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Masking by Object Substitution: Dissociation of Masking and Cuing Effects

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In a newly discovered form of visual masking, a target stimulus is masked by 4 flanking dots if their offset is delayed relative to the target (V. Di Lollo, J. T. Enns, & R. A. Rensink, 2000). In Di Lollo et al. (2000), the dot pattern also cued the relevant target and therefore required deliberate attention. In the present Experiments 2–6, a central arrow cued 1 of 2 letters for an *E/F* discrimination, with dots flanking both letters. Masking was reduced compared with the mask-cue procedure but was still robust. Delayed-offset dots flanking the nontarget also impaired performance, indicating competition for attention. Masking was unaffected by brightness of the dots relative to the target. Masking was attenuated not only by precuing attention to the target location but also by preview of an uninformative dot mask. Theories of masking by object substitution must therefore accommodate the prior context into which the target stimulus is introduced.

In general, *visual masking* refers to the impaired perception of a visual stimulus (the target) caused by the presentation of another visual stimulus (the mask) in close temporal and spatial proximity to the target. Because multiple neural, perceptual, and cognitive mechanisms appear to cause masking, masking effects have been classified by a variety of criteria including: (a) the type of masking stimulus (gross luminance changes, visual noise, spatially overlapping features, or adjacent but nonoverlapping contours); (b) imputed underlying mechanisms (erasure, integration, interruption, lateral inhibition, transient-sustained channel interactions, etc.); or (c) empirical differences (monotonic versus U-shaped functions of stimulus-onset asynchrony, presence or absence of forward masking, and presence or absence of dichoptic masking). (For comprehensive surveys of the masking literature, see Bachmann, 1994, and Breitmeyer, 1984.)

Recently, Di Lollo, Enns, and Rensink (2000; Enns & Di Lollo, 1997a) reported a hitherto unrecognized form of visual masking that appears to involve relatively high-level attentional and object-recognition mechanisms. Masking is produced by flanking the target stimulus by four dots corresponding to the corners of an imaginary square surrounding the target. The onset of the dots is simultaneous with the target. If their offset is also simultaneous with the target, there is little impairment of target visibility. However, if their offset is delayed relative to the target offset, discrimination performance drops rapidly, with maximum impairment occurring at offset delays of around 100–150 ms (with no recovery at longer delays).

The dot-masking effect seems to depend critically on division of attention over multiple objects in the visual field. For example, in Experiment 4 of Di Lollo et al. (2000), subjects were shown arrays of 1, 8, or 16 circles, with some having a vertical bar intersecting the bottom of the circle. The subjects' task was to determine whether the target stimulus, cued by the dot array, contained a vertical line. The target array was presented for 45 ms, with the dot-array offset 0, 45, 90, 135, or 180 ms later. For a 1-item array (target only), detection performance remained at about 90% regardless of mask duration. However, for 16-item arrays, line detection plummeted from about 80% with simultaneous offset to about 30% with 90-, 135-, or 180-ms delays.

Further evidence for an attentional factor was obtained in Experiment 6 of Di Lollo et al. (2000), in which the dot array was previewed for 0, 45, 90, 135, or 180 ms prior to the target-array onset, with a constant 90-ms offset delay. Here, performance improved continuously with longer preview duration. Di Lollo et al. presumed that the preview of the dot array facilitated the focusing of attention on the location of the target stimulus, with the consequence that the masking effect of the delayed dot offset was attenuated. (This result also demonstrates that the result of Experiment 4 in Di Lollo et al., 2000, was truly due to offset delay rather than total mask duration.)

Dot masking does not fit previously described categories of masking phenomena. Neither energy masking nor noise masking appears relevant, because there is no gross change in display luminance, nor do the dots provide sufficient visual noise to degrade the target stimulus pattern. *Pattern masking,* in which the mask consists of features on a similar scale to the target stimulus, is generally attributed to either of two hypothesized processes: integration or interruption (Kahneman, 1968). *Integration masking,* in which the mask features are integrated into the percept of the target, requires that the mask features actually overlap the region of the target. *Interruption masking,* in which a new stimulus

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terminates the processing of an earlier stimulus, depends on the mask onset following the target onset (like *metacontrast masking*, below). However, in the dot-masking procedure there is no spatial overlap and no delayed onset; the effect clearly depends on prolonged mask visibility.

As noted by Di Lollo et al. (2000), dot masking appears most similar to metacontrast masking (Alpern, 1953) insofar as there is no spatial overlap of the mask features with the target. However, metacontrast masking is typically found to depend on the mask contours being similar and closely adjacent to the target contours. Dots are unlikely to cause contour interactions with more complex patterns; further, Di Lollo et al. (2000, Experiment 3) found no effect of varying spatial separation between the dots and the target. Most important, metacontrast usually depends on the mask onset following the target onset by 50–150 ms. (Note that most experiments on metacontrast hold mask duration constant, so that onset delay is confounded with offset delay.) Theoretical accounts of metacontrast presuppose that a delay of the mask onset relative to the target onset is necessary for masking. For example, Breitmeyer and Ganz (1976) attributed metacontrast masking to inhibition of sustained-response channels (carrying identity information) by transient-response channels (carrying onset information). They argued that a delay of the mask onset relative to the target onset is necessary for masking because fast mask-transient signals have to coincide with the slow target-sustained signals at some level of the visual system. With simultaneous target and mask, the mask transients simply proceed ahead of the sustained target signals, just like the target transients.[1]

Di Lollo et al. (2000) proposed that dot masking occurs because the developing percept of the target is supplanted by a percept based entirely on the dots—hence, object substitution. A more detailed description of their theory will be deferred until the General Discussion. Meanwhile, note that in our own experiments the general notion of object substitution is consistent with the phenomenal experience of the masked target: Not only does the space inside the dots appear blank, but there is a strong subjective impression of the contours of a square connecting the dots. Furthermore, there is a subjective impression of enhanced brightness of the area within the square, very similar to the brightness enhancement that occurs within illusory contours or subjective contours resulting from long-duration inducing elements (Coren, 1972; Kanizsa, 1976; Petry & Meyer, 1987; Purghe & Coren, 1992).

The intent of the present experiments was to resolve some ambiguities regarding the role of attention in the dot-masking effect. In the experiments by Di Lollo et al. (2000), the target stimulus was always cued by the mask array. As such, the task required subjects to voluntarily attend to the mask pattern in order to locate the target.[2] Consequently, it is unclear whether dot masking in fact depends on voluntary attention to the mask pattern. Further, any manipulations of the mask pattern that moderate the masking effect might be due simply to changes in the effectiveness of the mask pattern as a location cue rather than as a mask per se.

To separate masking effects of the dot pattern from its cuing effects, in Experiments 2 through 6, we used a central arrow to cue one of two letters for an *E/F* discrimination. This allowed us to present dot patterns around both the target and nontarget letters, thereby rendering the dot patterns uninformative. Voluntary attention to the dot patterns should therefore not have contributed to the masking effects. In Experiment 3, we were able to test the hypothesis that delayed offset captures attention involuntarily, by delaying the offset of the dots around the nontarget letter instead of the target.

The use of a central cue also allowed us to address a more specific ambiguity in the work by Di Lollo et al. (2000). As discussed above, Di Lollo et al. (2000, Experiment 6) found that performance improved continuously with lengthened preview of the dot pattern. Di Lollo et al. attributed this improvement to earlier selective attention to the target location, thereby increasing the likelihood of target identification prior to object substitution by the mask. However, this conclusion was premature for two reasons.

First, Di Lollo et al. (2000) did not actually show that dot masking is attenuated by preview because they did not include conditions with a simultaneous mask offset. Consequently, the improvement in performance might be independent of the masking effect. For example, suppose that without preview, the proportions correct for simultaneous and delayed mask offsets were .80 and .60, respectively. Now, suppose that with preview, the corresponding proportions were 1.00 and .80. That performance in the delayed-offset condition has risen to the level of simultaneous offset without preview obviously would not imply that preview attenuates masking—the masking effect is .20 regardless of preview. When testing whether preview attenuates masking, it is logically necessary for preview to be manipulated factorially with offset delay.

