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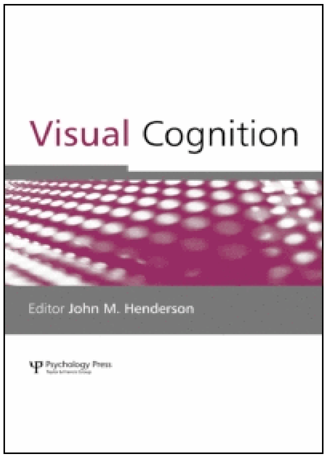

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Masked-target recovery requires focused attention on the target object

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Flashing a homogeneous light mask after the presentation of a masked target reduces the deleterious effects of the mask, a phenomenon often called target recovery. Target recovery has been studied using masking paradigms in which a target object is presented in isolation prior to the presentation of a mask, thus capturing attention. In the present study, we examined whether target recovery is possible when a target does not benefit from attentional capture. We hypothesized that target recovery would be eliminated when a target must compete with distractors for perceptual attention. Replicating classic studies, we observed target recovery when pattern and light masks followed an isolated target. However, target recovery was not observed when a light mask followed a masked visual search target. Furthermore, using an attentional-capture paradigm we found that sudden onset search targets were recoverable whereas nononset targets were not. The present findings indicate that attentional capture by a target prior to masking plays a critical role in the subsequent recovery of the target.

Almost a century's worth of research has used masking paradigms as tools to study the limits of visual processing. Classic studies of visual masking demonstrated that presenting a task-irrelevant masking stimulus very near a task-relevant target object in space and time interferes with the processing of the target (for reviews see Kahneman, 1968; Raab, 1963). Surprisingly, a number of studies report that the deleterious effects of a mask on an observer's ability to discriminate a target can largely be negated by the

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subsequent presentation of another stimulus (Dember & Purcell, 1967; Dember, Schwartz, & Kocak, 1978; Robinson, 1966, 1968; Schiller & Greenfield, 1969; Tenkink & Werner, 1981). This effect, known as target recovery or disinhibition, appears to be reliably obtained in backward masking paradigms although its theoretical explanation has yet to be agreed upon (e.g., Briscoe, Dember, & Warm, 1983). This phenomenon has been studied in the context of canonical pattern and metacontrast backward masking paradigms in which the target object is presented in isolation. However, we know that targets presented in isolation capture visual-spatial attention (e.g., Jonides & Yantis, 1988). It is possible that masked target recovery is dependent upon the target enjoying the benefits of focused attention given that attention has been shown to influence other masking effects (Enns & Di Lollo, 2000; Francis, 2003). In the present study, we sought to test the hypothesis that a target that captures perceptual visual-spatial attention can be recovered unlike a target that must compete for attention.

Visual masking has been used as a tool to study many facets of visual cognition. For example, masking paradigms have been used to reveal certain aspects of the formation of memory representations (e.g., Potter, 1976), whether attention selects objects or locations (e.g., Duncan, 1984), and the activation of semantic information in long-term memory by undetected stimuli (e.g., Marcel, 1983). However, our understanding of when masking is observed and theories of the underlying causes of masking continue to evolve (e.g., Di Lollo, Enns, & Rensink, 2000; Francis, 2003). The recent demonstration that visual search targets can be masked by strikingly low energy four-dot stimuli is one of such empirical findings that continue to challenge existing theories of masking (Enns & Di Lollo, 2000).

In the study of Di Lollo et al. (2000) target shapes were rendered unreportable by presenting a mask simultaneously with a visual search array and having the masking dots remain visible after the brief search array presentation. In addition, they found that the effectiveness of the four-dot mask was set size dependent. When the target was the only item present in the stimulus array, little or no masking was observed. It appears that, in order for substitution masks to be effective, the stimulus array containing the target needs to contain multiple objects that compete for perceptual attention. Supporting this notion are experiments demonstrating that the effectiveness of substitution masks can be negated by drawing an observer's attention to the target location with a spatial precue (e.g., Di Lollo et al., 2000; Neill, Hutchison, & Graves, 2002). Thus, object-substitution masking requires a diffuse deployment of attention across the possible target objects. This finding is notable because a competition for attention is not a necessary component of previously studied masking paradigms, although recent work suggests that attention can modulate the effect size of other forms of backward masking (Ramachandran & Cobb, 1995; Shelley-Tremblay & Mack, 1999).

