Research Report

OBJECT SUBSTITUTION:
A New Form of Masking in Unattended Visual Locations

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Abstract—Can four dots that surround, but do not touch, a target shape act as a mask to reduce target discriminability? Although existing theories of metacontrast and pattern masking say "no," we report this occurs when targets appear in unpredictable locations. In three experiments, a four-dot mask was compared with a standard metacontrast mask that surrounded the target. Although accuracy was predictably different for the two masks at a central display location in Experiment 1, both masks had similar strong effects on accuracy in parafoveal locations. Experiment 2 revealed that both four-dot and metacontrast masking were insensitive to contour proximity in parafoveal display locations, and Experiment 3 showed that four-dot masking could occur even at a central location if attention was distributed among several targets. We propose that targets in unattended locations are coded with low spatiotemporal resolution, leaving them vulnerable to substitution by the four dots when attention is directed to them.

We report a new form of visual masking that is critically dependent on the spatial distribution of attention and therefore provides insights into the perceptual organization of rapid visual sequences. This study was prompted by the simple observation that although four dots arranged in a notional square did not act as a mask when used in the manner of a standard metacontrast mask, the same dots acted as a powerful mask under other conditions. In this report, we make three direct comparisons between classical metacontrast and four-dot masking, highlighting important similarities and differences.

Metacontrast masking refers to "the reduction in the visibility of one briefly presented stimulus, the target, by a spatially adjacent and temporally succeeding, briefly presented second stimulus, the mask" (Breitmeyer, 1984, p. 4). It differs spatially from other forms of masking in that the target and mask contours must not overlap; otherwise, principles of masking by pattern (or noise) become relevant. It is also unique in its temporal characteristics. Target visibility is excellent when the mask leads or is presented simultaneously with the target. When the mask trails by 50 to 100 ms, target visibility decreases, but it increases again if the mask trails by a longer interval.

Theories of metacontrast masking are premised on local interactions among visually sensitive neurons early in the visual stream. Some theories focus on the interplay of excitation and inhibition (Weisstein, Ozog, & Szoc, 1975), others on the dynamics of transient and sustained responses (Breitmeyer & Ganz, 1976), and still others on signal summation (Burr, 1984). What is important for the present study is that none propose a role for spatial attention.

EXPERIMENT 1: METACONTRAST VERSUS FOUR-DOT MASKING

We began by replicating the essential aspects of classical metacontrast masking (Alpern, 1953; Werner, 1935) in a simple factorial design. The two factors were type of mask (a frame in Conditions A and C; four dots in Conditions B and D) and number of display locations in which the stimuli could be presented (one in Conditions A and B; three in Conditions C and D).

Method

In each condition in this and subsequent experiments, 10 observers with normal or corrected-to-normal acuity participated in a 1-hr session. On each trial, the observer discriminated among two possible targets presented briefly (30 ms) on a white Macintosh computer screen: a black diamond shape (0.62° in vertical extent) missing a point (0.17°) on either its left or right side. A mask was also presented briefly (30 ms) on each trial, randomly presented at various values of stimulus onset asynchrony (SOA), ranging from ~300 ms (mask preceded target) to +300 ms (target preceded mask). The empty space between two short vertical lines at the center of the screen (2° above and below fixation) served as a fixation marker.

In Conditions A and C, the mask was a frame (0.20° in width) that fit snugly around, but was separated by one screen pixel from the outside of the target (see Fig. 1). In Conditions B and D, the mask consisted of four dots (0.20°) centered on the corners of a notional square (1° on each side). The shortest distance between neighboring contours in the target and mask was about 0.35°, making these dots too distant and too meager for effective masking (Breitmeyer, 1984; Growney, Weisstein, & Cox, 1977).

Conditions A and B tested masking at a single location at the center of gaze, whereas Conditions C and D tested three horizontally arrayed target locations (3° left of center, center, and 3° right of center). In these latter conditions, a target and mask were each presented randomly in one of the three locations on each trial. This procedure not only introduced spatial uncertainty to the task, but also permitted masking to be tested in two parafoveal locations. Responses could be subdivided into the two thirds of trials on which the target and mask were in different locations versus the one third of trials on which the target and mask shared the same location. Masking was expected on the same trials, with the different trials serving as controls for discriminability in the absence of masking.

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Results

The data for all four conditions are shown in Figure 1. Condition A (Fig. 1a) replicated classical studies: A surrounding frame produced no masking when it was presented either before or simultaneously with the target. However, accuracy plunged to near chance levels when the mask trailed by 45 ms. By an SOA of 135 ms, accuracy was once again nearly perfect. Condition B (Fig. 1b) confirmed our expectation that the contours of the four dots were too distant and meager for effective masking: Accuracy was near-perfect at all SOAs.

