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Size (mostly) doesn't matter: the role of set size in object substitution masking

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Abstract Conscious detection and discrimination of a visual target stimulus can be prevented by the presentation a spatially nonoverlapping, but temporally trailing, visual masking stimulus. This phenomenon, known as *object substitution masking* (OSM), has long been associated with spatial attention, with diffuse attention seemingly being key for the effect to be observed. Recently, this hypothesis has been questioned. We sought to provide a definitive test of the involvement of spatial attention in OSM by using an eight-alternative forced choice task under a range of mask durations, set sizes, and target/distractor spatial configurations. The results provide very little evidence that set size, and thus the distribution of spatial attention, interacts with masking magnitude. These findings have implications for understanding the mechanisms underlying OSM and the relationship between consciousness and attention.

Keywords Attention · Visual awareness · Visual perception

A relatively recent discovery in the field of visual cognition has been object substitution masking (OSM; Enns & Di Lollo, 1997). In OSM, a visual stimulus—the mask (e.g., four dots)—is spatially separate from another stimulus—the target (e.g., a Landolt C)—and onsets simultaneously with it (the four dots surrounding the target). When the mask offsets simultaneously with the target image, the visibility of the target is unimpaired. However, if the mask offset is delayed relative to that for the target, the visibility of the target is reduced. OSM is thought to reflect the dynamics of reentrant neural processing (Fahrenfort, Scholte, & Lamme, 2005, 2007a, b; Lamme & Roelfsema, 2000; Lamme, Supèr, & Spekreijse, 1998), in which feedforward and feedback neural signals interact to resolve incongruent perceptual hypotheses at different levels of information processing (Di Lollo, Enns, & Rensink, 2000; Dux, Visser, Goodhew, & Lipp, 2010; Goodhew, Pratt, Dux, & Ferber, 2013; Jannati, Spalek, & Di Lollo, 2013). Specifically, visual information is fed from primary visual cortex to higher-level regions. During these processes, the "perceptual hypothesis" is constructed as to the properties and identity of the visual input. This initial hypothesis has a relatively low resolution, since the higher-level visual regions have relatively large receptive field sizes. To confirm the accuracy of the hypothesis, reiterative processes check the representation in high-level areas against sensory input in primary visual cortex. Due to its typical timing parameters, OSM can occur when there is a mismatch between the perceptual hypothesis (the target) and the contents of primary visual cortex (mask only) (Di Lollo et al., 2000).

A relatively late processing-stage locus for OSM has been suggested by the recent finding of *masking recovery*. Goodhew and colleagues found that when the mask remained on screen for an extended temporal period following the target offset (e.g., ~600 ms), discrimination of the target was better than at shorter mask offsets (Goodhew, Dux, Lipp, & Visser, 2012; Goodhew, Visser, Lipp, & Dux, 2011). In short, the effect of mask duration reflected a U-shaped function, which Goodhew et al. hypothesized occurred because the four-dot mask allowed a fragile representation of the target to be maintained that could be the focus of encoding once the mask was consolidated into a more durable store.

A factor often cited as separating OSM from other forms of masking, and indeed the reason for much of the interest in this

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phenomenon, is its suggested link with attention. A long-held view is that without dispersed attention OSM is not observed (Dux et al., 2010; Enns, 2004; Goodhew et al., 2013). Spatial attention in OSM paradigms has been manipulated in several different ways, but the typical approach is to vary the number of distractor items displayed along with the target stimulus. The logic of this approach is that with a greater number of distractors the demands placed on the attention system will increase (Di Lollo et al., 2000). In particular, diffuse attention may increase the number of reentrant iterations required to check the perceptual hypothesis against the correct target item as held in primary visual cortex (Di Lollo et al., 2000). If the target item is shown alone, with no distractors present, no difference is normally observed between simultaneous and delayed mask offset conditions (Di Lollo et al., 2000; Enns, 2004; Enns & Di Lollo, 1997; Goodhew et al., 2012; Goodhew et al., 2011), presumably as attention can be rapidly orientated to the target (Di Lollo et al., 2000). In addition, when distractor items are present, manipulations that rapidly draw attention to the target can spare any degraded performance from the mask. For example, masking is attenuated when the target's properties make it "pop out" from the background (Di Lollo et al., 2000), and when its location is precued (Di Lollo et al., 2000). This interaction between attention and masking has been taken as evidence for OSM being driven by "higher-level" visual processes, as opposed to low-level mechanisms, such as lateral inhibition, implicated in other forms of backward pattern masking (Di Lollo et al., 2000).

Contrary to high-level accounts of OSM, recent research has questioned the role attention plays in the phenomenon. Specifically, Argyropoulos, Gellatly, Pilling, and Carter (2013) reported a series of experiments that refuted the existence of an interaction between masking magnitude and set size. They claimed that previous examples of this interaction (Di Lollo et al., 2000; Enns & Di Lollo, 1997; Goodhew et al., 2012; Goodhew et al., 2011) were only observed due to ceiling effects at smaller set sizes, which compressed masking magnitude in these conditions. For example, when Argyropoulos et al. used a task in which performance at a set size of one was not at ceiling, no interaction between masking magnitude and set size was evident. They also examined other effects of spatial attention in OSM and that the previous findings relating to target pop-out (Di Lollo et al., 2000) and precuing (Di Lollo et al., 2000) both reflected performance being moved out of a measurable range—in other words, performance hit ceiling. The implications of these findings are considerable. If ceiling effects have been driving the interaction between attention and masking magnitude, then the role of attention is OSM is likely to be different to that previously presumed in the numerous models of OSM that have been developed (Goodhew et al., 2013). Thus, this will impact upon our conceptualization of OSM and the mechanisms hypothesized to underlie the phenomenon and, indeed, other forms of masking. In turn, this will also contribute to the current debate regarding the broader relationship between attention and consciousness (Cohen, Cavanagh, Chun, & Nakayama, 2012). In particular, growing evidence is indicating that attention and consciousness could be, at least partially, dissociable processes (Cohen et al., 2012; Lamme, 2004; Wyart, Dehaene, & Tallon-Baudry, 2012). This dissociation would be supported by the findings of OSM if the conclusions draw by Argyropoulos et al. were confirmed—that is, if attention does not influence a task assessing consciousness: OSM.

