

Goal-relevant events need not be rare to boost memory for concurrent images

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Abstract In the attentional boost effect, memory for images presented at the same time as unrelated targets (e.g., an orange square) is enhanced relative to images presented at the same time as distractors (e.g., a blue square). One difficulty in understanding the nature of this enhancement is that, in most experiments demonstrating the attentional boost effect, targets have been less common than distractors. As a result, the memory enhancement associated with target detection may have been driven by differences in the relative frequencies of targets and distractors. In four experiments, participants encoded images into memory at the same time that they monitored a second, unrelated stimulus stream for targets. In some conditions, targets were as common as distractors (1:1 ratio); in others, targets were rare (1:6 ratio). The attentional boost effect was present when the target and distractor frequencies were equated, ruling out oddball and distinctiveness effects as explanations. These effects were observed when targets required a buttonpress and when they were covertly counted. Memory enhancements were not observed for images presented at the same time as rare distractor stimuli. We concluded that selectively attending to events that require an overt or covert response enhances the processing of concurrent information.

Keywords Attention · Long-term memory · Dual-task processing · Attentional boost effect

The modern world is full of situations in which it is necessary to divide attention across multiple sources of

information and to perform more than one task at once, often over long periods of time. The attentional demands of such tasks are likely to vary over time, both as a result of changes in task difficulty and in response to the need to selectively attend to a particular object. Decades of work on dual-task performance and selective attention has provided clear and robust evidence that dividing attention across multiple tasks and stimuli impairs performance (Kahneman, 1973; Kinchla, 1992; Pashler, 1994), and that selective attention to one object often temporarily interferes with the ability to process other objects (Duncan, 1980; Dux & Marois, 2009; Raymond, Shapiro, & Arnell, 1992).

However, an increasing number of reports have suggested that the relationship between selective attention and dual-task performance may not simply be one of give and take. In one set of studies, participants were asked to encode a series of briefly presented images into memory. At the same time, they performed a target detection task on a second stimulus stream (e.g., searching for a white square in a stream of black squares; Swallow & Jiang, 2010). Some images were presented at the same time as targets, and other images were presented at the same time as distractors. This task required participants to divide attention across two tasks and required greater attention when a target appeared for the detection task (Duncan, 1980; Swallow & Jiang, 2010; Wolfe, Butcher, Lee, & Hyle, 2003). As a result, interference should have been greatest for those images that were presented at the same time as the target in the second stimulus stream. However, the opposite pattern was observed: Images that were presented at the same time as a target were recognized better than images presented at the same time as a distractor. This finding has been replicated with a variety of encoding and detection stimuli (Swallow & Jiang, 2010). It has been observed in measures of long-term memory, source memory, and short-

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term memory (Lin, Pype, Murray, & Boynton, 2010; Makovski, Swallow, & Jiang, 2011; Swallow & Jiang, 2010, 2011). Because these data suggest that increasing attention to the detection task when a target appears boosts performance on the second encoding task, this phenomenon has been referred to as the *attentional boost effect* (Swallow & Jiang, 2010). Similar effects have been observed in perceptual learning, with targets in one stimulus stream increasing later sensitivity to the perceptual features of task-irrelevant unattended background stimuli (*task-irrelevant perceptual learning*; Seitz & Watanabe, 2003).

In studies demonstrating an effect of target detection on processing unrelated information, targets have differed from distractors in several ways. Primary among these has been the targets' relevance to the current task. By definition, targets were events that signaled the need to generate a response, either by pressing a button or by updating working memory. Either target identity was reported at the end of a trial (Lin et al., 2010) or a manual response was made when a target was detected (Makovski et al., 2011; Swallow & Jiang, 2010, 2011). As a result, Swallow and Jiang (2010, 2011) and Lin et al. (2010) focused on the behavioral relevance of targets in their discussion of the effect. In particular, Swallow and Jiang (2010, 2011) suggested that detecting goal-relevant events may trigger an attentional orienting response that regulates the processing and encoding of perceptual information. According to this account, detecting goal-relevant events (such as the appearance of a target in a stream of distractors) orients attention to the moment in time that the event occurred.

Although discussions of the attentional boost effect have focused on the goal relevance of target events, it is also important to investigate whether other factors that distinguish targets from distractors play a central role in the effect. Of foremost importance would seem to be the fact that targets were less common than distractors in most studies that have shown target-detection-related enhancements of encoding. Trial frequency for targets and distractors was as high as 1:10 in Swallow and Jiang (2010, 2011), 1:16 in Lin et al. (2010), and 1:4 in Seitz and Watanabe (2003; Watanabe, Náñez, & Sasaki, 2001). The relatively low frequency of targets in these tasks made it possible that processes associated with detecting rare or distinctive events might have contributed to their associated memory enhancements. Indeed, rare, novel, and distinctive events, even those that are not perceptually distinctive, have long been known to influence encoding and long-term memory. In the isolation effect, long-term memory for a word is enhanced if the word perceptually or semantically differs from other words presented during the same encoding session (Fabiani & Donchin, 1995; Geraci & Rajaram, 2004; Hunt, 1995; Hunt & Lamb, 2001; Schmidt, 1991). In addition, novel or infrequent stimuli trigger

increased cognitive processing, perhaps reflecting an orienting response to external stimuli or the encoding of that information into memory (Donchin & Coles, 1988; Kiehl et al., 2005; Sokolov, Nezlina, Polyanskii, & Evtikhin, 2002; Tulving & Kroll, 1995).

If the attentional boost effect is largely due to memory processes triggered by rare events, then it should be absent when targets are as frequent as distractors. Four experiments were performed to evaluate this possibility. Two unrelated stimulus streams were presented simultaneously. Participants performed a detection or counting task on one stimulus stream while encoding another stream of images into memory for a later memory test. For the detection task, participants were asked to press a button as quickly as possible whenever a target was presented. Targets and distractors were intermixed throughout the task. In some conditions, targets were as frequent as distractors, while in other conditions they were relatively rare. In Experiment 1, participants monitored a centrally presented visual stream for targets (e.g., blue squares among orange squares), and the relative frequency of the target was varied across blocks. In Experiments 2 and 3, the target-to-distractor ratio was 1:1 in all blocks, and the roles of stimulus rarity and the task performed on targets were investigated. Finally, because rare auditory events appear to influence processing in ways that rare visual events do not (Van der Burg, Olivers, Bronkhorst, & Theeuwes, 2008), auditory target and distractor stimuli were used in Experiment 4. In all cases, the attentional boost effect was indexed by better recognition of images presented at the same time as an unrelated target than of images presented at the same time as a distractor. If the attentional boost effect is due to the rarity of the targets, it should be absent when targets are as frequent as distractors.

