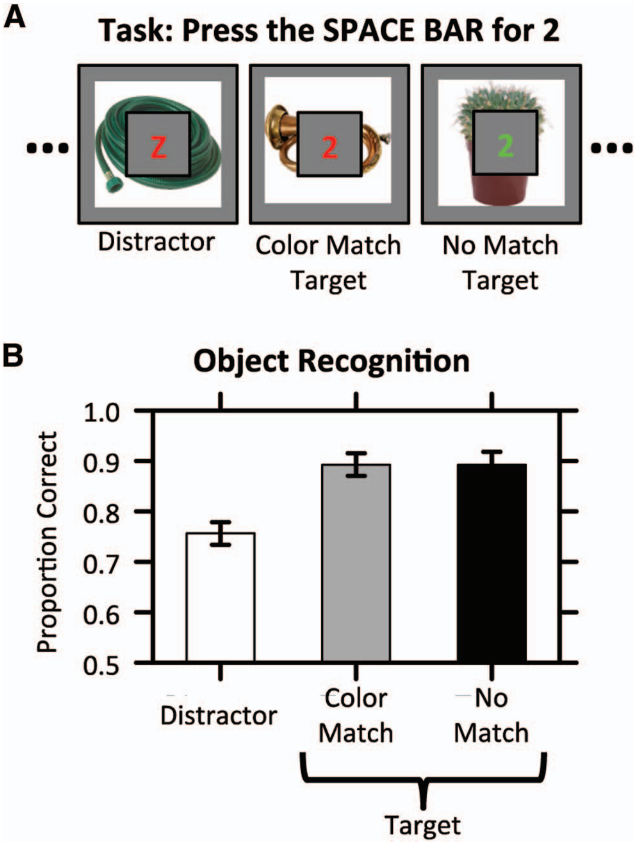

Figure 2. Design and data for Experiment 2. (A) On each trial, a picture of an object and a character (2 or Z) onset at the same time. Participants were instructed to remember the object and press the space bar whenever a prespecified target character appeared (e.g., a 2). Distractors were always one color. However, target characters could appear in green or red. Color match targets were the same color as the distractors (and therefore high in perceptual load). No match targets were a different color than the distractors (and therefore low in perceptual load). Items are not drawn to scale. (B) Recognition accuracy for the objects in each of the three encoding conditions. Error bars represent ± 1 SE around the mean.

tional boost effect occurred, resulting in a main effect of encoding condition in a one-way ANOVA on the proportion of correctly recognized objects, $F(2, 38) = 43.5$, $p < .001$, $\eta_p^2 = .696$. Moreover, both color match and no match targets produced a robust attentional boost effect: Objects presented with a color match target were later better recognized than those presented with a distractor, $t(19) = 7.45$, $p < .001$, $d = 1.36$; objects presented with a no match target were better recognized than those presented with a distractor, $t(19) = 8.02$, $p < .001$, $d = 1.26$. Recognition memory did not reliably differ for objects in the color match target and no match target conditions, $t(19) = 0$, $p > .90$. Detecting a target enhanced later memory for a concurrent object, even when doing so required more perceptual resources.

The confidence ratings for correctly recognized objects were consistent with the accuracy data (see Table 1). An ANOVA on encoding condition indicated that the main effect of encoding condition was significant. Follow-up *t* tests indicated that confidence ratings were higher for objects in the no match target condition, $t(19) = 4.2$, $p < .001$, $d = 0.82$, and color match target condition, $t(19) = 5.79$, $p < .001$, $d = 1.56$, than for objects in the distractor condition. Confidence ratings were higher for objects shown with a color match target than for those shown with a no match target $t(19) = 2.15$, $p = .04$, $d = 0.26$ (this *p* value does not survive Bonferonni correction, $p < .016$).