The results of Argyropoulos et al. (2013) are both provocative and important. However, they are arguably not definitive, since questions remain regarding the role of set size in OSM. In particular, four points are worthy of some consideration: First, ceiling and floor effects must be fully removed across all conditions and for all participants for the role of attention in OSM to be fairly judged. This requires a task in which a relatively large range of performance can be found without incurring the limits at floor or ceiling. For example, with a task that has two response options, performance needs to be greater than 50 % to avoid the floor, and less than 100 % to avoid the ceiling. This gives a performance range of less than 50 % accuracy to avoid the upper and lower extremes. On the other hand for a task consisting of eight response options performance needs to be greater than 12.5 % to avoid floor, and less then 100 % to avoid the ceiling. This gives a performance range of 87.5 % accuracy to avoid the upper and lower extremes. Using tasks that have a larger number of response options therefore gives more room to assess the effect of set size (or other manipulations of attention) on OSM.

Second, it is important that the mask offsets sampled include the maximal point of masking (the greatest amount of OSM), and that an interaction between masking magnitude and set size is not absent because of limited mask offset sampling. Effective sampling of mask offsets is best achieved by using a range of mask durations allowing the measurement of the masking function. Given that OSM tends to follow a U-shaped masking function (Goodhew et al., 2012; Goodhew et al., 2011), it would be fair to say that the finding of a plateau in performance, or more ideally a point at which there is some recovery from masking, is adequate.

Third, a range of set sizes needs to be employed to fully measure how performance changes with manipulations of this variable. This allows for the possibility that at some larger set sizes performance is mediated by other factors, such as crowding (Pelli & Tillman, 2008), through which discrimination of parafoveal stimuli can be disrupted with spatially proximal flanker items. Crowding has been shown to interact with masking effects (Vickery, Shim, Chakravarthi, Jiang, & Luedeman, 2009) and could lead to differences in masking between set sizes that are independent of spatial attention per se.

Finally, the distribution of attention across the visual field has to be taken into account. In the original experiments that reported an interaction between masking magnitude and set size, the distractor items were randomly located in the visual field (Di Lollo et al., 2000). However, in Argyropoulos et al. (2013), the items were always presented so as to be of equal distance from the fovea, and to be spread evenly around this space. These factors alter the predictability of the target and distractor locations, potentially altering search strategies, or the distribution of spatial attention at the start of a trial, and thus the time taken to identify the target stimulus (Chun & Jiang, 1998). The dispersal of attention, then, is an important factor in OSM, especially if the influence of attention on masking magnitude is under question.

In the present study, we sought to address these issues in relation to OSM magnitude and set size and provide a replication of the findings reported by Argyropoulos et al. (2013). Providing such a replication is an important consideration, given the long-standing belief that attention interacts with OSM (Dux et al., 2010; Enns, 2004; Goodhew et al., 2013) and the concern with a "replication crisis" in psychology research (Pashler & Harris, 2012; Simons, 2014). We used an eight-alternative forced choice (8AFC) task to give a broad range of performance within floor and ceiling. The variables of set size, mask duration, and spatial uncertainty were manipulated. Over four experiments, we found little evidence of an interaction between set size and mask duration, despite significant main effects for each of these variables.

Experiment 1

Experiment 1 investigated whether an interaction between set size and mask duration could be found with an 8 alternative forced choice task. Using a task with more response options than is typical in OSM studies allowed for a wider range of accuracy levels to be found, while avoiding floor and ceiling effects. The experiment consisted of target and distractor stimuli that were circles with lines projecting from their center outward (Fig. 1). The line could be at one of eight possible orientations. The mask consisted of four dots that surrounded the target stimulus, and was the means of signaling the target from the distractors. If OSM does interact with set size, performance should be impaired with increased mask duration, and this impairment should be greater for larger set sizes.

Method

Participants Eighteen undergraduate psychology students (mean age = 19 years, *SD* = 2.4; 11 women, seven men; five left-handed) took part for course credit. The University of Queensland Human Research Ethics Committee approved the study, and all participants gave informed consent before taking part.

Materials and procedure For the experiment we used stimuli consisting of a circle with a bisecting line (see Fig. 1). The line ran from the center of the circle outward, intersecting with the circle's circumference at one of eight possible orientations (0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315º). Each circle subtended a visual angle of 0.55° and appeared white on a black background. A central fixation dot was red.

Participants sat approximately 57 cm from the monitor (without a chinrest) and were asked to report the orientation of the target line from eight different response alternatives (8AFC). The target could be shown on its own (set size 1), with seven distractor items (set size 8), or with 15 distractor items (set size 16). The distractor stimuli were the same as the targets, and both the targets and distractors had randomly generated line orientations on each trial. The target was surrounded by four dots, which acted as both the mask and the means of demarcating the position of the target (see DiLollo et al., 2000). The dots were 0.08° of visual angle in width/height and were presented 0.11° of visual angle above/below the target. All of the target and distractor items were distributed equally around the circumference of an imaginary circle, the center of which was the fixation point (see Fig. 1). The stimuli were all presented at an eccentricity 3.55° of visual angle from the fixation.