Conditions C and D (Figs. 1c and 1d) showed that three display locations produced dramatically different results for both kinds of mask. Accuracy on different trials showed no hint of an SOA effect (i.e., masking) with either mask, although overall target discriminability was slightly lower with the metacontrast mask than the four-dot mask ($p < .05$). On same trials, however, masking with both mask types was strong (a reduction in accuracy of 30% or more at maximum); it was temporally extended (from SOAs of at least -45 ms to +135 ms), and the strongest masking effects were backward (i.e., accuracy was lowest at positive SOAs). Such powerful masking by four dots (Condition D) is indeed remarkable, given that this stimulus lacks the attributes said to be essential for metacontrast masking (substantial contours placed in close proximity to the target) and given that the four dots were ineffective as a mask in conventional viewing conditions (Condition B).

However, it must also be noted that the metacontrast mask itself acted very differently in the one- versus three-location conditions. To examine this difference more closely, we separated those same trials in Conditions C and D in which the target-mask complex occurred at the central location from those in which it occurred in the two parafoveal locations (see Fig. 2). The two masks had very different effects in the central location. The metacontrast mask yielded a deep U-shaped backward-masking function, whereas the four-dot mask produced almost no masking. In contrast, when these same masks were presented in the two parafoveal locations, they produced similar functions: Both showed substantial forward and backward masking, which seemed to reach maximum at SOAs around 45 to 90 ms.

These results suggest that masking in the parafovea produced by a metacontrast mask is not very different from that produced by a four-dot mask. Therefore, some account other than one based on low-level contour interactions is required, both for parafoveal metacontrast masking and for the four-dot masking.

EXPERIMENT 2: FOUR-DOT MASKING IS INSENSITIVE TO CONTOUR PROXIMITY

One of the hallmarks of metacontrast masking is its sensitivity to the spatial proximity of target and mask contours (Breitmeyer, 1984; Growney et al., 1977). We tested the sensitivity of four-dot masking to this factor by intermixing two contour proximities within the same block of trials. Thus, each mask was presented with both the same proximity used in the previous experiment and with a larger separation between contours. Proximity of the target and mask contours was increased from $0.02^\circ$ (near) to $0.2^\circ$. 
The results are shown in Figure 3. Condition A (Fig. 3a) replicated the classical result that metacontrast masking tested at a central display location is very sensitive to contour proximity: Masking was strong for the near proximity condition and nonexistent for the far condition. Condition B (Fig. 3b) demonstrated that the four dots in the central display location had no effect on target accuracy for either the near or the far condition in comparison to the no-mask control trials.

In sharp contrast to this pattern at the central location, both mask types and contour proximities showed substantial masking in parafoveal locations in Conditions C and D (Figs. 3c and 3d). There were some differences in detail. For example, the far condition produced masking that was slightly less in temporal extent than the near condition for both mask types. Also, metacontrast masking was greater in overall magnitude and extent than four-dot masking. However, the most striking result was the strong resemblance between four-dot and metacontrast masking, despite the vast differences in the stimuli used to produce masking.

The apparent lack of sensitivity to contour separation and contour amount suggests strongly that the masking obtained in the parafovea with either the four-dot or the surrounding-frame mask is based on mechanisms very different from those proposed for metacontrast masking. To explore this idea further, we examined the role of spatial attention in these forms of masking.

EXPERIMENT 3: FOUR-DOT MASKING IS INFLUENCED BY ATTENTION

Experiment 3 examined the role of spatial attention by means of a set-size manipulation. We compared masking with displays containing only one target located randomly in one of three locations (as before) with displays containing three targets on each trial, one in each location. In three-target displays, the four dots, or the surrounding frame, also served formally as a response probe for the observer, indicating which of the three targets was to be reported.

Masking was large in magnitude and extensive over time for both types of mask. In fact, it was so large with three-target displays in the parafoveal locations that even at the largest SOAs (±300 ms), target accuracy was still significantly reduced relative to one-target displays. However, the most revealing results were evident when the target appeared in the center location, so only these data are shown in Figure 4.

