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Object substitution masking for an attended and foveated target

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Running head: OSM for fully attended and foveated stimuli

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Abstract

A central assumption of models proposed to explain object substitution masking (OSM) is that the phenomenon arises only when attention is distributed across several possible target locations. However, recent work has questioned the role of attention in OSM, suggesting instead that ceiling effects might explain the apparent interaction between spatial attention and masking. Here we report definitive evidence that OSM does not depend upon attention being distributed over space or time. In two experiments, we demonstrate reliable OSM for constant, foveal presentations of a single target stimulus. Crucially, in our design participants' attention was always focused on the target, thus discounting the hypothesis that a key requirement for OSM is distributed attention. The findings challenge how OSM is conceptualised in the broader masking literature, and have important implications for theories of visual processing.

Visual masking is a key technique for investigating mechanisms of perception, particularly those involved in visual awareness (Breitmeyer & Öğmen, 2006). There are several types of masking, each of which is characterized by decreased detection or discrimination performance for a target when another stimulus is proximal in space or time. Amongst these variants, object substitution masking (OSM) is considered unique because it seems to require that attention be distributed across several potential stimuli or locations.

In the classic OSM paradigm a spatially separate mask, with minimal contours (e.g., four dots), is presented simultaneously, and with a delayed offset, relative to a target (Enns & Di Lollo, 1997). Typically, attention is dispersed by the presence of multiple distractor items or potential target locations (Di Lollo, Enns, & Rensink, 2000; Enns, 2004; Enns & Di Lollo, 1997; Germeys, Pomianowska, De Graef, Zaenen, & Verfaillie, 2010; Goodhew, Visser, Lipp, & Dux, 2011), or by an additional task load (Dux, Visser, Goodhew, & Lipp, 2010). OSM is not observed when attention can be rapidly focused on the target image, due to small numbers of distractor items (Di Lollo et al., 2000; Enns, 2004; Enns & Di Lollo, 1997; Goodhew et al., 2011), pre-cuing of the target location (Di Lollo et al., 2000), or if the target's features cause it to 'pop out' (Di Lollo et al., 2000). The apparent role of attention in OSM has driven much theorizing. Indeed, models based on recurrent processing (Di Lollo et al., 2000), lateral inhibition (Macknik & Martinez-Conde, 2007), and attentional gating (Põder, 2013), all include distributed attention as a central component of OSM (Goodhew, Pratt, Dux, & Ferber, 2013).

Recent findings suggest that ceiling level performance under low attentional load conditions may have limited masking effects, leading to previous reports of interactions between distractor set-size and OSM (Argyropoulos, Gellatly, Pilling, & Carter, 2013). Indeed, when ceiling and floor effects are avoided, there is no evidence for interactions between attention and masking magnitude (Argyropoulos et al., 2013; Filmer, Mattingley, & Dux, 2014; Jannati, Spalek, & Di Lollo, 2013; Pilling, Gellatly, Argyropoulos, & Skarratt, 2014). These findings imply that having attention dispersed over multiple items is not a requirement of OSM.

To date, however, there has been no definitive evidence that OSM is independent of attention, as all previous studies that have addressed ceiling effects have involved manipulations of attention and spatial uncertainty (Argyropoulos et al., 2013; Filmer et al., 2014; Pilling et al., 2014). In addition, increasing distractor set-size raises the likelihood that crowding (Pelli & Tillman, 2008) will interact with OSM (Vickery, Shim, Chakravarthi, Jiang, & Luedeman, 2009). To address these issues, we employed a single-target OSM paradigm with constant foveal presentation so attention was always devoted to the target. If OSM is present when the target is fully attended, the proposed critical relationship between attention and OSM can be discounted.

Experiment 1

Experiment 1 employed foveal presentation of a target image with no distractor items present. A forward mask was employed to disrupt early neural processing of the target (Macknik & Livingstone, 1998), and hence to weaken target signal strength sufficiently to bring performance off ceiling. If OSM arises for fully attended targets, then it should occur when performance is below ceiling for the simultaneous offset condition and above floor for the delayed offset (‘masked’) condition.

Method

Twenty-two participants completed Experiment 1 (19 females, mean age = 22). Stimuli were presented to participants via a 21” CRT monitor (100Hz refresh rate) and the background colour was set to dark grey (100:100:100, RGB; 28.15 cd/m2). Target images consisted of a circle (diameter 0.55º) with a small line-segment projecting from the center outwards in one of four directions (up, down, left or right; Figure 1A). Participants indicated the orientation of the line segment (Filmer et al., 2014) when prompted with “Line orientation?”. This response cue was presented in Helvetica 40-point font and appeared 1.16º above the center of the screen 360ms after the offset of the target. The timing and location of the response cue were chosen to avoid any overlap with the target and mask stimuli. A standard four-dot mask, surrounding the target image, was used to elicit OSM (Enns & Di Lollo, 1997), and the forward mask was a patch of visual noise the same size and location as the target. The forward mask did not overlap, spatially or temporally, with the four-dot mask. The colour of the four-dot mask and the target was set to light Grey (150:150:150, RGB; 60.35 cd/m2).

