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9           Object substitution masking and its relationship with visual crowding

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### Authors' note

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## Abstract

Object substitution masking (OSM) occurs when the perceptibility of a brief target is reduced by a trailing surround mask typically composed of four dots. OSM was originally deemed to be influenced by set size (Di Lollo et al., 2000). More recently, Camp et al. (2015) reported that *set size* had no specific effect on OSM, however distractor location did: OSM being more pronounced when distractors flanked the target, compared to when they flanked the location of a non-target positioned diametrically opposite. This flanker effect was interpreted as one of crowding influencing OSM. We test this interpretation. In three experiments we manipulate target-flanker distance while also varying mask duration. The relationship between target-flanker distance and OSM (as indexed by mask duration) was found to be quadratic, a pattern not predicted by the crowding-on-OSM account. We interpret these results as evidence of the converse process of OSM influencing crowding (Vickery et al., 2009). In this interpretation OSM increases the target's sensitivity to flankers across a broader spatial range than found under unmasked conditions. We argue that OSM reflects a process by which the visual system attempts to resolve a target from competing visual information present in both the temporal and spatial domains.

**Keywords:** Object Substitution Masking, Flankers, Crowding, Supercrowding

## Object substitution masking and its relationship with visual crowding

In standard models, visual masking is understood as a consequence of inhibition or interference associated with the mask's spatially-overlapping or adjacent edges with the target, or with the transients associated with the mask's delayed onset (Kahneman, 1968; Breitmeyer, Hoar & Randall & Conte, 1984). The phenomenon of Object Substitution Masking (OSM), first reported by Enns and Di Lollo (1997), has been argued to pose a challenge to standard models. In OSM a mask consisting of just four surrounding dots is sufficient to prevent awareness of the target when the mask lingers after the target offset, the duration of the trailing mask being associated with the strength of masking (Di Lollo, Enns & Rensink, 2000). In OSM the mask, in being comprised of just four dots, contains no significant overlapping or adjacent edges; the onset of the mask does not seem to play any special role (OSM occurs irrespective of whether the mask onsets simultaneously with the target or with a delayed onset). Instead it has been suggested that the processes in OSM are object-based with masking being a reflection of the process by which mask and target compete with each other as separate *perceptual objects* for conscious representation (Enns & Di Lollo, 1997; Di Lollo et al., 2000).

The original descriptions of OSM strongly emphasised the importance of attention as a factor in masking (Enns & Di Lollo, 1997; Di Lollo et al., 2000; Di Lollo, Enns & Rensink, 2002; Enns, 2004). The reason for this was that initial empirical studies of OSM seemed to indicate that masking only occurred when the target and mask were presented in the context of multi-element displays; with just the target and mask alone OSM -as indexed by the difference in performance between simultaneous and delayed mask offset conditions- seemed to be absent (Enns & Di Lollo, 1997). Later studies found what seemed to be a systematic relationship between *set size* (i.e. the number of display items) and the magnitude of OSM (Di Lollo et al., 2000; Kotsoni, Csibra, Mareschal & Johnson, 2007).

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More recently however a number of papers have reported results which challenge the status of attention in OSM (Argyropoulos, Gellatly, Pilling & Carter, 2013; Filmer, Mattingley & Dux, 2014; Pilling, Gellatly, Argyropoulos & Skarratt, 2014; Filmer, Mattingley & Dux, 2015; Goodhew, & Edwards, 2016). For instance, both Argyropoulos et al. (2013) and Filmer et al. (2014) failed to observe a set size  $\times$  mask duration interaction in OSM in their data. Both authors claim that the interactions reported in the original experiments of Di Lollo et al. (2000) were artefactual in nature, the product of ceiling effects in the smaller set size conditions (particularly when set size =1). When, as in these later studies, the discrimination task was made more difficult to bring performance in the smaller set size conditions into a measureable range a masking effect in these conditions became apparent. Under such conditions set size had a clear main effect on performance; however the interaction with mask duration was no longer found. More recently Filmer et al. (2015) showed that OSM can even occur under conditions where the target is the sole focus of attention and is presented at fixation.

Together these findings suggest that the original claims regarding the status of attention as a variable in OSM were, at best, overstated. It seems that attention has, if at all, only a small effect on OSM. Certainly at the very least, the role of attention cannot be considered a signature aspect of the OSM phenomenon as was originally claimed.

Though the role of attention is ostensibly small and though the presence of distractors has been demonstrated to be unnecessary for OSM to occur, recent research has suggested that distractors, where present, can influence OSM at least under some circumstances. Camp, Pilling, Argyropoulos and Gellatly (2015) in contrast to the earlier described findings of Argyropoulos et al. (2013) and Filmer et al (2014) found a reliable effect of set size on mask duration. Although OSM occurred without distractors, adding distractors to the display reliably increased the size of OSM. However, a further experiment showed that this effect

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3 was not a consequence of the changes in set size as Di Lollo et al. (2000) had earlier  
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5 assumed. Rather, this effect was explained by the relative position of the distractors in the  
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7 display with respect to the target. Where distractors were positioned to closely flank the  
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9 target location OSM was stronger than when the distractors flanked a location opposite the  
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11 target. This effect was found irrespective of overall set size. Camp et al. attributed this  
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13 increased OSM which occurred with flanking distractors (hereafter ‘flankers’) to an effect of  
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15 *crowding on OSM*.  
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21 Crowding is a well-established visual phenomenon (Levi, 2008; Whitney & Levi,  
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23 2011). One widely held theory of crowding deems it as a consequence of neural pooling or  
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25 signal averaging. On this account the features of a target and those of sufficiently closely  
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27 located flankers become mingled together, the result being that the visual system is unable to  
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29 bind only the appropriate features to the token representation of the target (Parkes, Lund,  
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31 Angelucci, Solomon & Morgan, 2002; Levi & Carney, 2009; Greenwood, Bex & Dakin,  
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33 2009). The interaction between OSM and crowding is interesting because it suggests the two  
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35 phenomena, though distinct, share common mechanisms.  
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41 Camp et al., (2015) argued that crowding the target degraded the initial target percept  
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43 and in doing so rendered it more susceptible to the trailing mask. They argued that the  
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45 converse possibility, that OSM influenced crowding, was ruled out as an explanation of the  
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47 interaction. This was argued on the basis of previous empirical findings and theoretical  
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49 claims which suggest that OSM occurs as a later stage process than crowding within the  
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51 visual processing hierarchy (Breitmeyer, 2014; Chakravarthi & Cavanagh, 2009)  
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56 Aside from OSM, some other forms of masking can influence crowding (Vickery,  
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58 Shim, Chakravarthi, Jiang, & Luedeman, 2009). Vickery et al. presented a brief target in a  
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60 location directly below the observer’s fixation. On unmasked trials no mask was present, on

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3 masked trials a surround ring (in a later experiment, a surround square) was presented around  
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5 the target and onset and co-terminated with it. Flankers were located at each of the four  
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7 cardinal positions around the target at one of three increasing distances from the target. This  
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9 flanker position manipulation was done on both unmasked and masked trials. On unmasked  
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11 trials a classic crowding effect was observed: accuracy was low when flankers were closest to  
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13 the target and much higher when at the middle and furthest distances given. With these outer  
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15 two distances accuracy was the same as a baseline unmasked condition in which no flankers  
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17 were present. On masked trials with flankers at the nearest position accuracy was similarly  
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19 low to that found on unmasked trials. However, unlike for unmasked trials accuracy remained  
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21 low for the middle and furthest flanker distances compared against a no flanker masked  
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23 baseline. Thus, when the target was masked the flankers continued to have a deleterious  
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25 effect on performance across a broader spatial range than they did under unmasked  
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27 conditions. This spatially extended crowding effect the authors dubbed ‘supercrowding’. This  
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29 effect occurred despite the fact that masking individually had only a marginal effect on  
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31 performance.  
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40 The current paper had two aims. The first was to attempt to replicate the finding of  
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42 Camp et al., (2015) that crowding and OSM interact. In only one of the four experiments of  
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44 Camp et al. was crowding specifically manipulated, given this it is important to demonstrate  
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46 that the interaction that Camp et al found is a replicable one. The paper’s second aim was to  
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48 more thoroughly explore the nature of the interaction. Specifically the aim was to determine  
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50 if the interaction is better understood as an effect of crowding on OSM (Camp et al. 2015), or  
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52 some other process, such as OSM affecting crowding (Vickery et al., 2009). Camp et al.  
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54 manipulated crowding only in a coarse way; the spatial character of crowding under masked  
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56 and unmasked conditions was not determined in their experiment. These limitations make it  
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58 difficult to determine what the relationship between crowding and OSM actually is. The  
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3 current set of experiments aimed to provide a clearer picture on this relationship by  
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5 presenting a greater number of crowding conditions, ones which allowed the spatial profile of  
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7 the crowding effect to be determined under masked and unmasked conditions. Crowding is  
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9 strongly sensitive to the spatial distance between the flankers and the target, indeed crowding  
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11 is typically operationalised in terms of this variable (Bouma, 1970; Whitney & Levi, 2011;  
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13 Pelli & Tillman, 2008). Crowding is typically maximal when the flankers are nearest to the  
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15 target and the effect declines monotonically as the distance is increased. The critical spacing  
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17 for crowding to occur is dependent on target eccentricity with critical spacing increasing  
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19 proportionally with the distance of the target from fixation. The effective distance for  
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21 crowding tends to be approximately half that of the target's distance from fixation though the  
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23 range of the effect does depend on several other factors such as the position of the target and  
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25 flankers with respect to fixation (Pelli & Tillman, 2008).  
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33 If crowding interacts with OSM because a crowded target is more susceptible to a  
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35 trailing mask then we should expect a certain pattern of data. Crowding is diminished as the  
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37 spatial distance between target and flankers increases. Therefore we should expect that the  
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39 effect on masking should also diminish in line with this reduction in masking. If such a  
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41 monotonic decline of the effect did not occur then this would constitute evidence against the  
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43 crowding on OSM explanation offered by Camp et al. Experiment 1 assessed this possibility.  
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## Experiment 1

In Experiment 1 three target-flanker distance conditions are given, each of which is compared against an uncrowded condition in which the flankers surround a non-target item at the same distance. A digit identification task was given.<sup>1</sup> The target, surrounded by a four dot mask (4DM) was presented at a random location on a virtual circle. On unmasked trials the 4DM co-terminated with the target, on masked trials it lingered on-screen for a period after the target offset.