Each trial began with a fixation for 800 ms, followed by the target and distractors for 100 ms. The mask then offset after a duration of 0, 80, or 160 ms, and a response was requested after a blank screen of 160, 80, or 0 ms (see Fig. 1). This approach was employed in order for each trial to have the same amount of time passed from target presentation to the response prompt, regardless of the mask duration; that is, if the mask offset was 0 ms, it was followed by a blank of 160 ms. Responses were elicited with a display listing the different possible line orientations (of which there were eight) and the associated response keys (A S D F G H J K). Only response accuracy was emphasized to the participants.

At the start of the experiment, participants completed two blocks (of 20 trials each) of practice. The first block contained trials in which target presentation time was increased (presented for 500 ms), whereas the second block used the parameters outlined above. Feedback was given during the practice trials. The main experiment consisted of 576 trials (64 trials per condition), broken into 16 blocks, each consisting of 36 trials. The different trial types were randomly mixed within each block. No feedback on accuracy was given during this stage. Between blocks, participants had the opportunity to take breaks. The experiment took around 45 min to complete.

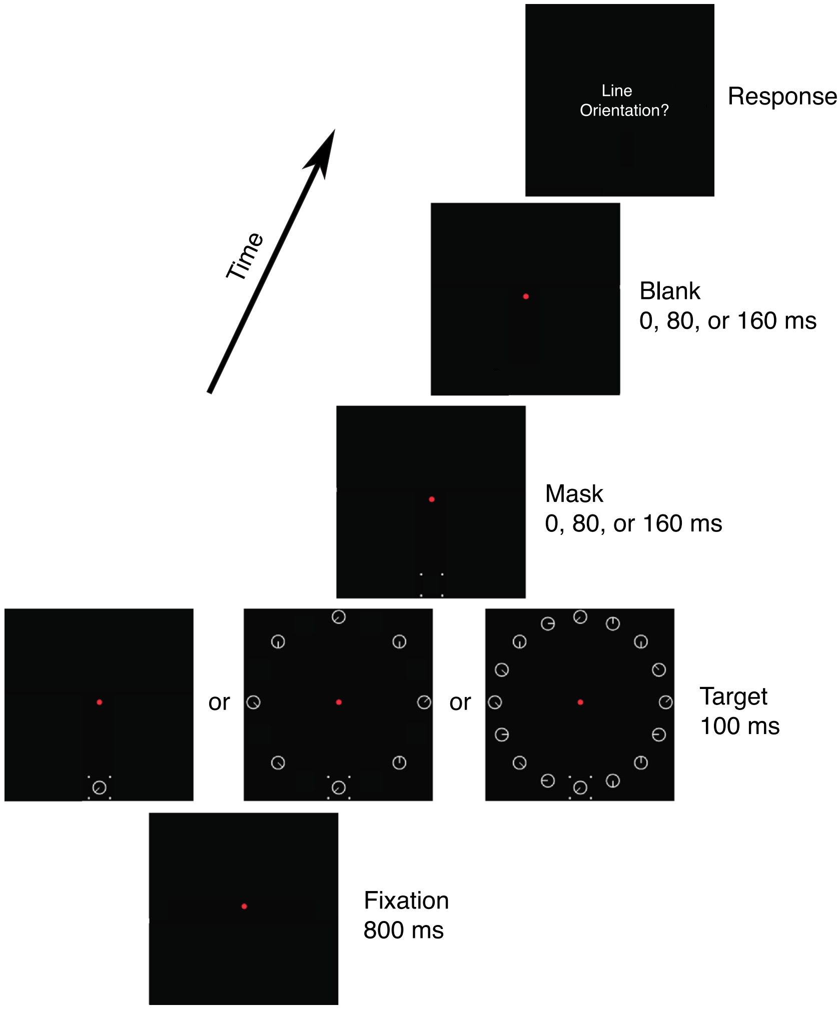

Fig. 1 Sequence of display events in a typical trial of the OSM task in Experiment 1. On each trial, the target was presented on its own, or with seven or 15 distractor items. The location of the target was demarcated by the mask, which was made up of four dots positioned at the corners of an imaginary square. The mask could either offset simultaneously with the target or remain on screen for up to 180 ms after target offset. Participants were asked to indicate the orientation of the line for the target stimulus, from among eight possible orientations, by pressing the relevant key on a keyboard (A, S, D, F, G, H, J, or K).

Results

The percentages of identification accuracy as a function of set size and mask duration are shown in Fig. 2A. A 3 × 3 repeated measures analysis of variance (ANOVA) revealed a significant main effect of mask duration [$F(2, 34) = 14.74$, $p < .001$], with accuracy decreasing as mask duration increased, indicating a significant OSM effect. We also observed a significant main effect of set size [$F(2, 34) = 99.2$, $p < .001$], which reflected reduced accuracy at larger set sizes.

The interaction between set size and mask duration was also significant [$F(4, 68) = 3.54$, $p < .05$]. However, examination of Fig. 2 suggests that the average performance at set size 1 was at ceiling (mean accuracy = 90 %, SEM = 1.5). Thus, performance may have been constrained by the upper limit. Performance for the set sizes of 8 and 16 items showed a similar masking magnitude (set size 8 = 13.5 %, SEM = 3.5; set size 16 = 12.5, SEM = 3.6), and the interaction between set size and mask duration was not significant for these two set sizes ($F < 1$). Hence, no evidence emerged for differential effects of set size as a function of mask duration.