Experiment 1: Visual detection and visual encoding

Experiment 1 evaluated whether the attentional boost effect is modulated by how frequently targets are presented relative to distractors. Participants performed two tasks simultaneously. They encoded a stream of faces into memory and monitored a concurrently presented stream of colored squares for targets. Although target and distractor squares were presented at the same time as faces, the two stimulus streams were unrelated to each other. Participants were required to remember all faces, regardless of whether they were presented with a target or distractor square.

The frequency with which targets were presented relative to distractors varied across blocks. In half of the blocks, target squares were rare, with a target-to-distractor ratio of 1:6. In the other half, target squares were common, with a target-to-distractor ratio of 1:1. If the attentional boost

effect reflects processes associated with the detection of rare events, it should be absent when the target squares and distractor squares are equally frequent. In contrast, if the attentional boost effect is triggered by goal-relevant events that signal the need for an overt or covert response, it should be similar in blocks with frequent and infrequent targets.

Method

Participants A group of 13 college students completed Experiment 1 for extra course credit (4 male and 9 females, 18–21 years old). One participant was replaced due to ceiling recognition performance. The University of Minnesota Institutional Review Board approved all procedures.

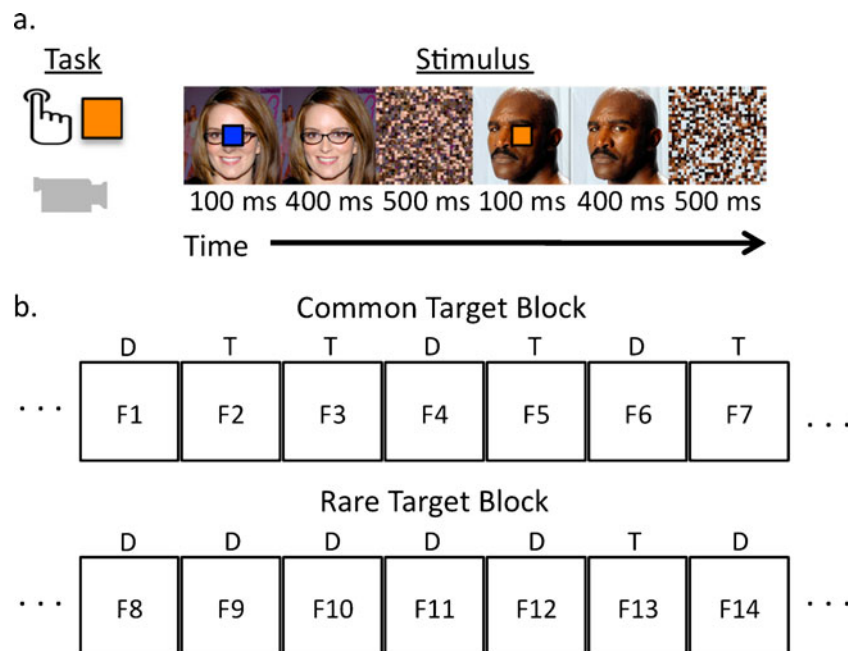
Materials A set of 280 color images ($12.7^\circ \times 12.7^\circ$ of visual angle in size) of celebrities, politicians, and sports figures was obtained through online searches. All images were photographs of recognizable individuals. For each participant, the images were randomly assigned to be 140 *old* images and 140 *new* images. An additional 14 images were used in a practice session that familiarized participants with the task and procedure. Masks were constructed by dividing each face into 1,024 pieces and randomly assigning each piece to a new location in the image.

Stimulus presentation was controlled with a MacMini Macintosh computer (Cupertino, CA) using MATLAB and the PsychToolbox (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 19-in. CRT color monitor ($1,024 \times 768$ pixels, 75 Hz) that was approximately 40 cm from the participant. Viewing distance was unrestrained.

Procedure There were two phases of the experiment. In the *dual-task encoding* phase, a sequence of trials was continuously presented to participants (Fig. 1). Each trial lasted 1 s, and the interval between trials was 0 ms. Trials consisted of a face (500-ms duration), a mask (500 ms), and a colored square (100-ms duration + 900-ms interval). The squares ($1.1^\circ \times 1.1^\circ$ in size) appeared in the center of each face for the first 100 ms of face presentation. After the square was removed from the screen, the face was presented on its own for 400 ms and then masked. The squares were either orange or blue. Participants performed two unrelated tasks. First, they encoded all of the faces into memory for a later memory test. Second, they pressed a key as quickly as possible whenever a prespecified colored square appeared (*target*). The square color assigned to the target condition was counterbalanced across participants. The trial sequence was paused every 70 trials (70 s) for a break, during which participants were given feedback on their overall speed and accuracy in the detection task. Participants performed a brief practice session of 14 trials prior to beginning the dual-task encoding phase. The practice session was divided into two 7-trial-long blocks, one in which targets were rare and one in which they were frequent. Participants were not explicitly informed of the frequency manipulation.

After completing the dual-task encoding phase of the experiment, participants performed an unspeeeded old/new recognition test on the faces. On each trial, a single face was presented at the center of the screen, and the participants pressed one of two keys to report whether they had seen the face in the encoding phase. After making the old/new response, participants rated their confidence on a

Fig. 1 Task design and stimuli used in Experiment 1. **a** Participants viewed a continuously presented series of trials that consisted of a face, its mask, and a colored square (not drawn to scale). Participants encoded all of the faces for a later memory test and pressed a key as quickly as possible whenever a target colored square (e.g., blue) appeared. **b** Trials were continuously presented in blocks of 70 trials. The target (T) to distractor (D) ratio was varied across blocks. In rare-target blocks, the target-to-distractor ratio was 1:6. In common-target blocks, the ratio was 1:1. Faces (Fs in the boxes) were assigned to appear in only one type of block and with only a target or a distractor



7-point Likert scale, with 1 indicating a *guess* and 7 indicating *absolute confidence*. Participants were instructed to use the full scale.