In the task on some trials two flanker digits flanked the target (designated *flanked-target* trials). On other trials the two flankers flanked a non-target digit located directly opposite the target on the virtual circle (designated *unflanked-target* trials). The distance between the flankers and the flanked item (i.e. target or non-target) was also manipulated. Four flanker distance positions were given across both the *flanked-target* trials and the *unflanked-target* trials. This flanker distance manipulation, it was assumed, would give us a measure of the spatial profile of the flanker effect on OSM. The inclusion of the unflanked-target trials conditions reflected the same basic design given in Camp et al. (2015). These trials were included for two reasons. Firstly their inclusion made the experiment design a symmetrical one: for each target-flanker distance there was an equivalent control condition. Secondly, because of this symmetry, flankers did not potentially serve as a spatial cue to the target location as they would have done had only flanked-target trials been given.

It was predicted that OSM would be greater on the flanked target trials than on the unflanked target trials (i.e. trials where the flankers surround the non-target), replicating the

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<sup>1</sup> The use of this digit identification task bequeathed a certain advantage. Having ten response options means that the baseline probability of a correct response occurring through random responding will be substantially lower than it would be in the standard four-alternative discrimination task typically used in OSM studies (e.g. Di Lollo et al., 2000). This is important in order to avoid the potential issues of ceiling and floor effects which sometimes plague the interpretation of results in OSM (see Argyopolous et al., 2013; Pilling et al. 2015; Filmer et al., 2015).

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3 finding reported by Camp et al. (2015). A further prediction was made based on the claim  
4 stated in Camp et al regarding the relationship between OSM and crowding. If Camp et al.  
5 are correct then OSM should be greatest when flankers were positioned closest to the target  
6 (where the crowding effect on the target was strongest) and diminish as the distance between  
7 the flankers and flanked target was increased. If this pattern is not found then it would be  
8 evidence against their interpretation of the relationship between OSM and crowding.  
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## 21 Method

### 22 *Participants*

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26 Thirty-five first year Oxford Brookes Psychology students (27 female) took part in the  
27 experiment. All gave informed consent and received course credits for completing the  
28 experiment. All reported normal or corrected-to-normal visual acuity. This and all other  
29 experiments in this paper received full approval by the Oxford Brookes University ethics  
30 panel.  
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### 38 *Design*

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41 The experiment had three factors, all repeated-measures: *mask duration* (0, 180 ms),  
42 *target condition* (flanked target, unflanked target), and *flanker distance* (0.63°; 0.89°; 1.15°;  
43 1.41°). The dependent variable was identification accuracy, measured by the percentage of  
44 correct responses.  
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### 50 *Stimuli and procedure*

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53 The experiment was conducted in a darkened and sound deadened room with back  
54 lighting. Stimuli were presented on a 20 inch Sony Trinitron CRT computer monitor  
55 (resolution = 1024×768; refresh rate = 100Hz). The monitor was controlled by an Intel  
56 Pentium 4 (2.66 GHz) PC fitted with a NVIDIA GeForce 4 graphics card. The monitor was  
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5 viewed by the participant from a distance of approximately 110cm. Bespoke software written  
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7 in the *BlitzMax* programming language (BlitzMax V. 1.5; Sibly, 2011) controlled all aspects  
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9 of stimulus presentation, randomisation and response recording. All stimuli were black (0.03  
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11 cd/m<sup>2</sup>) on a white (97 cd/m<sup>2</sup>) background. The stimulus array always consisted of four digits  
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13 (0-9) positioned on the circumference of a virtual circle around a central fixation point. Each  
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15 digit was in Arial font Pt. 32 (a subtended visual angle of 0.47° in height). The virtual circle  
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17 itself had a radius subtending 3.9° from the centre of the fixation cross to the centre of each  
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19 digit. One of the four digits was designated as the target, one as the non-target and the other  
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21 two as flankers. The target was presented at a point, randomly determined on each trial, on  
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23 the virtual circle. The non-target was always presented diametrically opposite the target on  
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25 the virtual circle. The target was identified in the stimulus array by the surrounding 4DM.  
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27 The 4DM was arranged in a virtual square (subtending 0.89° in height/width) around the  
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29 target. The dots comprising the mask were each 0.10° of visual angle in width/height.  
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36 On flanked-target trials the flankers surrounded the target location at one of four  
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38 distances 0.63°; 0.89°; 1.15°; or 1.41° (distances are expressed in units of subtended visual  
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40 angle of the circumferential distances between the mid-points of the surrounded item and the  
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42 flanker digits on the virtual circle).<sup>2</sup> On unflanked-target trials the flankers surrounded the  
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44 non-target location, again at one of four distances , 0.63°; 0.89°; 1.15°; or 1.41° (Figure 1  
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46 gives an example of a flanked and unflanked trial for the nearest of the four flanker distances  
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48 (0.63°).  
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53 The identity of the target digit was randomly determined on each trial with the  
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55 constraint that each of the ten digits appeared with equal frequency for all trial types. The  
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57 identity of the non-target and flanker digits on each trial was determined randomly with  
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59 replacement. A schematic depiction of an example trial sequence is shown in Figure 1. All  
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<sup>2</sup> Expressed in linear distance units these are 0.63°, 0.89°, 1.15° and 1.40° of visual angle.

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3 trials started with the onset of a blank white screen presented for 500ms. A frame was then  
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5 shown in which the fixation cross alone was presented for 250ms. The onset of this frame  
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7 was accompanied by a brief alerting tone. The stimulus array was presented with the 4DM  
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9 surrounding the target digit. The stimulus array frame was shown for 40ms. Then both the  
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11 stimulus array and mask disappeared from screen (0ms trailing mask), or the stimulus array  
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13 disappeared but the mask remained for a further 180ms (180ms trailing mask). The fixation  
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15 cross was present onscreen throughout these frames and remained visible until the participant  
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17 responded. The task was to identify the target digit. Participants responded by pressing the  
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19 corresponding key (0-9) on a standard computer keyboard. Immediate aural error feedback  
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21 was given following an incorrect response. The participant's response instigated the start of a  
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23 new trial.  
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30 There were 640 trials in total, 40 trials for each combination of mask duration, target  
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32 condition, and flanker distance. Trials were presented in 10 blocks of 64 trials. The computer  
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34 prompted the participant to take a brief break after each 64 trial increment. Five  
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36 demonstration trials presented at a slowed speed and 30 practice trials given at the real speed  
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38 of the experiment were undertaken prior to the start of the experiment. Participants were  
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40 instructed to emphasise accuracy in responding. The total session lasted approximately 30  
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42 minutes.  
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## Results

Figure 2a gives the mean percent correct responses for all conditions; Figure 2b shows the masking strength in the different target conditions (masking strength is calculated by subtracting performance in the 180ms mask duration trials from the corresponding 0ms trials). A three-way repeated measures ANOVA was performed to analyse the data. The three factors were *mask duration* (0, 180), *target condition* (flanked-target, unflanked-target), and *flanker distance* (0.63°; 0.89°; 1.15°; 1.41°). Significant main effects were found for all three factors: *mask duration* ( $F[1,34] = 212.77$ ,  $MS^{\text{error}} = 50.15$ ,  $p < .001$ , partial  $\eta^2 = .86$ ), *target condition* ( $F[1,34] = 174.56$ ,  $MS^{\text{error}} = 220.14$ ,  $p < .001$ , partial  $\eta^2 = .84$ ), and *flanker distance* ( $F[3,102] = 7.08$ ,  $MS^{\text{error}} = 44.46$ ,  $p < .001$ , partial  $\eta^2 = .17$ ).

A significant two-way *mask duration*  $\times$  *target condition* interaction was observed:  $F(1,34) = 5.44$ ,  $MS^{\text{error}} = 50.54$ ,  $p = .026$ , partial  $\eta^2 = .14$ . This reflects the fact that masking was stronger when the flankers surrounded the target compared to when they surrounded the non-target. This interaction supports our first prediction; it replicates the finding reported by Camp et al. (2015). The two-way *target condition*  $\times$  *flanker position* interaction was also significant:  $F(3,102) = 11.72$ ,  $MS^{\text{error}} = 47.26$ ,  $p < .001$ , partial  $\eta^2 = .26$ . This interaction simply reflects the fact that variation in flanker position has a greater effect on accuracy on flanked-target trials than on unflanked-target trials. The two-way *mask duration*  $\times$  *target position* interaction was not significant:  $F(3,102) = 1.47$ ,  $MS^{\text{error}} = 40.63$ ,  $p = .226$ . The three-way *mask duration*  $\times$  *target condition*  $\times$  *flanker position* interaction did not approach significance:  $F[3,102] = 0.61$ ,  $MS^{\text{error}} = 50.40$ ,  $p = .609$ .

\*\*\* Figure 2 about here \*\*\*

## Discussion

Our first prediction of an interaction between flanker position and mask duration was supported. The interaction reflects the fact that masking tended to be stronger when the flankers surrounded the target location compared to when they surrounded the non-target. This finding replicates that reported by Camp et al. (2015).

The second prediction was that OSM would be greatest when the flankers were located nearest to the target and diminish as flanker distance was increased. The data did not support this. Indeed the trend was in the opposite to the predicted direction. For instance, for flanked-target trials, contrary to prediction, slightly *more* masking was observed at the largest (1.41°) than the smallest (0.63°) flanker distance conditions. Secondly, and unexpectedly, flanker distance had at least of as much an effect on unflanked-target trials as it did for flanked ones (see Figure 2b). We shall defer from making any further interpretation of these results at this stage other than to state that the pattern of data obtained was inconsistent with the crowding on OSM hypothesis proposed by Camp et al. (2015).

Given the pattern of the data obtained in Experiment 1, Experiment 2 looked at the effect of flanker distance on OSM over a much larger spatial range. This was done to obtain a clearer picture of the relationship between these variables. In Experiment 1 a distinction was made between flanked-target trials and unflanked-target trials. It should be noted that the distinction was somewhat arbitrary given that all stimuli are positioned on the same virtual circle. This arbitrariness becomes more palpable when the distances of the flankers from the target (or non-target) are larger as they are for Experiment 2. Consequently for Experiment 2 it was deemed more appropriate to consider flanker distance as a single continuous variable.