To further protect against the influence of ceiling and floor effects, we reran the above analysis after excluding participants who were below chance in any of the conditions, correcting the data for guessing and performing a log transformation (Schweickert, 1985). Since this was a forced choice protocol, we assumed that when participants failed to identify the target, they had guessed its identity. Given that the target could be one of eight possible stimuli, if participants guessed, they had a 1-in-8 chance of being accurate. Therefore, to correct the data for guessing, we used the formula 100 – [(error rate/7) * 8]. The use of the log transformation (log to the base of 10) allowed us to rescale the data so that a manipulation that had the same proportional effect on the

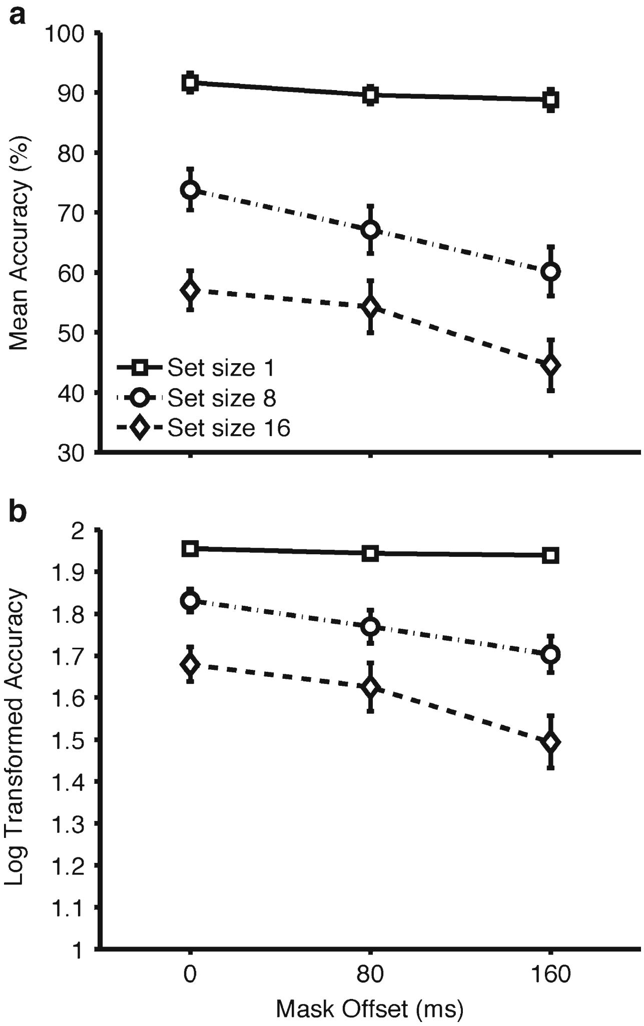

Fig. 2 (A) Mean accuracy rates (% correct) as a function of mask offset and set size in Experiment 1. (B) Guessing-corrected and log-transformed accuracy. Error bars represent *SEM*s.

process of interest would have the same absolute effect on the scale (Schweickert, 1985).

After performing the above correction and transformation, the pattern of results did not change [Fig. 2B; main effect of set size = $F(2, 34) = 54.72$, $p < .001$; main effect of mask duration = $F(2, 34) = 11.25$, $p < .001$]. Critically, when all three set sizes were entered into the ANOVA, a significant interaction was observed [$F(4, 68) = 4.16$, $p = .006$], but this was driven by set size 1, since the exclusion of this set size resulted in a nonsignificant interaction [$F(2, 34) = 1.09$, $p = .35$].

Discussion

The results of Experiment 1 allowed for two conclusions. First, when ceiling effects were present, a significant interaction between set size and mask duration was observed. Second, for larger set sizes, at which there was no ceiling effect, we found no evidence of an interaction between set size and mask duration. Overall, then, Experiment 1 both provided a replication of the original OSM effect reported by Di Lollo et al. (2000) and supported the findings of Argyropoulos et al. (2013), that no effect of set size on OSM is observed when ceiling effects are ruled out.

It is possible that the lack of difference in OSM magnitude found between set sizes 8 and 16 simply reflects the use of a relatively narrow set of mask durations. The inclusion of longer masking duration conditions could generate larger masking effects and reveal differences in the masking time courses for different set sizes.

Experiment 2

Experiment 2 included an additional set size (4) and a greater number of mask offsets (0–400 ms). These two changes allowed Experiment 2 to give a more sensitive measure of set size and ensure that the maximal point of masking had been achieved.

Method

The method was the same as Experiment 1, except where specified below.

Participants Eighteen new undergraduate students took part (mean age = 24 years, $SD = 9$; 11 women, seven men; one left-handed) for payment.

Materials and procedure The target presentation time was reduced to 60 ms, to increase the difficulty of the task. The set sizes of 1, 4, 8, and 16 were included in Experiment 2. The mask offsets were 0, 80, 160, 240, 320, and 400 ms. There were 60 trials per condition, giving a total of 1,440 trials. The experiment was split across two experimental sessions, each on different days.

Results

The results are shown in Fig. 3. We observed significant main effects of set size [$F(3, 51) = 57.18$, $p < .001$] and mask duration [$F(5, 85) = 4.97$, $p = .001$]. Looking at Fig. 3A, it appears that the masking magnitudes were comparable for set sizes 4 to 16, with less masking for set size 1. However, the interaction between set size and mask duration was not significant [$F(15, 255) = 1.15$, $p = .31$], providing no evidence of an interaction between set size and mask duration.

The data were subjected to a guessing correction and log transformation, as in the previous experiment. Seven participants were at floor (<12.5 % accuracy) in one or more of the experimental conditions, and these were removed from the analysis. After performing the correction and transformation (Fig. 3B), a main effect of set size was apparent [$F(3, 30) = 44.68, p < .001$], but only a marginally significant main effect of mask duration [$F(5, 50) = 1.2, p = .1$]. An interaction between set size and mask duration was not observed [$F(15, 150) = 1.11, p = .37$]. These results suggest that once the data were corrected for guessing and transformed, only a small OSM effect was present, and this effect did not interact with set size.