Design Target trials were presented with different frequencies in different blocks. Half of the blocks were *rare-target* blocks, in which one target appeared for every six distractors (1:6 ratio). The other half of the blocks were *common-target* blocks, in which half of the trials contained a target and half contained a distractor (1:1 ratio). To ensure that the global trial frequency was faithfully reflected in local trial statistics, one target appeared in each of 35 two-trial-long subblocks in the common-target condition. In the rare-target condition, one target appeared in each of 10 seven-trial-long subblocks. This constrained the number of distractors that could appear in a row to two in the common-target condition and twelve in the rare-target condition. No more than two targets could appear in a row in either condition.

For each participant, 70 faces were randomly assigned to the rare-target blocks (10 faces presented with the target squares and 60 with the distractor squares). An additional 70 faces were assigned to the common-target blocks (35 with the target squares and 35 with distractor squares). This design equated the numbers of to-be-remembered faces in the rare-target and common-target conditions, but varied the frequency with which faces appeared at the same time as target colored squares. The random assignment of faces to each condition ensured that there was no systematic relationship between a face and whether it appeared with a target or distractor or in a particular type of block.

There were 16 blocks of 70 trials each, 8 in the rare-target condition and 8 in the common-target condition. Block assignments were randomized, with the constraint that no more than two consecutive blocks were assigned to the same condition. All images were presented once per block and were shown again in the subsequent 7 blocks of a given condition. The condition of an image was consistent across image presentations (e.g., an image assigned to the rare-target ratio, distractor-square condition always appeared with a distractor square in rare-target blocks). Images were repeated across blocks to ensure that recognition performance was not at floor.

Results and discussion

Detection task performance Trials on which no response was made within 1 s of a target colored square (before the next trial) were classified as misses. Responses were counted as false alarms if they were made more than 200 ms into a distractor trial. The hit rates in the visual target detection task were similar for rare and common targets [rare targets, $M = .98$, $SD = .01$; common targets, $M = .99$, $SD = .01$; $t(12) = 1.75$, $p = .1$].

However, increasing target frequency led to more false alarms [rare targets, $M = .005$, $SD = .005$; common targets, $M = .022$, $SD = .018$; $t(12) = -3.84$, $p = .002$] and faster responses [rare targets, $M = 394$ ms, $SD = 25$, max = 424 ms; common targets, $M = 355$ ms, $SD = 18$, max = 381 ms; $t(12) = 6.77$, $p < .01$].

Recognition memory for faces To adjust for false-positive rates in the old/new recognition decision, recognition accuracy was measured as the proportion of correctly recognized old faces (hits) minus the proportion of incorrectly recognized new faces (false recognition). Because old and new faces were tested in a random order without regard to condition, the same false-recognition rate was used for all conditions. Overall, old faces were correctly recognized at a rate of .748 ($SD = .124$), and new faces were falsely recognized at a rate of .077 ($SD = .077$). Analyses of the hit rates alone led to the same conclusions as analyses on the corrected accuracy.

If the attentional boost effect reflects processes that are specific to infrequent stimuli, it should be eliminated when targets and distractors are equally frequent. In contrast, if the attentional boost effect reflects processes that are triggered when an event signals the need to make a cognitive or behavioral response (e.g., a target stimulus in this paradigm), it should be present when targets are as frequent as distractors. As illustrated in Fig. 2, faces that were presented at the same time as visual targets were recognized better than those presented at the same time as distractors [main effect of square status (target or distractor), $F(1, 12) = 27.4$, $p < .001$, $\eta_p^2 = .7$]. More importantly, there was no evidence that the relative frequency of the target square influenced the attentional boost effect [interaction between square status and target-trial frequency, $F(1, 12) =$

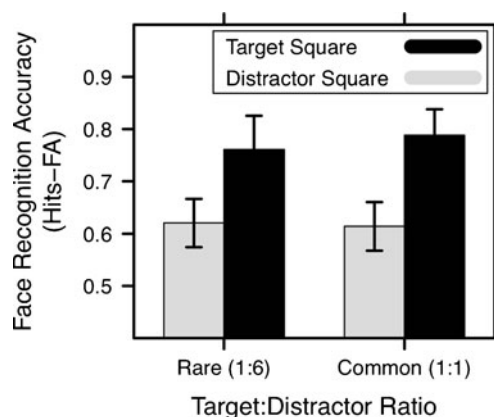


Fig. 2 Recognition test performance for images presented during the dual-task encoding phase in Experiment 1. Error bars represent the standard error of the mean

0.5, $p = .492$]. Images presented at the same time as visual targets were recognized better in both the common-target, $t(12) = 5.34$, $p < .001$, $d = 1.01$, and rare-target, $t(12) = 3.24$, $p = .007$, $d = 0.7$, conditions. The main effect of target-trial frequency was not reliable, $F(1, 12) = 0.1$, $p = .762$.

Confidence ratings for correctly recognized images followed a pattern similar to the one in the accuracy data and are reported in the [Appendix](#).

The observation that the attentional boost effect occurs both when targets are rare and when they are as frequent as distractors argues against the notion that it reflects processes triggered by rare events. In fact, Experiment 1 provided little evidence that the frequency with which targets appear has any effect on the encoding task. However, one difficulty in interpreting these data is the fact that the frequency of the target was manipulated within subjects. As a result, targets were less frequent than distractors across the entire experiment, and participants' estimates of target frequency might have been similar for rare- and common-target blocks. Even if participants distinguished between the two types of blocks, the effects of rare targets in some blocks might have influenced the way common targets were processed in the other blocks. To address these concerns, a second experiment was performed in which targets were always common. This experiment also investigated the role of the buttonpress task by varying the task participants performed in response to targets across blocks.

Experiment 2: Common targets in a counting task

To address the possibility that the presence of the rare-target blocks influenced performance in the common-target blocks of Experiment 1, Experiment 2 included only the common-target condition. The target-to-distractor ratio was 1:1 throughout the experiment. In Experiment 2, we also investigated whether the effects of processing goal-relevant events are restricted to events that require a manual response by varying the type of response participants made to target events. On some blocks, participants pressed a button when a target appeared, and on others they covertly counted the number of targets that were presented. If the attentional boost effect reflects processes associated with detecting rare stimuli, there should be no difference in memory for images presented with distractors and for those presented with targets. In contrast, if the effect reflects processes triggered by overt or covert responses to goal-relevant events, images presented with targets should be recognized better than those presented with distractors, both when they are counted and when they lead to a manual response.

Method

Participants A group of 14 college students completed Experiment 2 for extra course credit (5 male and 9 females, 18–22 years old). One participant was replaced due to ceiling performance in the recognition test.

