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Set-size and mask duration do not interact in object substitution masking[1]

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ABSTRACT

Object Substitution Masking (OSM) occurs when a mask, such as four dots that surround a brief target item, onsets simultaneously with the target and offsets a short time after it rather than simultaneously with it. OSM is a reduction in accuracy of reporting the target with the temporally trailing mask relative to with the simultaneously offsetting mask. It has been thought that OSM occurs only if attention cannot be rapidly focused, or pre-focussed, on the target location. One line of evidence for this is a reported interaction between target display set size and the duration of the trailing mask. We analyse the evidence for this interaction and suggest it occurs only as an artefact of data being compressed by a ceiling effect. We report six experiments that support this interpretation by showing that the interaction is always absent unless a ceiling effect is induced. We go on to analyse other evidence that attention modulates OSM and argue that in each case the data either reflect a ceiling effect or can be explained in another way. Our data and our analyses of the existing literature have strong implications for how OSM should be conceptualised.

Set-size and mask duration do not interact in object substitution masking

Introduction

Object Substitution Masking (OSM) refers to the observation that the visibility of a target stimulus can be reduced by the presence of a second, spatially non-overlapping stimulus (the mask) with minimal contour. OSM is frequently observed for tasks in which the mask consists of just four dots that surround the target and onset along with it (common onset), and either the two stimuli vanish together (common offset, or control, condition) or the mask offsets after the termination of the target (trailing mask, or masking, condition). Reporting of the target is reduced when mask offset trails target offset, and the difference between the two conditions is typically reported as an index of OSM. It has been thought that to obtain the effect the target must appear as part of a display of several items (as in Figure 3) and that the observer must not have advance knowledge of the target location (Di Lollo, Enns, & Rensink, 2000; Enns, 2004; Enns & Di Lollo, 1997; Enns & Di Lollo, 2000). In this paper, we will demonstrate that the first of these conditions does not apply and argue that, in fact, the second is not supported by the evidence.

The discovery of OSM challenges traditional accounts of visual masking. Whereas masking has usually been attributed to low level visual processes, OSM seems to indicate the involvement of higher level processing, and has been claimed to depend critically on the distribution of visual spatial attention (but see Averbach & Coriell, 1961; Ramachandran & Cobb, 1995 on the role of attention and top down processes on other forms of masking, too).

Di Lollo et al. (2000) highlighted the contribution of these processes by proposing a theoretical framework premised on the assumption of bidirectionality between hierarchically organised brain areas (Felleman & Van Essen, 1991). Stimulus onset activates low level cells that code only simple stimulus attributes and location information. A feed-forward sweep progresses this information to higher (extrastriate) visual areas which generate one or more perceptual hypothesis as to what the stimulus comprises. The receptive fields of the cells in the extrastriate visual areas are, however, large in size and the resultant hypothesis has poor spatial resolution. To resolve potential perceptual and location ambiguities, hypothesis information is sent back to low level areas via re-entrant projections where a matching process occurs. If the display remained the same (target plus mask) during the re-entrant loop, the hypothesis from the extrastriate areas will match the current activity in lower visual areas and a stable percept will be achieved. If, during the iterative loop, however, the displayed image changes (to mask alone) a mismatch is created between the re-entrant information and the current visual input and a new cycle of processing begins based only on the current sensory input activating lower level neurons.

According to Di Lollo et al. (2000), key evidence in support of the re-entrant hypothesis account comes from the fact that large masking effects are observed only with multi-element displays and relatively prolonged mask durations. To explain this, they suggest that when a large number of distractors is presented along with the target, attention takes longer to arrive at the target's location, which correspondingly increases the likelihood that before the target has been identified the display will have changed from target plus mask to mask only. Contrastingly, when a target "pops out", or is the only item in the display, attention becomes focused upon it rapidly and a robust target representation can be established before the display changes. If the mask lingers after target offset and the visual system has failed to confirm the initial hypothesis of target plus mask, then the representation of the mask alone will prevail in the perceptual system and only the mask will be consciously perceived. Di Lollo et al. instantiated their theory in a computational model (CMOS) of which a key parameter is the time for attention to contact the target item.

A critical aspect of Di Lollo et al.'s theory is the emphasis on the interaction between search array set size and mask duration, and it is worth noting that the present authors began the series of experiments reported here fully expecting to obtain such an interaction themselves, However, because – to preview what is to come – the expected interaction failed to materialize in our studies, it is relevant to consider Di Lollo et al.'s findings in relation to the interaction and the alternative interpretations of it they discussed.

In their Experiment 3, the stimuli consisted of circles, each with a gap at the top, left, bottom or right. The target was cued by four dots which also served as a mask, and, the observers' task was to report the orientation of the gap of the target circle. The results showed that set size and mask duration (after target offset) interacted such that OSM was maximal for the largest set-size at relatively long mask durations (Figure 1)

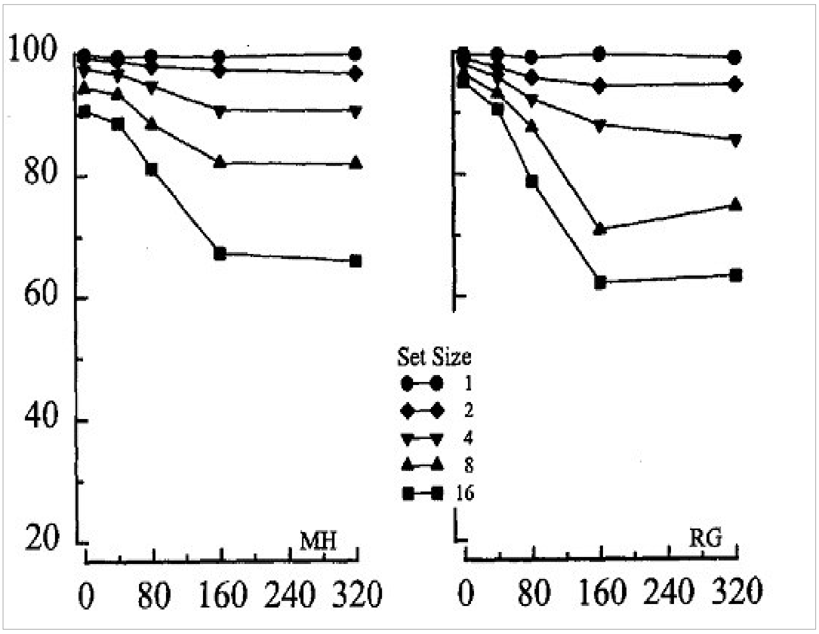

Figure 1. Mean percentage correct identification of the location of the gap in the target as a function of set size and mask duration for two observers (Figure 1 Adapted from "Competition for consciousness among visual events: The psychophysics of reentrant visual processes", V. Di Lollo, J. T. Enns, R. A. Rensink, 2000, Journal of Experimental Psychology: General,129(4), p.491. Copyright [2000] by the American Psychological Association, Inc.).