Discussion

Experiment 2 provided no support for an interaction between set size and masking magnitude. This was despite evidence of masking recovery at the longer mask offsets, supporting the point of maximum masking being achieved. It is worth noting that only a marginally significant effect of mask duration occurred following the removal of participants who performed at floor. The marginal significance was likely due to reduced analytical power with the diminished sample size. Overall, the findings of Experiments 1 and 2 either provided no evidence for an interaction between set size and mask duration or suggested that any interaction was driven by the comparison of the smallest and largest set sizes (e.g., set size 1 vs. 16). Thus, within the range of mask durations and set sizes presently employed, we found only minimal evidence of an interaction between set size and mask duration. At best, the conclusion thus far supports only a small and inconsistent relationship between OSM and the distribution of spatial attention.

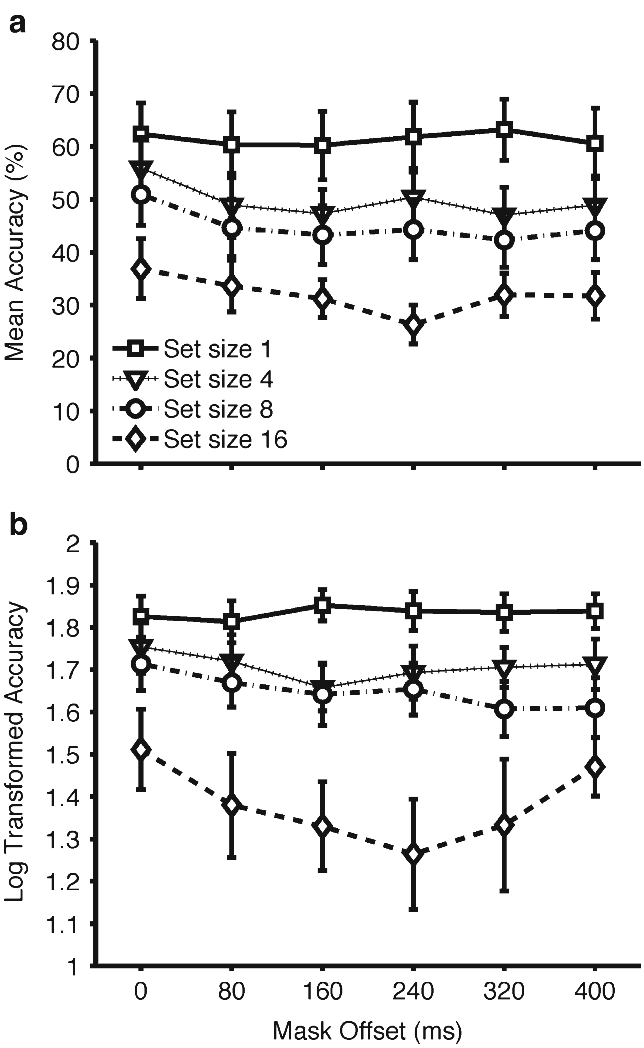

Fig. 3 (A) Mean accuracy rates (% correct) as a function of mask offset and set size in Experiment 2. (B) Guessing-corrected and log-transformed accuracy. Error bars represent *SEM*s.

Experiment 3

Experiments 1 and 2 provided no substantive evidence for an interaction between set size and OSM magnitude. However, it is possible that the relatively large increase in set size numbers between the intervals used (1, 4, 8, and 16) decreased our sensitivity to differences in masking magnitude with set size. Experiment 3 focused on small set sizes (1, 2, and 4) to explore the effect of mask duration with relatively few distractor items present. If an interaction between set size and mask duration does exist, some evidence should emerge from this smaller range of distractor numbers.

Method

The method was the same as that for Experiment 2, except where specified below.

Participants Sixteen new undergraduate students took part (mean age = 22 years, *SD* = 2.1; 13 women, three men; two left-handed) for payment.

Materials and procedure The set sizes were 1, 2, and 4, and the mask durations were to 0, 80, 160, 240, and 320 ms. We reduced the number of trials per condition (48), which allowed the experiment to be completed within one 50-min session.

Results

The results are shown in Fig. 4, where significant main effects of set size [$F(2, 30) = 23.49, p < .001$] and mask duration [$F(4, 60) = 2.87, p = .04$] can be seen. The main effect of mask duration was driven by a quadratic component [$F(1, 15) = 5.95, p = .028$]; the linear component was not significant [$F(1, 15) = 0.1, p = .75$]. The interaction between set size and mask duration was not significant ($F < 1$). Figure 4A shows a hint of increased masking magnitude at larger set sizes, but the statistics did not support any such relationship.

Following the guessing correction and log transformation, two participants were at floor (<12.5 % accuracy) in one or