Second, a real reduction in masking by preview might not be due to advance focusing of attention. It seems likely that little masking should occur from display features that are present long before the target onset. Otherwise, all sudden-onset stimuli would be masked by the visual context in which they occur, such as the corners of the computer monitor. (Recall that Di Lollo et al. [2000] found no effect of spatial separation.) In other words, it seems

[1] This type of masking was presaged in previous experiments by Di Lollo and colleagues (Di Lollo, Bischof, & Dixon, 1993; Enns & Di Lollo, 1997b). Di Lollo et al. (1993) observed that a mask pattern typical of metacontrast studies (a square mask pattern closely surrounding a square target) caused severe impairment if the mask and target onsets were simultaneous but the mask offset was delayed. Enns and Di Lollo (1997b) reported masking by a four-dot pattern and showed that this masking differed from classical metacontrast. However, mask duration was held equal to target duration, and so effects of offset asynchrony were not distinguished from effects of onset asynchrony. It was the Di Lollo et al. (2000) article in which dot masking was demonstrated with simultaneous target and mask onsets, thereby most clearly distinguishing this effect from metacontrast masking.

[2] An arguable exception is Experiment 5 of Di Lollo et al. (2000). Here, subjects were required to detect whether a vertical bar intersected the target circle, as in Experiments 4 and 6. However, none of the distractor circles contained a vertical bar. Dot masking was reduced but not eliminated. Di Lollo et al. interpreted the reduction as being due to perceptual pop out of the vertical bar, such that attention to the target was facilitated. They interpreted the residual masking effect as evidence that voluntary attention to the dot pattern was not necessary to the masking effect, because the mask was redundant with the vertical bar. However, redundancy does not guarantee that subjects did not use the dot pattern as a locational cue. Indeed, the residual masking effect could reflect trials in which perceptual pop out of the vertical bar failed to occur.

probable that for object substitution to occur, the onset of the substituting object (i.e., the mask) should be in close temporal proximity to the target. Thus, a preview of the mask pattern may attenuate masking even if it does not cue selective attention to that location. The use of a central cue allowed us to distinguish the effects of *precuing* from the effects of *preview*. Thus, in Experiment 4, the target location was precued without preview of the dot pattern; conversely, in Experiments 5 and 6, the dot patterns were previewed without precuing the target location.

Experiment 1

Our first experiment was designed simply to replicate some of the essential findings of Di Lollo et al. (2000) by using an *E/F* discrimination task: On each trial, eight letters (each randomly *E* or *F*) were displayed in a square pattern around fixation for 17 ms. Subjects were instructed to determine whether the letter flanked by four dots was an *E* or an *F* (see Figure 1). The dot pattern either (a) began and ended simultaneously with the target array, (b) began 133 ms before the target array but ended simultaneously with it, or (c) began simultaneously with the target array but ended 133 ms after the target array.

Method

Subjects. Subjects were 20 University at Albany, State University of New York (SUNY Albany) undergraduates who participated to fulfill an experiment requirement in an introductory psychology course. All subjects reported normal or corrected-to-normal vision. Each subject was tested individually in a cubicle illuminated by two overhead 53-watt incandescent light bulbs in a single session of approximately 35–45 min.

Stimuli and apparatus. Micro Experimental Laboratory (MEL; Schneider, 1988) was used to program the experiment on a Gateway 2000 PC-compatible microcomputer. The stimuli were capital letters *E* and *F* drawn from the default MEL character set, presented on a Vivitron 1572 color monitor. A plus sign centered on the monitor screen was used as a fixation point. The stimuli were presented as white characters (MEL brightness code = 15) on a black background. At an average viewing distance of approximately 60 cm, each letter subtended a visual angle of approximately 0.5° vertically and 0.3° horizontally. The letters were centered approximately 2.3° above or below fixation and/or 2.5° to the left or right of fixation, such that eight letters formed a rectangular pattern around fixation. The mask pattern consisted of four dots corresponding to the corners of an imaginary rectangle 1.2° in height and 1.0° in width, centered around one of the target letters. Each dot was actually a small square of 3 pixels vertically and 3 pixels horizontally.

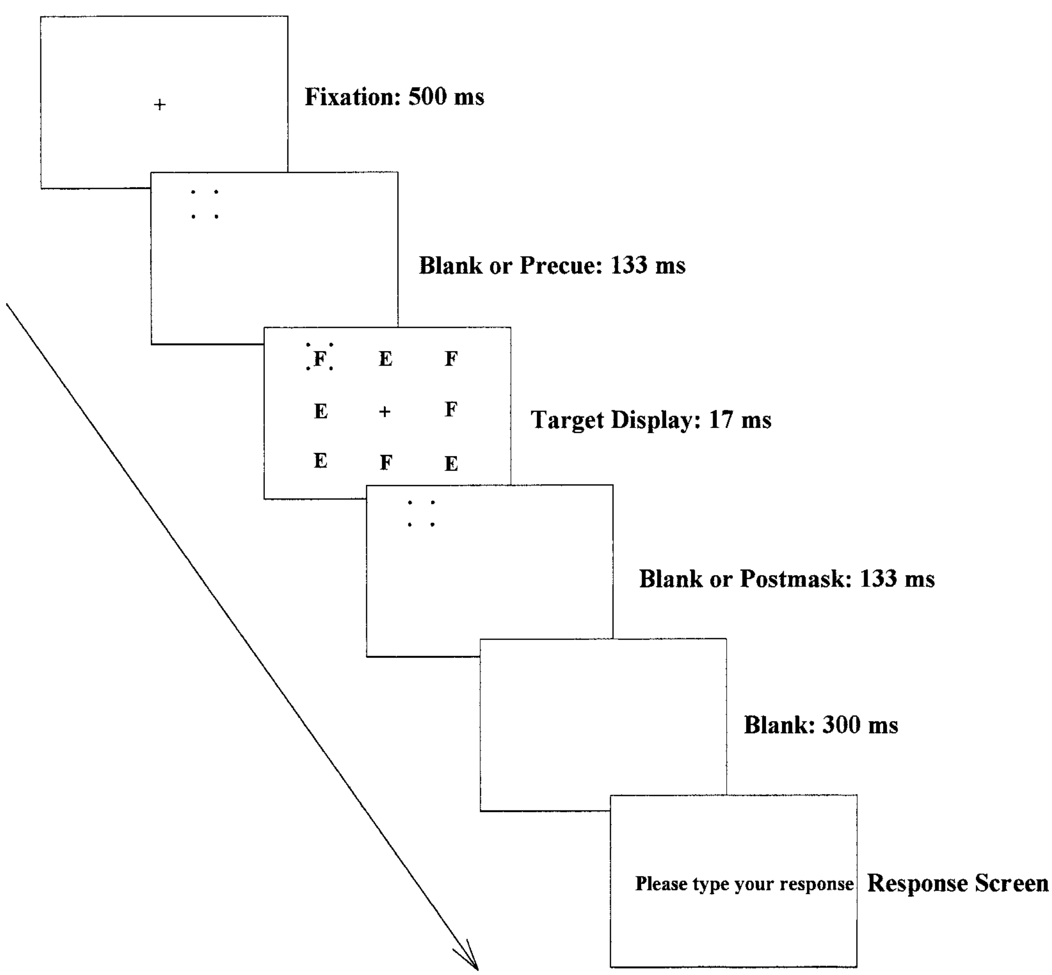

Figure 1. Schematic of procedure for Experiment 1. (Displays were actually white letters on a black background.)

The *Z* and *?/* keys of the computer keyboard were relabeled *E* and *F*, respectively, and were used to register subjects' responses.

Procedure. Each trial began with a 500-ms fixation cross. In the *preview* condition, the dot pattern was then presented at one of the eight possible target positions for 133 ms, followed by the target array accompanied by the dot pattern for 17 ms. The screen was then blanked for 433 ms, followed by the instruction, *Please type your response*. In the *simultaneous* condition, the screen was blank for 133 ms after the fixation cross, followed by the target array and dot pattern for 17 ms, and then a blank period of 433 ms preceding the report instruction. The sequence of events was the same for the *delayed-offset* condition, except that the dot pattern remained in view for 133 ms after the target-array offset, followed by a blank period of 300 ms preceding the report instruction.

Subjects identified the target letter as *E* or *F* by pressing one of the two labeled keys on the computer keyboard. They were instructed to respond as accurately as possible, with no emphasis on speed. It may be noted the report instruction was delayed for 433 ms from the offset of the target array for all three conditions. A subject's response was not registered until the report instruction was displayed; if the subject responded prematurely, he or she had to respond again during the report instruction. When the response was registered, the report instruction was replaced by feedback indicating whether the response was correct or incorrect. An intertrial interval of 1,000 ms preceded the beginning of the next trial. Each subject received 16 practice trials and 480 experimental trials. A rest period was provided after every 48 trials.