In a subsequent experiment (Experiment 4), the target and distractors were replaced by closed circles and half of them had a vertical line segment through them while the other half did not. The observers had to report whether or not the target contained the vertical segment. In keeping with Experiment 3, a significant interaction was obtained, with the masking effect becoming multiplicatively stronger with increasing number of distractors and longer mask duration (Figure 2).

The claim that the magnitude of OSM is critically dependent on the joint effects of set size and mask duration can be called into question on the grounds that ceiling effects were evident in both experiments. For instance, in Experiment 3 performance for the small set sizes was close to or at 100% for all levels of mask duration. In addition, performance in the common offset condition was close to ceiling for all set sizes as indicated by the narrow vertical spread of the data when mask duration was 0 ms. These features of the data suggest performance for certain conditions may not have been fully revealed because it was compressed by the limits of the response scale. Di Lollo et al. noted that crowding acts to reduce the detectability of the target in larger set sizes. This means ceiling performance for larger set sizes could be less

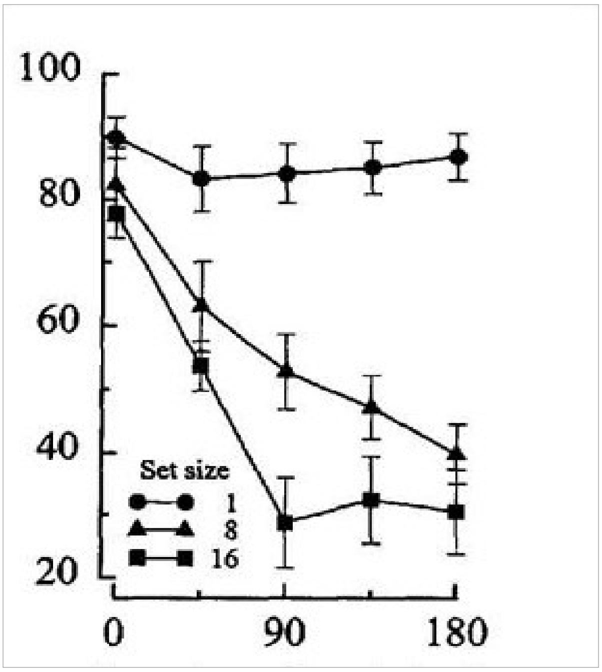

Figure 2. Mean percentage correct target identifications, when the target contained a vertical segment, as a function of set size and mask duration (Figure 2 Adapted from "Competition for consciousness among visual events: The psychophysics of reentrant visual processes", V. Di Lollo, J. T. Enns, R. A. Rensink, 2000, Journal of Experimental Psychology: General,129(4), p.493. Copyright [2000] by the American Psychological Association, Inc.).

than 100%, so producing some vertical spread even at 0 ms mask duration (Di Lollo et al.'s term for the mask offsetting simultaneously with the target). Similar implications are evident in the results of Experiment 4. Although data for trials in which the target contained a vertical bar show a clear interaction between set size and mask duration (Figure 2), for trials in which the bar was absent, Di Lollo et al. report that "…accuracy was at ceiling except at a mask duration of zero, when the results were comparable to those obtained when the vertical segment was present." (p.493). It is, therefore, possible the interaction between set size and mask duration for target present trials reflects a response bias. The fact that performance for bar absent trials was at ceiling for almost all mask durations indicates that participants set a high criterion for reporting having seen the target. If the criterion varied with set size such that it was even higher for larger set sizes, this would have produced the observed interaction.

In fact, Di Lollo et al. themselves considered in relation to the data of their Experiment 1 whether the set size times mask duration interaction they obtained could be due to a ceiling effect. This experiment was the same as their Experiment 3, described above, except that the cue/mask was a circle rather than four dots. They argued (p.488) that a ceiling effect interpretation did not apply since performance for most set sizes at most mask durations was below ceiling, and they did not re-consider the possibility in relation to their subsequent experiments. However, they also argued that the data of their Experiment 1 showed the effect not just of high level substitution masking but also of low level interaction between the closely fitting circular mask and the circular targets they employed. Indeed, in their Experiment 2 they repeated their Experiment 1 under conditions of dark adapted viewing intended to eliminate or reduce low level contour interactions. They once again observed an interaction of set size and mask duration but in the presence of ceiling or close to ceiling performance with smaller set sizes and for all set sizes at 0 ms mask duration (common offset). In fact performance was similar to that in their Experiment 3 (see Figure 1). In other words, to the extent that dark adapted viewing reduced low level contour interactions, it also served to undermine the argument against a ceiling level interpretation of the interaction.

Have other studies of OSM that independently manipulated both set size and mask duration obtained an interaction between the two factors? It was only when – to preview what is to come – the expected interaction failed to materialize in our studies, that we began to comb the literature with this in mind, and came to realise the paucity of evidence for its existence.

Another study for which a set size times mask duration interaction was reported was also less than fully conclusive. Kotsoni et al. (2007) performed two experiments employing circles with or without a vertical segment and with set sizes one and nine and trailing mask durations of zero or 93 ms. Target duration was 13 ms in Experiment 1 and 40 ms in Experiment 2, and both sets of data were analyzed in terms of d-prime values. Both sets showed a trend towards the interaction but this was significant only for Experiment 2. However, group mean performance for the set size one and common offset condition was at 93% and 95% in the two experiments, suggesting that for many participants performance in this condition, and thus the extent of the OSM effect for set size one, was being artificially influenced by a ceiling.