The literature also shows that the deleterious effects of classic varieties of backward visual masks (e.g., metacontrast and pattern masks) can be negated by the presentation of yet another stimulus following the mask. After vigorous study of this phenomenon several decades ago it has received little scrutiny in the last 20 years. In one of the last empirical studies of this masking effect in the literature, Briscoe and colleagues (1983) found that when a target letter ("q" vs. "p") was followed by a pattern mask, observers were at chance at discriminating the target's identity. However, if the pattern mask was followed by yet another stimulus, a circular light mask, observers' ability to discriminate the target shape drastically improved. This effect has been called disinhibition or masked-target recovery, with these terms referring to the differing explanations that the second stimulus either stops the inhibition of the target by the first mask (Robinson, 1966) or that the light mask enhances processing of the defining features of the masked target (Purcell, Stewart, & Hochberg, 1982).

Masked-target recovery has been observed in the context of metaconstrast (e.g., Schiller & Greenfield, 1969) and pattern masking paradigms (e.g., Dember et al., 1978), and is found when the recovering stimulus and the masked target are presented to different eyes (i.e., dichopticly), indicating that the recovery phenomenon is not a retinal-based effect (Robinson, 1968). However, all of the previous paradigms used to study masked-target recovery presented the target in isolation and often at a fixed location. These are exactly the conditions that promote the focusing of attention on the target location. Moreover, because the target was the only object to suddenly onset in these paradigms, attention would have been captured by the target even if attention had been directed elsewhere in the visual field when the target was presented (Jonides & Yantis, 1988). It is possible that, like object-substitution masking, target recovery is also sensitive to the deployment of attention.

The hypothesis we tested in this study is that masked-target recovery is dependent upon the target receiving the benefit of focused perceptual attention when presented. Given the observations that attention can significantly modulate other masking effects, an analogous situation might exist for masked-target recovery with attention playing an important role in this phenomenon as well. That is, if a recovering light mask was presented after a masked target in a situation in which multiple object onsets competed for attention, it is possible that no recovery effect would be observed because the target did not enjoy the initial benefit of selection by perceptual attention mechanisms. Theoretical work has already identified a lack of data relating the effects of attention to masking phenomenon as a weakness in our ability to evaluate comprehensive models of masking and visual processing

(Enns & Di Lollo, 2000; Francis, 2003). Based on the hypothesis that focused attention on the target is a prerequisite for recovery, we would predict that the recovery phenomenon would not occur when a visual search target embedded among distractors is rendered unreportable by a mask. In contrast, if recovery is not related to how attention is deployed, it should be found in masking paradigms regardless of whether multiple items simultaneously compete for attention.

EXPERIMENT 1

The goal of Experiment 1 was to determine whether we could replicate an existing report of target recovery (e.g., Briscoe et al., 1983) using a slightly different target discrimination task and a larger range of variability in target locations. To this end, we required observers to perform a target discrimination task in which the target (a Landolt-C with a gap to the left or to the right) was briefly presented in isolation (see Figure 1A). This target was either the only stimulus presented on each trial or it was followed by one of three different mask–stimulus sequences. On pattern-masking trials, the

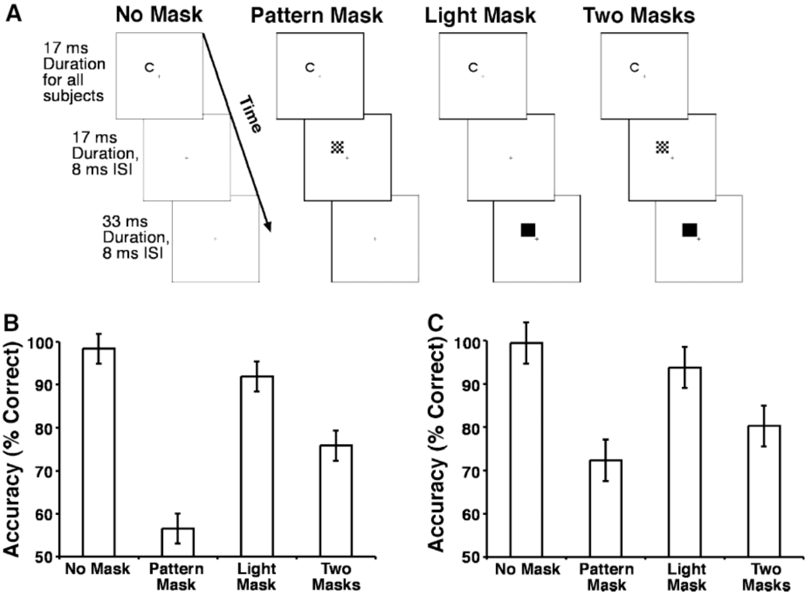

Figure 1. Illustration of the stimulus sequences and results of Experiment 1. A: Examples of the four masking conditions. B: Mean target discrimination accuracy with the white stimuli on a black background. C: Target discrimination accuracy with the black stimuli on a white background. The error bars represent 95% within-subjects confidence intervals (Loftus & Masson, 1994).