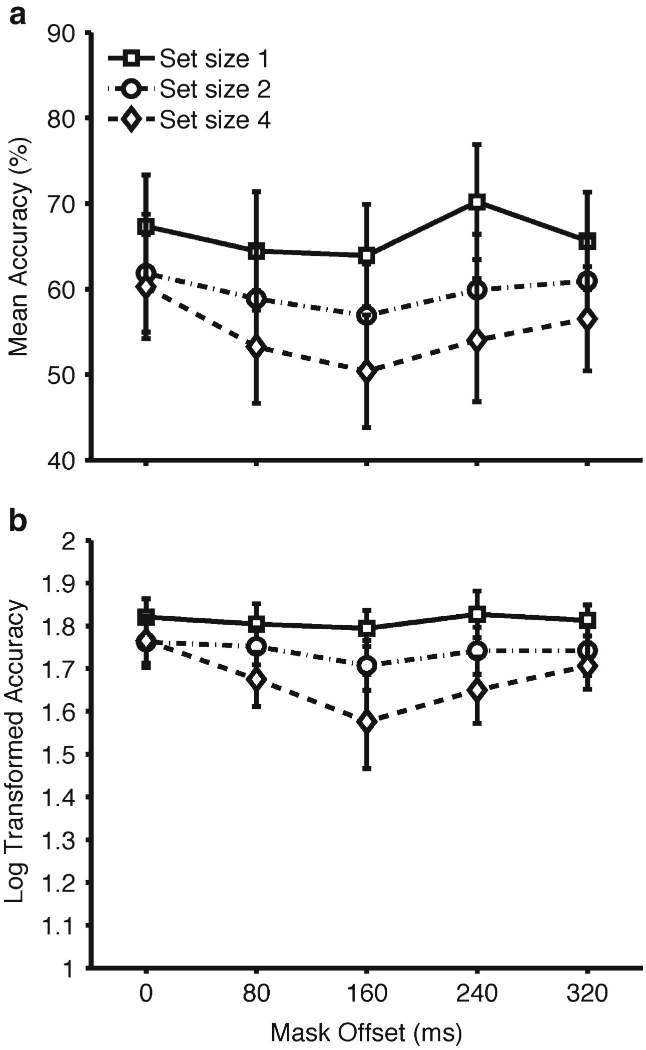

Fig. 4 (A) Mean accuracy rates (% correct) as a function of mask offset and set size in Experiment 3. (B) Guessing-corrected and log-transformed accuracy. Error bars represent *SEM*s.

more of the experimental conditions, and they were removed from the analysis. An identical analysis with these data revealed a main effect of set size [$F(2, 26) = 19.39$, $p < .001$], but only a marginally significant main effect of mask duration [$F(4, 52) = 2.48$, $p = .08$].

An interaction between set size and mask duration was not observed [$F(8, 104) = 0.88$, $p = .49$]. The results again suggest that, once the data were corrected for guessing and transformed, only a small OSM effect was present, and this did not interact with set size.

Discussion

The results of Experiment 3 showed a small numerical trend for an interaction between set size and masking magnitude. However, this interaction was not significant. The main effect of mask duration reflected only a quadratic component (reflecting a U-shaped masking function), whereas Experiment 2 had shown both quadratic and linear components. The lack of a linear component in this experiment hints at a less consistent and/or smaller masking effect than had been found previously. This could be argued as being driven by the small set sizes used in Experiment 3; if set size and masking magnitude are indeed related, then using only smaller set sizes could limit the masking effects. However, since very little evidence of an interaction between mask duration and set size had been found at the larger set sizes (Exps. 1 and 2), this seems unlikely to explain the lack of any evidence for an interaction between set size and masking magnitude.

Experiment 4

Experiment 4 explored the possible effect of distractor arrangement on the interaction between set size and masking magnitude. Thus far, the distractors were *equally distributed across the possible stimulus locations*. However, in the original work by Di Lollo et al. (2000), the locations of the distractor items were randomized. Using random locations for the distractors would provide a less predictive array of stimuli, and this reduced certainty could lead to larger masking magnitudes (irrespective of set size), since target localization could take longer (Chun & Jiang, 1998). By inducing larger masking magnitudes, we would have increased sensitivity to detect an effect of set size on OSM. To test this, in Experiment 4 we used a random allocation of distractors to possible locations. The set sizes were also changed to 3, 5, and 7, to give an increased spread of relatively small set sizes and to ensure larger (than in Exp. 3) and significant OSM in the present conditions.

Methods

The method was the same as that for Experiment 3, except where specified below.

Participants Sixteen new undergraduate students took part (mean age = 22 years, *SD* = 1.6; 12 women, four men; one left-handed) for payment.

Materials and procedure The materials and procedures were identical to those of Experiment 3, with two exceptions. First, the set sizes were changed to 3, 5, and 7. Second, the distractor locations were chosen randomly, with the constraint that they always appeared on the circumference of an imaginary circle, in order to control for eccentricity. To prevent stimulus overlap, the stimulus could be presented at 16 possible locations on the circumference. These locations were the same as those shown in Fig. 1 for set size 16.

Results

The results are shown in Fig. 5. We found significant main effects of set size [$F(2, 32) = 24.09$, $p < .001$] and mask duration [$F(4, 64) = 15.81$, $p < .001$]. The main effect of mask duration reflected both a linear [$F(1, 16) = 22.58$, $p < 0.001$] and a quadratic [$F(1, 16) = 25.4$, $p < .001$] component, confirming both that a significant masking effect was present, and some recovery from this masking at the longer mask durations. The interaction between set size and mask duration was not significant ($F < 1$), despite the significant effect of mask duration on performance.

Following the guessing correction and log transformation, four participants were at floor (<12.5 % accuracy) in one or more of the experimental conditions, and they were removed from the analysis. An ANOVA identical to that above (Fig. 5B) demonstrated a main effect of set size [$F(2, 22) = 15.66$, $p < .001$] and a main effect of mask duration [$F(4, 44) = 8.04$, $p < .001$]. The interaction between set size and mask duration was not significant ($F < 1$). The results show the same pattern as the percent accuracy data, and suggest that after correction for guessing and log transformation, no interaction was apparent between mask duration and set size, despite the presence of a significant effect of mask duration on performance.

Discussion

Experiment 4 again showed no evidence of an interaction between mask duration and set size. This lack of an interaction was observed even though the significant effect of mask duration reflected both linear and quadratic functions, and hence significant OSM and a recovery. The difference in performance for the three set sizes appeared to be relatively small, but these differences were significant. The random distribution of distractor items in this experiment, then, led if anything to a clearer main effect of mask duration, yet it provided no evidence for an interaction with set size.