To better illustrate the effects of perceptual load and target detection on concurrent object memory, the color match conditions from Experiments 1 and 2 were plotted alongside the no match distractor condition from Experiment 1 (see Figure 3). The color match targets (Experiment 2) and the color match distractors (Experiment 1) were both high in perceptual load; perceptual discrimination required shape analysis. However, the color match target resulted in target categorization while the color match distractor did not. The no match distractor condition was low in load and did not result in target detection. As can be seen in Figure 3, increasing the perceptual load of the distractor characters in the detection task negatively impacted concurrent object encoding. The perceptual load manipulation effectively interfered with object memory when the item was a distractor. In contrast, target detection boosted encoding, even under conditions of high perceptual load.

Unlike previous experiments (Swallow & Jiang, 2010), increasing the difficulty of the detection task did not eliminate the attentional boost effect in long-term memory. This finding is consistent with the dual-task interaction model: because the decision that an item is a target triggers the boost, increasing task demands that occur after that decision (e.g., response selection) should interfere with the boost, but increasing task demands before that decision (e.g., perceptual difficulty) should have relatively little effect. Neurophysiological studies found analogous results: The LC-NE response to targets was unrelated to the perceptual discrimination difficulty of the target detection task (Rajkowski, Majczynski, Clayton, & Aston-Jones, 2004).

Table 1
Mean and SEs of Confidence Ratings for Correct Recognition Responses in Experiments 2 and 3

Encoding instruction	Distractor	Color match target	No match target
Exp. 2: Intentional	5.19 (0.14)	5.9 (0.14)	5.72 (0.15)
Exp. 3: Incidental	4.16 (0.25)	4.71 (0.3)	4.46 (0.29)

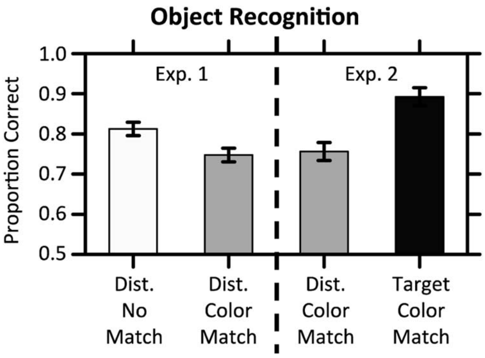

Figure 3. The need to analyze the shape of a character to categorize it as a target or distractor impaired memory for concurrent images when the character was categorized as a distractor (Experiment 1). In contrast, memory for the concurrent object was enhanced when the character was categorized as a target (Experiment 2). Data are replotted from Figures 1 and 2. Error bars represent ± 1 SE around the mean.

One surprising outcome of Experiment 2 was that there was little numeric difference in memory for objects that were presented with the two types of targets, even though perceptual load was higher in the color-match condition than in the no-match condition. In fact, confidence ratings were slightly greater for objects presented with the color match target than for objects presented with the no match target (see Table 2). This was true despite the fact that the color match targets produced lower hit rates and slower response times than the no match targets in the encoding phase. Moreover, the perceptual load manipulation used here effectively increased interference in Experiment 1 (e.g., Figure 1). The accuracy data from Experiment 1, the visual search pilot data, and previous research (e.g., Duncan & Humphreys, 1989; Roper et al., 2013) indicate that the color match manipulation used here influences perceptual load and produces robust interference effects when the item is ultimately classified as a distractor. The lack of interference from increasing the perceptual load of the target is surprising. Experiment 3 offered an opportunity to determine whether it is replicable.

Experiment 3: Incidental Encoding

The dual-task interaction model's claim that target detection produces a broad perceptual encoding enhancement suggests that the attentional boost effect should be present for objects that are ignored, as well as those that are actively encoded into memory. However, although a number of studies have tested whether such an effect occurs, the data have been mixed (Dewald, Sinnett, & Doumas, 2011, 2013; Swallow & Jiang, 2011), with the full range of outcomes: interference, no effect, and enhancement. Experiment 3 was performed for several reasons. The first was to provide an additional test of whether task-irrelevant images are enhanced when a target is detected. This also allowed us to better characterize when we should expect to see an enhancement. In addition, Experiment 3 provided an opportunity to replicate the null effect of the target's perceptual load observed in Experiment 2.