Results

Proportions of correct responses in each condition were calculated for each subject and entered into a one-way repeated measures analysis of variance (ANOVA). The effect of mask condition was highly significant, $F(2, 38) = 168.92$, $MSE = 0.002$, $p < .001$. Planned comparisons indicated worse performance in the delayed-offset condition ($M = .613$) than in the simultaneous condition ($M = .805$), $t(19) = 14.16$, $p < .001$ (two-tailed), and better performance in the preview condition ($M = .870$) than in the simultaneous condition, $t(19) = 5.04$, $p < .001$ (two-tailed).

Discussion

The results replicate the dot-masking effect reported by Di Lollo et al. (2000). Considering that chance performance in this task is .50, the drop from .805 to .613 with delayed mask offset is quite striking. The results are roughly comparable to those obtained by Di Lollo et al. in their conditions most similar to the present experiment: In their Experiment 4, subjects were required to detect a vertical bar intersecting a target circle. On bar-present trials in eight-item arrays, detection performance was approximately .82 with simultaneous offsets and .46 with a 135-ms delay. However, Di Lollo et al. also reported that performance was at ceiling on bar-absent trials with nonzero offset delays, presumably because subjects never guessed the bar to be present if they did not see it. Averaging over bar-present and bar-absent trials to scale their data comparably to ours, overall performance was about .82 and .73 in their simultaneous and 135-ms delay conditions, respectively. Apart from the difference in task, however, other procedural differences preclude a direct comparison of experiments. For example, our eight stimuli appeared in fixed positions, whereas the stimuli varied randomly over a 4 × 4 array in Di Lollo et al., but our exposure duration was only 17 ms, in contrast to 45 ms in Di Lollo et al.

The facilitation resulting from preview of the mask pattern indicates that mask duration longer than target duration is not sufficient by itself to cause masking: The mask duration was 150 ms for both the preview and delayed-offset conditions. In the present preview condition, the mask offset was simultaneous with the target offset; in contrast, Di Lollo et al. (2000, Experiment 6) used a constant 90-ms offset delay in their preview conditions. In neither case can any conclusion be drawn regarding whether preview reduces masking; as discussed in the introduction, this requires a factorial manipulation of preview and offset conditions. However, the present result underscores our point that preview might simply improve target discrimination, even without moderating the masking effect.

Experiments 2A and 2B

In the experiments reported by Di Lollo et al. (2000) and in the present Experiment 1, the target stimulus was cued by the dot pattern. This raises the question of whether deliberate attention to the dot pattern is necessary for the masking effect. It is possible, for example, that when subjects direct attention to the dot pattern, they tend to dwell on the dots at a cost to processing the target. With simultaneous offset, subjects may be able to switch attention sooner to the target in order to capitalize on briefly available sensory persistence or iconic memory (e.g., Sperling, 1960). With delayed offset, switching attention may not occur until the perceptual trace of the target has seriously decayed.

In Experiments 2A and 2B, we compared masking effects in a two-letter array when the target was cued by the dot array with effects when both letters were surrounded by dots and a central arrow was used to indicate the target (see Figure 2). In the latter case, the dot patterns would not be informative. If delayed-offset masking was still obtained, the effect presumably could not be attributed to voluntary attention to the dot pattern. Experiments 2A and 2B were identical, except that the brightness of the stimuli was reduced from white to gray in Experiment 2B. In Experiment 2A, a possible ceiling effect on performance in the simultaneous-offset conditions might have compromised the comparison of masking effects between the two cue conditions. Therefore, we ran Experiment 2B as a replication, with the expectation that reduced contrast would lower overall performance.

Method

Subjects. Subjects were SUNY Albany undergraduates (18 in Experiment 2A, 26 in Experiment 2B) who participated to fulfill an experiment requirement in an introductory psychology course. All reported normal or corrected-to-normal vision; none had participated in Experiment 1. Each subject was tested individually in a session of approximately 45–60 min.

Stimuli and apparatus. Stimuli and apparatus were identical to Experiment 1, except that letter arrays consisted of only two letters centered 1.6° to the left and right of fixation. An arrow cue was constructed of two hyphens and an inequality sign (- - > or < - -). In Experiment 2A, the stimuli appeared white on a black background (MEL brightness code = 15); in Experiment 2B, they appeared gray (MEL brightness code = 7).

Procedure. Subjects participated in two blocked cue conditions, with order randomly assigned: For both cue conditions, each trial began with a 500-ms fixation cross followed by a 133-ms blank interval. In the mask-cue condition, two letters, each randomly *E* or *F*, then appeared to the left and right of the fixation cross for 17 ms. One of the two letters, randomly determined, was flanked by the dot pattern. In the simultaneous-offset

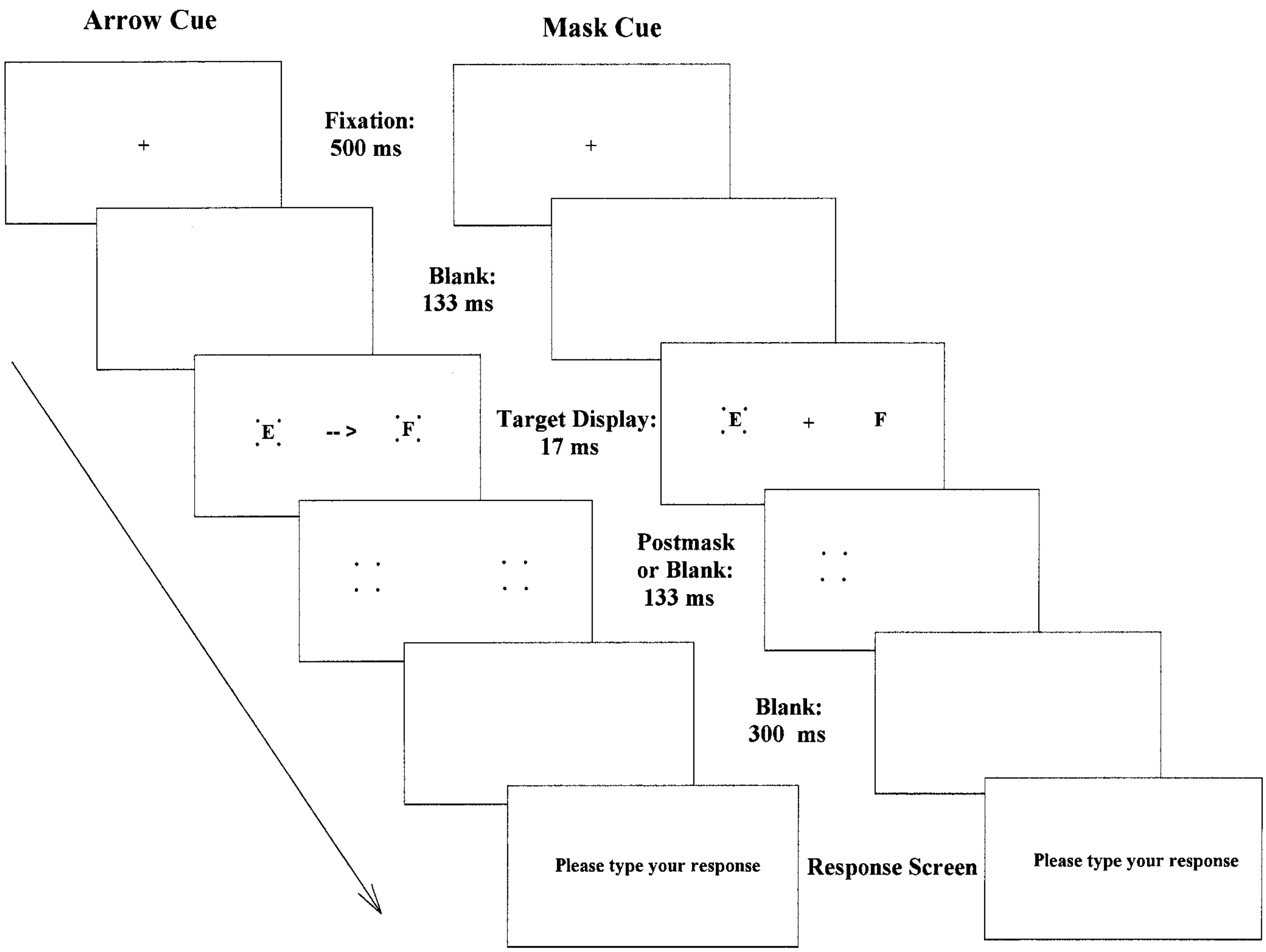

Figure 2. Schematic of procedure for Experiments 2A and 2B. (Displays were actually white or gray letters on a black background.)

condition, the screen was then blanked for 433 ms; in the delayed-offset condition, the mask pattern remained in view for another 133 ms, followed by a 300-ms blank interval. The signal to respond followed the blank interval.