Moreover, even though chance was 50%, mean performance on the set size 9 and 93 ms trailing mask condition was 33% and 38% in the two experiments, indicating that a strong response bias affected the results for that condition in both experiments.

Similar problems arise in connection with two sets of experiments recently reported by Goodhew and colleagues (Goodhew, Dux, Lipp, & Visser, 2012; Goodhew, Visser, Lipp, & Dux, 2011) which also compared set sizes one and nine, but in each case across a greater range of mask durations. Although their experiments focussed on a separate issue, the authors reported interactions between set size and mask duration for most, though not all, of their experiments, and Goodhew et al. (2011, p590), citing Di Lollo et al. (2000), assert that "this interaction is the hallmark of OSM". However, in all their experiments except the one that failed to produce a significant interaction, performance for set size one was well above 90% for all mask durations, and frequently close to 100%. As before, ceiling effects make it impossible to interpret the interaction, even when it is significant.

In the remainder of this paper we will argue that far from being a hallmark of OSM, the interaction between set size and mask duration is a rare beast, and that when it is sighted it is very likely to be an artefact of ceiling and/or floor effects.

Experiment 1

Our first experiment employed a four alternative discrimination task and, in terms of the nature and size of the stimuli, was deliberately modeled on Experiments 1 to 3 of Di Lollo et al. (2000), although using squares with gaps rather than circles. However, whereas Di Lollo et al.. displayed their stimuli in virtual square array, the stimuli in all our studies were presented in a virtual circle so distance of the target from fixation was constant. The initial aim was simply to validate our experimental method by replicating the effects of set size and mask duration and the interaction between them so that we could then go on to investigate other issues. The experiments we report all had the approval of the University Research Ethics Committee of Oxford Brookes University.

Method

8

Participants were eleven undergraduate and postgraduate students and members of the public (8 females) with an average age of 22.2 years (s.d.= 4.4).. All participants reported normal or corrected-to-normal visual acuity. They gave informed consent and they received a small financial recompense. In the present and subsequent experiments participants were pre-warned that they should not take part if they had a medical history of epilepsy or of visual migraine caused by extended exposure to a television screen or flashing images.

In all the experiments reported in the present study, the stimuli were presented on a 20-inch CRT computer monitor running at 100Hz. They were black (0.35 cd/m^2]) on a white background (97.25 cd/m^2) and they were displayed at a viewing distance of 113cm in a dimly lit room. The experiments were written in and controlled by Matlab using the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997)

On any given trial, the display consisted of 4 or 16 squares, each having a gap in the top, bottom, left or right side. The side of the gap was randomised. The centres of the squares were equally spaced around the circumference of a virtual circle with radius 2.98°. On each trial one of the items was surrounded by four dots (the mask), which also served as a cue to single out the target. The mask always onset simultaneously with the target and the distractors; these then either all offset together (blank frame) or the mask lingered for 60ms or 180ms (Figure 3).

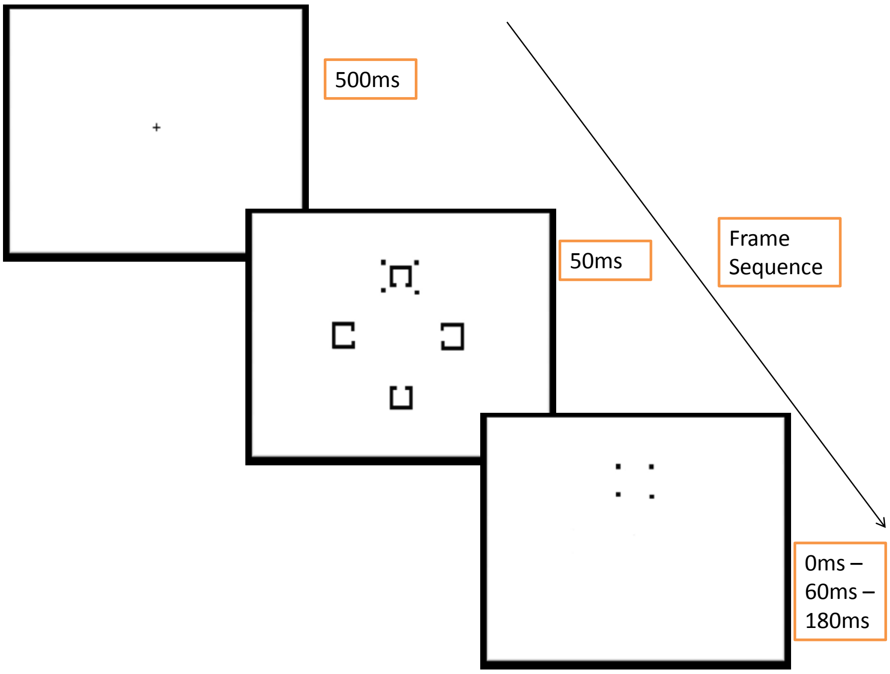

Figure 3. In each trial four or sixteen squares with a small gap located randomly on one of their sides were presented in a circular array. Participants were asked to report the location of the gap of the square that was surrounded by four dots.

In units of visual angle, each side of the square subtended for 0.3°, the gap was 0.1° and the lines forming the square were of thickness 1.5 min arc. The thickness of each dot was 3 min arc and the distance between them was 0.5°.

Each participant underwent 240 trials which resulted from the factorial combination of 2 set sizes x 3 mask durations x 40 trials per condition. 24 demonstration trials with extended frame durations (to ensure participants fully understood the task) and 48 practice trials preceded the main experiment. Every 60 trials the computer prompted the participants to have a brief break. The total duration of the experiment was approximately 25 minutes. At the beginning of each trial a fixation cross was presented for 500ms at the centre of the screen followed by a frame that contained the target, the mask and the distractors for 50ms. A subsequent frame was either blank – common offset condition - or contained only the trailing mask for 60 ms or 180 ms. Participants were instructed to press one of four arrow keys on a computer keyboard if they thought that the gap was on the right, left, top or bottom side of the target-square. Participants were informed that accuracy not speed of response was of importance.