Table 2

Mean and SEs of the Proportion of Correctly Recognized Objects in Experiments 2 and 3

Encoding instruction	Distractor	Color match target	No match target	Mean
Exp. 2: Intentional	.772 (.018)	.89 (.018)	.899 (.02)	.824 (.021)
Exp. 3: Incidental	.728 (.027)	.785 (.028)	.788 (.03)	.744 (.137)
Mean	.752 (.016)	.842 (.018)	.849 (.019)	.784 (.019)

Method

Participants. Twenty college students (7 male; 18–23 years old) completed Experiment 3. Statistical power was equivalent in Experiments 2 and 3. One participant was replaced because of high false alarm rates (more than 10% false alarms).

Design and procedure. This experiment was identical to Experiment 2, except that in the encoding phase participants were instructed to focus on the colored characters and ignore the background objects. A surprise memory test on the objects was administered after the single-task encoding phase.

Results and Discussion

Target detection. In Experiment 3, responses to color match targets were again less accurate (M = .974; $SE = .01$) and slower (M = 389 ms; $SE = 7.2$) than those to no match targets (hits: M = .992, $SE = .002$; response time: M = 374 ms, $SE = 5.5$), $t(19) = 2.18$, $p = .04$, $d = 0.57$ for hit rate and $t(19) = 4.02$, $p = .001$, $d = 0.53$ for response time.

Object recognition. The recognition data (the proportion of correctly recognized objects; see Figure 4) were consistent with the intentional encoding data from Experiment 2. First, a main effect of encoding condition indicated that incidental memory for objects was enhanced when the objects coincided with a target character, rather than with a distractor character, $F(2, 38) = 4.13$, $p = .024$, $\eta_p^2 = .178$. The attentional boost effect occurred for task-irrelevant information. Replicating Experiment 2, the attentional boost effect was present for both no match targets, $t(19) = 2.75$, $p = .013$, $d = 0.35$, and color match targets, $t(19) = 2.28$, $p = .034$, $d = 0.38$ (this test does not survive Bonferonni correction, $p < .016$). As in Experiment 2, there was little numeric difference in incidental memory for objects coinciding with no match targets (M = .77; $SE = .035$) and color match targets (M = .772; $SE = .034$), $t(19) = -0.12$, $p < .908$.

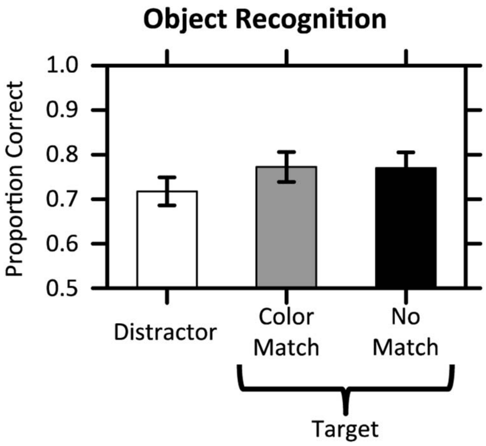

Figure 4. Recognition memory of objects after incidental encoding during a detection task in Experiment 3. Error bars represent ± 1 SE around the mean.

Confidence ratings for correctly recognized objects (see Table 1) also followed the pattern observed in Experiment 2: they were greatest for objects in the color match target condition, intermediate for objects in the no match target condition, and lowest for objects in the distractor condition. An ANOVA indicated that confidence ratings reliably differed across encoding conditions, $F(2, 38) = 7.05$, $p = .002$, $\eta_p^2 = .271$. Follow-up *t* tests indicated that the difference between the color match target and distractor conditions was reliable, $t(19) = 3.71$, $p = .001$, $d = 0.46$ (Bonferonni corrected $p < .016$). However, confidence ratings for objects in the no match target condition only marginally differed from those for objects in the other two conditions, $t(19) = 1.89$, $p = .074$, for the comparison to distractors, and, $t(19) = -1.9$, $p = .073$, for the comparison to color match targets.