## Experiment 2

The aim of Experiment 2 was to explore the effect of flanker distance on OSM over a larger distance range than in Experiment 1. This distance covered the range of the entire arc of the virtual circle. Methods were the same as Experiment 1 except for the differences thus described. The aim of this experiment was to get a clearer indication of the relationship between flanker position and mask duration than was apparent from Experiment 1.

### Method

#### *Participants*

Thirty two undergraduate and postgraduate Oxford Brookes Psychology students (27 female) were recruited for the experiment. All participants reported normal or corrected-to-normal visual acuity. None had taken part in Experiment 1. Participants received course credits for taking part in the experiment.

#### *Stimuli and procedure*

The basic procedure was the same as Experiment 1. A target digit was presented with a non-target located directly opposite it on a virtual circle. The 4DM surrounded the target and identified it within the array. The mask either offset with the target or trailed it by 180 ms. The dimensions of the digits and of the virtual circle were the same as in Experiment 1. Two flankers were presented on the virtual circle at one of the six target-flanker (circumferential) distances ( $0.63^\circ$ ,  $3.02^\circ$ ,  $4.9^\circ$ ,  $7.35^\circ$ ,  $9.23^\circ$ ,  $11.62^\circ$ )<sup>3</sup>. Note that the symmetrical nature of the flanker positions is maintained in Experiment 2 as it was in Experiment 1. For instance the condition in which flankers are nearest to the target ( $0.63^\circ$ )

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<sup>3</sup> These distances correspond with  $0.63^\circ$ ,  $2.95^\circ$ ,  $4.58^\circ$ ,  $6.31^\circ$ ,  $7.22^\circ$  and  $7.77^\circ$  of linear distance.

has a corresponding condition in which the flankers are the same distance from the non-target (11.62°).

There were 480 trials, 60 trials for each factorial combination of masking and flanker position. The trials were presented within 10 blocks each of 48 trials. Participants were given a short break after completion of each block.

### Results

The mean percent correct responses are given in Figure 3a. The data were analysed using a two-way repeated measures ANOVA. The factors were *mask duration* (0ms, 180ms) and *target-flanker distance* (0.63, 3.02°, 4.9°, 7.35°, 9.23°, 11.62°). This analysis showed significant main effects for both masking ( $F[1,31]=130.53$ ,  $MS^{\text{error}}=53.70$ ,  $p<.001$ ,  $\eta_p^2=.81$ ) and target-flanker distance ( $F[5,155]=97.93$ ,  $MS^{\text{error}}=41.85$ ,  $p<.001$ ,  $\eta_p^2=.69$ ). There was also a significant masking  $\times$  target-flanker distance interaction, one which displayed a quadratic trend ( $F[1,31]=10.42$ ,  $MS^{\text{error}}=26.57$ ,  $p=.003$ ,  $\eta_p^2=.25$ ). The quadratic nature of this interaction reflected the fact that masking –as defined by the performance difference between masked and unmasked trials- exhibits an *inverted U-shaped function* with respect to target-flanker distance (Figure 3b). That is, masking was greatest not at the nearest target-flanker distance (0.63°), but at an intermediate distance (3.02°); it was lower when flankers were placed closer to or further from the target than this<sup>4</sup>.

\*\*\*Insert Figure 3 here\*\*\*

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<sup>4</sup> A reanalysis was performed on the Exp. 2 data to test against the possibility that the interaction was a consequence of ceiling and/or floor effects in the measurable range of performance. Any participant performing lower than 20% or higher than 80% in any single condition was removed. Under these criteria five participants were removed from the analysis. The repeated ANOVA still produced a significant quadratic function ( $F=4.92$ ,  $p=.003$ ) suggesting that the data pattern was not a consequence of restrictions in the range of measurable performance



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3 A further analysis was performed in the form of a piecewise linear regression. These  
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5 line fits are often used to characterise crowding functions (Pelli, Palomares & Majoaj, 2004;  
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7 Yeshuran & Rashal, 2010). The fits were performed on the raw accuracy data for the two  
8  
9 masked conditions. The fitting was done using a least squares method. In this equation the fit  
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11 was constrained by a two line solution; the single hinge-point ( $k$ ) between the two line  
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13 segments was implemented as a free parameter. In this analysis the linear distances, rather  
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15 than the circumferential differences, were used. The resulting  $k$  values along with the slopes  
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17 for the first and second lines ( $A_1, A_2$ ) are presented in Table 1. The line fits are somewhat  
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19 different for the unmasked and mask conditions as might be expected given the interaction.  
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21 The breakpoint of the line  $k$  is similar for the masked and unmasked conditions though it  
22  
23 occurs at a slightly greater target-flanker distance under masked conditions. More evident is  
24  
25 the fact that the slope of the first line segment is shallower under masked conditions; that of  
26  
27 the second line segment is steeper under masked conditions. This second line segment had a  
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29 near zero slope when unmasked; under masked conditions it had a distinct positive slope.  
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31 Thus the quadratic effect in the masking data can be characterised as a consequence of the  
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33 difference in slopes of the recovery function associated with flanker distance under masked  
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35 and unmasked conditions.  
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\*\*\*Insert Table 1. here\*\*\*

## Discussion

Experiment 2 was more revealing of the spatial character of the relationship between target-flanker distance and OSM than Experiment 1. Contrary to the prediction OSM did not decline and then asymptote as flanker distance was increased. Instead the relationship between target-flanker distance and OSM was *quadratic* (inverted-U shaped) in nature.

Before discussing this further it should be noted that the interpretation of a quadratic masking function arguably rests on the position of a single data-point. If accuracy in the condition with a  $0.63^\circ$  target-flanker distance and trailing mask had been rather lower than observed then the masking function would have appeared monotonic rather than quadratic, and would have arguably supported our original prediction of an effect of crowding on masking. Given this fact Experiment 3 was conducted to clarify the seeming quadratic relationship between OSM and flanker distance found in Experiment 2.

## Experiment 3

Experiment 3 consisted of two parts (3a, 3b). Both experiments had the same two factor design as Experiment 2. In both cases the factors were mask duration and target-flanker distance. Three mask durations were presented in these experiments (0 ms, 60 ms, 180 ms). The additional masking condition presented additional data points on which to assess the nature of the masking function with respect to flanker distance. A further change from Experiment 2 was also implemented. The eccentricity of the stimuli with respect to fixation was increased from that in the previous two experiments. This was done to amplify the overall crowding effect on the target (Gurnsey, Roddy & Chanab, 2011; Pelli, Palomares & Majaj, 2004).

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3 Experiment 3, as in Experiment 2, had two factors (*mask duration, target-flanker*  
4 *distance*). Like in Experiment 2 target-flanker distance was manipulated to sample across the  
5 entire available range on the virtual circle. In Experiment 3a the stimulus array was presented  
6 at an eccentricity of 4.75°, in Experiment 3b the stimulus array was presented at an  
7 eccentricity of 5.4° (compared with an eccentricity of 3.9° in Experiments 1 and 2). The  
8 same target-flanker distances were given in Exp. 3a and 3b with the exception that Exp. 3b  
9 had an additional target-flanker distance condition which was allowed for by the larger  
10 circumferential distance of the virtual circle in a 5.4° display. The aim of Experiment 3 was to  
11 confirm whether the interaction between masking and crowding has an inverted U-shape.  
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## 28 Method

### 29 Participants

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33 Forty four undergraduate and postgraduate Oxford Brookes Psychology students (35  
34 female) took part in the experiment. Half the participants were allocated to Exp. 3a., half to  
35 Exp. 3b by a random process. All participants gave informed consent and received course  
36 credits (undergraduate students) or financial remuneration (£7 GBP) for completing the  
37 experiment. All had normal or corrected-to-normal visual acuity.  
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### 45 Stimuli and procedure

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48 The stimuli and procedure were identical to those of Experiment 2 except where  
49 stated. For Experiment 3a the radius of the display was 4.75° of visual angle and for  
50 Experiment 3b was 5.4° of visual angle. For both experiments trailing mask duration was one  
51 of three conditions (0 ms, 60 ms, or 180 ms). In Exp. 3a there were seven target-flanker  
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distances (1°, 3°, 5°, 7°, 9°, 11°, 13°).<sup>5</sup> In Exp. 3b the target-flanker distances were 1°, 3°, 5°, 7°, 9°, 11°, 13° and 15° of circumferential visual angle.<sup>6</sup>

For both experiments there were 30 trials for each factorial combination of masking and target-flanker distance. This resulted in a total of 630 trials in Exp. 3a and 720 trials in Exp. 3b. Trials were presented in 10 blocks each of equal length. Participants were asked to take a short break at the end of each block. Participants were shown a demonstration and given practice trials were given before undertaking the main experiment.

## Results

### Experiment 3a

The average percent correct responses in each factorial condition of mask duration and target-flanker distance are shown in Figure 4a. These data were analysed using a 3×7 repeated measures ANOVA with *mask duration* (0 ms, 60 ms, 180 ms) and *target-flanker distance* (1°, 3°, 5°, 7°, 9°, 11°, 13°) as the two factors. A significant main effect was found for mask duration  $F(2,42)=31.48$ ,  $MS^{\text{error}}=85.31$ ,  $p<.001$ , partial  $\eta^2=.60$ , and with a Greenhouse-Geisser correction for target-flanker distance,  $F(3.11,65.40)=23.52$ ,  $MS^{\text{error}}=97.77$ ,  $p<.001$ , partial  $\eta^2=.53$  respectively. A significant quadratic mask duration × target-flanker distance interaction was found:  $F(1,21)=10.98$ ,  $MS^{\text{error}}=43.57$ ,  $p=.003$ , partial  $\eta^2=.34$  (see Figure 4a). The quadratic nature of the masking effect with respect to target-flanker distance can be seen in the masking function in Figure 4b<sup>7</sup>.

<sup>5</sup> These values represent the represent the circumferential distance between the centre of the target and flanker digits expressed in units of visual angle, as per Experiment 1 and 2. The values for target-flanker distance in Exp 3a correspond with 1°, 2.95°, 4.77°, 6.38°, 7.17°, 8.70°, 9.31° of linear visual angle.

<sup>6</sup> Expressed in linear distances for Exp 3b these are respectively 1°, 2.96°, 4.82°, 6.52°, 7.99°, 9.19°, 10.08° and 10.62° of visual angle.