Results and Discussion

Figure 4 shows mean percentage correct responses for each combination of set size and mask duration. Chance performance is 25% correct. The data were analysed in a two way repeated measures ANOVA. In this and all subsequent analyses, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity where appropriate. Results from the ANOVA showed significant main effects of set size $F(1, 10) = 14.28$, $p < .005$, partial $\eta^2 = .58$) and mask duration $F(1.3, 13) = 14.90$, $p < .005$, partial $\eta^2 = .59$). However, what was critical to the present study – and in contrast to Di Lollo et al.'s (2000) findings – was the lack of an interaction between those two factors [$F(2,20) = .06$, $p > .05$].

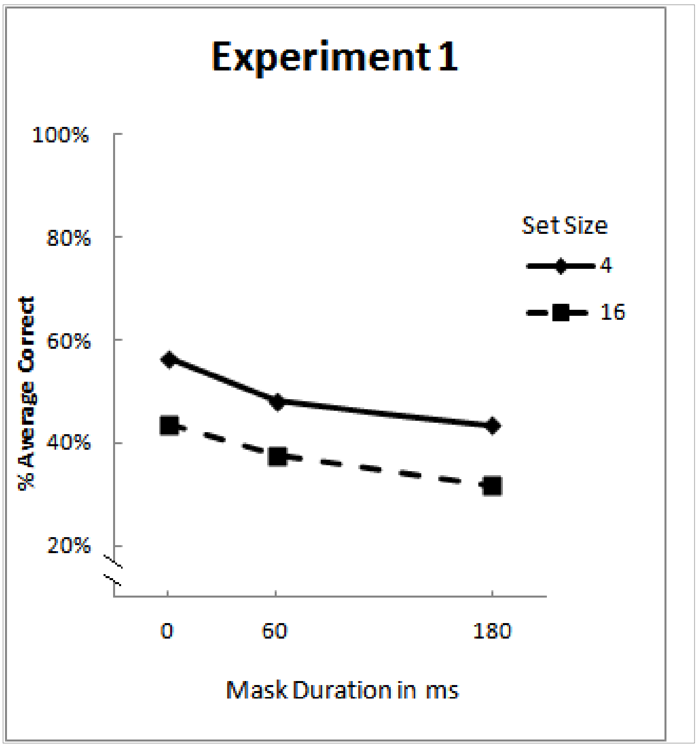

Figure 4. Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the two set sizes.

A possible explanation for this lack of interaction could lie in the overall level of performance. In Di Lollo et al.'s (2000) study (Experiment 3) performance for all set sizes in the common offset condition was consistently high (on average above 90%), and even at longer mask durations performance for smaller set sizes varied between 70% and 100%. In our Experiment 1, however, performance for the common offset condition was much lower, 56% for set size of four and 44% for set size of sixteen. Furthermore, performance for the larger set size and longest mask duration (32%) was not very far above the chance level of 25%. Although the group mean was significantly different from chance ($t(10) = 10.99$, $p < .001$), results for some participants may have been compressed by a floor effect. Certainly performance on our task was much lower than on Di Lollo et al.'s task, and it is possible that the relatively close to floor performance for the larger set size at the longest mask duration might have disguised the expected interaction.

To test this possibility, a second experiment was run in which the task was made easier for participants by completely omitting one side of each square instead of having only a gap. It was expected that this change would raise overall performance levels and eliminate the danger that a floor effect for the most difficult condition might be masking the expected interaction.

Experiment 2

Method

There were 10 psychology undergraduate participants (8 females) with an average age of 30.8 years (s.d. = 13.2). They were recruited from the OBU Psychology Department Participants Panel and received course credits for taking part in the study. Stimuli were identical to those used in Experiment 1 except that instead of each square having a small gap in one of its sides, a whole side was missing. The procedure was identical to that in Experiment 1.

Results and Discussion

Figure 5 shows the mean percentage correct responses over set size and mask duration. As expected, the replacement of the small gap with a missing side markedly improved discrimination performance. A two way repeated measures ANOVA revealed a significant main effect of set size [$F(1,9) = 28.04$, $p < .001$, partial $\eta^2 = .76$] and of mask duration [$F(2,18) = 26.29$, $p < .001$, partial $\eta^2 = .75$]. However, as in Experiment 1, there was no interaction between these two factors [$F(2,18) = .86$, $p > .05$]. Increasing the size of the target gap had the desired effect of raising overall performance levels and also resulted in steeper masking functions but did not otherwise alter the pattern of results from those of Experiment 1. Although the difference in accuracy between set sizes 4 and 16 does increase slightly across set sizes, the interaction does not even approach significance.

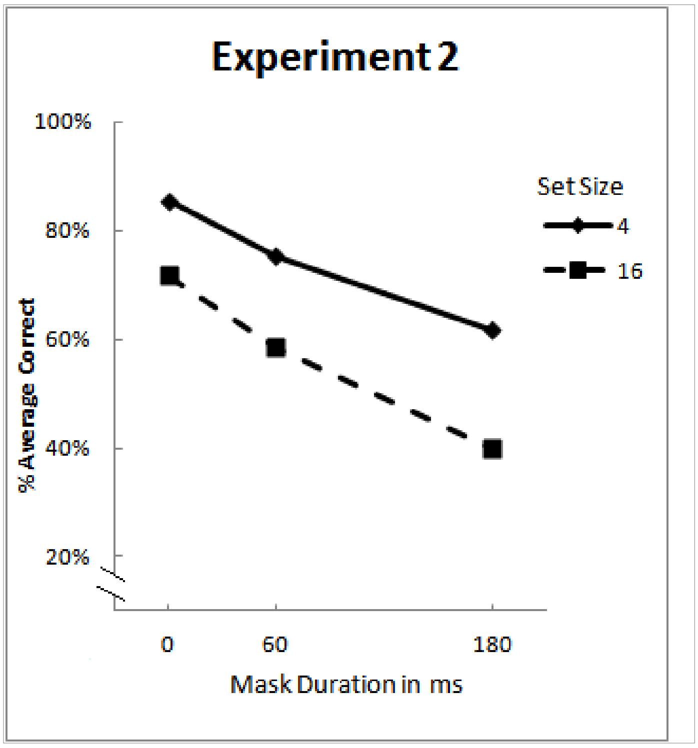

Figure 5. Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the two set sizes.