Materials The stimulus set used in Experiment 1 was increased to 320 color images ($12.7^\circ \times 12.7^\circ$) of celebrities, politicians, and sports figures. Images were obtained through online searches and were photographs of recognizable individuals. For each participant, the images were randomly assigned to be 160 old images and 160 new images. An additional 64 images were used in a practice session that familiarized participants with the task and procedure.

Procedure and design The stimuli and procedures of the dual-task encoding and recognition tasks were identical to those used in Experiment 1, with the following exceptions. Targets appeared on 50% of the trials in all blocks, resulting in a consistent target-to-distractor ratio of 1:1 throughout the dual-task encoding phase. The local frequencies of targets were controlled as in Experiment 1. The participants were asked to remember all of the faces and to monitor the second visual stimulus stream for a particular prespecified colored square. The number of times each image was presented was reduced from 8 to 5.

The task that participants performed on the square varied across 50 blocks, each consisting of 6–10 target trials (the mean number of targets per block was 8). On half of the blocks, participants pressed a key as quickly as possible whenever a prespecified target colored square occurred. On the other half of the blocks, participants counted the number of times a target colored square appeared. For the counting task, participants were instructed to avoid making verbal or motor responses to the targets. Blocks were grouped into sets of 5 for the same task. Thus, the same task was performed over sets of 40 target and 40 distractor trials. There were a total of 800 trials, evenly divided across tasks and target/distractor conditions.

At the end of each block, the detection task paused to provide feedback, in the case of the detection task, or to prompt the participant to report the number of targets in the previous block for the counting task. Participants reported counts of 6, 7, 8, 9, or 10 targets by pressing the A, B, C, D, or E keys on the keyboard, respectively. Feedback on the counting response was given immediately. Participants were instructed to avoid pressing keys during the counting task. If a buttonpress was made during the counting task, feedback included a report of the number of times the button was pressed and a reminder that no buttonpresses should be made during the counting task. Participants were

given a brief instruction about which task to perform prior to each block.

As in Experiment 1, the dual-task encoding phase started with a brief practice session using different images. The number of trials in the practice session was increased to ensure that participants were able to comfortably switch between the two tasks and that they performed the counting task as instructed. An old/new recognition test on the faces was administered after participants completed the dual-task encoding phase.

Results and discussion

Detection and counting task performance Participants performed the buttonpress and counting tasks as instructed. Participants made few buttonpresses in response to distractors ($M = .009$, $SD = .008$). They quickly pressed a key in response to most targets presented during the buttonpress task ($M = .974$, $SD = .033$; response time, $M = 364$ ms, $SD = 39$) and made few manual responses to targets presented during the counting task ($M = .017$, $SD = .025$). Performance on the counting task was also high (proportion of correct responses: $M = .951$, $SD = .067$; all incorrect responses were 1 target too high or too low).

Recognition memory The mean hit (correct recognition) rate of old faces was $.716$ ($SD = .138$). The mean false-recognition rate of new faces was $.153$ ($SD = .125$). Recognition memory performance, measured as hits minus false recognition, for each of the four conditions is illustrated in Fig. 3. If the pattern of data observed in the common-target condition of Experiment 1 was due to the inclusion of rare-target blocks, then there should be no difference in memory for images presented at the same time as target or distractor squares in Experiment 2. However, images presented at the same time as targets were

recognized better than those presented at the same time as distractors, as indicated by a reliable main effect of square status, $F(1, 13) = 16.2$, $p = .001$, $\eta_p^2 = .56$. Thus, the attentional boost effect was reliably observed when targets were as common as distractors.

It has been proposed that, in contrast to target distinctiveness or rarity, the attentional boost effect reflects processes that are triggered by the occurrence of goal-relevant events that require an overt or covert response (Lin et al., 2010; Makovski et al., 2011; Swallow & Jiang, 2010, 2011). One implication of this proposal is that the effect does not depend on the production of a manual response to the targets. If this is the case, then the memory advantage for images presented with targets should be present in both the buttonpress and counting tasks. As can be seen in Fig. 3, images presented at the same time as targets were indeed recognized better than those presented with distractors in both tasks, $t_s(13) > 2.9$, $p_s < .012$, $d_s = 0.66$. There were no overall differences in memory for images across tasks, $F(1, 13) = 0.353$, $p = .563$, and task did not interact with square status, $F(1, 13) = 0.138$, $p = .716$.

The presence of the attentional boost effect in both Experiments 1 and 2 when targets were as frequent as distractors argues strongly against the proposal that this effect is due to the rarity of those events or reflects the same processes that produce the memory isolation effect. Instead, the attentional boost effect appears to be a consequence of detecting an event that requires a response. The data from Experiment 2 also provide some evidence that a manual response to a target is not necessary to produce the attentional boost effect. As in the buttonpress task, images presented at the same time as targets that were counted were better recognized than those presented at the same time as distractors. This extends a previous report of an attentional boost effect when manual responses to each target were delayed (Lin et al., 2010). Although it is difficult to rule out the possibility that participants never produced any sort of motor response to the targets (such as subvocalization of their internal counts), these data do generalize the attentional boost effect to a task for which such responses are not necessary and are less likely to be performed.

These findings also extend a recent report on the attentional boost effect in short-term memory. When participants were asked to perform a change detection task on arrays of color patches, a small memory advantage was observed for encoding displays presented with an unrelated target letter rather than a distractor letter (Makovski et al., 2011). The magnitudes of this advantage were similar when the target-to-distractor ratios were 1:4 and 1:1, but in both cases the magnitude of the effect was small (about 3%). The relatively small effect in short-term memory made it difficult to rule out the possibility that the large advantage for images presented in target displays reported in other

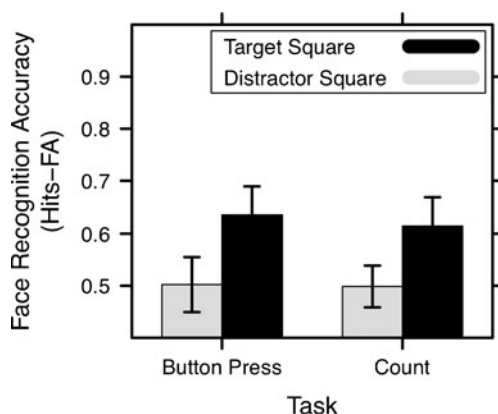


Fig. 3 Recognition test performance for images presented during the dual-task encoding phase in Experiment 2. Error bars represent the standard error of the mean

studies (e.g., Lin et al., 2010; Swallow & Jiang, 2010) was not due to mnemonic processes triggered by rare or distinctive events. The repeated observation that the attentional boost effect is present in long-term memory, even when targets are as frequent as distractors, combined with the lack of a clear interaction of target trial frequency with this effect, addresses these concerns.