Finally, the data from Experiments 2 and 3 were combined to increase statistical power and to determine whether the relevance of the background object modulates the attentional boost effect. With an *N* of 40, the power to detect an effect of perceptual load as large as that observed in Experiment 1 (no match distractors vs. color match distractors, see Experiment 2 Methods) is .97. The power to detect a mean difference of .04 ($SD = .1$) is .8.

Consistent with a role of the relevance of the background object in the attentional boost effect, an ANOVA on the proportion of correct responses (see Table 2) with encoding condition (distractor, no-match target, or color-match target) and encoding instruction (intentional or incidental encoding) as factors revealed a significant interaction, $F(2, 76) = 6.04$, $p = .004$, $\eta_p^2 = .137$. The attentional boost effect was smaller under incidental encoding instructions. Significant main effects of instruction, $F(1, 38) = 6.15$, $p = .018$, $\eta_p^2 = .139$, and encoding condition, $F(2, 76) = 32$, $p < .001$, $\eta_p^2 = .457$, were also observed. There was no evidence that the perceptual load of the target influenced object memory, $t(39) = -0.1$, $p > .90$. The data suggest that the attentional boost effect is similar for targets that are high and low in perceptual load, can occur under incidental encoding conditions, and is modulated by the background objects' relevance.

Experiment 3 provided a clear replication of the main findings from Experiment 2. Detecting a target character enhances later memory for concurrent objects even when it requires additional perceptual resources to identify. Moreover, these extra demands on perceptual processing do not appear to impair memory to the degree that they would if the character were ultimately categorized as a distractor (e.g., Experiment 1; Figure 3). This was true even when participants ignored the background objects, a condition that is typically used in studies that demonstrate that increasing the target's perceptual load reduces the processing of task-irrelevant items (Lavie, 1995). We will return to this point in the General Discussion.

The fact that target detection is essential for the attentional boost effect may help account for other data that apparently contradict the present findings. In Huang and Watanabe (2012), STM for scenes that were presented at the same time as a dim target was worse than for scenes presented at the same time as a bright target. Dim targets should have required more perceptual resources to identify than bright targets. However, they were also missed more often than bright targets (~7% more). If detecting a target is necessary for the attentional boost effect to occur, then conditions that produce more misses should also produce a weaker effect, particularly when memory is probed on a trial-by-trial basis.

In addition to replicating the findings from Experiment 2, the present results indicated that the attentional boost effect occurs even for task-irrelevant objects. Although there is no way to be certain that the objects were never attended, it is clear that participants paid less attention to them under incidental encoding conditions. Participants were instructed to ignore the objects, reported that they followed this instruction, and showed poorer recognition performance under incidental encoding than intentional encoding conditions. However, target detection still enhanced memory for concurrent and task-irrelevant images. This suggests that target detection triggers a broad encoding enhancement that is not limited to task-relevant images. Nonetheless, the enhancement is greater when participants were instructed to attend to and memorize the background pictures.

This point could help explain the wide range of results that exist in previous experiments on this issue. Previous studies used a design with trials broken into a large number of conditions (Swallow & Jiang, 2011), presented a small number of task-irrelevant but suprathreshold words more than a hundred times (Dewald et al., 2013), or presented a larger set of words a few times (Dewald et al., 2011). These studies found no effect, an enhancement, and interference in memory for task-irrelevant stimuli that coincided with an unrelated target, respectively. Statistical power and the likelihood that attention was paid to any given background stimulus (that should increase as the number of times a stimulus is presented increases) are likely to be factors in these findings. With regard to our own previous research, multiple factors changed from Swallow and Jiang (2011) to the current study's Experiment 3 (e.g., objects rather than scenes, fewer image presentations, fewer conditions, and more images per condition in the current study) that could have made the current study more sensitive or changed the effectiveness of the relevance manipulation. What seems clear, however, is that both studies support the conclusion that the relevance of the background image modulates the magnitude of the attentional boost effect.