Contrast of the forward mask was thresholded using a three-staircase PEST procedure (Taylor & Creelman, 1967) to achieve 70% accuracy (below ceiling/above floor) for simultaneous dot-mask offset (see below). The thresholding was administered as a separate block at the start of the session, and took around 10 minutes to complete. Five participants were excluded as their performance was at ceiling even when the forward mask was at maximum contrast, leaving a final sample of 17 participants. The mean thresholded contrast (which could vary from 0 to 100) of the forward mask for the included 17 participants was 74.08 (min = 59.29, max = 94.86). After thresholding, the offset of the four-dot mask varied pseudo-randomly between one of five possible timings: 0, 90, 180, 270, or 360 ms (see Figure 1A). Participants completed 84 trials per mask offset.

Results and Discussion

The results of Experiment 1 are shown in Figure 1B. Accuracy at the 0 ms mask offset was 70%. All participants performed below ceiling and above floor (range: 45 – 87% correct), verifying the efficacy of the thresholding procedure. As the duration of the four-dot mask increased, accuracy decreased. The main effect of mask offset showed a large effect size ($\eta_p^2 = 0.383$), reflecting a significant change in accuracy across mask duration ($F(4,64) = 9.951$, $p < 0.001$). The design of Experiment 1 ensured that maximum attentional resources were available for processing the target stimulus. The results provide clear evidence that OSM can occur for fully attended, foveal target stimuli.

Experiment 2

A crucial aspect of our design in Experiment 1 was the addition of a forward mask to disrupt early neural activity associated with the target. It is possible that the onset of the forward mask was somehow distracting, however, capturing attention shortly before the appearance of the target and four-dot mask. We addressed this possibility in Experiment 2 by increasing the duration of the forward mask, thus eliminating any abrupt onset in close temporal proximity to the target. Due to the increased duration of the forward mask, we also changed the thresholding procedure to maximise the number of participants that were thresholded successfully. The new procedure thresholded performance by varying properties of the target image directly (as opposed to forward mask properties, as in Experiment 1), which allowed us to examine masking using a different method for reducing the salience of the target.

Method

Twenty individuals (17 females, mean age = 21) participated in Experiment 2. The design was similar to that of Experiment 1, with a few exceptions (see Figure 2A). The forward mask now appeared well before the target (by 800 ms) and remained on screen throughout its presentation. In addition, the transparency of the target was thresholded (using the same PEST staircase procedure as Experiment 1) to achieve 70% accuracy with target and mask co-terminating. The contrast of the forward mask was set to 70 (out of maximum of 100) for all participants, and remained constant through the entire experiment. The mean transparency (with 0 representing complete transparency, and 255 complete opacity) of the target was 145.87 (min = 123.9, max = 162). In addition to the mask offsets used in Experiment 1, we included the mask offset of 450 ms to provide a more extensive measure of the OSM curve. Participants completed 84 trials per mask offset, with the offset of the four-dot mask varied pseudo-randomly between trials.

Results and Discussion

The results of Experiment 2 are shown in Figure 2B. Accuracy at the 0 ms mask offset was 68%. All participants performed below ceiling and above floor (range: 52 – 79% correct), verifying the efficacy of the transparency based thresholding procedure. As in Experiment 1, as the duration of the four-dot mask increased, accuracy decreased. The main effect of mask offset showed a moderate effect size ($\eta_p^2 = 0.191$), reflecting a significant change in accuracy across mask duration ($F(5,95) = 4.497$, $p = 0.001$). Hence the findings of Experiment 2 replicate those of Experiment 1, and discount explanations of the OSM reported in that experiment as being due to distraction caused by the forward mask appearing just before the target, or due to specific properties of the thresholding procedure.

Conclusions

Here we asked whether OSM can occur for attended and foveated stimuli. In two experiments, a single target was presented at fixation and there were no concurrent distractor stimuli. To avoid the possibility that ceiling effects might limit masking magnitude (Argyropoulos et al., 2013; Filmer et al., 2014; Pilling et al., 2014), we used a forward mask to disrupt early neural processing of the target (Macknik & Livingstone, 1998), and thus reduce its salience. A PEST staircasing procedure (Taylor & Creelman, 1967) determined the forward mask contrast (Experiment 1) or the target transparency (Experiment 2) required for participants to achieve 70% discrimination accuracy with simultaneous four-dot mask offset. Both experiments revealed a substantial OSM effect for longer mask offsets, with moderate to large effect sizes.