<sup>7</sup> As with Experiment 2 a reanalysis of the Exp 3a data was performed using the same exclusion criteria for participants. Under these criteria five participants were removed from the analysis. The ANOVA was then repeated. This still produced a significant quadratic interaction ( $F=6.22$ ,  $p=.024$ ). Thus the interaction was not a consequence of restrictions in measurable performance.

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\*\*\* Figure 4 about here \*\*\*

### Experiment 3b

The average percent correct responses in each factorial condition of mask duration and target-flanker distance are shown in Figure 5a. These data were analysed using a 3×8 repeated measures ANOVA with mask duration (0 ms, 60 ms, 180 ms) and target-flanker distance (1°, 3°, 5°, 7°, 9°, 11°, 13°, 15°) as the two variables of interest. Significant main effects were found for masking and target-flanker distance:  $F(2,42)=20.96$ ,  $MS^{\text{error}} = 102.75$ ,  $p<.001$ , partial  $\eta^2=.50$  and  $F(7,147)=51.12$ ,  $MS^{\text{error}} = 67.01$ ,  $p<.001$ , partial  $\eta^2=.71$  respectively. A significant quadratic mask duration × target-flanker distance interaction was found,  $F(1,21)=10.75$ ,  $MS^{\text{error}} = 64.09$ ,  $p=.004$ , partial  $\eta^2=.34$ . The quadratic nature of the masking effect with respect to target-flanker distance can be seen in the masking function in Figure 5b <sup>8</sup>.

\*\*\* Figure 5 about here \*\*\*

### Piecewise regression

The same piecewise regression described for Exp. 2 was also done for the Exp 3a and Exp 3b data. The resulting knot points and slopes are presented in Table 2 and 3 for the two respective experiments. Unlike for Exp. 2, the knot points of line fits occurred at a nearer target-flanker distance for the masked conditions compared to the unmasked. However for

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<sup>8</sup> The same reanalysis to check for ceiling/floor issues was also performed for the Exp 3b data using the same criteria. Under these criteria eight participants were removed from the analysis. The ANOVA was then repeated. This still produced a significant quadratic interaction ( $F=5.47$ ,  $p=.036$ ). This again shows that the interaction was not a consequence of restrictions in measurable performance.

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3 the slopes the same basic pattern was found as for Experiment 2: masked conditions resulted  
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5 in shallower slopes for the first line segments and steeper slopes for the second line segments,  
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7 the line segment being effectively flat in both cases for the unmasked baselines.  
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14 \*\*\*Insert Table 2 and 3 here\*\*\*  
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## 20 Discussion

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22 Both Experiment 3a and 3b found an interaction between flanker position and mask  
23 duration. Importantly in both cases masking exhibited an unambiguous function for both the  
24 short and long mask conditions. The effect was just as evident for both the short and long  
25 trailing mask conditions. The data pattern cannot be simply attributed to ceiling and/or floor  
26 effects. Performance was well within a measureable range of performance for most  
27 participants. The quadratic function was obtained even when further analysis removed  
28 participants performing close to ceiling or floor in any condition were removed.  
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## 43 General Discussion

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46 Camp et al. (2015) claimed, that crowding and OSM interact because crowding a  
47 target increases its vulnerability to substitution masking processes. If this were the case  
48 masking should have been observed to be strongest with flankers closest to the target and  
49 then decline to asymptote as target-flanker distance was increased. No such data pattern was  
50 found in any of our experiments. Instead target-flanker distance and OSM showed a robust  
51 inverted U-shaped relationship.  
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3 Our data do support Camp et al (2015)'s general claim of an interaction between  
4 OSM and crowding. They do not, however, support Camp et al.'s explanation of that  
5 interaction. We argue that the best interpretation of the data pattern is that it reflects a process  
6 in which *OSM modulates crowding*. What we mean by this is that OSM -additional to having  
7 a deleterious effect on target perceptibility itself- has the further effect of increasing the  
8 sensitivity of the target to flanker interference across a broader spatial range. This explanation  
9 is highly similar to the 'supercrowding' explanation offered by Vickery et al. (2009),  
10 however here our emphasis is on the consequences for masking rather than crowding. Before  
11 discussing this issue any further however we wish to first present and then contend against  
12 some alternative interpretations of our results that might be made.  
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27 One might argue that the findings we reported are accounted for by spatial attention.  
28 In this explanation the differences in masking strength across the different target-flanker  
29 distances are associated with differences in how attention is spread across the display in the  
30 different conditions. It can be argued that the greater effect of mask duration at intermediate  
31 target-flanker distances is reflective of attention being most diffuse in those particular  
32 conditions.  
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42 There are good reasons for rejecting this attentional interpretation.<sup>9</sup> Firstly, it is  
43 unclear why the particular target-flanker distances in which masking was most evident should  
44 be ones in which attention would be most diffuse. Presumably attention would tend to be  
45 most spread out in circumstances in which the display elements (the target and flankers) were  
46 furthest apart from each other. However if we take Experiment 2 as an example, the display  
47 elements are most broadly distributed in the 4.9° and 7.35° conditions. However, it is the  
48 3.02° target-flanker condition in which the effect of mask duration is most evident (see  
49 Figure 3). There are other good reasons for doubting the attention account. As originally  
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<sup>9</sup> It should be noted that such an explanation could also be proposed to explain Vickery et al's (2009) data.

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noted by Argyropoulous et al. (2013) the OSM target is a ‘pop out’ stimulus within the display in being uniquely defined by the four dots; the target is therefore one which should attract attention to its location. This means that attention is likely to be rapidly deployed towards its location irrespective of the number or arrangement of other display items. Indeed the general insensitivity of OSM to spatial attention is evident in a number of recent studies using different attentional manipulations (Pilling, Gellatly, Argyropoulos & Skarratt, 2014; Goodhew & Edwards, 2016).

Further to this the pattern of accuracy we obtained, when looked at in detail, also fails to support the attention account. One way that we can evaluate the effect of attention in the different target-flanker conditions is to look at the unmasked trials. It is on these trials that we can most easily evaluate the effect of attention on target perceptibility independent on any effect on OSM. Were attention more diffuse with intermediate target-flanker distances then we should presumably observe that accuracy in reporting the target on these unmasked trials was also reduced. To evaluate this possibility the most reasonable comparison to make is between the intermediate flanker positions against those where the flankers are furthest from the target (judging the intermediate flanker positions against the conditions where the flankers are nearest to the target would potentially conflate any putative attention effects from those that arise from crowding). However in neither Experiment 2 nor Experiment 3 was this data pattern found; for example in Experiment 3b accuracy in unmasked trials was slightly *higher* in intermediate target-flanker conditions when compared against the largest target-flanker conditions. This suggests that attention was not more diffuse in the conditions in which we observed the most masking.

Secondly, one might argue that our observed interaction was an indirect consequence of the circumferential organisation of the stimuli we had in our experiment. In this interpretation masking is greater at larger target-flanker distances because of the greater



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3 likelihood of the target and flankers being presented in different visual fields due to the  
4  
5 circular stimulus arrangement. Under such circumstances greater masking is found because of  
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7 the induced *interhemispheric competition* between the target and flanker objects (Geng, Eger  
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9 & Ruff, Kristjansson, Rotshtein & Driver, 2006; Szczepanski & Kastner, 2013). Here  
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11 masking is amplified under such conditions of interhemispheric competition because  
12  
13 attention is drawn away from the hemisphere containing the target because of processing of  
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15 the irrelevant distractor(s) in the other hemifield. However again such an explanation would  
16  
17 not properly account for the data we obtained in our experiments. Were this explanation  
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19 correct then the most masking should have been found in our data in the trials in which the  
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21 target-flanker distance was greater than a quarter circumference away. Under these  
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23 circumstances at least one of the distractors would always be in the opposite hemisphere to  
24  
25 the target (for Experiment 2 this would be all conditions  $\geq 7.31^\circ$ , in Exp 3a, condition  $\geq 9^\circ$   
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27 and Exp 3b  $\geq 11^\circ$ ). However in many cases very little masking was found in these trials. In  
28  
29 particular the largest target-flanker distances (ones where both flankers would be in the  
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31 opposite hemisphere to the target on almost all trials) tended to produce very little masking  
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33 (see esp. the  $15^\circ$  condition in Exp. 3b). Thus this hemispheric competition interpretation is  
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35 one which fits poorly with our data.  
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44 A third account that might be proposed is that the interaction is simply a consequence  
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46 of OSM limiting the maximum achievable performance level. In this explanation OSM and  
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48 crowding have no specific interactive effect on each other as cognitive processes; the  
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50 observed 'interaction' is instead a consequence of the different performance limits for  
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52 masked and unmasked conditions. Thus performance would curtail the height of the  
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54 crowding function under masked conditions, not because masking impacted on crowding in  
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56 any selective way, but because of the putative ceiling on accuracy it introduces.  
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3 This account can explain why masking is initially increased as the flankers are moved  
4 away from the closest distance to the target: it occurs because the recovery from crowding  
5 towards the maximum achievable performance level is greater in the unmasked condition  
6 than the masked condition. However the account does not explain why masking then  
7 subsequently declines with further increases in target-mask distance. If the initial increase in  
8 masking was a consequence of a performance constraint then we would have observed a  
9 monotonic increase in masking as flanker distance was increased followed by a plateau once  
10 the putative performance limit was reached for the masked trials. There is no obvious plateau  
11 in the masking functions in any of our experiments, beyond peak level masking; instead  
12 masking always shows a general trend to reduce with further increases in flanker distance.  
13 This further reduction in masking largely occurs because of what happens on masked trials,  
14 performance continues to increase as flankers are moved further from the target beyond the  
15 point at which peak masking occurs.  
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34 This fact is attested to by the positive slopes found in the second segments of the  
35 fitted regression lines for all masked conditions which in every case are steeper for the  
36 masked than for the corresponding unmasked conditions. Thus the performance limit  
37 explanation does not account for our data. Furthermore no account of masking specifically  
38 predicts that masking introduces upper limits in performance of the kind this account  
39 assumes.  
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50 In summary there was no support either theoretically or empirically for the possibility  
51 that the quadratic interaction we observed was mediated by spatial attention or some other  
52 form of competition related to the spatial organisation of the stimuli. Nor was there support  
53 for the possibility that the interaction was a consequence of some form of induced  
54 performance constraint. Instead we think that when a target is masked through OSM this  
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3 results in changes in the spatial range in which flankers have an influence on the  
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5 perceptibility of a target. We shall now look at this claim in more detail.  
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#### 10 11 12 13 14 15 OSM, flanker distance and ‘supercrowding’ 16