In the arrow-cue condition, both letters were flanked by a dot pattern, and the fixation cross was replaced by an arrow pointing to one of the letters. The arrow was terminated with the target array. As in the mask-cue condition, the dot patterns either terminated with the target array or remained in view for another 133 ms with a blank interval (433 or 300 ms, respectively) preceding the report signal.

At the beginning of each block, subjects were given instructions to either identify the target flanked by a single dot pattern or to identify the target signaled by the arrow. They then received 12 practice trials and 320 experimental trials for that condition. Other aspects of the procedure were similar to Experiment 1.

Results

For each experiment, the proportion of correct responses in each condition was calculated for each subject and entered into a 2 × 2 × 2 mixed-model ANOVA with between-subjects variables of cue-condition order (mask first or arrow first) and within-subject variables of cue condition (mask or arrow) and dot-array offset (simultaneous or delayed).

Experiment 2A. Delayed-offset masks resulted in poorer performance overall ($M = .801$) than did simultaneous-offset masks ($M = .947$), $F(1, 16) = 26.43$, $MSE = 0.014$, $p < .001$. A Cue × Offset interaction approached significance, $F(1, 16) = 3.75$, $MSE = 0.003$, $p = .071$. As shown in Figure 3, the masking effect due to delayed offset was slightly smaller with the arrow cue than with the mask cue. However, planned comparisons indicated that both masking effects were highly significant at $p < .001$.

A three-way interaction of Cue × Offset × Order barely attained statistical significance, $F(1, 16) = 4.50$, $MSE = 0.003$, $p = .050$. Masking effects (simultaneous − delayed difference) were greater in the cue conditions performed first (mask cue, $M = .189$; arrow cue, $M = .157$) than in cue conditions performed second (mask cue, $M = .152$; arrow cue, $M = .086$). However, because performance in at least two conditions approached ceiling in both orders for the simultaneous mask-cue conditions (performed first, $M = .957$; performed second, $M = .977$), caution is warranted in interpreting this interaction.

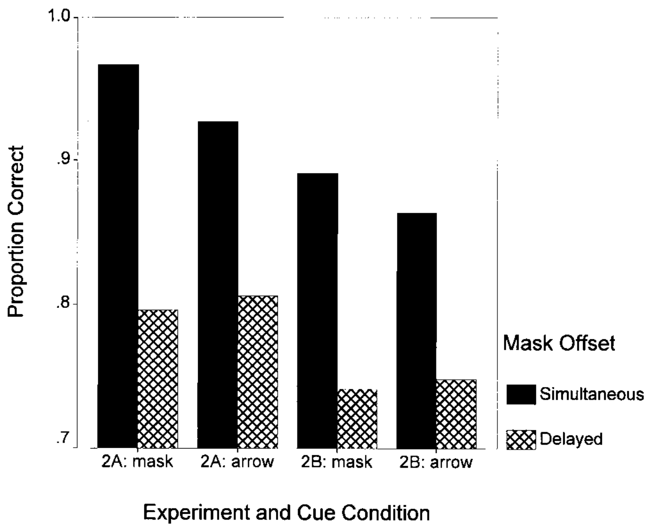

Figure 3. Proportion of correct responses in Experiments 2A and 2B as a function of cue type (mask or arrow) and simultaneous or delayed dot-mask offset.

Experiment 2B. Delayed-offset masks again resulted in poorer performance (M = .745) than did simultaneous-offset masks (M = .878), $F(1, 26) = 54.98$, $MSE = 0.009$, $p < .001$. The Cue × Offset interaction was significant, $F(1, 26) = 4.46$, $MSE = 0.002$, $p < .05$, reflecting a greater masking effect in the mask-cue condition than the arrow-cue condition (see Figure 3). However, both masking effects were again highly significant at $p < .001$. The three-way interaction in Experiment 2A was not replicated in this experiment, $F(1, 26) = 1.08$, *ns*, but a Cue × Order interaction approached significance, $F(1, 26) = 3.98$, $MSE = 0.012$, $p = .057$, reflecting better performance in cue conditions performed second (mask, M = .844; arrow, M = .821) than in cue conditions performed first (mask, M = .789; arrow, M = .792).

Combined analysis. Performance was worse overall in the delayed-offset condition (M = .773) than in the simultaneous condition (M = .912), $F(1, 42) = 76.35$, $MSE = 0.011$, $p < .001$, and offset interacted with cue, $F(1, 42) = 8.41$, $MSE = 0.002$, $p < .01$, reflecting the greater masking effect for the mask cue found in both experiments. The Cue × Order interaction was significant, $F(1, 42) = 4.91$, $MSE = 0.010$, $p < .05$, reflecting better performance in cue conditions performed second (mask, M = .873; arrow, M = .846) than in cue conditions performed first (mask, M = .826; arrow, M = .826). The Cue × Offset × Order interaction was also significant, $F(1, 42) = 6.00$, $MSE = 0.002$, $p < .02$, reflecting greater masking (simultaneous − delayed difference) for cue conditions performed first (mask, M = .181; arrow, M = .134) than for cue conditions performed second (mask, M = .141; arrow, M = .102). The first interaction is similar to that obtained in Experiment 2B, and the triple interaction is similar to that obtained in Experiment 2A. Notably, neither interaction was qualified by further interactions with experiment.

As expected, overall performance was reduced in Experiment 2B (M = .811) relative to Experiment 2A (M = .874), $F(1, 42) = 4.32$, $MSE = 0.039$, $p < .05$. However, experiment did not enter into any significant interactions with any other variables (all ps > .20).

Discussion

The result of primary importance in this experiment was that dot masking in the central arrow-cue condition was quite robust, even though slightly reduced in comparison with the mask cue. This implies that deliberate attention to the dot pattern is not necessary for the masking effect, although it may exacerbate it. The masking effects were smaller than in Experiment 1, as expected, given the dependence of such masking on set size (Di Lollo et al., 2000). The magnitude of masking here is similar to that reported by Di Lollo et al. (2000, Experiment 3) for a display size of two in a task that required subjects to report the location of a gap in a circular target.

The results also suggest that the masking effect diminishes somewhat with practice insofar as there was less masking overall in cue conditions performed second than in cue conditions performed first. That this is a nontrivial observation is highlighted by the fact that the Experiment × Offset interaction was far from significant ($F < 1$). Therefore, magnitude of masking does not simply depend on overall task difficulty. We speculate that practice may enable more efficient switching of attention to the target; according to the theory advanced by Di Lollo et al. (2000), this should attenuate the magnitude of the masking effect.

That the dot-mask cue resulted in greater masking than did the central arrow cue has several possible explanations. One possibility is that the arrow cue was more effective at directing attention to the target location, thereby attenuating the effect of the dot mask. But, this would predict poorer performance overall in the mask-cue condition than in the arrow condition; there was in fact no overall difference between the two cue conditions (mask, M = .849; arrow, M = .836), $F < 1$. As shown in Figure 3, performance was actually somewhat better in the mask-cue simultaneous condition than in the arrow-cue simultaneous condition, suggesting that a single dot-pattern was actually a more effective cue for locating the target. A more parsimonious interpretation of the Cue × Offset interaction is that the mask and target competed for attention: Although a mask cue facilitated locating the target, deliberate attention to the mask enhanced object substitution either by facilitating the perception of an object based solely on the dots (i.e., a square) or by slowing identification of the target letter.

Experiment 3

That dot masking occurs with a central arrow cue implies that deliberate attention to the mask pattern is not necessary for dot masking to occur. However, this does not rule out the possibility that involuntary attention contributes to the effect. That is, a delayed-offset mask may tend to capture attention, thereby reducing resources available for processing the target. Indeed, the fact that greater masking occurs in the mask-cue procedure than in the arrow-cue procedure (Experiments 2A and 2B) strongly suggests that the mask and target compete for attention. If a delayed-offset mask does capture attention, then it should do so even when presented around a nontarget letter. Thus, in Experiment 3 we used a central arrow to cue the target but randomly delayed offset of the dot-pattern around either the target or nontarget letter. Because the delayed offset was not predictive of the target location, we again expected subjects would not deliberately attend to the dot pattern.