Experiment 3

In both the first two experiments, discrimination performance decreased with increasing set size and mask duration. However, contrary to Di Lollo et al. (2000) and Kotsoni et al. (2007, Experiment 2) the two factors did not interact. The masking effect was not the product of an interaction between set size and mask duration but rather the additive result of the effect of each factor individually. One difference between our two studies and those of Di Lollo et al, is that we used only two set sizes whereas for their comparable experiments they used five. Possibly this might have led to participants employing different processing strategies. Furthermore, in their experiments the effect of mask duration for set size 4 lay somewhere between that for set sizes 1 and 16. Possibly we might find an interaction if we included more levels of the set size variable and a greater range of values of set size. In Experiment 3, therefore, we added two more set sizes of 1 and 8 items. However, employing a square with a missing side as a stimulus could result in performance always at ceiling when 1 item was presented. Conversely, a stimulus with too small a gap could conduce to performance close to chance levels for the larger set size and longest mask duration (as in Experiment 1). Consequently, in an effort to avoid ceiling and/or floor effects, the stimuli in Experiment 3 were constructed with larger gaps than in Experiment 1 but not with missing sides.

Method

There were 10 psychology undergraduate participants (7 females) with an average age of 22.7 years (SD = 5.17). They were recruited from the OBU Psychology Department Participants Panel for course credits. Stimuli were identical to those used in Experiment 1 except for the two following changes; instead of a small gap (0.1°) there was now a larger gap of 0.2°. Also, two extra set sizes of 1 and 8 items were added. As a result, the total number of trials was increased from 240 to 480 (from the factorial combination of 4 set sizes X 3 mask durations X 40 trials per condition). The procedure was identical to that of Experiment 1.

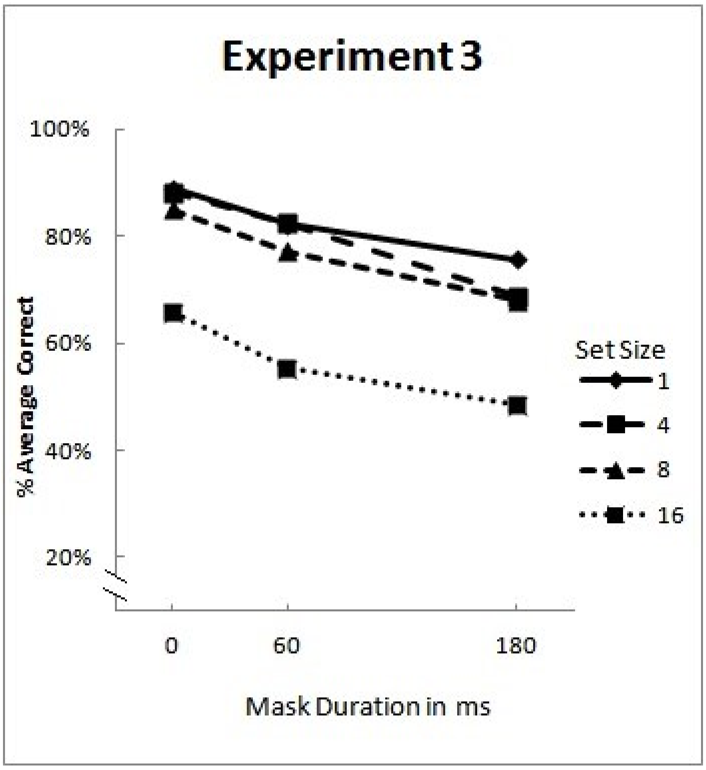

Figure 6. Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the four set sizes.

Results and Discussion

Figure 6 shows the mean percentage correct responses over the 4 set sizes and the 3 mask durations. Similar to Experiments 1 & 2, there were significant effects of set size [$F(1.5, 13.4) = 35.12$, $p < .001$, partial $\eta^2 = .79$ and mask duration [$F(2,18) = 34.02$, $p < .001$, partial $\eta^2 = .79$] but not an interaction between these two factors [$F(6,54) = .92$, $p > 0.05$]. The results of Experiment 3 are entirely consistent with those of Experiments 1 and 2. Increasing the number and range of set sizes did nothing to promote an interaction with mask duration.

That OSM in Experiment 3 was just as strong for set size 1 as for the larger set sizes is a theoretically important finding. It shows that, contrary to what has been thought previously, it is not necessary for the target to be part of a multi-element display in order for OSM to be obtained (see also Dux, Visser, Goodhew, & Lipp, 2010). In contrast to the data of Di Lollo et al., the spread of the functions for set sizes 1, 4 and 8 is very small, with the main difference being between 8 and 16 items. Di Lollo et al. remarked on the role crowding plays in reducing performance for larger set sizes and a likely explanation for why such a large difference was found between set sizes 8 and 16 of Experiment 3 is that in our circular displays of equally spaced items crowding may have come into play only for the latter displays. We will be reporting investigations of the relationships between set size, mask duration and crowding effects in another paper (Argyropoulos, Gellatly, & Pilling, 2012).

An argument that might be made about our first three experiments is that each of them employed a relatively small number of participants, and that perhaps an interaction would have emerged if larger number of participants had been employed. Because, despite the differences in gap size in each experiment, all three studies were very similar and all included set sizes 4 and 16, we entered the relevant data into a single 3 x 3 x 2 mixed ANOVA, with one between participants factor (experiment) and two within participant factors (mask duration and set size). There were main effects of Experiment [$F(2, 28) = 15.03$, p , 0.001, partial $\eta^2 = .52$], mask duration [$F(2, 56) = 63.21$, $p < .001$, partial $\eta^2 = .69$] and set size [$F(1, 28) = 99.86$, $p < .001$, partial $\eta^2 = .78$]. Experiment interacted significantly with set size [$F(2, 28) = 3.96$, $p < .05$, partial $\eta^2 = .22$], and its interaction with mask duration was approaching significance [$F(4, 56) = 2.27$, $p < .1$, partial $\eta^2 = .14$]. Most importantly, there was not an interaction between set size and mask duration [$F(2, 56) = .63$, $p > 0.05$, partial $\eta^2 = .02$]], nor a 3-way interaction [$F(4, 56) = .85$, $p > 0.05$, partial $\eta^2 = .06$]. Thus even with a total of 31 participants, there was no hint of an interaction between set size and mask duration.