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18 We noted how the data we obtained has parallels with the ‘supercrowding’ effect  
19 reported by Vickery et al. (2009). It must be noted that there are some differences between  
20 our experiments and those of Vickery et al. (2009). The main one is in the type of mask used.  
21  
22 In our experiments the mask, in consisting of just four surrounding dots, contained no  
23 significant contour. In Vickery et al, in their first two experiments, the mask consisted of an  
24 unbroken contour which enclosed the target. The main effect of such masks is likely to be in  
25 generating surround suppression of the target (Meese & Baker, 2009). The masks also had  
26 different temporal characteristics and masking was defined differently. It is perhaps notable  
27 that in a later experiment Vickery et al. (2009) used a backwards mask, rather than a  
28 simultaneous surround mask. This backwards mask onset after the target onset yet produced  
29 the same supercrowding effect seen with the simultaneous surround mask. The effect of this  
30 backwards mask may arguably in part be attributable to OSM (Di Lollo et al., 2000; Enns,  
31 2004; Lleras & Moore, 2003; Jannati, Spalek & Di Lollo., 2013). Despite this possibility  
32 Vickery et al. (2009) explicitly described the ‘supercrowding’ effect they obtained in all  
33 experiments exclusively in terms of a consequence of ‘lower-level masking effects’.  
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54 How might masking a target, either through surround suppression, pattern masking or  
55 OSM lead to ‘supercrowding’? One consequence of masking is reduced target visibility;  
56 however this alone does not explain the phenomenon. Vickery et al. (2009) demonstrated  
57 that simply reducing target visibility by reducing its stimulus contrast had no effect on the  
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3 spatial range of crowding. Instead Vickery et al. suggest that the critical factor to produce  
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5 ‘supercrowding’ is *increased noise* in the visual system when a target is masked. Their model  
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7 assumes that the visual system requires information to be amalgamated across a number of  
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9 individual *feature integrators* (Hanson & Hess, 2007), ones crucial for visual identification of  
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11 a target. These integrators are argued to vary in a number of response characteristics: their  
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13 spatial position in the visual field, in the size of their spatial and temporal receptive fields and  
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15 in their selectivity towards certain features.  
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20         Vickery et al. (2009) argue that in order to identify a target only those integrators with  
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22 spatial and temporal fields which overlap the target location have to be selected for analysis.  
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24 The standard crowding effect (e.g. Bouma, 1971) is easily accounted for in this framework:  
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26 for a peripheral target flankers which occupy a region closely adjacent to the target fall within  
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28 the same receptive fields as the integrators with even the narrowest spatial tuning. This means  
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30 that the flankers become pooled together with the target leading to a breakdown in target  
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32 identification. ‘Supercrowding’ is explained to occur as a result of changes in the types of  
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34 integrators used to pool together to analyse the target which occurs under masked conditions.  
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36 It is assumed that there are integrators with wide spatial fields as well as narrow ones which  
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38 can analyse input associated with the spatial location of the target. These wide field  
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40 integrators are mostly superfluous for target identification: there are sufficient numbers of  
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42 integrators with spatially narrow fields for them to be excluded from the pooling process  
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44 without having any effect on target perceptibility. The problem for target identification  
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46 occurs when the target is masked, in addition to having flankers present just outside of the  
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48 normal crowding range. The presence of the mask means that some of the narrow field  
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50 integrators must themselves be excluded because, for instance, they lack the feature  
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52 selectivity to differentiate the target from the mask. To compensate for these lost spatially-  
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54 narrow integrators under masked conditions, the visual system is then forced to recruit wider  
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3 spatial field integrators. This means that any flankers located within the spatial range of these  
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5 wide field integrators now become merged with the target signals. The consequence of this is  
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7 a breakdown in target identification similar to that seen in standard crowding though here  
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9 with flankers outside of the traditional window.  
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13 Vickery et al. (2009)'s proposed model of the 'supercrowding' effect is by their own  
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15 admission a speculative one. It is also incomplete with respect to certain details, in particular  
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17 regarding how the integrators are utilised or excluded, e.g. whether this process is done in a  
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19 bottom-up or top-down directed manner. However nothing in their model seems to preclude  
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21 OSM from inducing 'supercrowding', in the same way as did the masks in their experiments.  
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26 An issue we should also note here is that the spatial range of crowding tended to be  
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28 generally larger in our studies than it is in most classical studies of crowding, even on  
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30 unmasked trials. Crowding is typically found to occur in a spatial range which extends to  
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32 approximately half the distance of the target eccentricity. (Bouma, 1970; Pelli & Tillman,  
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34 2008). However even in the baseline (unmasked) conditions the crowding effects we  
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36 observed from our flankers were typically in excess of this. However it must be noted that  
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38 our experiments were ones which followed the standard paradigms used in OSM rather than  
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40 those in crowding. This meant that the presentation of our target stimulus was much briefer  
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42 (40ms) than it would be in a standard crowding experiment. This fact alone may explain the  
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44 generally larger crowding effects. Tripathy, Cavanagh & Bedell (2014) have recently  
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46 demonstrated that the crowding effect tends to be amplified under conditions of brief  
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48 presentation.  
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55 Another difference is the fact that the spatial position of the flankers was moved along  
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57 a virtual circle. This design is one which is typical of OSM experiments and it is done in  
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59 order to control for eccentricity (Jiang & Chun, 2001; Lleras & Moore, 2003; Enns, 2004;  
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3 Jannati et al., 2013). However it is untypical of standard crowding experiments where the  
4 flankers tend to be shifted in a linear direction from the target and only the eccentricity of the  
5 target is held constant (Pelli, 2008). Finally the target in our experiment could occur in any  
6 spatial location on the virtual circle on each trial. Thus a location occupied by a flanker might  
7 on a later trial be occupied by a target. In standard crowding experiments the target is often at  
8 a fixed single display position. This spatial uncertainty means that in our experiments  
9 observers cannot give attentional priority to the location of the upcoming target nor can they  
10 selectively inhibit the flanker locations (Cave, Kim, Bichot & Sobel, 2005) as they could –at  
11 least in principle- in a standard crowding paradigm. Given these differences it is unsurprising  
12 that crowding in our experiment was generally more prevalent than is typically found in a  
13 standard crowding paradigm.  
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### 33 OSM and the object processing hierarchy

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36 The ‘supercrowding’ explanation of our data seems at first glance to conflict with  
37 accounts that claim OSM to be a process which occurs post-crowding (Chakravathi &  
38 Cananagh, 2009; Brietmeyer, 2014; Breitmeyer 2015). The main evidence for this claim  
39 comes from a study reported by Chakravarthi & Cavanagh (2009). In this study the authors  
40 presented a target Landolt square in the visual periphery which was flanked at all cardinal  
41 positions by four other Landolt squares each in a random orientation. The presence of these  
42 flankers resulted in a standard crowding effect on the target, accuracy in reporting the target  
43 was significantly reduced against a no-flanker baseline. On certain trials these flankers were  
44 masked by one of three types of backward mask, a noise mask, a metacontrast mask, or a  
45 4DM. Both the noise and metacontrast mask resulted in some recovery from crowding. It  
46 seemed the masking reduced the flankers’ effectiveness in crowding the target. For the 4DM  
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3 no such recovery from crowding was obtained: crowding was the same as in the no-mask  
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5 baseline condition. The ineffectiveness of the 4DM in reducing crowding was not explained  
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7 by it being a weaker form of masking. A later experiment showed that when observers had to  
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9 report the identity of one of the masked flankers rather than the target the perceptibility of the  
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11 flankers was just as reduced by the 4DM as by the other two mask types. The authors argued  
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13 instead that the differential effectiveness of the masks in reducing crowding reflected on the  
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15 nature of the underlying masking processes. It was argued that the noise and metacontrast  
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17 mask disrupted processing of the flankers at an early stage, one which occurred prior to the  
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19 crowding process in which the flanker and target signals become pooled together. By contrast  
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21 it was argued that the OSM process that underlie the 4DM effect were late stage, occurring  
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23 subsequent to this pooling operation, therefore rendering the mask ineffective in modulating  
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25 crowding generated by the flankers.  
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32 Thus, our results seen in comparison with those of Chakravarthi and Cavanagh (2009)  
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34 seem to present an enigma: When a 4DM is used to mask flankers it has no discernible effect  
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36 on crowding, yet when it is used to mask the target it has a reliable effect on crowding. If  
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38 OSM occurs at a post-crowding stage -as Chakravarthi and Cavanagh claim- then masking of  
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40 the target should not be able to affect crowding. However our findings, we believe, show that  
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42 OSM masking of the target *does* influence crowding.  
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47 How do we reconcile these findings? We suspect that the findings of the Chakravarthi  
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49 and Cavanagh (2009) paradigm concern different aspects of visual processing to those in the  
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51 current experiments. The results of Chakravarthi & Cavanagh (2009) reflect the extent to  
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53 which a mask suppresses interference from task-irrelevant spatially proximal objects  
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55 (flankers). Our results, however, reflect the consequences of how the visual system adapts to  
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57 competition from a temporally defined mask when engaged in target identification.  
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There is no reason to assume that these different processes that we describe are ones which operate within the same time frame or which are susceptible or immune to the same manipulations. The pooling which occurs in the standard crowding effect between a target and spatially proximal flankers may, as Chakravarthi & Cavanagh (2009) claim, be a rapid and feedforward one. Consequently such pooling can only be prevented by the fast inhibitory effects of noise or metacontrast masking (Rolls & Tovee, 1994). By contrast the assumed process, described earlier, by which the visual system adjusts itself in accordance with the presence of the trailing mask, may be one which occurs over a more protracted time course. The process by which integrators are excluded may not be one which can be achieved in a rapid and feedforward manner. Instead it may depend on a process of recurrent exchanges between different levels of the visual system to respond to the dynamic changes in input associated with a trailing mask (Di Lollo et al., 2000; Fahrenfort, Scholte & Lamme, 2008; Scholte, Jolij, Fahrenfort & Lamme, 2008). Thus the ‘supercrowding’ which emerges from this process may have a longer latency of emergence than does standard crowding and thus may be susceptible to different types of manipulation. If this is the case then the type of mask may be less important in supercrowding than in the traditional crowding investigated by Chakravarthi & Cavanagh (2011).<sup>10</sup>

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<sup>10</sup> Of course the assumption of a different time course of the crowding and supercrowding processes is as yet an untested one. One way to test this is by investigating how different types of masking affect release from supercrowding. In such a paradigm a supercrowding effect would first have to be instigated by masking the target in some way in a context in which flankers are presented outside of the normal crowding window (Vickery et al. 2009). The effect of masking these distant flankers could then be observed for different types of mask, similar to what was done in Chakravarthi & Cavanagh (2009). If, as we claim, supercrowding processes have a longer latency than of standard crowding then we would expect differences in terms of release from crowding. Specifically we may find that supercrowding is disrupted by masking the flankers even when a 4DM is used. This possibility awaits empirical test.