target was followed by a high-contrast checkerboard stimulus (17 ms duration, 8 ms interstimulus interval (ISI)). Light-mask trials consisted of the target presentation followed by the presentation of the homogeneous white square mask (33 ms duration, 33 ms ISI). Finally, on two-mask trials, the target was followed by both the checkerboard mask and the light mask. During the practice blocks, only no-mask trials were presented and the target duration was adjusted by a stair-step procedure (Brown, 1996; Lleras & Moore, 2003). The stair-step procedure shifted the target duration in 8 ms steps to keep performance on no-mask trials at 90% correct. The target duration achieved during practice was then used for all conditions in the subsequent experimental block, and was adjusted between each block based on performance on no-mask trials. This procedure was utilized with the goal of making the targets sufficiently difficult to discriminate in all conditions such that ceiling or floor effects would not obscure potential masking effects. Based on the reports in the literature, we predicted that observers would be significantly better at discriminating targets that were followed by both the pattern and light masks than targets followed by only the pattern mask.

Method

Participants. Ten observers (18–32 years old) from Vanderbilt University participated in exchange for course credit or monetary compensation after informed consent was obtained. All observers had normal or corrected-to-normal visual acuity.

Stimuli and procedure. The stimuli were presented using the Psychophysics Toolbox for Matlab (Brainard, 1997) on a 19-inch flat CRT monitor (120 Hz refresh rate). Observers viewed the stimuli in a completely dark room at a distance of approximately 120 cm. The target stimulus was a white ring (0.38° diameter, 0.09° line thickness, 110.3 cd/m^2) with a gap (0.14°) on the left or the right side presented on a black background ($<$0.001 cd/m^2) with a white fixation point (0.12° $\times$0.12°). As illustrated in Figure 1A, the target was randomly placed in one cell of a 4 $\times$ 4 matrix centred on the screen, such that targets were centred between 0.47° and 1.99° from fixation. The target appeared in each of the cells of the position matrix with equal frequency. The checkerboard mask stimulus was a 5 $\times$ 5 matrix that alternated between cells of black and white (black: $<$0.001 cd/m^2; white: 110.3 cd/m^2; each cell 0.09° $\times$0.09°). The homogenous light mask was a white square (110.3 cd/m^2, 0.56° $\times$0.56°). When shown, these masks were presented centred over the location of the target for that trial.

On every trial, the observer's task was to determine which of the two possible target shapes was presented, and to indicate that a Landolt-C with a gap to the left or a Landolt-C with a gap to the right was present by pressing the left or right arrow keys on the keyboard, respectively. Subjects were instructed to be as accurate as possible in their response regardless of the trial type. Responses were not speeded, and only a circular fixation point remained on the screen until a response was made.

On each no-mask trial, the fixation point was presented for approximately 500 ms before the target shape appeared, and was extinguished after the participants responded. The target presentation duration was determined using an up–down staircase procedure (Brown, 1996) that was set to achieve 90% correct target discrimination when no masks were presented. The minimum duration of target duration was set to two frames (approximately 17 ms) based on the target duration used in previous reports (i.e., Briscoe et al., 1983). All subjects achieved that level of performance during the 64 practice trials in which no masks were presented. The target duration was the same across the different trial types. Each pattern-mask trial was identical to the no-mask trials except that a checkerboard was presented for 17 ms at the target location 8 ms after the offset of the target. The light-mask trials consisted of the presentation of the target followed 33 ms later by the 33 ms presentation of the white square. In the two-mask trials, the target was followed by an 8 ms ISI, the checkerboard mask was then presented for 17 ms, another 8 ms ISI followed, and then the light mask was presented for 33 ms. Thus, both masks had exactly the same temporal relationship with the target as when they were presented alone in the single mask trials.

Each subject performed six blocks of 32 trials each. The first two blocks of practice only contained no-mask trials. Each of the remaining four blocks contained an equal number of trials across the different masking conditions (no-mask, pattern-mask, light-mask, and two-mask trials), which were randomly interleaved within each block. Subjects were allowed to rest between blocks.