General discussion

We ran four experiments to investigate the relationship between spatial attention and OSM. We manipulated the factors of set size, mask duration, and distractor item spatial distribution. An 8AFC task was chosen to give a larger performance window between floor and ceiling. Our findings revealed some evidence for an interaction between mask duration and set size (Exp. 1). However, this evidence was limited to interactions between the smallest and largest set size when performance in the former was close to ceiling. When ranges of smaller set sizes were included (e.g., set sizes between 1 and 8), we found no evidence that set size interacted with mask duration. Overall, the findings provide support for the suggestion that mask duration and set size do not interact in OSM when floor and ceiling effects are avoided. This conclusion supports the findings of Argyropoulos et al. (2013), and contributes an important replication. The present results also complement those of Jannati et al. (2013), who reported comparable masking functions across set sizes when the interval between the target and the mask was manipulated. Collectively, our findings call into question the proposed relationship between OSM and spatial attention.

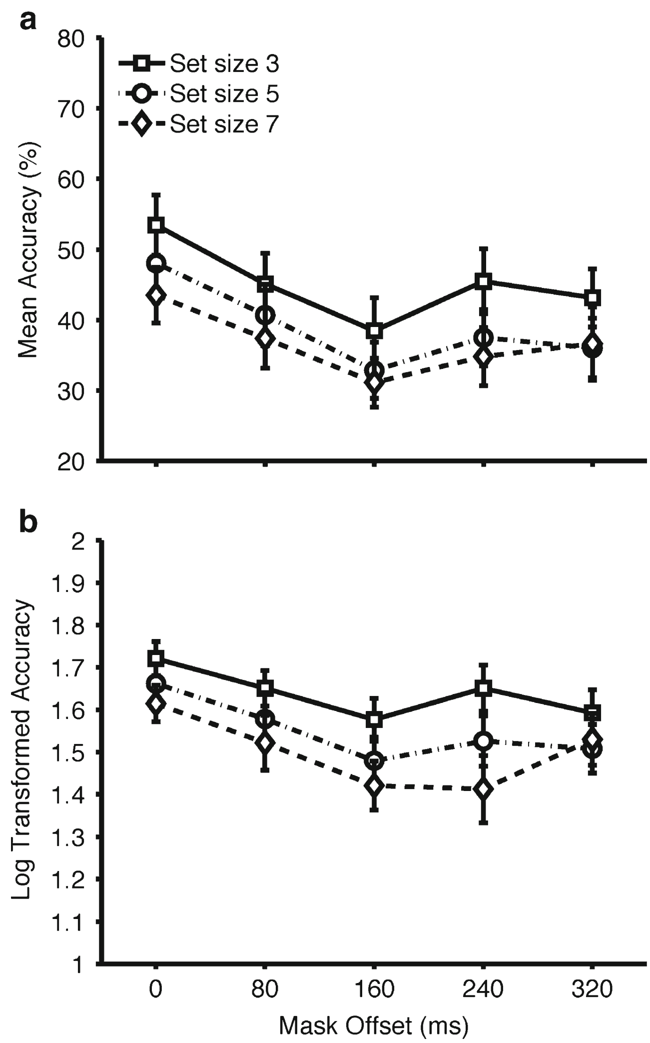

Fig. 5 (A) Mean accuracy rates (% correct) as a function of mask offset and set size in Experiment 4. (B) Guessing-corrected and log-transformed accuracy. Error bars represent *SEM*s.

For all of the experiments reported by Argyropoulos et al. (2013), and for Experiments 1–3 in this article, the locations of the distractor items were fixed and equally spaced around an imaginary circle. This gave some considerable predictability to the target and distractor locations and likely influenced how quickly the target could be localized and, thus, identified. In the original work by Di Lollo et al. (2000), the locations of the target and distractor items were randomly distributed across the screen. In Experiment 4, we showed that allowing the distractors to be randomly located on the screen did not lead to any evidence for an interaction between set size and masking when floor and ceiling effects are avoided—on the contrary, there was not even a numerical hint of an interaction.

Did we fail to observe a set size and mask duration interaction due to the targets in our experiments giving rise to some form of "pop out," allowing for the rapid focusing of attention on the target regardless of the number of distractor items present? Target pop out could have moderated or eliminated the differences between the set sizes. For all trials, the target was the only item surrounded by four dots and hence may have stood out from the distractor items. The use of the mask as the means of identifying the target is typical of the OSM literature, and the possibility of a pop-out effect mediating the impact of set size on masking magnitude could equally be applied to many experiments (Argyropoulos et al., 2013; Di Lollo et al., 2000; Enns & Di Lollo, 1997; Goodhew et al., 2012; Goodhew et al., 2011). However, in all of these studies, and the study reported here, a masking effect was found, which would not be predicted if pop out were present (Di Lollo et al., 2000). In addition, all the experiments reported in this article showed a main effect of set size. This is the classic indication that pop out has not occurred in a visual search (Wolfe & Horowitz, 2004).

Another potential issue with our design is that at larger set sizes, it is possible that visual crowding affected performance. Visual crowding refers to the impaired peripheral target perception observed if other items are spatially proximal to it (Pelli & Tillman, 2008). At set size 16, and to some extent set size 8, the items were presented relatively close together in space (separation between the centers of neighboring stimuli: set size 8 = 2.72° visual angle, set size 16 = 1.39° visual angle; separation between the edges of neighboring stimuli: set size 8 = 1.62° visual angle, set size 16 = 0.29° visual angle). Thus, crowding could lead to a general degradation in performance, regardless of the mask condition, or interact with mask duration to produce variable masking effects (Vickery et al., 2009). The fact that no evidence was found for an interaction between mask duration and set size at smaller numbers of distract items (e.g., one vs. four items), for which crowding should be minimal (distance between neighboring stimuli edges in set size 4 = 3.92° visual angle; Pelli & Tillman, 2008), indicates that crowding did not play a key role in limiting the extent to which we were able to observe an interaction between set size and mask duration.