## Conclusion

Fundamentally these results show that OSM – or at least OSM as operationally defined as the effect of mask duration (Di Lollo et al., 2000)– is affected by the spatial configuration of the display. The presence and position of distractors, or other display elements, can modulate the intensity with which OSM occurs, even when such elements are some distance from the location of the target. Our claim that OSM is dependent on non-local factors is in some respects similar to recently reported findings by Goodhew, Greenwood and Edwards (2016). These authors showed that the presence of a repeated stimulus of the same categorical type would affect OSM even though the repeated stimulus item was located some distance from the target on the viewed display.

The OSM effect can be argued to be one which essentially reflects the extent to which the visual system can resolve a briefly presented target from competing visual stimulus information that is present in both the temporal and spatial domains. Given this the masking effect observed tends to reflect both the temporal properties of the mask as well as the spatial locus of distractor elements. In this respect our results are consistent with other claims regarding the close interdependence of spatial and temporal factors in masking, and in visual processing more generally (Enns, 2004; Herzog, 2007; Hermens, Luksys, Gerstner, Herzog & Ernst, 2008; Ghose, Hermens & Herzog, 2012; Lleras & Moore, 2003; Lev & Polat, 2015; Yeshurun, Rashal & Tkacz-Domb, 2015).

## References

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60
- Argyropoulos, Y., Gellatly, A. R. H., Pilling, M., & Carter, W. (2013). Set size and mask duration do not interact in object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance*, *39*, 646-661.
- Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature*, *226*, 177-178.
- Breitmeyer, B. G., Hoar, W. S., Randall, D. J., & Conte, F. P. (1984). *Visual masking: An integrative approach*. Clarendon Press.
- Breitmeyer, B. G. (2014). *The Visual (un)Conscious and Its (dis)Contents: A Microtemporal Approach*. Oxford University Press: Oxford.
- Breitmeyer, B. G. (2015). Psychophysical “blinding” methods reveal a functional hierarchy of unconscious visual processing. *Consciousness and Cognition*, *35*, 234-250.
- Camp, S. J., Pilling, M., Argyropoulos, I., & Gellatly, A. (2015). The role of distractors in object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance*, *41*, 940-957.
- Cave, Kyle R. ; Kim, Min-Shik ; Bichot, Narcisse P. & Sobel, Kenith V. (2005). The FeatureGate model of visual selection. In Laurent Itti, Geraint Rees & John K. Tsotsos (eds.), *Neurobiology of Attention*. Academic Press
- Chakravarthi, R., & Cavanagh, P. (2009). Recovery of a crowded object by masking the flankers: Determining the locus of feature integration. *Journal of Vision*, *9*, 4.
- Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: the psychophysics of reentrant visual processing. *Journal of Experimental Psychology: General*, *129*, 481-507.

- 1  
2  
3 Di Lollo, V., Enns, J. T. & Rensink, R. A. (2002). Object substitution without re-entry?  
4  
5  
6 *Journal of Experimental Psychology: General*, 131, 594-596.  
7  
8  
9 Enns, J. T. (2004). Object substitution and its relation to other forms of visual  
10  
11 masking. *Vision Research*, 44, 1321-1331.  
12  
13  
14 Enns, J. T., & Di Lollo, V. (1997). Object substitution: A new form of masking in unattended  
15  
16 visual locations. *Psychological Science*, 8, 135-139.  
17  
18  
19 Enns, J. T., & Di Lollo, V. (2000). What's new in visual masking?. *Trends in Cognitive*  
20  
21 *Sciences*, 4(9), 345-352.  
22  
23  
24  
25 Enns, J. T., & Di Lollo, V. (2002). What competition?. *Trends in cognitive sciences*, 6(3),  
26  
27 118.  
28  
29  
30 Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2008). The spatiotemporal profile of  
31  
32 cortical processing leading up to visual perception. *Journal of Vision*, 8(1), 12-12.  
33  
34  
35  
36 Filmer, H., Mattingley, J., & Dux, P. (2014). Size (mostly) doesn't matter: the role of set size  
37  
38 in object substitution masking. *Attention, Perception & Psychophysics*, 76, 1620-  
39  
40 1629.  
41  
42  
43 Filmer, H. L., Mattingley, J. B., & Dux, P. E. (2015). Object substitution masking for an  
44  
45 attended and foveated target. *Journal of Experimental Psychology: Human Perception*  
46  
47 *and Performance*, 4, 6-10.  
48  
49  
50  
51 Gellatly, A., Pilling, M., Carter, W., & Guest, D. (2010). How does target duration affect  
52  
53 object substitution masking? *Journal of Experimental Psychology: Human Perception*  
54  
55 *and Performance*, 36, 1267-1279.  
56  
57  
58  
59 Geng, J. J., Eger, E., Ruff, C. C., Kristjánsson, Á., Rotshtein, P., & Driver, J. (2006). On-line  
60  
attentional selection from competing stimuli in opposite visual fields: Effects on

1  
2  
3 human visual cortex and control processes. *Journal of Neurophysiology*, 96(5), 2601-  
4  
5 2612.  
6  
7

8  
9 Ghose, T., Hermens, F., & Herzog, M. H. (2012). How the global layout of the mask  
10  
11 influences masking strength. *Journal of vision*, 12(13), 9-9.  
12  
13

14  
15 Goodhew, S. C., & Edwards, M. (2016). Object individuation is invariant to attentional  
16  
17 diffusion: Changes in the size of the attended region do not interact with object-  
18  
19 substitution masking. *Cognition*, 157, 358-364.  
20  
21

22  
23 Goodhew, S. C., Greenwood, J. A., & Edwards, M. (2016). Categorical information  
24  
25 influences conscious perception: An interaction between object-substitution masking  
26  
27 and repetition blindness. *Attention, Perception, & Psychophysics*, 78(4), 1186-1202.  
28  
29

30  
31 Greenwood, J. A., Bex, P. J., & Dakin, S. C. (2009). Positional averaging explains crowding  
32  
33 with letter-like stimuli. *Proceedings of the National Academy of Sciences*, 106(31),  
34  
35 13130-13135.  
36  
37

38  
39 Gurnsey, R., Roddy, G., & Chanab, W. (2011). Crowding is size and eccentricity  
40  
41 dependent. *Journal of Vision*, 11, 15.  
42

43  
44 Hansen, B. C., & Hess, R. F. (2007). Structural sparseness and spatial phase alignment in  
45  
46 natural scenes. *JOSA A*, 24(7), 1873-1885.  
47

48  
49 Hermens, F., Luksys, G., Gerstner, W., Herzog, M. H., & Ernst, U. (2008). Modeling spatial  
50  
51 and temporal aspects of visual backward masking. *Psychological Review*, 115(1), 83-  
52  
53 100.  
54  
55

56  
57 Herzog, M. H. (2007). Spatial processing and visual backward masking. *Advances in*  
58  
59 *Cognitive Psychology*, 3(1-2), 85-92.  
60

- 1  
2  
3 Jannati, A., Spalek, T. M., & Di Lollo, V. (2013). A novel paradigm reveals the role of re-  
4  
5 entrant processes in object substitution masking. *Attention, Perception and*  
6  
7 *Psychophysics*, 75, 1118-1127.  
8  
9  
10  
11 Jiang, Y., & Chun, M. M. (2001). Asymmetric object substitution masking. *Journal of*  
12  
13 *Experimental Psychology: Human Perception and Performance*, 27, 895-918.  
14  
15  
16  
17 Kahneman, D. (1968). Method, findings, and theory in studies of visual  
18  
19 masking. *Psychological Bulletin*, 70(6p1), 404-425.  
20  
21  
22 Kotsoni E, Csibra G, Mareschal D,& Johnson, M. H.. (2007). Electrophysiological correlates  
23  
24 of common-onset visual masking. *Neuropsychologia*, 45, 2285-2293.  
25  
26  
27  
28 Lev, M., & Polat, U. (2015). Space and time in masking and crowding. *Journal of vision*,  
29  
30 15(13), 10-10.  
31  
32  
33 Levi, D. M. (2008). Crowding- an essential bottleneck for object recognition: a mini-review.  
34  
35 *Vision Research*, 48, 635-654.  
36  
37  
38 Levi, D. M., & Carney, T. (2009). Crowding in peripheral vision: Why bigger is  
39  
40 better. *Current Biology*, 19(23), 1988-1993.  
41  
42  
43  
44 Lim, S. W. H., & Chua, F. K. (2008). Object substitution masking: When does mask preview  
45  
46 work?. *Journal of Experimental Psychology: Human Perception and*  
47  
48 *Performance*, 34(5), 1108-1115.  
49  
50  
51  
52 Lleras, A., & Moore, C. M. (2003). When the target becomes the mask: using apparent  
53  
54 motion to isolate the object-level component of object substitution masking. *Journal*  
55  
56 *of Experimental Psychology: Human Perception & Performance*, 29, 106-120.  
57  
58  
59  
60 Meese, T. S., & Baker, D. H. (2009). Cross-orientation masking is speed invariant between  
ocular pathways but speed dependent within them. *Journal of Vision*, 9(5), 2-2.