General Discussion

The attentional boost effect is, to our knowledge, the only example of a dual-task performance enhancement that results from increasing attention to another task. Although controversy exists as to whether dual-task interference can be overcome with practice (Schumacher et al., 2001; Tombu & Jolicoeur, 2004), there has been little doubt that it exists in most unpracticed tasks. If this is the case, then how is it possible that increasing attention to one task boosts performance in another? The dual-task interaction model (Swallow & Jiang, 2013) proposes a parsimonious answer. Consistent with the broader attention literature, it claims that dual-task interference can occur at multiple stages of processing. It also claims that target detection triggers a broad perceptual encoding enhancement that is selective for time, but not necessarily for spatial locations, task, or modality. Experiments 1–3 supported the latter claim, providing evidence that the attentional boost effect is closely tied to the decision that an item is a target. The data showed negative effects of perceptual load when the detection item was a distractor, but positive effects of targets, regardless of their perceptual load and the relevance of the background image. There are two main conclusions from these data: The attentional boost effect is triggered by target detection regardless of detection difficulty, but its effect on long-term image memory is enhanced by the relevance of the background image.

Target Detection Produces the Attentional Boost Effect

Previous research has repeatedly demonstrated that targets are associated with better memory for concurrent images than are distractors (Leclercq & Seitz, 2012; Lin et al., 2010; Makovski et al., 2011; Spataro et al., 2013; Swallow & Jiang, 2010, 2011, 2012, 2013). The challenge, however, has been accounting for why. For example, early studies demonstrating the attentional boost effect used rare targets among common distractors, making it possible that the enhancement was somehow related to the distinctiveness of the target. However, several subsequent studies eliminated many potential explanations of the attentional boost effect. These include the perceptual salience of the target (Spataro et al., 2013; Swallow & Jiang, 2010), its distinctiveness (Makovski et al., 2011; Swallow & Jiang, 2012), alerting and attentional cueing (Swallow & Jiang, 2011), and the motor response to the target (Swallow & Jiang, 2012, see also, Makovski, Jiang & Swallow, 2013). Still other data suggest that the attentional boost effect does not occur for all types of behaviorally relevant events, such as cues that validly predict target onset (Leclercq & Seitz, 2012).

Therefore, it appears that the attentional boost effect is specific to how a target, rather than a distractor, is processed. Indeed, this is one central claim of the dual-task interaction model (Swallow & Jiang, 2013), which proposes that perceptual encoding enhancements are triggered by the categorization of an item as a target. However, the earlier data were also consistent with an alternative interpretation: That the attentional boost effect is triggered by an item that *could* be a target. Access to either the color or the shape of an item in the center of the screen does not rely on attentional selection (Huang & Pashler, 2008; Treisman & Gelade, 1980). The proposal that matching a feature of this item to the target template triggers an encoding enhancement is therefore just as plausible as the suggestion that it is generated by target detection. Indeed, this sort of enhancement could be used to resolve the item's identity. However, the data from Experiment 1 failed to find evidence in support of a feature matching account of the attentional boost effect. The attentional boost effect occurs when a target is detected but not when items that share features with a target are presented (Experiment 1). In fact, items that are similar to a target interfered with concurrent image encoding (Experiment 1). These data clearly show that target detection is necessary for the attentional boost effect in long-term memory to occur.

The present study also provided new evidence to suggest that target detection produces an attentional boost effect in a broader set of conditions than previously believed (Experiments 2 and 3). In particular, conditions that were designed to draw perceptual resources away from the background image (high perceptual load and irrelevance) did not eliminate the effect. Moreover, although Experiment 3 provided some evidence that attention to the background image contributes to the magnitude of the effect, there was no evidence that the enhancement was diminished when more perceptual resources were needed to identify the target (Experiment 2). The attentional boost effect is therefore closely tied to the decision that an item is a target.