As an exploratory variable, we also manipulated dot-mask offset delay (133, 250, 500, and 1,500 ms) to test for a U-shaped masking function of offset delay, as found in metacontrast (but here with a much longer recovery time). Across experiments, Di Lollo et al. (2000) found dot masking to reach a maximum at about 90-ms delay, with little further change with delays of up to 320 ms. Although it is known that offset transients can contribute to masking (Breitmeyer & Kersey, 1981), they would be unlikely to interact with sensory processes at these longer delays. On the other hand, it is possible that the mask offset might interfere with later cognitive processes such as the decision regarding target identity or memorial encoding for subsequent report. We expected that 1,500 ms should be sufficient for such processes to be completed. To control for possible effects of delayed report, we also used four simultaneous-offset conditions with report delay equated with the four delayed-offset conditions.

Method

Subjects. Subjects were 37 SUNY Albany undergraduates who participated to fulfill an experiment requirement in an introductory psychology course. All reported normal or corrected-to-normal vision; none had participated in the earlier experiments. Each subject was tested individually in a single session of approximately 45–60 min.

Stimuli and apparatus. Stimuli and apparatus were identical to Experiment 2B.

Procedure. A trial began with a fixation cross of 1,500 ms. The target letter, distractor letter, and arrow cue then appeared for 17 ms, with dot patterns flanking both letters. The letters and cue were then terminated. On one third of the trials, randomly determined, the dot pattern flanking the distractor was also terminated, and the dot pattern that had flanked the target remained in view for an additional 133, 250, 500, or 1,500 ms (*target-mask* condition). On another third of the trials, the dot pattern flanking the target was terminated, and the dot pattern that had flanked the distractor remained in view for an additional 133, 250, 500, or 1,500 ms (*distractor-mask* condition). In the remaining third of the trials, both dot patterns were terminated with the target display, and the screen was left blank for 133, 250, 500, or 1,500 ms (*control* condition). At the end of the delay interval for all three mask conditions, the screen was blanked for an additional 300 ms, followed by the signal to respond. An intertrial interval (ITI) of 1,000 ms after the subject's response preceded the next trial.

Each subject received 16 practice trials and 576 experimental trials (48 trials in each combination of mask condition and offset delay). Other aspects of procedure were identical to Experiments 2A and 2B.

Results

The proportions of correct responses by each subject in each condition were entered into a 3 × 4 repeated measures ANOVA with variables of mask (target masked, distractor masked, or control) and offset delay (133, 233, 483, or 1,483 ms). Only the main effect of mask condition was significant, $F(2, 72) = 39.37$, $MSE = 0.010$, $p < .001$. Neither the main effect of delay nor the Mask × Delay interaction approached significance (both Fs < 1). As shown in Figure 4, the delay functions were essentially flat for all three mask conditions.

An analysis excluding the distractor-mask condition indicated significantly worse performance in the target-mask condition ($M = .719$) than in the control (simultaneous-offset) condition ($M = .816$), $F(1, 36) = 58.07$, $MSE = 0.010$, $p < .001$. Neither the main effect of delay nor the Mask × Delay interaction approached significance (both Fs < 1).

An analysis excluding the target-mask condition also indicated significantly worse performance in the distractor-mask condition

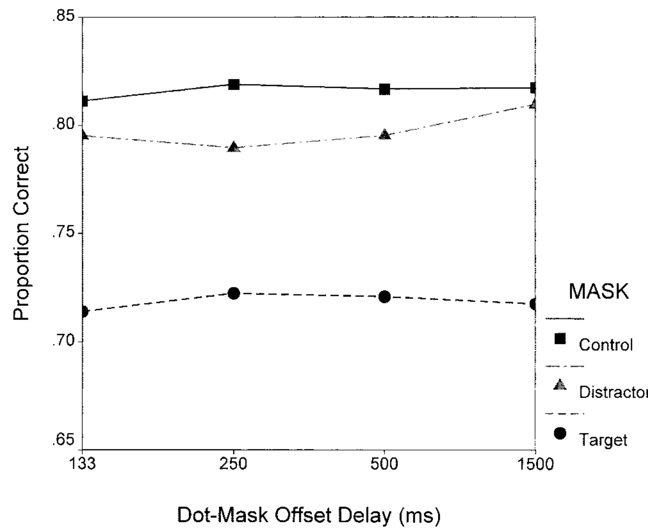

Figure 4. Proportion of correct responses in Experiment 3 with dot masking at the target or distractor location, as a function of dot-mask offset delay. In the control conditions, mask offset was simultaneous with target offset, but the report instruction was delayed by intervals equated with the delayed-offset conditions.

($M = .797$) than in the control (simultaneous-offset) condition, $F(1, 36) = 4.87$, $MSE = 0.005$, $p < .05$. Neither the main effect of delay nor the Mask × Delay interaction approached significance (both Fs < 1).

Discussion

The result of primary interest in this experiment is that delayed-offset masking of the distractor letter resulted in a small but significant impairment of target-letter report. This implies that the delayed offset does in fact tend to capture attention, to the detriment of target identification. (Note that this is a particularly conservative test of attentional capture insofar as masking the distractor should reduce its competition with the target.) At the same time, as evident in Figure 4, the magnitude of the masking effect is much smaller than that occurring with the target mask. One possibility is that the residual target-masking effect is due to some factor other than attentional capture. On the other hand, an attentional-capture effect might be much stronger if attention has already been directed by the arrow cue to the general vicinity of the mask pattern. Therefore, although attentional capture appears to contribute to the dot-masking effect, it is unclear whether attentional capture can completely account for the effect.

There appears to be virtually no change in the masking effect for delayed offsets ranging from 133 to 1,500 ms, consistent with the findings of Di Lollo et al. (2000) for durations ranging from 90 to 320 ms. (Delays shorter than 90 ms did, however, yield reduced masking effects in Di Lollo et al., 2000) It may also be noted that report delay had no effect on the control (simultaneous-offset) condition, indicating that report delay had little if any effect on performance in this task.

Experiment 4

As discussed in the introduction, Di Lollo et al. (2000) concluded that preview of a dot-mask cue attenuated masking, because it allowed attention to be directed to the target location more quickly, thereby attenuating object substitution. However, they did not actually demonstrate that preview of the dot pattern reduces masking but only that preview facilitated performance on a target with a delayed-offset mask. Further, it is ambiguous whether any benefit of preview was due to the precuing of attention to the target location or simply due to a dependence of masking on temporal proximity of the target and mask onsets.

The arrow-cue procedure allowed us to precue the target location without a preview of the mask pattern. We also manipulated simultaneous versus delayed mask offset, orthogonally with presence or absence of a precue. If selective attention to the target location helps to protect the target from masking, as asserted by Di Lollo et al. (2000), then the masking effect (simultaneous − delayed difference) should be smaller with a precue than without a precue.

As an exploratory variable, we also manipulated duration of the arrow cue (17 or 150 ms). This was motivated by variations in the magnitude of the masking effect across other experiments. We hypothesized that a cue of longer duration might be processed more efficiently, thereby facilitating selective attention to the target location and attenuating the masking effect.

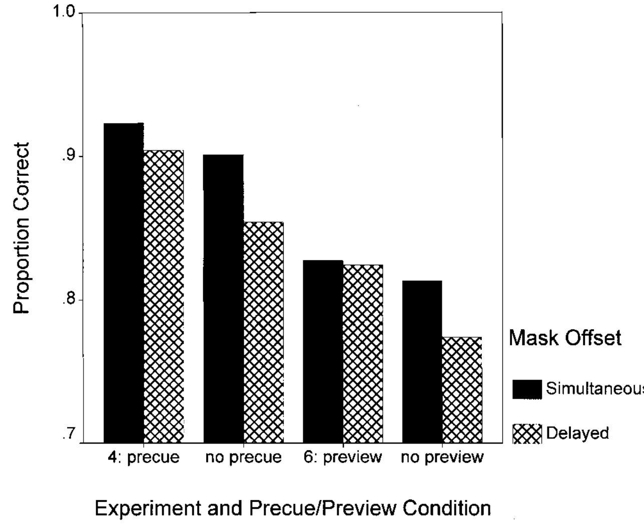

Figure 5. Proportion of correct responses in Experiments 4 and 6 as a function of target precue or mask preview and simultaneous or delayed dot-mask offset.