In the experiments reported here with longer mask durations included, we observed evidence of OSM recovery. This result allows for two conclusions. First, the point of maximal masking was reached in the present design. Therefore, that the lack of interaction found was not simply due to us missing a crucial mask duration for OSM. Second, the findings replicate previous work (Goodhew et al., 2012; Goodhew et al., 2011) and provide further evidence that the target representations are not irrevocably lost in OSM.

Overall, it would appear that there is very little evidence, when ceiling and floor effects are accounted for, of an interaction between set size and mask duration. This conclusion has important implications for how we conceptualize OSM. The role of attention is not completely removed by these findings, but the results do imply that the higher-level visual-processing mechanism that is likely to be disrupted in OSM has a more subtle relation to attention than was previously thought. Mounting evidence is showing that attention and consciousness could be, at least partially, dissociable (Cohen et al., 2012; Lamme, 2004; Wyart et al., 2012). The findings of this article support the possibility that consciousness can be disrupted relatively independently of a manipulation of spatial attention. Hence, although the growing evidence against an interaction between set size and mask duration in OSM undoubtedly questions our understanding of OSM, it also provides a further avenue for researching and understanding visual processing and how the processes of attention and consciousness interact.

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References

Argyropoulos, I., Gellatly, A., 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.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36,* 28–71. doi:10.1006/cogp.1998.0681

Cohen, M. A., Cavanagh, P., Chun, M. M., & Nakayama, K. (2012). The attentional requirements of consciousness. *Trends in Cognitive Sciences, 16,* 411–417.

Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: The psychophysics of reentrant visual processes. *Journal of Experimental Psychology: General, 129,* 481–507. doi:10.1037/0096-3445.129.4.481

Dux, P. E., Visser, T. A., Goodhew, S. C., & Lipp, O. V. (2010). Delayed reentrant processing impairs visual awareness an object-substitution-masking study. *Psychological Science, 21,* 1242–1247.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research, 44,* 1321–1331. doi:10.1016/j.visres.2003.10.024

Enns, J. T., & Di Lollo, V. (1997). Object substitution: A new form of masking in unattended visual locations. *Psychological Science, 8,* 135–139. doi:10.1111/j.1467-9280.1997.tb00696.x

Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2005). Masking interrupts feedback processing. *Journal of Vision, 5*(8), 963a. doi:10.1167/5.8.963

Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. (2007a). Masking disrupts reentrant processing in human visual cortex. *Journal of Cognitive Neuroscience, 19,* 1488–1497.

Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2007b). Perception correlates with feedback but not with feedforward activity in human visual cortex. *Journal of Vision, 7*(9), 388a. doi:10.1167/7.9.388

Goodhew, S. C., Dux, P. E., Lipp, O. V., & Visser, T. A. (2012). Understanding recovery from object substitution masking. *Cognition, 122,* 405–415.

Goodhew, S. C., Pratt, J., Dux, P. E., & Ferber, S. (2013). Substituting objects from consciousness: A review of object substitution masking. *Psychonomic Bulletin & Review, 20,* 859–877. doi:10.3758/s13423-013-0400-9

Goodhew, S. C., Visser, T. A., Lipp, O. V., & Dux, P. E. (2011). Competing for consciousness: Prolonged mask exposure reduces object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 588–596.

Jannati, A., Spalek, T. M., & Di Lollo, V. (2013). A novel paradigm reveals the role of reentrant visual processes in object substitution masking. *Attention, Perception, & Psychophysics, 75,* 1118–1127. doi:10.3758/s13414-013-0462-9

Lamme, V. A. F. (2004). Separate neural definitions of visual consciousness and visual attention; a case for phenomenal awareness. *Neural Networks, 17,* 861–872. doi:10.1016/j.neunet.2004.02.005

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences, 23,* 571–579. doi:10.1016/S0166-2236(00)01657-X

Lamme, V. A. F., Supèr, H., & Spekreijse, H. (1998). Feedforward, horizontal, and feedback processing in the visual cortex. *Current Opinion in Neurobiology, 8,* 529–535. doi:10.1016/S0959-4388(98)80042-1

Pashler, H., & Harris, C. R. (2012). Is the replicability crisis overblown? Three arguments examined. *Perspectives on Psychological Science, 7,* 531–536.

Pelli, D. G., & Tillman, K. A. (2008). The uncrowded window of object recognition. *Nature Neuroscience, 11,* 1129–1135. doi:10.1038/nn.2187

Schweickert, R. (1985). Separable effects of factors on speed and accuracy: Memory scanning, lexical decision, and choice tasks. *Psychological Bulletin, 97,* 530–546. doi:10.1037/0033-2909.97.3.530

Simons, D. J. (2014). The value of direct replication. *Perspectives on Psychological Science, 9,* 76–80.

Vickery, T. J., Shim, W. M., Chakravarthi, R., Jiang, Y. V., & Luedeman, R. (2009). Supercrowding: Weakly masking a target expands the range of crowding. *Journal of Vision, 9*(2), 12, 1–15. doi:10.1167/9.2.12

Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Reviews Neuroscience, 5,* 495–501. doi:10.1038/nrn1411

Wyart, V., Dehaene, S., & Tallon-Baudry, C. (2012). Early dissociation between neural signatures of endogenous spatial attention and perceptual awareness during visual masking. *Frontiers in Human Neuroscience, 6,* 16. doi:10.3389/fnhum.2012.00016