Task-Relevance Modulates the Magnitude of the Attentional Boost Effect

The attentional boost effect was initially demonstrated in a dual-task paradigm that required participants to intentionally encode background images into memory at the same time that they performed a detection task (Lin et al., 2010; Swallow & Jiang, 2010). Since that time, the importance of the instruction to attend to the background image has remained unsettled (Dewald et al., 2011; 2013; Swallow & Jiang, 2011). The data from the current study help to clarify the role of task relevance in the attentional boost effect in memory. The effect does appear to be modulated by the task-relevance of the background image. However, intentional encoding of images may not be necessary for the attentional boost effect to occur, as long as central mechanisms are available for consolidating those images into long-term memory (Dell'acqua & Jolicoeur, 2000; Jolicoeur & Dell'Acqua, 1998; Wolfe et al., 2007) and there is sufficient power to detect the weaker effect.

The modulatory role of the relevance of the background images raises another important question: Does increasing the cognitive demands of the detection task influence the attentional boost effect? Increasing the cognitive demands that are placed on the system once a target is detected could interfere with the ability to consolidate the images into long-term memory (Dell'acqua & Jolicoeur, 2000; Jolicoeur & Dell'Acqua, 1998; Wolfe et al., 2007). This prediction is consistent with a previous study that manipulated response selection of the target (Swallow & Jiang, 2010), which should increase demands on central processes rather than on perceptual processes (Pashler, 1994). It is also supported by a follow-up experiment that directly manipulated the working memory demands of the target. In this study, participants responded to letters that appeared in a prespecified target color (e.g., red; distractors were green). On some blocks they said the most recent target letter aloud and held it in memory. On other blocks they said the two most recent target letters aloud and held them both in memory. In contrast to an earlier study that required target discrimination (Swallow & Jiang, 2010), this manipulation loaded working memory and control processes. It therefore should have interfered with the ability to consolidate the background images into memory (Dell'acqua & Jolicoeur, 2000; Jolicoeur & Dell'Acqua, 1998; Wolfe et al., 2007). The attentional boost effect was present when only one letter needed to be remembered, but absent when two letters needed to be remembered. This pattern was observed with both intentional and incidental encoding instructions. Thus, increasing the cognitive demands of the detection task does interfere with the attentional boost effect in long-term memory.

There is evidence that target detection influences perceptual processing even when the information that is later tested is presented outside conscious awareness. Seitz and Watanabe (2003) found that later sensitivity to directions of motion that are repeatedly paired with a target is enhanced (*task-irrelevant perceptual learning*; TIPL). This effect is observed when the motion directions are presented subliminally (see also Choi, Seitz, & Watanabe, 2009). However, TIPL is not observed when the participant is consciously aware of the motion (Tsushima, Seitz, & Watanabe, 2008), in a situation that is very much like the one used in Experiment 3. To account for these data, it has been proposed that suprathreshold, task-irrelevant stimuli are inhibited, and therefore do not benefit from the learning that occurs in response to detecting a target (e.g., Roelfsema, van Ooyen, & Watanabe, 2010). These data raise questions about the degree to which the attentional boost effect in long-term memory and TIPL reflect the same mechanisms, even if they do utilize similar methodologies.