Experiment 3: Rare distractors

Although the attentional boost effect occurs even when targets appear relatively frequently, it is still possible that rare or distinctive stimuli in the detection task could facilitate performance on a secondary image-encoding task. Therefore, in Experiment 3 we introduced a third type of detection stimulus. Participants monitored a stream of colored squares and pressed a button whenever the square was a target color. The target-to-distractor ratio was 1:1. However, there were two types of distractors: one that was common, appearing on 40% of the trials, and another that was rare, appearing on 10% of the trials. The attentional boost effect to common targets was further generalized by using a new set of images, everyday objects, and by reducing the number of image presentations. If rare or distinctive stimuli enhance the processing of concurrently presented information, then images presented at the same time as rare distractors should be recognized better than images presented at the same time as common distractors.

Method

Participants A group of 12 college students (1 male and 11 females, 20–23 years old) completed Experiment 3 for their choice of extra course credit or cash compensation.

Materials A set of 320 colored photographs of everyday objects ($12.7^\circ \times 12.7^\circ$ of visual angle in size) was obtained from Tim Brady's website (Brady et al., 2008). We used everyday objects rather than faces to generalize the data to a new stimulus set and to permit fewer image presentations (preliminary data showed that face memory was very poor with only a few image presentations). For each participant, the images were randomly assigned to be 160 old objects and 160 new objects. Masks were constructed by dividing each image into 1,024 pieces and randomly assigning each piece to a new location in the image. The squares were colored red (RGB: [240 38 0]), blue [3 52 255], or green [0 140 0]). These colors were chosen to meet the constraints that they be relatively equidistant on the color wheel while maintaining equiluminance (RGB values were determined

using a program that adjusts the red–green–blue components of two rapidly alternating colors until the screen appears steady rather than flickering).

Procedure and design Experiment 3 was similar to the common-target condition of Experiment 1. As before, each 1,000-ms-long trial in the dual-task encoding phase included an image (500 ms), a colored square (100 ms), and a mask (500 ms). Participants were instructed to encode the images into memory and to press a button as quickly as possible whenever a target square of a prespecified color appeared. Distractor squares could appear in two different colors, one that appeared relatively frequently (*common distractors*) and one that appeared relatively rarely (*rare distractors*). The target-to-common-distractor-to-rare-distractor ratio was 5:4:1. The colored squares assigned to each condition were counterbalanced across participants.

For each participant, 80 old objects were randomly assigned to the target condition, 64 were randomly assigned to the common-distractor condition, and 16 were randomly assigned to the rare-distractor condition. All images were presented three times, with the color of the square (and the corresponding condition) that appeared at the same time as the image held constant across presentations. The resulting 480 trials were evenly divided into six blocks of 80 trials (80 s per block). Half of the images were shown in each block, and all images were shown before any images were repeated. Participants were given a break between blocks, as well as feedback on the speed and accuracy of their buttonpresses in response to targets. False alarms were also reported.

Following the dual-task encoding phase, participants were given an old/new recognition memory test on the objects. Feedback was provided after each trial and at the end of the experiment.

Results and discussion

Detection task performance Participants quickly and accurately responded to the targets in the detection task (hit rate, $M = .981$, $SD = .022$; median response times, $M = 383$ ms, $SD = 54$). The false alarm rate was low ($M = .03$, $SD = .018$), and the rates were similar on common-distractor ($M = .03$, $SD = .022$) and rare-distractor ($M = .035$, $SD = .035$) trials, $t(11) = 0.43$, $p = .679$.

Recognition memory Overall, the mean hit rate for old objects was $.697$ ($SD = .085$). New objects were falsely recognized at a mean rate of $.171$ ($SD = .098$). Recognition accuracy (hits minus false alarms) for images presented in the three encoding conditions is illustrated in Fig. 4.

The recognition accuracy of images of objects was reliably influenced by the status of the square (common

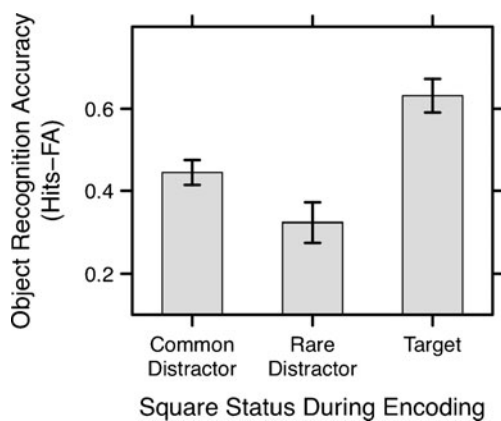


Fig. 4 Recognition test performance for images presented during the dual-task encoding phase in Experiment 3. Error bars represent the standard error of the mean

distractor, rare distractor, or target) that the image was presented with during image encoding, $F(2, 22) = 25.8$, $p < .001$, $\eta_p^2 = .7$. In this experiment, target colored squares were more frequently presented than squares in either the common-distractor and rare-distractor colors. Even so, images of objects that were presented at the same time as a target colored square were recognized better than images in the common-distractor and rare-distractor conditions, $t_s(11) > 5.79$, $ps < .001$, $ds > 1.5$. Furthermore, if rare detection stimuli can enhance memory for concurrent images, then images in the rare-distractor condition should have been recognized better than images in the common-distractor condition. The data indicate that this was not the case: Images presented with rare distractors were recognized more poorly than those presented with common distractors, $t(11) = 3.16$, $p = .009$, $d = 0.87$. Confidence ratings, reported in the [Appendix](#), followed the same pattern.

Experiment 3 replicated the observation that images presented with targets are recognized better than those presented with distractors, even when the targets are common. Moreover, it extends an earlier finding that task-irrelevant, rare stimuli do not enhance memory for concurrently presented images (Swallow & Jiang, 2010). Here, the data showed that the distinctiveness of task-relevant stimuli presented as part of the detection task is not sufficient to enhance memory for the concurrently presented image. Indeed, an interesting aspect of these data is the fact that images presented with rare distractors were actually recognized more poorly than images presented at the same time as common distractors. Rare nontarget stimuli, even those that are task-irrelevant, elicit a neurophysiological response (the P3a in electroencephalogram [EEG] measures of neural activity) that is thought to reflect the orienting of attention to novel events (Nieuwenhuis, Aston-Jones, & Cohen, 2005; Polich, 2007; Ranganath & Rainer, 2003). Therefore, one explanation for the difference

between the common- and rare-distractors conditions is that rare distractor stimuli may capture attention and divert processing resources from the encoding task. These data further distance the attentional boost effect from stimulus novelty and distinctiveness or the mnemonic processes that produce the distinctiveness effect in long-term memory.