Data analysis. The accuracy of target discrimination in terms of percentage correct was entered into an analysis of variance (ANOVA) with the within-subject factor of mask sequence (no-mask, pattern-mask, light-mask, vs. two-mask condition). Pairwise planned comparisons were performed because the masked-target recovery effect is defined as superior performance on two-mask trials compared to pattern-mask trials. Only data collected after the first two blocks of practice trials were included in the analyses.

Results and discussion

Mean accuracy across observers for each trial type is shown in Figure 1B. Observers were highly accurate at discriminating targets on both no-mask trials ($M = 98.4\%$ correct), and trials in which only the light mask was presented following the target ($M = 91.9\%$ correct).

Relative to performance on no-mask trials, performance on pattern-mask trials was severely impaired ($M = 56.5\%$ correct). Target discrimination performance on two-mask trials ($M = 75.8\%$ correct) was far better than on pattern-masking trials (i.e., a 19.3% difference). Statistical support for these observations was found in the main effect of mask sequence, $F(3, 27) = 95.62$, $MSE = 3491.01$, $p < .001$. Planned comparisons indicated that performance was significantly better on the two-mask trials than on the pattern-masking trials ($p < .01$).

These findings indicate that target discrimination improved when a second homogeneous light mask followed the pattern mask. In a control experiment, we wanted to address the possibility that slow phosphor decay might be responsible for the results of Experiment 1. To address this question we required a new group of 10 observers to perform exactly the same task as in Experiment 1, except that the contrasts of the stimuli and background were reversed. In this way, the target was presented in black (all raster guns off) on a white background (all raster guns on). As shown in Figure 1C, the same pattern of effects was obtained, resulting in a significant main effect of mask sequence, $F(3, 27) = 22.63$, $MSE = 1526.55$, $p < .001$, and a significant difference between target discrimination accuracy on pattern mask and two-mask trials ($p < .01$). These findings indicate that the target recovery we observed in Experiment 1 was not simply due to the possibly slow phosphor decay of the monitor.

Having determined that we could obtain the recovery effect in a typical pattern-masking paradigm similar to that used in previous reports, we sought to determine whether a similar target recovery effect is observed in masking paradigms in which multiple objects compete with the target for perceptual attention. Thus, in Experiment 2, we had observers perform the same target discrimination task; however, they were shown either isolated targets or a target embedded in an array of distractors. Both types of target were followed by pattern masks, light masks, or both pattern and light masks on a subset of trials.

EXPERIMENT 2

In Experiment 2 we investigated whether masked-target recovery is observed in a masking paradigm in which multiple possible target stimuli onset simultaneously and compete for perceptual attention. Specifically, subjects discriminated target objects presented in isolation (as is the case in the modal pattern-masking paradigm and Experiment 1) or presented surrounded by 15 distractor objects. During a quarter of the isolated target and search-target trials, the target array was presented and followed by no other stimuli. On a different quarter of trials, the pattern mask followed the target array. On another quarter of trials, the light mask followed the target. On the final type of trials, a sequence of both the first pattern mask and the second light mask were presented following the target. All of these types of trials were randomly interleaved within each block of trials.

Given the ubiquitous observation that light masks can recover masked-target stimuli in a variety of different backward masking paradigms, it is possible that recovery would also be observed when a search target is masked. On the other hand, it is possible that recovery is dependent upon attention. If attention plays a role in target recovery analogous to its importance in other masking phenomenon, then it may be critical that previous work on recovery had always shown isolated targets. As this stimulus presentation method causes the target to capture attention, the targets always enjoyed the benefit of undivided visual-spatial attention. Given this hypothesis, if focused attention on the target is a prerequisite for recovery, we expected to observe recovery only when the isolated target captures attention and not when multiple object onsets compete for attention during search.

Method

Participants. Ten observers from the same pool as in Experiment 1 participated. All reported normal or corrected-to-normal visual acuity.

Stimuli and procedure. The stimuli and procedure on isolated-target trials were identical to those from Experiment 1 with the exception that they were randomly interleaved with search-target trials (for an example see Figure 2A). During the search-target trials the target object was always presented embedded in an array of 15 distractor objects. The target was presented equally often at each of the 16 possible target locations in the search array. The distractors were identical to the target except that the gap on the Landolt-C was on the top or the bottom of the circle. The location of the gap on each distractor was determined randomly. Except for the presence of distractors, the target-discrimination task and the mask stimuli were identical. The checkerboard mask had the same physical and temporal parameters as in Experiment 1 (17 ms duration, 8 ms ISI between target and mask). The light mask, a homogeneous white square, was presented on light- and two-mask trials as in Experiment 1 (i.e., a 33 ms duration, 8 ms ISI between the pattern mask and light mask). No mask was presented on 25% of trials for both the isolated and the search targets, and these are the baseline no-mask trials. The mask, light-mask, and two-mask trials were equally likely (each 25% of trials for that type of target array).