Theoretical Implications

The current study substantiates the dual-task interaction model's claim that the attentional boost effect is linked to the decision that an item is a target. To account for the attentional boost effect, the dual-task interaction model proposes that the decision that an item is a target triggers a temporally precise but otherwise nonspecific perceptual enhancement. This temporal selection mechanism is roughly similar to those that have been proposed by others to account for the attentional blink (Bowman & Wyble, 2007; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005; Olivers & Meeter, 2008). In contrast to these models, however, the dual-task interaction model suggests that temporal selective attention produces a brief perceptual enhancement that is not restricted to the target itself, the spatial location of the target, or its modality. This broad boost in perceptual processing should increase the likelihood that behaviorally relevant items and their context are processed before they are masked by subsequent stimuli. Its existence is supported by several lines of evidence indicating that the enhancement is selective for information coinciding with the target, but occurs across modalities and probably also across locations (see Swallow & Jiang, 2013 for a review).

The close relationship between the attentional boost effect and target detection is consistent with the proposal that the boost is related to phasic activity in the LC-NE system (Swallow & Jiang, 2013). LC neurons transiently increase their firing rate after a target is presented and before a manual button press is made (Aston-Jones & Cohen, 2005). Making targets more difficult to distinguish from distractors delays both manual responses and phasic LC-NE activity. However, phasic LC-NE activity is similar in magnitude for easy and difficult targets and consistently occurs 100–200 ms before the manual response is executed (Aston-Jones & Cohen, 2005; Rajkowski et al., 2004). This pattern suggests that, like the attentional boost effect, the LC-NE response is closely tied to the categorization of an item as a target.

It seems unlikely that there is anything particularly important about items that have been labeled targets by an experimenter. Rather, we believe the key feature of what we have called a target is that it requires a response, resulting in a change in the participant's task state. Responses include overt and covert execution of an activity and the cancellation of a planned behavior (e.g., when most items require a button press, but a rare item does not). Consistent with this possibility, memory is enhanced for faces that do not require a button press, but only if they appear in a stream of faces that usually do require a button press (e.g., the face is a no-go cue; Makovski et al., 2013). Moreover, phasic LC-NE activity occurs following a variety of events that require a perceptual or cognitive shift (e.g., changes in reward contingencies or the occurrence of novel and unexpected stimuli should trigger a change in behavior). Data such as these have led to the proposal that the phasic LC-NE response resets functional networks, allowing them to more accurately represent the current situation (Corbetta, Patel, & Shulman, 2008; Sara, 2009). Consistent with this possibility, events that signal a change in a task, such as auditory target tones (e.g., a button press or no go cue), trigger broad increases in the activity of early visual cortex (visual targets elicit similar activity in auditory cortex; Jack, Shulman, Snyder, McAvoy, & Corbetta, 2006; Swallow et al., 2012).

The current study also may have important implications for how perceptual resources are used when multiple stimuli are presented (Lavie, 1995; Lavie & Tsal, 1994; Treisman, 1969). Despite being more difficult to detect, targets that were high in perceptual load produced an attentional boost effect that was similar in magnitude to that produced by low perceptual load targets. Although this is a null finding, it deserves consideration for several reasons. The first is that the same load manipulation impaired memory for images that coincided with distractors in Experiment 1. Whereas distractors that matched the target in color produced interference (Experiment 1), targets that matched the distractor in color did not (Experiments 2 and 3, see Figure 3). Further, visual search data demonstrated that distractors that match targets in color produce inefficient visual search. The second is that it replicated in two groups of participants and when the images were ignored. These data converge to a surprising conclusion: that increasing the perceptual resources needed to identify a target does little to interfere with encoding the concurrently presented object.

The assumption that perceptual processes are limited occurs throughout the attention literature. Indeed, one prominent account of how attention influences which information is processed claims that all available perceptual resources are used even if it results in poorer performance (Lavie, 1995; Lavie & Tsal, 1994; Treisman, 1969). This claim implies that increasing the perceptual load of the target should always reduce resources available for encoding the concurrent image. The finding that it does not suggests one of two possibilities. The first is that target detection rapidly increases the amount of perceptual resources that are available. Such an increase would need to be much faster and more temporally specific than changes because of alerting and arousal (Posner & Boies, 1971; Swallow & Jiang, 2011). The second possibility is that enhancements to image encoding that facilitate long-term memory may be offset by interference to other, as yet undetermined aspects of perceptual processing. Research confirming the lack of an effect of the target's perceptual load on image encoding and the nature of the enhancements that they produce is needed to better account for these data.