Experiment 4: Auditory detection and visual encoding

The data from Experiments 1–3 provide clear demonstrations that a visual target need not be rare to produce a relative memory advantage for concurrently presented images. An important question to address, however, is whether the same is true for auditory targets. EEG measures of neural activity following the presentation of a novel stimulus suggest a larger, more reliable P3a response when the stimulus is auditory rather than visual (Nieuwenhuis et al., 2005). In addition, an early component of the electrophysiological response associated with detecting changes in perceptual information, the mismatch negativity, is more consistently observed for auditory than for visual stimuli (Luck, 2006). Moreover, rare auditory, but not visual, events can influence performance on visual tasks (Olivers & Van der Burg, 2008; Van der Burg et al., 2008; Vroomen & de Gelder, 2000). To determine whether the attentional boost effect in response to auditory targets reflects the processing of rare or novel auditory events, this experiment replicated Experiment 1 with auditory detection stimuli.

Method

Participants A group of 13 college students completed Experiment 4 for extra course credit (3 male and 10 females, 18–22 years old). Three additional participants were replaced due to recognition test performance that was at chance in 1 case and perfect in 2 others.

Procedure and design The dual-task encoding and recognition tasks were identical to those used in Experiment 1, with the exception that the colored squares were replaced with auditory tones. On each trial in the dual-task encoding phase, an auditory tone that was either low (350 Hz) or high (650 Hz) in pitch was played for the first 100 ms of face presentation (Fig. 5), followed by 900 ms of silence. Participants were asked to remember all faces and also to press a key as quickly as possible whenever a prespecified target tone occurred. The auditory tone assigned to the target condition was counterbalanced across participants (high tones for 7 of the participants, and low tones for the remaining 6). Other aspects of the experiment were the same as in Experiment 1.

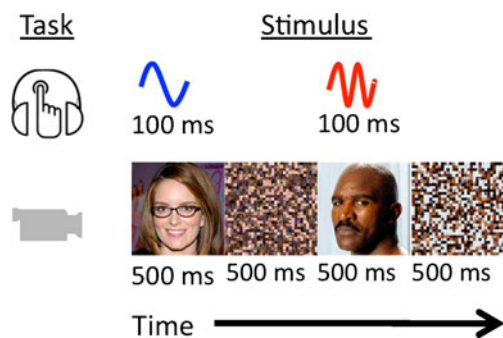


Fig. 5 Tasks and stimuli used in Experiment 4. The design of this experiment was identical to that used in Experiment 1, save for the 100-ms presentation of a high- or low-pitched auditory tone at the beginning of each trial. Participants encoded the faces into memory and pressed a key as quickly as possible whenever a prespecified target tone (such as the low tone) occurred

Results and discussion

Detection task performance Participants responded to most of the target tones in the detection task (rare-target blocks, $M = .988$, $SD = .012$; common-target blocks, $M = .978$, $SD = .022$). There was a trend for poorer target detection in the common-target block, $t(12) = 1.82$, $p = .09$. The false alarm rate was also low (rare-target blocks, $M = .007$, $SD = .007$; common-target blocks, $M = .041$, $SD = .04$), though it was significantly higher in the common-target than in the rare-target blocks, $t(12) = -3.34$, $p = .006$. Response times were slower in the rare-target blocks (rare-target blocks, $M = 361$ ms, $SD = 40$, $\max = 438$; common-target blocks, $M = 342$ ms, $SD = 43$, $\max = 409$), $t(12) = 2.76$, $p = .02$.

Recognition memory Overall, old images were correctly recognized at a mean rate of .797 ($SD = .118$), and new images were false recognized at a mean rate of .12 ($SD = .068$). As is illustrated in Fig. 6, images that were presented at the same time as targets were recognized better than images

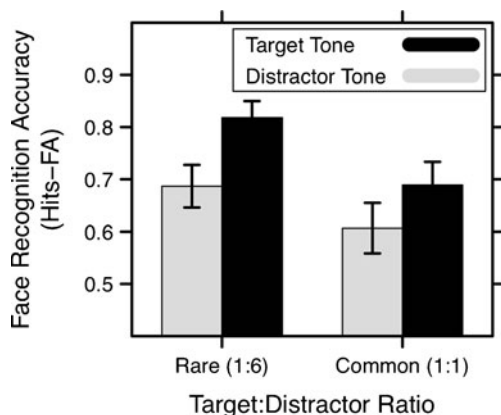


Fig. 6 Recognition test performance for images presented during the dual-task encoding phase in Experiment 4. Error bars represent the standard error of the mean

presented at the same time as distractors in both the common-target and rare-target conditions. An ANOVA indicated that the main effect of target presence and the main effect of target frequency were both reliable [main effect of targets, $F(1, 12) = 38.2$, $p < .001$, $\eta_p^2 = .76$; main effect of frequency, $F(1, 12) = 27.9$, $p < .001$, $\eta_p^2 = .7$]. Moreover, t tests confirmed that images presented at the same time as targets were recognized better than those presented at the same time as distractors in both the common-target, $t(12) = 2.97$, $p = .012$, $d = 0.49$, and rare-target, $t(12) = 5.06$, $p < .001$, $d = 1$, conditions. The interaction between tone status (target or distractor) and target trial frequency was not statistically reliable, $F(1, 12) = 1.41$, $p = .256$.

Although this was not consistent across individuals, the overall magnitude of the attentional boost effect was less in the common-target condition than in the rare-target condition. Indeed, these data provide some evidence that the frequency with which auditory, but not visual, targets occur may influence face encoding. An ANOVA on participants from Experiments 1 and 4 with detection task modality as a factor was performed to evaluate this possibility. This analysis confirmed that increasing target trial frequency had detrimental effects on face encoding when the detection stimuli were auditory, but not when they were visual, producing a reliable interaction between target trial frequency and task modality, $F(1, 24) = 8.56$, $p = .007$, $\eta_p^2 = .262$. No other interactions were reliable [target–distractor \times trial frequency interaction, $F(1, 24) = 0.06$, $p = .812$; target–distractor \times modality interaction, $F(1, 24) = 2.14$, $p = .156$; target–distractor \times trial frequency \times modality interaction, $F(1, 24) = 1.73$, $p = .201$], nor was the main effect of modality, $F(1, 24) = 0.005$, $p = .943$.