Experiment 4

In all three experiments reported so far the target and the distractors were squares and observers had to report the orientation either of a gap or a missing side. In some of Di Lollo et al.'s experiments and in Kotsoni et al.'s studies, however, the stimuli consisted of circles, and participants had to report whether or not the target contained a vertical segment.. For the next few experiments we adopted similar stimuli to see if a change of task and stimuli would lead to the expected interaction.

Method

There were 18 psychology undergraduate participants (15 females) with an average age of 19.5 years (s.d. = 1.3). They were recruited from the OBU Psychology Department Participants Panel for course credits.

The present and subsequent experiments were designed to resemble Experiment 4 from Di Lollo et al.'s study. Circles were employed and observers had to report whether the target contained a bisecting vertical bar (Figure 7). The decision to employ a bisecting vertical bar (instead of a shorter vertical segment as in Di Lollo et al.'s study) was based on results from a pilot study which showed that observers performed at or around chance level when stimuli contained a short vertical segment. But, when the segment was extended upwards to intersect with the circumference of the circle dividing it into two equal parts, measurable performance was obtained. The stimuli consisted of 1, 8 or 16 circles half of which had a bisecting vertical bar. The common onset mask either offset simultaneously with the target and the distractors or it lingered for 60ms or 180ms. On average, on half of the trials the target contained a vertical bar and on the other half it did not (hereafter, bar present/absent conditions).

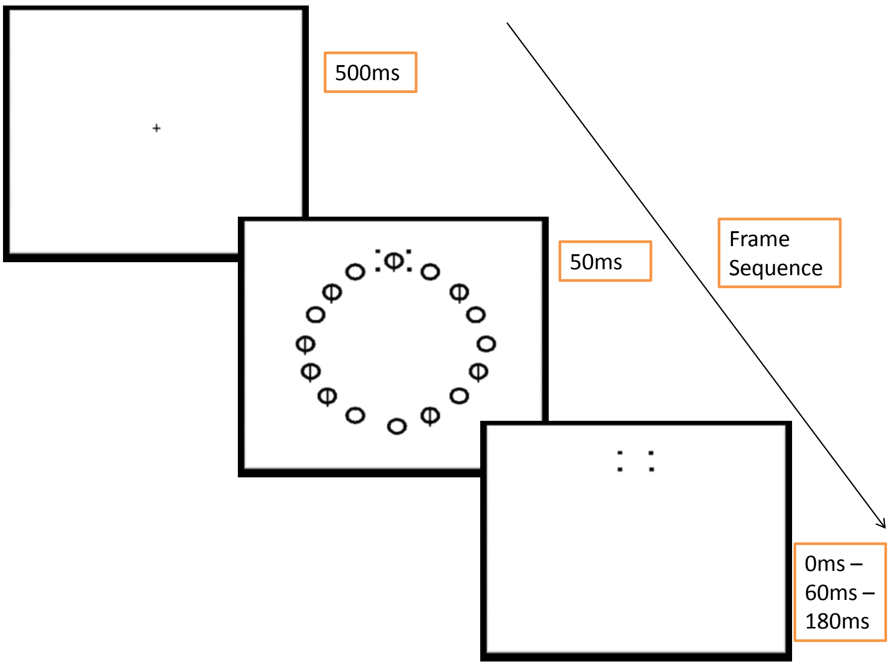

Figure 7. In each trial one, eight or sixteen circles were presented in a circular array. On average, on half of the trials, the target circle contained a bisecting vertical bar. Participants were asked to report whether the target circle contained the bisecting vertical bar.

In units of visual angle, the radius of the annular array was 2.98^{o} and of each circle was 0.15^{o}. The bisecting vertical bar subtended for 0.38^{o} and its thickness was 1.5 min arc. The distance between the dots was 0.5^{o} and each dot had a thickness of 3 min arc. Luminance values of stimuli and background were as in the previous experiments.

Each participant contributed to 540 trials resulting from the factorial combination of 2 bar present/absent conditions x 3 set sizes x 3 mask durations x 30 trials per condition. Every 60 trials the programme prompted observers to have a brief break. The total duration of the experiment was approximately 45 minutes. Similarly to the previous experiments, a session of 12 demonstration trials with extended frame durations and 36 practice trials preceded the main experiment.

At the beginning of each trial a cross was presented in the centre of the screen for 500ms on which participants were told to fixate. Immediately after the cross offset, the target, the distractors and the mask were flashed for 50ms followed by either a blank frame or a frame containing the trailing mask. Participants were informed that, on average, half of the times the target would contain a bisecting vertical bar and the other half it would not. They were instructed to press the “Y” key on a standard computer keyboard if they thought that the circle contained the vertical bar or the “N” key if they thought it did not. They were also informed that accuracy of rather than speed of response was of importance.

Results and Discussion

Illustrated in Figure 8 are mean percent correct responses as a function of set size and mask duration. For target present trials (right side of the graph) a two-way repeated measures ANOVA showed significant main effects of both set size,[$F(2,34) = 39.24$, $p < .001$, partial $\eta^2 = 0.69$] and mask duration [$F(2,34) = 46.43$, $p < .001$, partial $\eta^2 = 0.73$] and, most importantly, a significant interaction between the two factors [$F(4,68) = 2.82$, $p < .05$, partial $\eta^2 = 0.14$]. The effect of set size was stronger for longer mask durations and, conversely, mask duration had its greatest effect at larger set sizes.