Open Questions

As suggested by the theoretical implications of this study, the present results raise several additional questions about the nature of the attentional boost effect and perceptual processing. First among these is the nature of the encoding enhancement itself. The experiments presented here used long-term memory to evaluate whether certain conditions produce an attentional boost effect. However, an increasing variety of measures have been used to evaluate the effect of target detection on perceptual encoding, including perceptual priming and visual adaptation (Pascucci & Turatto, 2013; Spataro et al., 2013). It will be important for future efforts to evaluate whether our findings generalize to these other measures.

A related consideration is the timecourse of the attentional boost effect. In previous experiments we observed that the effect occurs for images that are presented for 100 ms, but only if they coincided with the target (Swallow & Jiang, 2011). These data are important for two reasons. First, they demonstrate that the enhancement does not reflect cuing and alerting effects that develop over longer periods of time (e.g., Posner & Boies, 1971). Second, they show that the enhancement is temporally precise and is limited to perceptual information presented within 100 ms of the target's presentation (and before interference effects like the attentional blink, Raymond, Shapiro, & Arnell, 1992). However, both points suggest a need for additional research exploring the timecourse of the attentional boost effect. If the enhancement reflects the decision that an item is a target, then it likely influences processes that occur later, rather than earlier in perception (i.e., facilitating the processing of representations that already exist in some form, Swallow & Jiang, 2011).

Experiments 2 and 3 also point to the need for additional research examining the stability and reliability of the attentional boost effect for task-irrelevant background information. Although the claim that task-relevance modulates the magnitude of the attentional boost effect is consistent with the available data, other measures, like priming (cf. Spataro et al., 2013), may be more sensitive to its effects. Therefore, they may be better suited for examining this question in the future.

The dual-task interaction model makes additional claims that were not tested in the current set of experiments. According to this model, the long-term memory data reflect the combination of two effects: Interference because of capacity limitations in perceptual and cognitive processing, and facilitation because of a boost triggered by the decision that an item is a target. The suggestion that categorizing an item as a target produces the attentional boost effect predicts that the effect should occur for false alarms, but not for misses. In the current study the images were presented three times, mitigating the effects of detection errors on the data (that were already low) and reducing ambiguity about when processes associated with target detection were engaged. However, future research that presents images for a single time could examine whether the attentional boost effect occurs for false alarms, but not for misses and provide a critical test of the dual-task interaction model.

In addition, it will be important for future research to test whether the interference and boost effects incorporated into the dual-task interaction model are truly independent. One way to do this, adopted by the current study and others (e.g., Swallow &

Jiang, 2010), is to directly manipulate the amount and type of interference produced by the target detection task (e.g., by varying the perceptual load of the detection task and overall dual-task interference effects). Another complimentary approach would be to examine interference effects in situations in which the detection-related boost should not be observed. For example, if the attentional boost effect reflects phasic responses of the LC-NE system to targets, then it should be modulated by overall levels of arousal (Aston-Jones & Cohen, 2005). However, the neural source of the attentional boost effect is currently unknown. The data from Experiments 1–3 tie it closely to the decision that an item is a target, circumstantially linking it to the LC-NE system. The data are also consistent with a source that relies on central resources and therefore can be disrupted by increasing cognitive load.

Conclusions

The attentional boost effect represents perhaps the only situation in which increasing attention to an item boosts, rather than impairs, performance in a second task. Consistent with the dual-task interaction model, this boost is closely tied to the decision that an item is a target and requires a response. It is also likely to occur alongside central, but not perceptual, interference effects that are typically observed in dual-task performance. The close relationship between this boost and target detection suggests that it could be generated by the phasic LC-NE response to targets, though additional research is needed to test this possibility.

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