The differences in the effect of target frequency in the auditory and visual modalities raises the possibility that, when targets are presented in the auditory modality, their frequency may contribute in part to the attentional boost effect. This possibility seems particularly important, given the effects of rare auditory events on visual processing (Olivers & Van der Burg, 2008; Van der Burg et al., 2008; Vroomen & de Gelder, 2000). For example, in the pip-and-pop effect, a single, rare auditory tone facilitates performance on a visual search task (Van der Burg et al., 2008). The pip-and-pop effect compares visual processing when an auditory tone is present to visual processing when no tone is present. However, it is not known whether the same effect is produced by infrequent or oddball tones presented in a stream of standard tones. If it is, this effect could potentially contribute to the attentional boost effect in the low-frequency blocks.

Alternatively, the nonsignificant reduction in the magnitude of the attentional boost effect in the common-target condition could be related to greater dual-task demands in that condition. Indeed, face recognition was significantly

worse in the common-target than in the rare-target condition. Previous neuroimaging data have shown decreased activation in visual areas when attending to both visual and auditory information (relative to visual information alone; Johnson & Zatorre, 2006; Loose, Kaufmann, Auer, & Lange, 2003), and behavioral data have demonstrated cross-modal interference effects in selective attention (e.g., Arnell & Duncan, 2002; Jolicoeur, 1999). Increasing the difficulty of the detection task could interfere with the attentional boost effect (Swallow & Jiang, 2010), decreasing the magnitude of the effect when auditory targets are relatively common rather than rare.

General discussion

Previous reports of the attentional boost effect have demonstrated that detecting targets that occasionally appear in a stream of distractors enhances memory for concurrently presented but unrelated stimuli (Lin et al., 2010; Makovski et al., 2011; Swallow & Jiang, 2010, 2011). Data from the four experiments reported here indicate that these enhancements are not specific to rare targets. Memory for faces presented concurrently with a target was enhanced even when the targets were as frequent as distractors. This pattern was observed when the targets and distractors were either visual or auditory, when targets were common throughout the encoding session, and when participants responded to targets by counting them rather than by pressing a button. The only reliable effect of increasing target frequency was an overall reduction in face recognition when people also monitored auditory tones. This observation is consistent with behavioral and neurophysiological evidence of interference across stimulus modalities (Arnell & Duncan, 2002; Johnson & Zatorre, 2006; Jolicoeur, 1999; Loose et al., 2003). Finally, rarity was not associated with a memory enhancement when the rare stimulus was a distractor. The attentional boost effect is more clearly related to processes that are triggered by events that signal the need for an overt or covert response than it is to distinctiveness or oddball processing.

The finding that the attentional boost effect is preserved for common targets has important implications for identifying its neural and cognitive mechanisms. Detecting goal-relevant events, such as targets, could influence memory at one or multiple stages of memory formation, including the amount of attention that is directed to the images, how the images are encoded into memory, the organization of memory representations of the encoding task, and finally how those images are retrieved from memory during the memory test. The data from Experiments 1 to 4 argue

against certain mnemonic processes that underlie distinctiveness effects in long-term memory. The isolation effect is a recall (and sometimes recognition) memory advantage for items in a to-be-memorized list that are either perceptually or conceptually distinct from the other items on the list (Fabiani & Donchin, 1995; Geraci & Rajaram, 2004; Hunt, 1995; Hunt & Lamb, 2001; Schmidt, 1991). Although the isolation effect may partially reflect attentional orienting, many theories have also focused on differences in the way isolated words are encoded into, organized in, and retrieved from memory (Fabiani & Donchin, 1995; Geraci & Rajaram, 2004; Hunt & Lamb, 2001; Schmidt, 1991). It has been suggested that the isolated words are stored in separate, smaller clusters of items in memory than the nonisolated words, and as a result are more completely retrieved from memory (Bruce & Gaines, 1976; Fabiani & Donchin, 1995). In addition, Hunt and Lamb (2001) proposed that the isolation effect reflects greater item-specific processing of the isolated words than relational processing during encoding. However, when targets were as frequent as distractors, item-specific processing, relational processing, and cluster sizes in episodic memory should have been similar for images presented with targets and images presented with distractors. Moreover, the data from Experiment 3, which showed that rare events in one task do not always produce an attentional boost effect, suggest that the isolation effect does not necessarily spread from the rare stimulus to other concurrently presented stimuli. Because the attentional boost effect does not appear to depend on the targets being relatively rare events, it is less likely that mnemonic mechanisms that facilitate memory for rare or isolated events are also critical for the attentional boost effect.

How does target detection enhance memory for unrelated images?

One initial study that described the attentional boost effect was designed to investigate the effect of task-relevant changes in events, and in one's own activity, on concurrent perceptual processing (Swallow & Jiang, 2010). Task-relevant changes in events were operationalized as the occasional appearance of a stimulus that required a response (a target) in a stream of stimuli that required no response (distractors). In this design, a target clearly represented an unpredicted change from the preceding context that required a change in the participant's activity. Indeed, better memory for images presented at the same time as a target is consistent with behavioral, neuroimaging, and theoretical work that has suggested that unpredicted changes in ongoing events are associated with increased

processing of and sensitivity to incoming perceptual input (Boltz, 1992; Newton & Engquist, 1976; Swallow, Zacks, & Abrams, 2009; Zacks et al., 2001; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). As in this initial study, targets in other tasks that produce an attentional boost effect are distinguished from distractors in that they signal that the participants' activity (or lack thereof) cannot continue as before (Lin et al., 2010; Makovski et al., 2011; Swallow & Jiang, 2011). They are events that require additional processing (e.g., selection, verification, decision processes, or memory updating) to generate an appropriate response. However, the observation that the attentional boost effect is similar when targets are as frequent as distractors raises the question of which features of participants' cognitive and behavioral response to targets are important for generating the attentional boost effect.