Method

Subjects. Subjects were 25 SUNY Albany undergraduates who participated to fulfill an experiment requirement in an introductory psychology course. All subjects reported normal or corrected-to-normal vision; none had participated in the earlier experiments. Each was tested individually in a single session of approximately 45–60 min.

Stimuli and apparatus. Stimuli and apparatus were identical to Experiment 2B.

Procedure. The procedure was identical to the arrow-cue condition of Experiments 2A and 2B, except for the following: On half of the trials (randomly selected) the arrow cue appeared 133 ms prior to the target and nontarget letters. In addition, the arrow cue was displayed for either 17 or 133 ms, randomly selected for each trial. Subjects received 16 practice trials, followed by 480 experimental trials.

Results

Proportions of correct identifications for each subject in each condition were entered into a 2 × 2 × 2 repeated measures ANOVA with variables of precue (arrow cue preceding or simultaneous with target display), cue duration (17 or 150 ms), and mask offset (simultaneous or delayed).

Precuing resulted in a significant enhancement of performance overall (*M*s = .913 vs. .877 for precue vs. simultaneous cue, respectively), $F(1, 24) = 24.94$, $MSE = 0.003$, $p < .001$. An overall masking effect was obtained, reflected in a main effect of mask offset (*M*s = .879 delayed vs. .912 simultaneous), $F(1, 24) = 20.36$, $MSE = 0.003$, $p < .001$. Most important, as shown in Figure 5, the masking effect was reduced in the precue condition relative to the simultaneous cue condition, $F(1, 24) = 12.41$, $MSE = 0.001$, $p < .002$. Planned comparisons indicated that the masking effect with a simultaneous cue (.901 − .854 = .047) was significant at $p < .005$, whereas the effect with a precue (.923 − .904 = .019) was nonsignificant. Cue duration did not yield any significant effects (all *p*s > .10).

Discussion

The present results indicate that precuing attention to the target location does attenuate the dot-masking effect, as concluded by Di Lollo et al. (2000). It is important to note that this conclusion holds even without a preview of the mask pattern at the cued location. That is, the mask pattern onset was always simultaneous with the target and nontarget letters, with precuing effected by the central arrow cue.

That cue duration did not yield any significant effects simply suggests that a 17-ms exposure of the present cue was sufficient for optimal cuing of selective attention to the left or right target position. Of course, this does not preclude the possibility that relatively less discriminable cues would hamper effective switching of attention.

Experiments 5A and 5B

Experiment 4 demonstrated that precuing attention to the target location can attenuate the dot-masking effect. However, as discussed in the introduction, it seems likely that a preview of the mask pattern should also attenuate masking even if it does not specifically cue attention to the target location. This is because a transient-onset target is always presented against a background of relatively static objects, such as the computer monitor itself. If the mechanism of dot masking were not sensitive to the preexisting context into which the target was introduced, then all transient-onset targets would be immediately masked by their context.

To simulate a static visual context, we used a relatively long preview of the dot patterns: 1,500 ms. Because the dot patterns flanked both the target and nontarget letters, they could not cue selective attention to the target location. After subjects completed Experiment 5A, they participated in Experiment 5B. The difference between the two experiments was that a 1,500-ms offset delay was used in Experiment 5A, but in Experiment 5B the delayed-offset dot patterns simply remained in view until the subject responded. This variation was introduced in order to definitively exclude offset, per se, of the mask pattern as a possible cause of interference with target report.

Method

Subjects. Subjects were 23 SUNY Albany undergraduates who participated to fulfill an experiment requirement in an introductory psychology course. All had normal or corrected-to-normal vision. The same subjects participated in both Experiments 5A and 5B; none had participated in the previous experiments. Each was tested individually in a single session of approximately 45–60 min.

Stimuli and apparatus. Stimuli and apparatus were identical to Experiment 2B.

Procedure. Each trial began with the fixation cross displayed for 1,500 ms. In the preview condition, the dot patterns were displayed around both possible letter locations during the fixation interval; in the no-preview condition, only the fixation cross remained in view for that time. The two letters were then displayed for 17 ms, accompanied by the dot patterns, and the fixation cross was replaced by an arrow cue. Presence or absence of preview was randomly determined on each trial, as was simultaneous or delayed offset.

In the simultaneous-offset condition, the mask pattern terminated with the letter display, and the arrow cue remained in view for 1,500 ms preceding the report signal. In the delayed-offset condition, both the mask pattern and arrow cue remained in view for 1,500 ms before the report signal. In Experiment 5B, there was no report signal; rather, subjects were instructed to respond whenever they had made their decision about the target identity. In the simultaneous-offset condition, only the arrow cue remained in view after the letters and mask were terminated, until the subject's response. In the delayed-offset condition, the mask pattern and arrow cue both remained in view until the subject responded. Subjects participated in Experiment 5B after completing Experiment 5A. (Because we did not intend a direct comparison between the two experiments, we did not counterbalance the order of presentation.)

At the beginning of each experiment, subjects were given instructions appropriate to the respective report condition. They then received 16 practice trials, followed by 320 experimental trials in that experiment.

Results

For each experiment, the proportions of correct responses by each subject in each condition were entered into a 2 × 2 repeated measures ANOVA with variables of preview (preview or no preview) and mask offset (simultaneous or delayed).

Experiment 5A. Delayed mask offset impaired performance overall relative to simultaneous offset (*M*s = .852 vs. .882), $F(1, 22) = 18.61$, $MSE = 0.001$, $p < .001$. The main effect of preview was not significant, $F(1, 22) = 2.05$, $MSE = 0.003$, $p = .166$. However, the effect of delay interacted significantly with preview, $F(1, 22) = 7.29$, $MSE = 0.001$, $p < .02$. As shown in Figure 6, significant masking occurred without preview ($p < .001$) but not with preview.

Experiment 5B. Delayed mask offset impaired performance overall relative to simultaneous offset (*M*s = .812 vs. .835), $F(1, 22) = 5.64$, $MSE = 0.010$, $p < .05$. Performance was also better overall with preview (*M*s = .832 vs. .815), $F(1, 22) = 4.67$, $MSE = 0.007$, $p < .05$. Again, however, these two variables interacted, $F(1, 22) = 10.24$, $MSE = 0.010$, $p < .004$, reflecting significant masking without preview ($p < .005$) but not with preview.

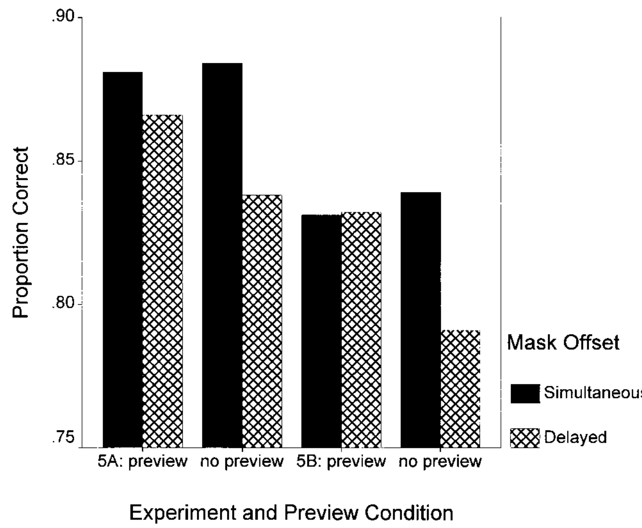

Figure 6. Proportion of correct responses in Experiments 5A and 5B as a function of preview and simultaneous or delayed dot-mask offset.

Discussion

Both experiments found that a long preview of the dot patterns eliminated the dot-masking effect. Because the dot patterns were uninformative as to the target location, this cannot be attributed to selective attention directed more quickly to the target location. Also, because preview had virtually no effect on simultaneous-offset patterns (see Figure 6), the differential masking effects cannot be attributed to differences in target discriminability due to the preview. Rather, it seems likely that temporal proximity of the mask onset to the target onset is necessary for object substitution to occur.

As in Experiment 2, these experiments also found highly significant dot masking in the absence of preview despite very long offset delay (Experiment 5A) or a delay of offset until response (Experiment 5B).[3] This rules out the dot-pattern offset per se as the cause of masking, consistent with the assertion by Di Lollo et al. (2000) that it is the continued presence of the dot pattern that is responsible.