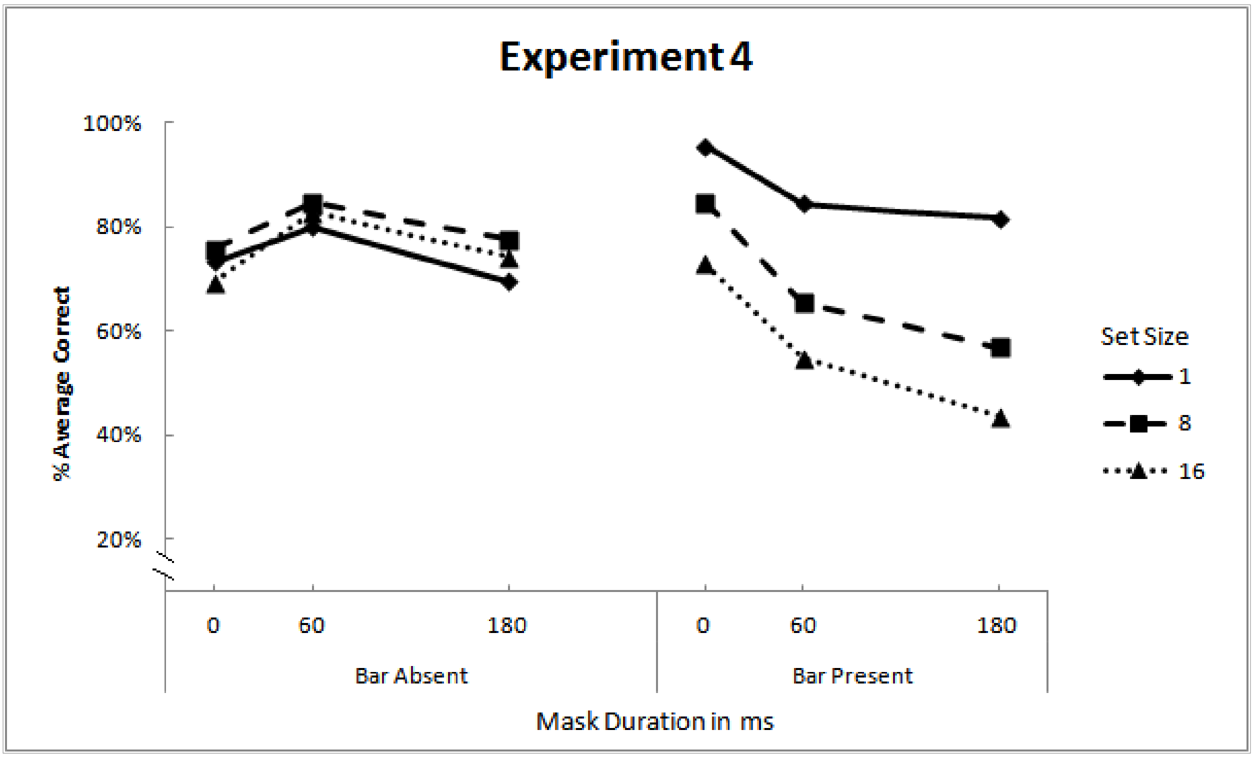

Figure 8. Mean percentage correct detection of the presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided in to scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and to scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.

For target absent trials (left side of the graph) mask duration had a significant effect [$F(1.4, 20.7) = 12.87$, $p < .005$, partial $\eta^2 = .46$] but neither set size [$F(1.3, 20.12) = .55$, $p > 0.05$] nor the interaction between these two factors [$F(4, 60) = 1.2$, $p > 0.05$) were significant.

A rather surprising finding is that for target absent trials observers' accuracy in the common offset conditions was worse than or comparable to in the extended mask duration conditions. A similar finding was also reported by Di Lollo et al. and shows that observers are as likely or more likely to commit false alarms (i.e. report that there was a vertical bar in the target when there was not) in the control condition than in the delayed mask conditions. The main point, however, is that unlike in Di Lollo et al.'s results, performance in the bar absent conditions was not at ceiling; there were appreciable false alarm rates for all conditions. There are a number of ways in which the data can be considered in the light of this finding. The simplest treatment is to perform a guessing correction by subtracting false alarms in the bar absent condition from correct detections in the bar present condition. Figure 9 illustrates the results of this procedure. When the data were entered into an 3 (set size) by 3 (mask duration) ANOVA, there was a main effect of set size [$F(1.45, 21.9,14) = 24.99$, $p < .0001$, partial $\eta^2 = .63$] and of mask duration [$F(2,30) = 32.48$, $p < .001$, partial $\eta^2 = 0.68$] but the interaction was not significant [$F(4,60) = .74$, $p > 0.05$]

The same total absence of interaction was found with d-prime and A-prime analyses.

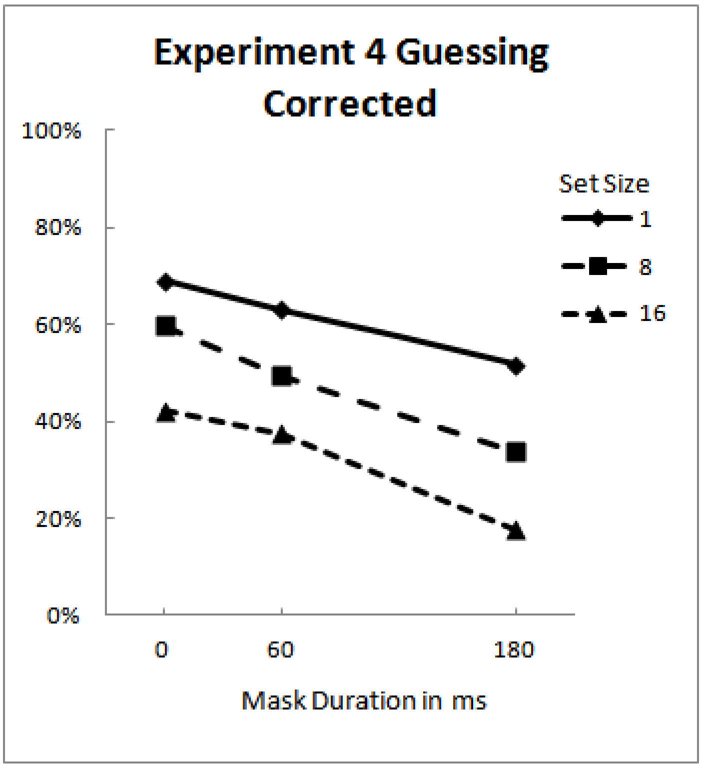

Figure 9. Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.