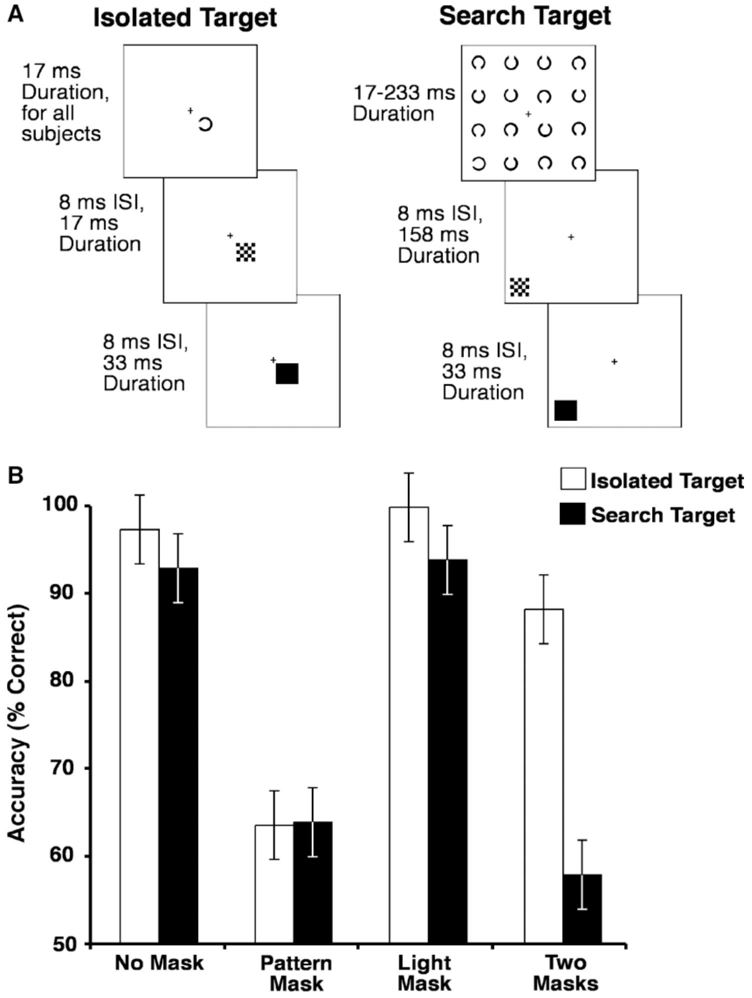

Figure 2. Illustration of the stimulus sequences and results of Experiment 2. A: Examples of the stimulus sequences in isolated-target trials and in search-target trials. B: Mean target discrimination accuracy for isolated and search targets as a function of masking sequence.

To equate unmasked target discrimination performance on search- and isolated-target trials, the presentation durations of the two types of unmasked target arrays were adjusted independently using the same staircase procedure described in Experiment 1. Two independent staircase algorithms adjusted isolated target and search array durations to achieve 90% correct target discrimination performance for the isolated-target arrays and the search arrays in which no masks were shown. The target durations were further adjusted between blocks as in Experiment 1. The minimum presentation duration for either type of array was two frames or approximately 17 ms. The mean duration of isolated targets determined by the up–down procedure was 18.3 ms for this group of observers (with individual subjects varying between 17 and 33 ms). The mean for targets presented among distractors was 55.0 ms (with subjects varying between 17 and 267 ms).

As in Experiment 1, the subjects first performed two blocks of trials in which stimulus durations were adjusted and no masks were shown. Observers then performed four blocks of 64 trials that contained an equal number of trials in each combination of target array type (isolated target or search target) and stimulus sequence (no-mask, mask, light-mask, and two-mask trials). These eight types of trials were randomly interleaved within each block. Between blocks of trials subjects were allowed to rest.