Experiment 6

Experiments 5A and 5B found dot masking to be eliminated by a long preview of the mask patterns around both the target and distractor letters. This raises the question of whether a much shorter preview would also be sufficient to eliminate masking—for example, a preview of the same duration as the precue (without preview) in Experiment 4 (i.e., 133 ms). In the present experiment, we again manipulated preview and offset delay orthogonally, using an offset delay duration of 133 ms as in Experiments 2 and 4.

In addition, we explored the effect of dot brightness, relative to target brightness, on dot masking. Di Lollo et al. (2000) equated

[3] Di Lollo et al. (1993) reported a similar effect, with mask offset delayed until response, with a close-contour mask more typical of metacontrast-masking studies (see Footnote 1).

the subjective brightness of the dot mask in the simultaneous and delayed-offset conditions by reducing the intensity of the dot mask in the latter condition. We did not do so in the present experiments. According to Bloch's Law (Bloch, 1885; Boynton, 1961), temporal summation increases brightness linearly with duration up to about 100 ms. Therefore, simultaneous-onset/delayed-offset dots in our experiments would appear brighter than the simultaneous-onset/simultaneous-offset dots. Intuitively, if the masking effect is characterized as object substitution, one might anticipate that relatively brighter dots would enhance the likelihood of substituting the perception of a square for the perception of the target letter. On the logical assumption that brightness contrast is also influenced by differences in real intensity, we orthogonally varied the target and mask intensities, using the brightness levels shown to affect overall performance between Experiments 2A and 2B.

Method

Subjects. Subjects were 20 SUNY Albany undergraduates who participated to fulfill an experiment requirement for an introductory psychology course. Each subject was tested in a single session of approximately 45–60 min. All had normal or corrected-to-normal vision; none had participated in the previous experiments.

Stimuli and apparatus. Stimuli and apparatus were identical to Experiments 2A and 2B.

Procedure. The procedure was identical to the arrow-cue condition of Experiments 2A and 2B except for the following: On each trial, presence or absence of a 133-ms preview, simultaneous or 133-ms offset delay, dot-pattern intensity (white or gray), and target intensity (white or gray) were selected randomly and independently. The intensity values were those used in Experiments 2A (white) and 2B (gray). On both simultaneous- and delayed-offset trials, the arrow cue remained in view for 133 ms after termination of the letters. Subjects received 16 practice trials, followed by 480 experimental trials.

Results

Proportions of correct identifications for each subject in each condition were entered into a 2 × 2 × 2 × 2 repeated measures ANOVA with variables of preview (preview or no preview), mask offset (simultaneous or delayed), dot-mask intensity (gray or white), and target intensity (gray or white).

Performance on white targets (M = .819) was significantly better than on gray targets (M = .801), $F(1, 19) = 8.96$, $MSE = 0.003$, $p < .01$, replicating the difference between Experiments 2A and 2B. Delayed-offset masks resulted in worse performance overall (M = .799) than simultaneous masks (M = .820), $F(1, 19) = 9.16$, $MSE = 0.005$, $p < .001$. On the other hand, mask preview facilitated performance overall (M = .826) relative to simultaneous onset (M = .794), $F(1, 19) = 15.90$, $MSE = 0.005$, $p < .001$. Most important, the Preview × Offset interaction was significant, $F(1, 19) = 6.22$, $MSE = 0.026$, $p < .05$. Whereas significant masking occurred without mask preview (Ms = .813 vs. .774, $p < .001$), it did not occur with mask preview (Ms = .827 vs. .824, $p > .20$).

Performance was marginally better overall with gray dot masks (M = .818) than with white dot masks (M = .802), $F(1, 19) = 3.36$, $MSE = 0.020$, $p = .082$. Notably, neither dot-mask intensity nor target intensity entered into any interactions with mask delay (all Fs < 1). However, dot-mask intensity did interact with preview, $F(1, 19) = 15.51$, $MSE = 0.023$, $p < .001$. With white dots, preview significantly facilitated target identification relative to no preview (Ms = .826 vs. .777, $p < .001$), whereas the facilitation was not significant for the gray dots (Ms = .825 vs. .810, $p > .10$). Alternatively, the interaction can be characterized as no effect of dot brightness with preview (Ms = .826 vs. .825) but a relative impairment by white dots with no preview (Ms = .777 vs. .810). Either way, the interaction seems to reflect poorer performance in the no-preview condition with white dots (M = .777) than with the other three combinations of dot luminance and preview presence or absence.

Discussion

The present experiment demonstrates that dot masking can be virtually eliminated by preview of uninformative mask patterns as short as 133 ms. As shown in Figure 5, the attenuation of masking is essentially the same as that caused by a 133-ms precue without preview of the mask pattern. (Differences in overall level of performance probably reflect other variables that differed between the two experiments.) We surmise that detection of the mask onset ahead of the target onset is by itself sufficient to isolate the target perception from object substitution by the mask pattern. It may be noted that Enns and Di Lollo (1997b) found dot masking with delayed mask onsets (see Footnote 1); thus, detection of a mask onset following target offset does not seem to offer similar protection.

Dot masking was unaffected by brightness contrast between the target and mask pattern. That the manipulation of brightness here was reasonably potent is evidenced by the effect of target brightness on overall performance, as well as the interaction of dot brightness with preview. Of course, more extreme manipulations of brightness contrast might well affect the magnitude of dot masking. (Imagine, e.g., the likely effect of reducing dot-pattern intensity to subthreshold levels.)

The interaction of dot brightness with preview was unanticipated. The interaction appears to be due to somewhat worse performance in the no-preview condition with bright dots than in the conditions with preview and/or gray dots. A possible explanation is that with no preview (i.e., simultaneous onsets), the onset of bright dots momentarily distracted processing from the target, regardless of the offset-delay condition. With preview, any such distraction may have subsided by the time of target presentation.

General Discussion

In the present experiments, target letters were flanked by a pattern of four dots. The focal variable was whether the dot-pattern offset was simultaneous with the target or delayed by 133 ms or longer. In all experiments, delayed offset impaired *E/F* discrimination, provided that the target and mask shared a common onset. As such, the results replicate the dot-masking effect reported by Di Lollo et al. (2000). Across experiments, we manipulated different variables expected to influence selective attention to the target and mask. We summarize the major findings below:

1. Significant dot masking occurred even if the mask itself was uninformative about the target location (Experiments 2–6). Therefore, deliberate attention to the dot pattern is not necessary for the masking effect.

2. An informative dot pattern produced a somewhat larger masking effect than did an uninformative dot pattern (Experiments 2A and 2B). Thus, deliberate attention to the dot pattern enhances masking, consistent with the hypothesis that the dot pattern competes for attention with the target.

3. A delayed-offset mask impaired target discrimination even when it occurred at a nontarget location (Experiment 3). Thus, a delayed offset does capture attention involuntarily. However, the effect was small relative to a delayed offset at the target location.

4. Dot masking was virtually unaffected by increasing offset delays beyond 133 ms (Experiments 3 and 5A) and occurred even if dot patterns were terminated after the subject's response (Experiment 5B). Therefore, it is the persistence of the mask pattern, not its offset per se, that causes the masking effect.

5. Dot masking was eliminated if attention was precued to the target location 133 ms in advance (Experiment 4). Notably, this occurred without preview of the dot pattern itself.

6. Both long (1,500-ms) and short (133-ms) previews of uninformative dot patterns eliminated the masking effect (Experiments 5A, 5B, and 6). Thus, the attenuation of dot masking by preview does not require precuing of attention to the target location. Preview of uninformative dot patterns had no effect on performance on simultaneous-offset trials. Therefore, the moderating effect of preview on dot masking cannot be attributed to direct effects of mask preview on target perceptibility.

7. Target perceptibility (Experiments 2A vs. 2B; Experiment 6), dot intensity, and relative intensity of target versus mask (Experiment 6) had little effect on the magnitude of dot masking. Therefore, it is unlikely that masking due to delayed offset in the present experiments was caused by temporal summation resulting in greater brightness for the delayed-offset mask.

Di Lollo et al. (2000) proposed that masking by object substitution is caused by reentrant processes in the visual cortex of the brain. According to their conception, information from the primary projection area (striate cortex, area V1) is initially fed forward to secondary areas that represent objects more abstractly (extrastriate cortex, possibly areas V3 and/or V4). A hypothesis regarding the whole pattern, which is based on initially received input, is fed back to V1 to test for further relevant features and to enhance the feed-forward perception of those relevant features. As new features are received by the secondary areas, the developing percept of the object is strengthened or altered, depending on the consistency of the received features with the hypothesized pattern.