Within the context of the encoding task used in this study, targets differed from distractors in that detecting a target required selective attention and the engagement of processes that led to an appropriate response. Along these lines, we have proposed that the attentional boost effect reflects a temporal attentional orienting response to the moment in time that the target was presented (Swallow & Jiang, 2011). In a series of experiments that manipulated the relative onsets of targets, distractors, and the images, only those images that both were task-relevant and overlapped with a target in time were later better remembered. In one experiment, images that were presented 100 ms after the target were not recognized better than images presented after a distractor. The attentional boost effect therefore does not appear to reflect prospective attentional cuing to the image or alerting effects in response to a target. In another experiment, no memory enhancement occurred for images that appeared shortly before a target but did not overlap with it in time. Images that are highly predictive of targets were not enhanced, suggesting that the attentional boost effect is not due to predictive learning. Rather, the enhancements associated with the attentional boost effect are selective for the moment in time that the target was presented. Finally, images presented on their own (without a target or distractor square) were remembered as well as images presented at the same time as a distractor, arguing against the possibility that distractor rejection inhibits processing of the concurrent image. Thus, the attentional boost effect could reflect a processing enhancement of task-relevant perceptual information that coincides with events that require a cognitive or behavioral response.

The available data do not allow for more than speculation about the underlying mechanisms of the attentional boost effect. However, one neurophysiological system, the

locus coeruleus–norepinephrine (LC-NE) system, is closely tied to target detection and attention. Indeed, it has been proposed that the transient LC-NE response to targets facilitates the production of an appropriate response to a target by acting as a temporal attentional filter (Aston-Jones & Cohen, 2005; Nieuwenhuis et al., 2005) or by facilitating the updating of neural representations to produce a cognitive shift (Bouret & Sara, 2005). In addition to the LC-NE response, targets also elicit a closely related neurophysiological response known as the *P3b* in EEG measures of neural activity (Donchin & Coles, 1988; Nieuwenhuis et al., 2005; Pritchard, 1981). Although the *P3b* and the LC-NE response are often characterized as reflecting responses to rare or unexpected events, they occur even when target stimuli are frequent (Aston-Jones & Cohen, 2005; Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994; Duncan-Johnson & Donchin, 1977; Nieuwenhuis et al., 2005). The preservation of the memory enhancement when targets were common in Experiments 1–4 may therefore be consistent with a role of the LC-NE system (and the *P3b*) in the attentional boost effect. However, unlike the LC-NE response and the *P3b*, the magnitude of the enhancement did not reliably decrease as target frequency increased. Future research will need to directly examine the relationship between the attentional boost effect, the *P3b*, and the LC-NE response to target events.

Conclusion

When performing two tasks at once, performance in one task usually suffers as the other task demands more attention. However, the data reported here and elsewhere show that selectively attending to an item is not always detrimental to the ability to process other information. Rather, in the attentional boost effect, detecting a target in one stimulus stream facilitates the encoding of concurrent and unrelated information into memory. Four experiments demonstrated that these enhancements occur both when targets are rare and when they are as frequent as distractors, ruling out processes that are specific to rare or distinctive events. Thus, the attentional boost effect may reflect the orienting of attention to the moments in time when a stimulus indicates that an appropriate cognitive or behavioral response is necessary.

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Appendix: Statistical analyses of confidence ratings for correct old/new responses

Experiment 1

Like recognition accuracy, confidence ratings were greater for correctly recognized images that were presented along with targets, relative to those presented along with distractors, $F(1, 12) = 30.7, p < .001, \eta_p^2 = .719$. Overall, there was a trend for lower confidence ratings for images presented in the common-target blocks, $F(1, 12) = 3.6, p < .082, \eta_p^2 = .231$. However, the effect of targets on confidence ratings did not interact with target trial frequency, $F(1, 12) = 0.16, p = .694$. See Table 1.

Table 1 Mean confidence ratings for correctly recognized images in Experiment 1

	Rare Target		Common Target		New Images
	Distractor	Target	Distractor	Target	
Confidence	6.5 (0.41)	6.8 (0.23)	6.44 (0.43)	6.69 (0.34)	5.77 (1.05)

Standard deviations are in parentheses

Experiment 2

As with recognition accuracy, confidence ratings were greater for correctly recognized images presented with targets than for those presented with distractors, $F(1, 13) = 16.5, p = .001, \eta_p^2 = .56$, in both the buttonpress and counting tasks, $t_s(13) > 2.28, ps < .04, ds > 0.22$. Confidence ratings were lower for images presented with distractors in the counting task, $t(13) = 2.42, p = .03, d = 0.37$, resulting in a marginal main effect of task, $F(1, 13) = 2.98, p = .108, \eta_p^2 = .187$, and a reliable interaction between task and square type, $F(1, 13) = 8.8, p = .011, \eta_p^2 = .403$. See Table 2.

Table 2 Mean confidence ratings for correctly recognized images in Experiment 2

	Buttonpress		Count		New Images
	Distractor	Target	Distractor	Target	
Confidence	6.04 (0.8)	6.22 (0.82)	5.74 (0.82)	6.2 (0.8)	5.31 (1.04)

Standard deviations are in parentheses

Experiment 3

Confidence ratings for correctly recognized objects followed the same pattern as recognition accuracy; they were highest for old objects presented with targets ($M = 6.57,$

$SD = 0.5$), and lowest for old objects presented with rare distractors ($M = 6.13, SD = 0.9$; common distractors, $M = 6.33, SD = 0.69$; new images, $M = 5.92, SD = 0.85$). This resulted in a main effect of square status on confidence ratings, $F(2, 22) = 5.79, p = .01, \eta_p^2 = .34$. The differences in ratings for old objects presented with targets versus those presented with common and rare distractors was reliable, $t_s(11) > 2.38, ps < .041, ds > 0.39$. The difference in ratings for images presented with rare distractors versus those presented with common distractors was marginal, $t(11) = -1.89, p = .085, d = -0.24$.

Experiment 4

Confidence ratings for correct recognition responses followed the same pattern as the accuracy data: higher confidence for images presented with target tones rather than distractor tones, $F(1, 12) = 5.86, p = .032, \eta_p^2 = .33$, and higher confidence for images presented in the rare-target blocks, $F(1, 12) = 6.42, p = .026, \eta_p^2 = .35$. As with recognition accuracy, the effect of tone status (target or distractor) on confidence ratings did not interact with target trial frequency, $F(1, 12) = 0.11, p = .744$. See Table 3.

Table 3 Mean confidence ratings for correctly recognized images in Experiment 4

	Rare Target		Common Target		New Images
	Distractor	Target	Distractor	Target	
Confidence	6.6 (0.41)	6.8 (0.32)	6.39 (0.39)	6.64 (0.28)	5.54 (0.76)

Standard deviations are in parentheses

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