Results and discussion

Mean target discrimination for each trial type is shown in Figure 2B. Target discrimination on unmasked trials was highly accurate regardless of whether the target was presented in isolation ($M = 96.9\%$ correct) or embedded in an array of distractors ($M = 92.5\%$ correct). The results of the ANOVA yielded a significant effect of target array type, $F(1, 9) = 12.35$, $MSE = 161.89$, $p < .01$; mask sequence, $F(3, 27) = 117.49$, $MSE = 44.92$, $p < .0001$; and an interaction of these factors, $F(3, 27) = 11.06$, $MSE = 83.59$, $p < .0001$. As is evident, the significant interaction between target type and mask sequence was driven by the difference in discrimination of search targets and isolated targets when both masks were shown. Planned comparisons confirmed that target recovery occurred only when a masked-isolated target was followed by a light mask (63.4% vs. 87.8% correct, on mask and two-mask trials, respectively), $F(1, 9) = 52.85$, $MSE = 56.21$, $p < .0001$, not when a masked-search target was followed by a light mask (63.8% vs. 57.8% correct, on mask and two-mask trials, respectively).

The findings of Experiment 2 indicate that light masks can recover targets presented in isolation but not visual search targets embedded in an array of distractors. During pattern masking trials the sudden onset of the isolated target object captures attention, whereas the onset of the distractors at the same time as the target object during visual search causes all of the objects to compete for attention. We suggest that the lack of focused attention on the search targets prevents the light mask from effectively recovering the target.

Although we believe that differences in the deployment of perceptual attention account for the findings of Experiments 2, we wanted to convince ourselves with an additional test of this hypothesis. Specifically, we used an attentional capture paradigm in which we could more precisely control where attention was deployed. This allowed us to further test the hypothesis that attention plays a pivotal role in masked-target recovery.

EXPERIMENT 3

In Experiment 3 we manipulated which search item onset suddenly and, thus, captured attention. As illustrated in Figure 3A, we used a sudden onset paradigm in which one of the search elements onsets suddenly while the other search stimuli simultaneously revealed their gaps by offset. Previous research has shown that in this paradigm attention is captured by the sudden

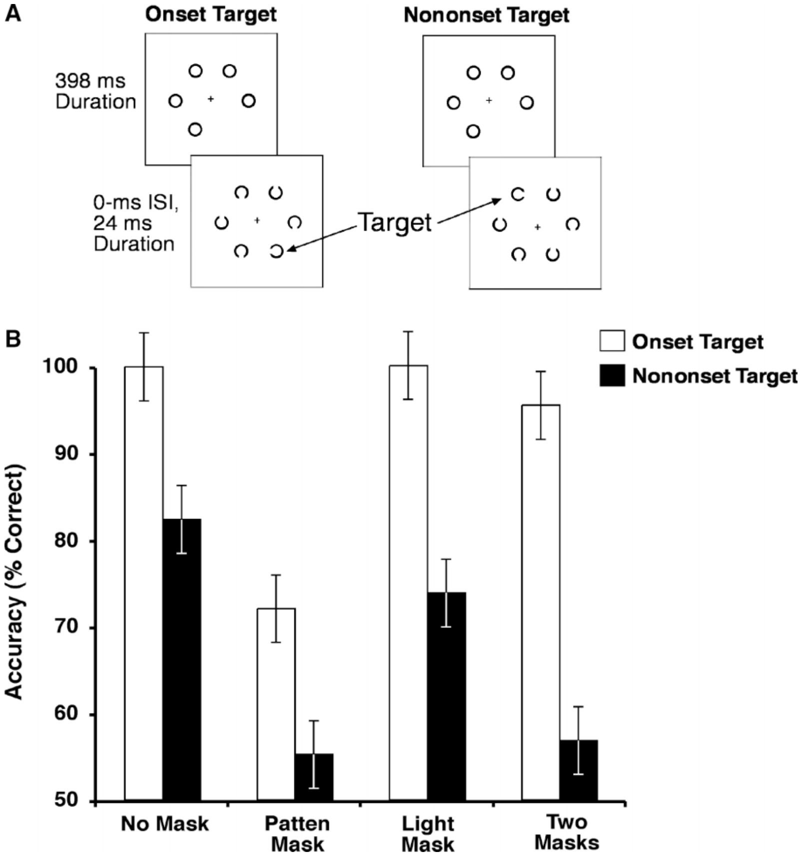

Figure 3. Illustration of the stimulus sequences and results of Experiment 3. A: Examples of an onset-target trial, left, and a nononset target trial, right. B: Mean target discrimination accuracy as a function of mask sequence and target type.

onset of the new object (e.g., Jonides & Yantis, 1988; Theeuwes, 1995; Yantis & Jonides, 1984, 1990). We manipulated the location of the target shape such that the target was the sudden onset item on one sixth of all trials. Note that with a set size of six this frequency should discourage subjects from strategically deploying attention to the onset item because it will be the target no more often than chance. On half of all trials, regardless of its onset status, the target was followed by one of three possible mask sequences centred on the target location: a pattern mask, a light mask, or both a pattern and light mask. Based on our previous findings, we predicted that light masks would be effective in recovering a masked target when it was the sudden-onset object, but not when a sudden-onset distractor captured attention and the target was one of the nononset items.