- 1  
2  
3 Moore, C. M., & Lleras, A. (2005). On the role of object representations in substitution  
4  
5 masking. *Journal of Experimental Psychology: Human Perception and*  
6  
7 *Performance*, 31, 1171-1180.  
8  
9
- 10  
11 Parkes, L., Lund, J., Angelucci, A. Solomon, J. A. & Morgan, M. (2001). Compulsory  
12  
13 averaging of crowded orientation signals in human vision. *Nature Neuroscience*, 4,  
14  
15 739-744.  
16  
17
- 18  
19 Pelli, D. G. (2008). Crowding: A cortical constraint on object recognition. *Current Opinion in*  
20  
21 *Neurobiology*, 18, 445-451.  
22  
23
- 24  
25 Pelli, D. G., Palomares, M., & Majaj, N. J. (2004). Crowding is unlike ordinary masking:  
26  
27 distinguishing feature integration from detection. *Journal of Vision*, 4, 1136-1169.doi:  
28  
29 10.1167/4.12.12.  
30  
31
- 32  
33 Pelli, D. G. & Tillman, K. A. (2008). The uncrowded window of object recognition. *Nature*  
34  
35 *Neuroscience*, 11, 1129-1135.  
36  
37
- 38  
39 Pilling, M., Gellatly, A., Argyropoulos, Y., & Skarratt, P. (2014). Exogenous spatial precuing  
40  
41 reliably modulates object processing but not object substitution masking. *Attention,*  
42  
43 *Perception and Psychophysics*, 76, 1560-1576.  
44  
45
- 46  
47 Rolls, E. T., & Tovee, M. J. (1994). Processing speed in the cerebral cortex and the  
48  
49 neurophysiology of visual masking. *Proceedings of the Royal Society of London-B-*  
50  
51 *Biological Sciences*, 257(1348), 9-16.  
52  
53
- 54  
55 Scholte, H. S., Jolij, J., Fahrenfort, J. J., & Lamme, V. A. (2008). Feedforward and recurrent  
56  
57 processing in scene segmentation: electroencephalography and functional magnetic  
58  
59 resonance imaging. *Journal of Cognitive Neuroscience*, 20(11), 2097-2109.  
60
- Sibley, M. (2011). BlitzMax [Version 1.44]. Auckland, New Zealand: Blitz Research Ltd.

1  
2  
3 Szczepanski, S. M., & Kastner, S. (2013). Shifting attentional priorities: control of spatial  
4 attention through hemispheric competition. *The Journal of Neuroscience*, 33(12),  
5  
6 5411-5421.  
7  
8

9  
10  
11 Tripathy, S. P., Cavanagh, P., & Bedell, H. E. (2014). Large crowding zones in peripheral  
12 vision for briefly presented stimuli. *Journal of vision*, 14(6), 11-11.  
13  
14

15  
16 Vickery, T., J., Shim, W, M., Chakravarthi, R., Jiang, Y. V., Luedeman, R. (2009).  
17 Supercrowding: Weakly masking a target expands the range of crowding. *Journal of*  
18 *Vision*, 9, 1-5.  
19  
20  
21  
22  
23

24 Whitney, D., & Levi, D. M. (2011). Visual crowding: a fundamental limit on conscious  
25 perception and object recognition. *Trends in Cognitive Sciences*, 15, 160-168.  
26  
27  
28

29  
30 Yeshurun, Y., Rashal, E., & Tkacz-Domb, S. (2015). Temporal crowding and its interplay  
31 with spatial crowding. *Journal of vision*, 15(3), 11-11.  
32  
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## Tables

Table 1. Knot-point ( $k$ ) and slope ( $a$ ) values resulting from piecewise linear regression of Experiment 2 data.

	$k^*$	$A_1$	$A_2$
0 ms mask	2.95	7.98	0.34
180 ms mask	3.26	5.62	1.58

\*These  $k$  values in all tables are expressed in terms of the knot position in linear distance units.

Table 2. Knot-point ( $k$ ) and slope ( $a$ ) values resulting from piecewise linear regression of Experiment 3a data.

	$k$	$A_1$	$A_2$
0 ms mask	3.84	6.68	0.12
60 ms mask	3.26	4.58	0.74
180 ms mask	2.95	4.58	1.03



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Table 3. Knot-point ( $k$ ) and slope ( $a$ ) values resulting from piecewise linear regression of Experiment 3b data.

	$k$	$A_1$	$A_2$
0 ms mask	3.73	8.32	0.13
60 ms mask	2.96	6.34	0.96
180 ms mask	3.12	7.34	0.76

## Figure headings

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Figure 1. A schematic depiction of the trial sequence in Experiment 1. The left side of the figure shows the trial sequence for flanked-target trials. In the given example the flankers are at the closest given position ( $0.63^\circ$ ) with respect to the target which is indicated by the surrounding four dots. The right side of the figure gives the equivalent sequence for an unflanked-target trial. Here the flankers closely surround the non-target.

Figure 2. Performance in Experiment 1. Plate A (left) shows the accuracy (% correct) in for the four flanker distances ( $0.63^\circ$ ,  $0.89^\circ$ ,  $1.15^\circ$ ,  $1.41^\circ$ ) for each of the two mask durations (0,180ms) for flanked and unflanked target conditions. Plate B (right) shows the masking effect for each combination of flanker distance and target-condition. Masking is calculated as the difference in accuracy between the respective 0ms and 180ms mask duration conditions.

Figure 3. Performance in Experiment 2. Plate A (left) shows accuracy (% correct) for each of the six target-flanker distances shown separately for each of the two mask durations (0,180ms). Plate B (right) shows the masking effect (difference between 0ms and 180ms mask duration conditions) for each target-flanker distance.

Figure 4. Performance in Experiment 3a. Plate A (left) shows accuracy (% correct; plate A) for each of the seven target-flanker distances shown separately for each of the three mask durations. Plate B (right) shows the masking effect (difference between the 60 and 180ms mask duration conditions each from the 0ms mask duration baseline).

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6 Figure 5. Performance in Experiment 3b. Plate A (left) shows accuracy (% correct; plate A)  
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8 for each of the eight target-flanker distances shown separately for each of the three  
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10 mask durations. Plate B (right) shows the masking effect (difference between the 60  
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12 and 180ms mask duration conditions each from the 0ms mask duration baseline).  
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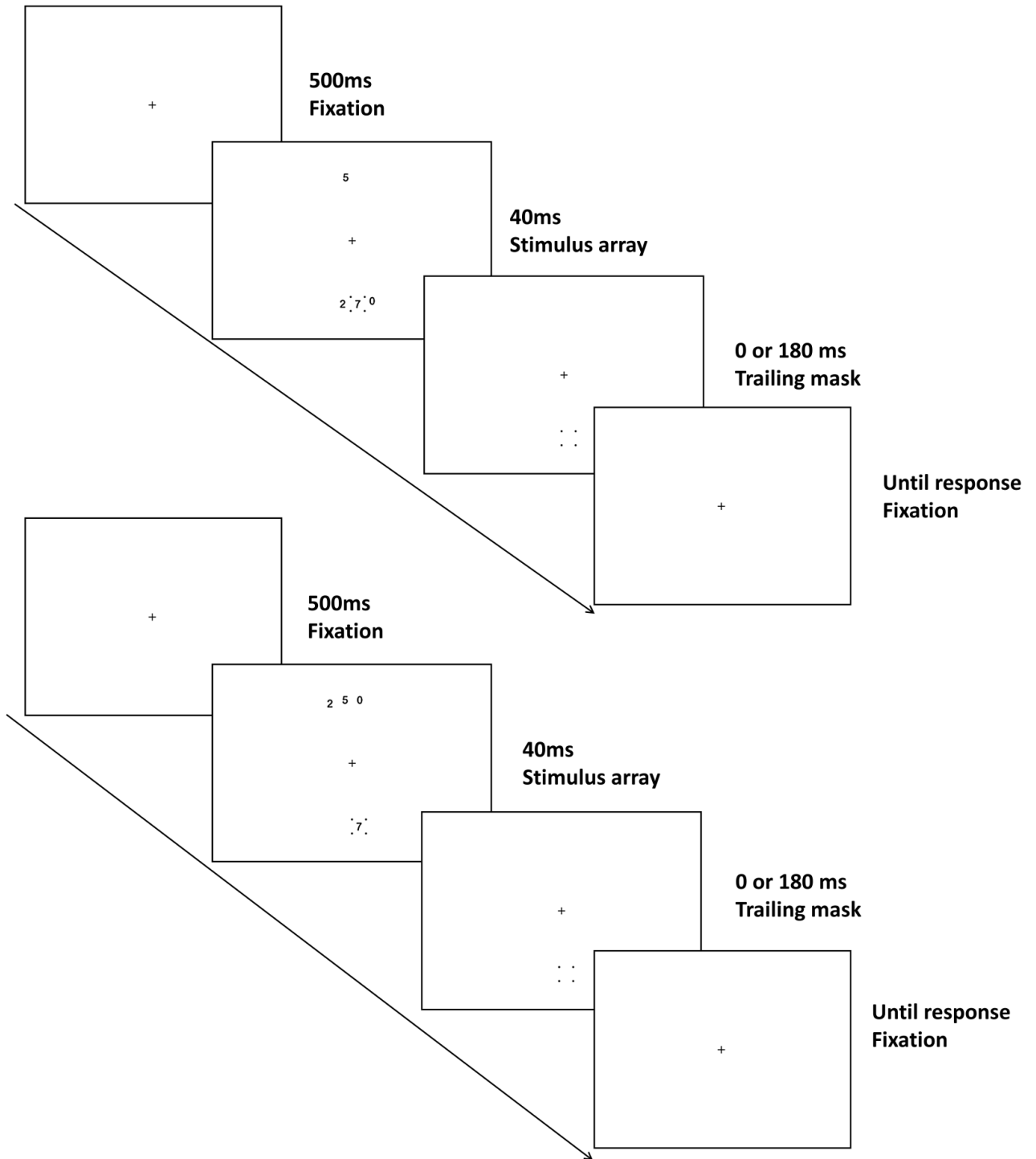


Figure 1.