For the metacontrast mask, target number had very little influence on the amount and extent of the masking in the central location: The accuracy function for each target number resembled the metacontrast masking seen previously at the central location. However, for the four-dot mask, there was a large effect of target number. Although target accuracy was very good at all SOAs when there was only one target, sizable masking occurred with three-target displays. Most remarkable was that this masking occurred despite the target being presented in the central location. Such masking cannot be attributed to eye movements to the parafoveal locations because the SOAs at which maximal masking occurred were too brief to permit eye movements away from the central location. Moreover, only backward masking was observed. It is important to note that this masking did not represent a decay of target information solely through the passage of time. When the mask was delayed by 180 ms or more, accuracy returned to its high baseline level. Instead, these data suggest that the need for observers to distribute their attention over all three targets, prior to the onset of the four dots, resulted in masking of even the foveated target shape.

Experiment 3 therefore confirmed the critical role of spatial attention in four-dot masking: Attentional distribution over multiple targets produced masking even at the center of gaze. We turn now to a discussion of how the deployment of attention may mediate this form of masking.

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This is not the first demonstration of the role of attention in masking. For example, Averbach and Coriell (1961) reported that metacontrast masking of letters was stronger in multi- than in single-letter displays: more recently, Ramachandran and Cobb (1995) demonstrated that metacontrast masking could be modulated by figural organization. However, these are both demonstrations that spatial attention can modulate contour-based masking. The present study is the first to demonstrate that a mask with a minimum of contour, and one with its contours quite distant from the target, acts very much like a standard metacontrast mask when spatial attention is distributed.
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How might such masking come about? The present data make it clear that it cannot be accomplished by the contour-based mechanisms proposed for metacontrast masking. First, four-dot masking does not show the sensitivity to contour proximity that is the signature of metacontrast masking. Second, none of the proposed contour-sensitive mechanisms have been predicted to operate differently as a function of attention. Third, masking under conditions of distributed attention is not only backward, as is predicted by theories of metacontrast, but is also in part forward and simultaneous.

It is our view that this new form of masking occurs when the emerging representation of the target object comes into conflict with the emerging representation of the mask object at the same visual field location. Although in a strict sense the four-dot masks are not pattern masks, in that there is no spatial overlap of target and mask contours, the literature on pattern masking is helpful in pointing to two separate sources for spatiotemporal conflicts of this sort (Breitmeyer, 1984; Ganz, 1975; Turvey, 1973). The first, camouflage masking, refers to a degradation in the representation of a target through the addition of noise from the mask. Its signature characteristics are approximately symmetrical masking functions around an SOA of 0, a release from masking beyond an SOA of about 100 ms in each direction, and an insensitivity to attentional load. In short, this form of masking appears to reflect stimulus degradation through a process equivalent to adding simultaneous noise (the mask) to a signal (the target).

The second source of pattern masking is interruption. This occurs when the mask appears before the target has been fully processed and represents a competition for higher level mechanisms involved in object recognition. Its characteristics are that masking occurs only when the mask follows the target, masking is maximal at positive SOAs and wanes with increasing SOA, and both the magnitude and the temporal extent of masking increase with attentional load, as indexed by the number of items in the display.

We propose that targets in unattended locations are coded with low spatiotemporal resolution, leaving them vulnerable to substitution by the four dots when attention is directed to them. Therefore, the four-dot mask behaves like a classical pattern mask when attention is not focused on the relevant location. One of the important functions served by attention is an improvement in the spatiotemporal resolution of objects presented to nonfoveal regions (Moran & Desimone, 1985; Posner, 1980; Treisman & Gelade, 1980; Tsai, Meiran, & Lamy, 1995). Both masking mechanisms—camouflage and interruption—may have combined to produce the four-dot masking functions. That is, four dots may have acted as a camouflage mask over a brief interval surrounding the zero-SOA point, and as an interruption mask, competing with the target for object recognition mechanisms, at positive SOA values. Because this latter form of masking occurs only for temporally trailing masks, it accounts nicely for the temporal asymmetries seen in the four-dot masking functions.

We prefer the term substitution, rather than interruption, for this form of masking because the mask appears to do more than simply terminate processing of the target. The mask itself appears to be the new focus of object recognition mechanisms. This substitution process was observed quite directly in studies conducted recently on visual masking in the so-called attentional blink effect in rapid serial visual presentations (e.g., Giesbrecht & Di Lollo, 1996; Martin, Isaak, & Shapiro, 1995). In these studies, substitution was most clearly seen in the false-positive reports made by observers for items that followed, and therefore masked, the target.

In conclusion, four-dot masking demonstrates a tendency for trailing objects to interfere with the perception of temporally leading ones, even when the contours of these objects do not overlap. Because a key ingredient of this form of masking is an incomplete focusing of spatial attention, we suspect that further studies will tell us much about how the brain represents those vast regions of the visual field that at any point in time are unattended.
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