Our findings provide definitive evidence that OSM arises for fully attended and foveated stimuli. We therefore assert that, contrary to previous proposals (Di Lollo et al, 2000; Enns, 2004; Enns & Di Lollo, 1997, 2000), OSM does not depend on attention being distributed over space or time, provided floor and ceiling effects are avoided. Our findings challenge some key assumptions concerning the mechanisms underlying OSM. This in turn has implications for the theories and models that have been developed to explain masking generally. For example, the attentional gating model (Põder, 2013) describes divided attention at the start of each trial as a critical component of OSM. The inclusion of attention as a key component of OSM is difficult to reconcile with our findings. However, the change in our conceptual understanding of OSM need not invalidate all previous accounts. For example, the influential recurrent processing model (Di Lollo, 2014; Di Lollo et al., 2000) would still hold if the OSM effect is assumed to arise under conditions in which target salience is reduced through distributed attention or forward masking, as we have shown. In addition, the lateral inhibition model (Macknik & Martinez-Conde, 2007) includes attention as a separate process to masking, and therefore could be modified to exclude a role for attention in OSM. In sum, the current findings require a change in how OSM is conceptualized within the broader masking literature, and challenge the notion that this phenomenon is closely tied to attention.

A further question concerns whether the present masking paradigm influences only the feed-forward sweep of visual information, or whether it also engages reentrant processing of the target stimulus. Put differently, does OSM influence the analysis of feed-forward information? This issue could be examined by using our novel approach to measure target detection for an elementary feature such as line orientation, which may only require feed-forward processing. An alternative approach would be to employ electroencephalography to measure neurophysiological markers of target processing under the new masking protocol introduced here.

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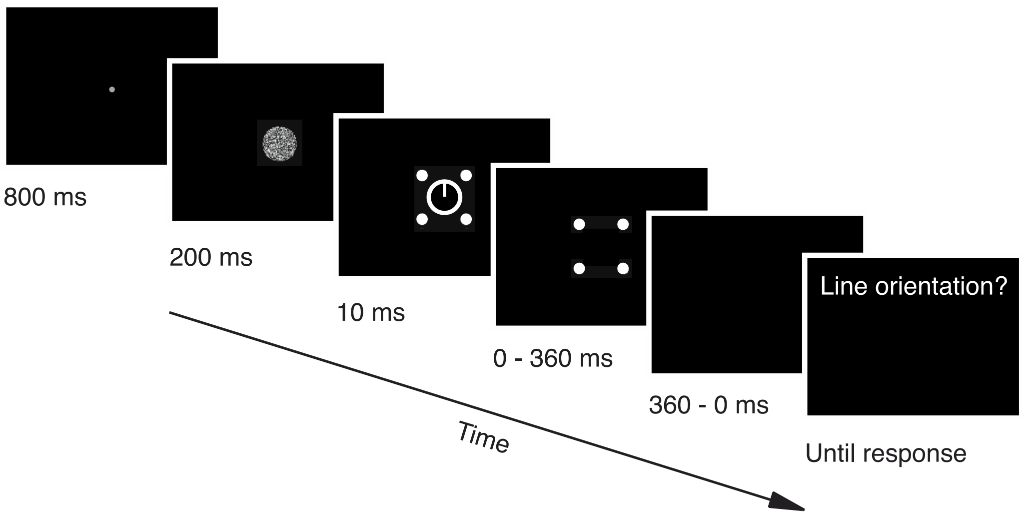
Figure 1: Example trial sequence and results from Experiment 1. **(A)** Standard trial outline. Each trial consisted of a fixation period (800 ms), the forward mask (200ms), the target and four-dot mask (10ms), the four-dot mask alone (0 – 360 ms), a blank screen (0 – 360 ms, depending on the mask offset), and a prompt to report the line orientation using the arrow keys on a keyboard without time pressure. The response prompt appeared above the target and mask positions, 360ms after target offset, to ensure it did not influence target processing. **(B)** Mean accuracy for each of the four-dot mask offsets. Error bars represent 95% confidence intervals for the within-subjects variance (Loftus & Masson, 1994).

A



B

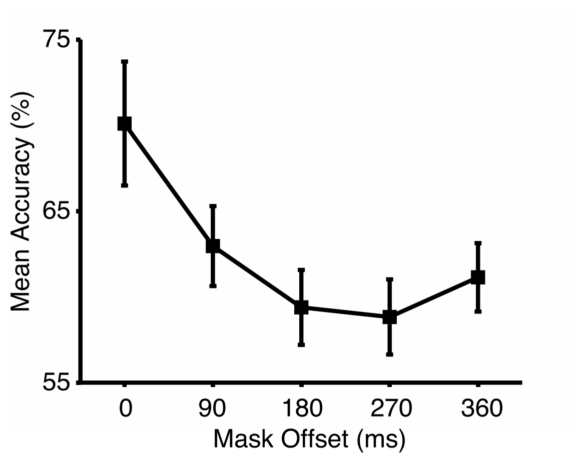


Figure 2: Example trial sequence and results from Experiment 2. **(A)** Standard trial outline. Each trial consisted of a forward mask (800ms), the target and four-dot mask (10ms), the four-dot mask alone (0 – 360 ms), a blank screen (0 – 360 ms, depending on the mask offset), and a prompt to report the line orientation using the arrow keys on a keyboard without time pressure. **(B)** Mean accuracy for each of the four-dot mask offsets. Error bars represent 95% confidence intervals for the within-subjects variance (Loftus & Masson, 1994).