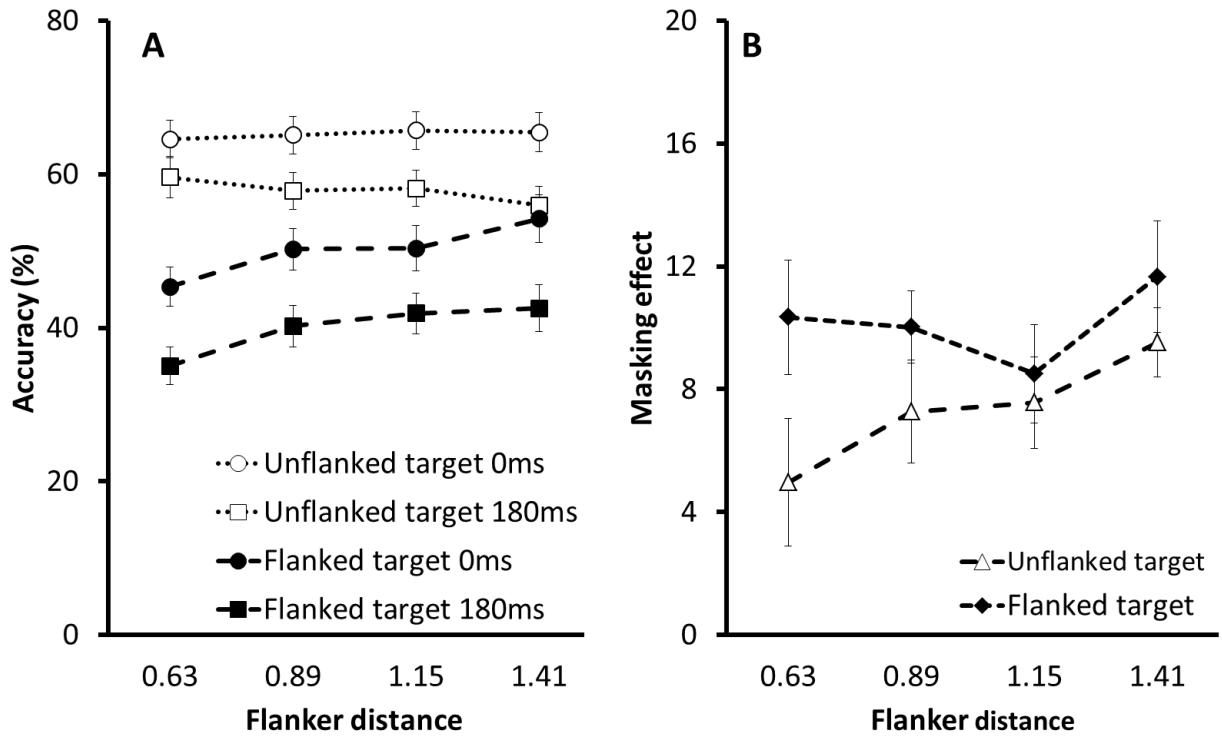


Figure 2.

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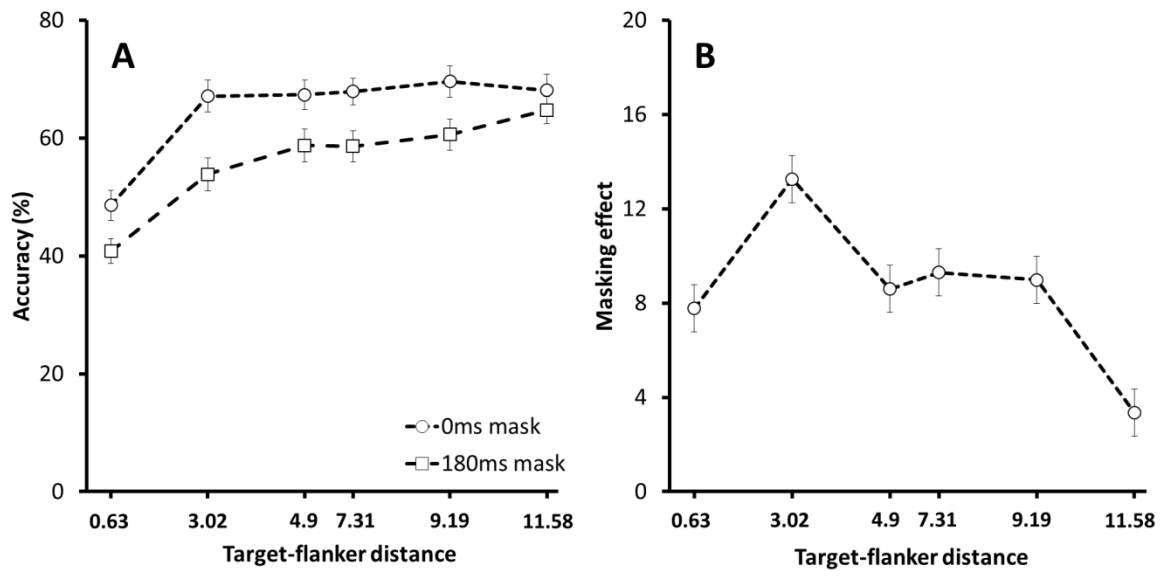


Figure 3.

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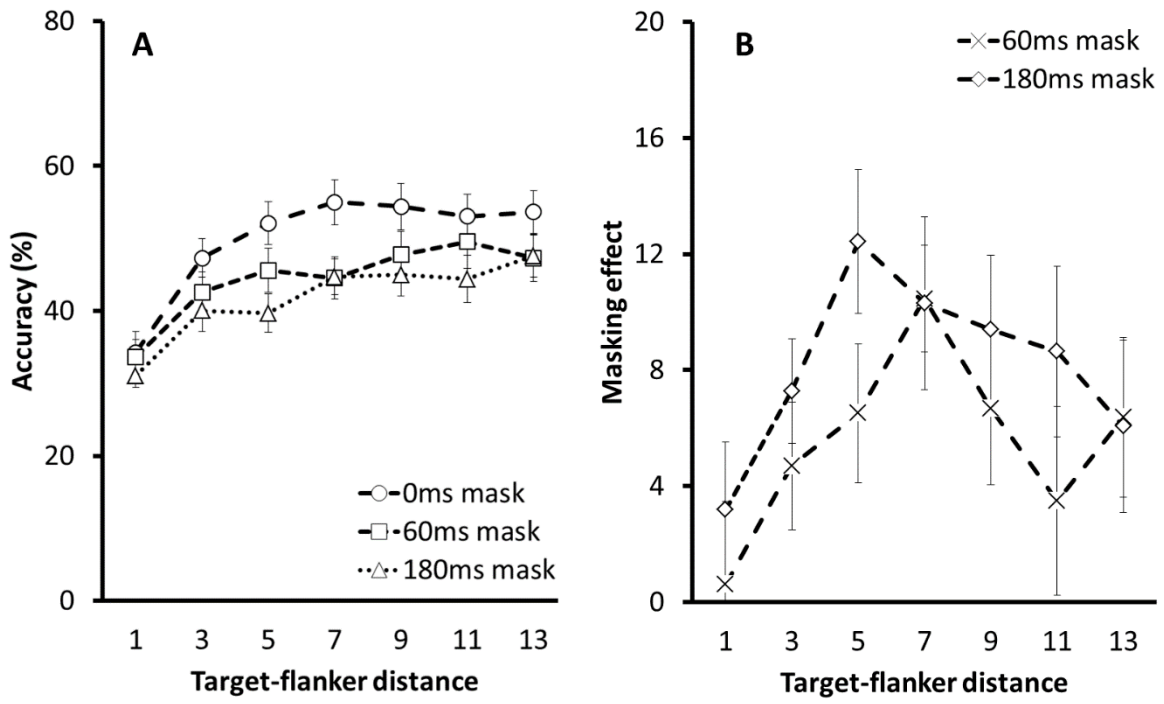


Figure 4.

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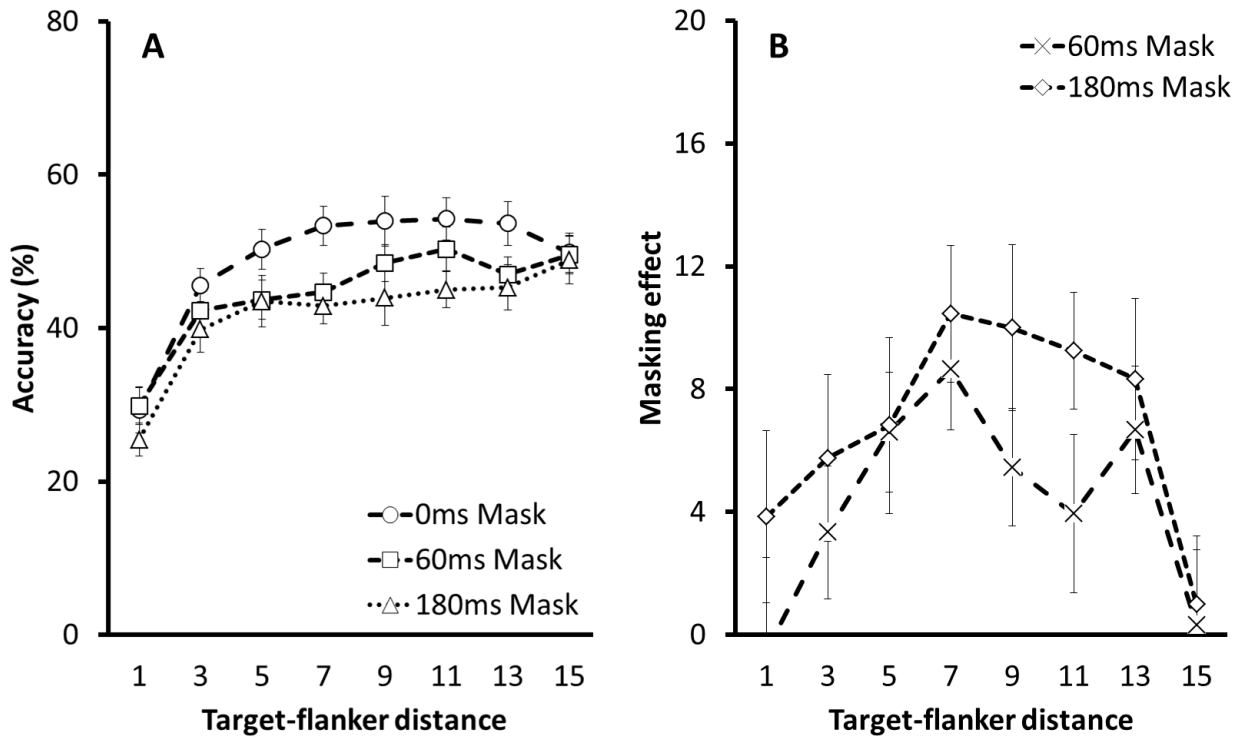


Figure 5.

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