Method

A new group of 10 observers participated after informed consent was obtained. Examples of the search array stimulus sequences are shown in Figure 3A. Three observers were replaced because unmasked target discrimination was below 65% correct averaged across onset and nononset targets. Each trial began with the presentation of a fixation point (0.2°, 110.3 cd/m^2) for approximately 500 ms and then the onset of five white circles (0.7° $\times$0.7°, 110.3 cd/m^2) centred 2.5° from fixation along an imaginary circle. These circles were presented for 398 ms, at which point arcs were removed from the circles revealing gaps (0.3°) on either the top or bottom of the circle (i.e., the nontarget stimuli) or a gap on the left or right side (i.e., the target stimulus). Simultaneously, with the removal of the arcs from the nononset items was the onset of a Landolt-C at an unoccupied location along the imaginary circle of possible target locations. The search array consisting of the Landolt-C stimuli was presented for a 24 ms duration. When the pattern mask (0.8° $\times$0.8°, with 0.15° black, $<$0.001 cd/m^2, and white, 110.3 cd/m^2, cells) was presented, it was shown for 17 ms and was presented simultaneously with the search array offset. When the light mask (0.9° $\times$0.9°, 110.3 cd/m^2) was presented, it was visible for 32 ms, 24 ms after the offset of the search array. To maximize the number of experimental trials that we could obtain from each observer, we did not use the up–down procedure to set the search array duration; instead a fixed duration target array of 24 ms was used across all observers.

Each observer received one 32-trial block of practice before beginning the experimental trial blocks. The experimental trials consisted of 18 blocks of 32 trials with rest periods between each block. As a result, each observer viewed 24 trials of each of the four stimulus sequences (i.e., target array, pattern mask, light mask, and two masks) for onset targets and 120 trials of each sequence for nononset targets.

Results and discussion

Figure 3B plots the accuracy of target discrimination in Experiment 3 separately for sudden onset and nononset targets as a function of the mask sequence. Target discrimination was more accurate when the target was the onset item than when it was a nononset item. The pattern mask effectively reduced target discrimination regardless of whether the target was the sudden onset item. However, the light mask was only effective in recovering the target when it followed a masked sudden-onset target not a masked nononset target. The results of the ANOVA provide statistical support for these observations. There was a significant effect of onset status of the target, $F(1, 9) = 53.92$, $MSE = 227.50$, $p < .0001$, a significant effect of mask sequence, $F(3, 27) = 34.37$, $MSE = 87.72$, $p < .0001$, and a significant interaction between these factors, $F(3, 27) = 9.41$, $MSE = 54.57$, $p < .001$. Planned comparisons of target discrimination on pattern mask compared to two-mask trials yielded a significant difference when the target was an onset item, $F(1, 9) = 17.82$, $p < .01$, but no significant difference when it was a nononset item ($F < 1$).

The results of Experiment 3 support the hypothesis that the target must capture attention for masked-target recovery to be observed. That is, we observed masked-target recovery of sudden-onset targets. However, when the same two-mask sequence followed a nononset target, no benefit was observed compared to trials in which just the pattern mask followed the nononset target. Furthermore, the results were obtained while the duration of target display was kept constant across conditions. This suggests that the difference in target duration between the isolated- and search-target trials in the previous experiment does not account for the failure of masked-target recovery in search arrays. Overall, these findings converge with those of Experiment 2 in supporting the hypothesis that the target must capture attention for masked-target recovery to be observed.

GENERAL DISCUSSION

The goal of this study was to determine the sensitivity of the masked-target recovery phenomenon to the deployment of attention. Specifically, we contrasted a canonical backward masking paradigm that causes perceptual attention to be captured by the target with a masked search paradigm in which multiple stimuli onset simultaneously and compete for limited-capacity visual-spatial attention. We found that target recovery was only observed when the target was presented in isolation, not when a target was presented simultaneously with distractor objects. Moreover, we found converging evidence implicating attention in target recovery using a sudden onset search paradigm. These findings indicate that attentional capture by the target plays a critical role in the subsequent recovery from masking.