In the dot-masking paradigm, information about the target stimulus (e.g., *E* or *F*) and the accompanying dots begins to accumulate in the secondary projection areas, and a perception of the target begins to develop. However, after the target offset, only information about the dots is available at V1. The feedback of the target hypothesis results in a mismatch, whereas feedback regarding the dots is confirmed. Over successive iterations, the perception of an object determined by the dots alone is strengthened at a cost to the perception of the target. Over time, the perception of an illusory object determined by the dots is substituted for the perception of the target.

The process of object substitution is presumed to occur prior to the arrival of focal attention to the target. In the computational model of object substitution (CMOS) offered by Di Lollo et al. (2000), the probability of correct target identification is proportional to the strength of the target percept relative to the mask percept (and to sensory noise) at the time of arrival of attention. Therefore, a major parameter in the prediction of masking effects is the time required for attention to be directed to the target following its onset. If there are no distractors, or if the target location is cued sufficiently in advance, there will be no masking because attention is immediately present. Di Lollo et al. did not precisely specify the role of attention once it has arrived at the target location, but they asserted that "visual representations of attended items are fundamentally different from those of unattended items" and that "especially important to the perception of rapid temporal sequences and visual masking is the increased spatiotemporal resolution and durability of attended items" (p. 496).

The results of the present experiments are broadly consistent with the theory put forth by Di Lollo et al. (2000), although we believe that certain findings require some modification of the theory. That dot masking occurs with a central arrow cue is certainly expected, because overt attention to the dot pattern is explicitly deemed unnecessary to the effect (Di Lollo et al., 2000, pp. 494–495). Indeed, the only considered role of deliberate attention to the dot pattern is facilitatory, in directing attention to the target location. As such, the reduction of dot masking with an arrow cue, relative to a mask cue, should be attributed to faster switching of attention. However, Experiments 2A and 2B found slightly better performance with a mask cue than with an arrow cue, for simultaneous-offset patterns. Thus, there is no evidence that the arrow cue directed attention more quickly to the target location.

That masking was somewhat reduced with the arrow cue suggests instead that competition of the mask with the target is heightened if the mask is deliberately attended to. Although Di Lollo et al. (2000) did not consider inhibitory effects of attending to the mask, such effects seem consistent with the theory. That is, to the extent that attention to the mask pattern delays attention to the target, masking should be increased. Similarly, the small but significant impairment of performance when a distractor letter was masked (Experiment 3) is not unexpected if the delayed mask offset captures attention.

A problematic finding for the theory proposed by Di Lollo et al. (2000), as instantiated in CMOS, is that preview of the dot patterns eliminated dot masking even though the dots were uninformative as to target location. In Experiment 6 of Di Lollo et al., preview of the mask cue around a target stimulus among multiple distractors attenuated the masking effect. The authors attributed the attenuation to the precuing of attention to the target location, thereby reducing the time between target onset and the arrival of attention. In CMOS, the effect of precuing is simulated simply as a reduction of switching time to the target, reducing the number of iterations required to identify the target. Otherwise, the model does not incorporate any history preceding the target presentation at all. Indeed, its explicit assumption is that a working buffer in which the perceptual input and pattern hypotheses are compared is reset to zero upon target presentation (Di Lollo et al., 2000, p. 497).

The present results indicate that the reentrant processes theory must be modified in some way that maintains a representation of the objects already present in the visual field when the target stimulus is introduced. Object substitution may depend on the initial encoding of something like *an object appeared at time x*, and the development of competing object representations is keyed somehow to the common onset. However, it must also be noted that Enns and Di Lollo (1997b) found masking by what appears to be object substitution when the mask onset followed the target onset. Thus, the detection of a mask onset *after* the target does not prevent the mask from entering into the reiterative computation of the target identity. Although objects present at time $x - t$ are isolated from the computation of the target identity, objects present at time $x + t$ are not. If the computation is keyed to a particular onset time, it is unclear why one onset asymmetry would protect the target from masking but the opposite asymmetry would not.

Although our results are otherwise generally consistent with the theory offered by Di Lollo et al. (2000), we believe it worthwhile to consider whether other types of theories might also account for object-substitution masking. The central tenet of Di Lollo et al.'s theory is that reentrant processes, specifically feedback from secondary projection areas to area V1, enable top-down control of early visual representation. The arguments put forth by Di Lollo et al. are twofold: First, there are ample anatomical and neurophysiological data indicating the presence of such connections; hence, there is some face validity to the argument that such connections could support the processes hypothesized to account for dot masking. Second, current feed-forward explanations of pattern masking and metacontrast masking fail to account for dot masking, as discussed in the introduction, and so some other mechanism must be postulated. But, of course, this argument does not preclude the possibility of an alternative feed-forward mechanism.

As an example, suppose that features are fed forward to secondary projection areas, where they begin to activate possible object representations. Over time, accumulated features will favor one interpretation over the others. Let us suppose that an interpretation is forwarded to conscious awareness (wherever that may reside in the brain) either when one interpretation reaches some critical signal-to-noise ratio or when there is no further increment in the signal-to-noise ratio for any of the potential interpretations. When the mask terminates with the target, there is no further increment to any interpretation, so the interpretation likely to be the strongest, the target surrounded by dots, is forwarded to conscious awareness to serve as the basis for response. However, if the mask persists beyond the target offset, then an alternative interpretation of an object determined by the dots alone continues to accrue support until that interpretation finally reaches a critical signal-to-noise ratio and becomes the object represented in conscious awareness.

Within such a theoretical framework, selective attention to the target location might enhance the quality of sensory information, thereby increasing the probability that the target + mask interpretation reaches the critical signal-to-noise ratio. Alternatively, attention might function to actively suppress contextually less probable interpretations of the stimulation, such as an object determined solely by the dots (cf. Neill, 1979, 1989; Neill & Westberry, 1987).

A potential problem for such a theory is that it would seem to predict even greater masking from previewed dot patterns than from simultaneous-onset dot patterns, because more information would have accrued supporting perception of the dot pattern.[4] Of course, this is contrary to the results of Experiments 5 and 6, in which preview of uninformative dot patterns attenuated the masking effect. However, this objection highlights one of our major points, that any theory of object-substitution masking—feedback or feed-forward—must have a mechanism that distinguishes features of the preexisting context from features of the target and features that appear in close temporal contiguity with it. Just as the reentrant processes theory must be augmented by a representation of pretarget history, so must any feed-forward theory.

A feed-forward process such as that suggested above would still be consistent with the general construct of object substitution. That is, it still assumes that an object percept develops incrementally over time and is therefore susceptible to accumulating evidence supporting an alternative object before the object is represented in conscious awareness. It should also be noted that a feed-forward concept of object substitution is suggested by Marcel's (1983a, 1983b) characterization of subliminal priming by pattern-masked words. That is, the word activates multiple associations in semantic memory, but the mask pattern supplants the word and its associates in conscious awareness, which is presumed to occur at a later stage of processing than lexical access in memory (see also Neill, 1989).

It is notoriously difficult to empirically distinguish top-down control processes from decision processes operating solely at the higher level of representation. For most phenomena that have been attributed to top-down control processes, equally plausible feed-forward decision processes have been hypothesized (Fodor, 1983; Fodor & Pylyshyn, 1988; Neill & Klein, 1989). Di Lollo et al. (2000) argued,

> a question that still remains is whether the comparison process . . . needs to be a reentrant one. We think it does because the comparison is between a visual signal already in the mind (the memory of the target display) and a visual signal currently in the eye (the sensory presence of the four dots). This is reentry by any definition. (p. 502)

We disagree. That a memory for past sensory stimulation is compared with, and affected by, current sensory stimulation does not at all imply that a lower-level representation of the current stimulation is altered by the comparison. If subjects base their responses directly on what is represented in the aft end of the brain (i.e., primary visual cortex), such reasoning might apply. However, if they respond on the basis of a highly abstracted percept, possibly at the opposite end of the brain (frontal cortex), it may be only changes in the higher-level memory that determine performance. Whether the substitution is caused by feed-forward processes alone or by reentrant feedback processes is not addressed by the currently available data.

[4] We thank Jim Enns (personal communication, May 29, 2001) for raising this problem.

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