A growing body of evidence has shown that the deployment of attention across the visual field can interact with the efficacy of masking stimuli. For example, the object-substitution masking paradigm has effectively demonstrated that visual search targets can be masked by a very low energy stimulus when attention is diffusely spread across multiple items in the visual field. Moreover, Neill et al. (2002) showed that object-substitution masking can be eliminated by precueing the target location such that attention is focused at the target location when the search array appears. Recently it has been demonstrated that attention can also modulate masking effects during more traditional paradigms. Even during metacontrast masking paradigms a spatial precue or dividing attention can modulate such masking effects (Ramachandran & Cobb, 1995; Shelley-Tremblay & Mack, 1999). The present study extends these findings by showing that the masked-target recovery phenomenon is also sensitive to how attention is deployed. Future research will be needed to determine whether attentional capture is a necessary condition for target recovery or whether recovery is observed when attention is endogenously oriented. Although we cannot provide a complete account of what causes masked-target recovery based on the present findings, they do provide boundary conditions for when recovery is observed and this can constrain models of visual processing during masking.

How might attentional capture allow a recovering stimulus to mediate the effects of the ordinarily potent mask? We consider three possibilities. First, attentional capture during target recovery paradigms may serve to boost the gain of the cells coding the target representation (e.g., Hillyard, Vogel, & Luck, 1998). In doing so, the target representation is made sufficiently robust as to survive the presentation of the first mask in a form that allows the second mask to enhance the neural representation of the target features. This idea is similar to a previously proposed hypothesis regarding the ability of the recovering stimulus to enhance the features of the target (Briscoe et al., 1983). Second, given that attention enhances temporal integration of visual objects (e.g., Visser & Enns, 2001), it is possible that focusing attention on the target location results in a weaker mask because the pattern mask and light mask are integrated together. This results in a lower contrast, and therefore, less effective mask. However, given such an account it remains to be seen why the first mask integrates with the second mask and not also the target object. Third, it is possible that the recovery stimulus serves as a posttarget cue indicating the location of the task-relevant information.

In nearly all masking paradigms, the masks not only interfere with the perception of the target features but also indicate the spatial location of the target that needed to be discriminated (i.e., serve as spatial poststimulus cues). Canonical pattern, metacontrast, and object-substitution masking paradigms share this feature, although they differ in whether the target location is ambiguous. It is striking that such masks are effective given abundant evidence that postperceptual attentional selection is possible. A number of classic studies using partial report paradigms have demonstrated that poststimulus cues allow subjects to more accurately report the cued information than when full report of all of the presented information is required (i.e., Averbach & Coriel, 1961; Sperling, 1960). For example, Averbach and Coriel (1961) searched for an effective cue that would allow observers to postperceptually select information from an array for storage in short-term memory. In doing so, they discovered that a ring surrounding the previous location of an item actually masked the cued item and made the item more difficult to report than an uncued stimulus. In contrast, a small bar presented next to the previous location of one of the stimuli did not cause such masking and made the cued item trivial to report. These results show that seemingly minor differences in stimuli can change a mask into a postperceptual cue. Their findings emphasize that, even when perceptual processing cannot be influenced by cues, postperceptual mechanisms can be focused on the most relevant information being processed by the visual system. In the masked-target recovery paradigm, it is possible that the transient visual responses caused by the recovery stimulus following the masks may cause enhanced postperceptual processing of the previous presented target provided it initially received the benefit of focused visual-spatial attention. We hope future experiments will be able to test these competing hypotheses regarding how selection mechanisms contribute to target recovery.

The present results serve to further constrain models of masking and visual processing. For example, some models of visual processing make specific predictions about the anatomical locus of attention effects found in masking paradigms. Both the sustained-transient channel theory of Breitmeyer (1984) and the perceptual retouch theory of Bachmann (1994, 1997) have proposed that midbrain structures such as the pulvinar and superior colliculus serve to modulate the processing of targets in certain masking paradigms (Breitmeyer & Ogmen, 2000). Cells in these structures have been shown to be sensitive to attentional manipulations (e.g., Goldberg & Wurtz, 1972; LaBerge & Buchsbaum, 1990). The sustained-transient channel model has suggested that previous demonstrations of attentional influences on other masking phenomena are due to processing in these midbrain structures being a combination of bottom-up visual input and top-down attentional selection. This anatomical hypothesis regarding the locus of attention effects during masked-target recovery should be a testable hypothesis for future research using single-unit recording or neuroimaging methods.

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