A first feature of these results to note is that the finding of OSM for set size 1 displays is replicated in the guessing corrected data. In comparing the present results to those of Di Lollo et al., two main points warrant discussion. First, the pattern of results for the bar present trials resembles that found in Di Lollo et al.'s study (Figure 2 above),in that there was an interaction between mask duration and set size. However, when bar absent trials are taken into account, this joint effect vanishes as shown in the analysis of guessing corrected data. As mentioned in the introduction of the present paper, Di Lollo et al. reported that “On trials in which the target did not contain the vertical segment […], accuracy was at ceiling except at mask duration of zero...” (p. 493). This statement indicates that the accuracy data for the bar absent conditions were constrained by a ceiling effect. This was not the case in our experiment where relatively high rates of false alarms were obtained, which when taken account of by guessing correction resulted in the complete lack of a significant interaction. Second, the failure to find a significant interaction cannot readily be attributed to stimulus presentation differences (a square matrix in Di Lollo et al. versus an annular array in the present study). When Di Lollo et al. analyzed their results based on the degree of eccentricity (Experiment 1) they found that although a stronger masking effect was present at greater eccentricities, the pattern of results remained similar across eccentricities. Moreover, the eccentricity of the annular array of the present experiment was deliberately very similar (3^{o}) to that of the outer positions of their matrix (2.8^{o}). However, the size of the circles differed considerably between the two studies (0.15^{o} in our experiment, 0.4^{o} in Di Lollo et al.). Conceivably, this might have resulted in higher false alarms rates. For this reason, and to ensure the reliability of our findings, we conducted a further experiment.

Experiment 5

The present experiment was identical to Experiment 4 apart from the following changes. First, the eccentricity of the annular array was decreased from 2.98^{o} to 1.77^{o}. This change was expected to produce an improvement in overall discrimination performance and so eliminate concerns about possible floor effects. Secondly, an additional mask duration of 360 ms was employed. Although Di Lollo et al. found that the effect of mask duration reached a plateau by 180 ms or sooner, it is possible that in the conditions of our experiments the main effect might operate over a longer duration. Similarly, although we have failed to obtain an interaction with set size in any of our first four experiments, it is possible that one might emerge at a mask duration longer than those we used previously.

A further twist to Experiment 5 is that we ran two versions of it. In discussing the results of their Experiment 4 (see Figure 2), Di Lollo et al. noted that "…the lower limit of accuracy in Figure 9 is more properly regarded as being zero rather than the 50% chance level. This is because the observers indicated whether they had seen the vertical segment in the target. Thus, a score below 50% would indicate that the vertical segment, although present, was not seen because it had been masked. On trials on which the target did not contain the vertical segment ….accuracy was at ceiling except at a mask duration of zero….Ceiling effects for accuracy on target absent trials are commonly found in visual search experiments because observers are reluctant to guess that a feature they did not see was actually present". Another way of expressing the last point is to say that observers set a high criterion for reporting target presence. Although Di Lollo et al. do not report the precise instructions given to their participants, the ceiling level performance on target absent trials indicates that participants so interpreted the instructions that they did indeed set a high criterion for reporting having seen a line segment in the target circle. This contrasts with the results of the present Experiment 4 (see Figure 8) in which false alarms on target absent trials averaged around 25%. We therefore ran two versions of Experiment 5 with different experimental instructions. For Experiment 5a, the instructions were exactly as for Experiment 4, making Experiment 5a a replication and extension of Experiment 4. For Experiment 5b, participants were instructed to press *yes* only if they were certain that the target contained the bisecting vertical bar, otherwise to press *no*. Our intention was to see whether the different instructions would influence performance level by changing participants' criterion, and how this might affect the appearance of an interaction between set size and trailing mask duration

Method

For Experiment 5a there were 16 psychology undergraduate and postgraduate students and members of staff (11 females) with an average age of 30.43 years (SD = 9.85). For Experiment 5b there were 13 psychology undergraduate participants (all females) with an average age of 19.61 years (SD = 1.75). Participants were either unpaid volunteers or were recruited from the OBU Psychology Department Participants Panel for course credits. The stimuli were the same to those in Experiment 4 except for the differences described above. Additionally, in order to retain an analogous spatial relationship between the target-circle and the masking dots, the distance between the dots decreased from 0.5^{o} to 0.4^{o}. An additional mask duration of 360ms was added and the number of trials remained at 30 per condition. As a result each participant contributed a total of 720 trials.

Results

The results for Experiments 5a and 5b are shown in Figure 10 and 11,and Figures 12 and 13 respectively. Figure 10 illustrates the average percent correct as a function of bar absent/bar present conditions, set size and mask duration in Experiment 5a. The data of 5a were submitted to two separate repeated measures ANOVAs for the bar absent and bar present conditions. For the former conditions, there were main effects of set size [$F(2,24) = 5.62$, $p < .05$, partial $\eta^2 = .31$] and mask duration [[$F(1.4, 1.7) = 7.66$, $p < .05$, partial $\eta^2 = .39$] and a significant interaction between them [$F(6, 72) = 5.48$, $p < .005$, partial $\eta^2 = .31$]. For trials when the target included a bar, there were again main effects of set size [$F(2, 24) = 21.26$, $p < .0001$, partial $\eta^2 = .64$] and mask duration [$F(1.8, 22) = 27.27$, $p < .0001$, partial $\eta^2 = .69$] and also a significant interaction between them [$F(6,72) = 6.17$, $p < .005$, partial $\eta^2 = .34$].

As for Experiment 4, the target present and target absent data of Experiment 5a were combined using a guessing correction procedure, the results of which are shown in Figure 11. The individual scores were entered into an ANOVA, which yielded significant main effects of set size [$F(2,24) = 36.74$, $p < .001$, $\eta^2 = .75$] and mask duration [$F(3,36) = 53.60$, $p < .001$, $\eta^2 = .81$] but no interaction between these factors [$F(6,72) = .71$, p = n.s., $\eta^2 = .05$]. Once again d-prime and A-prime analyses gave the same result.

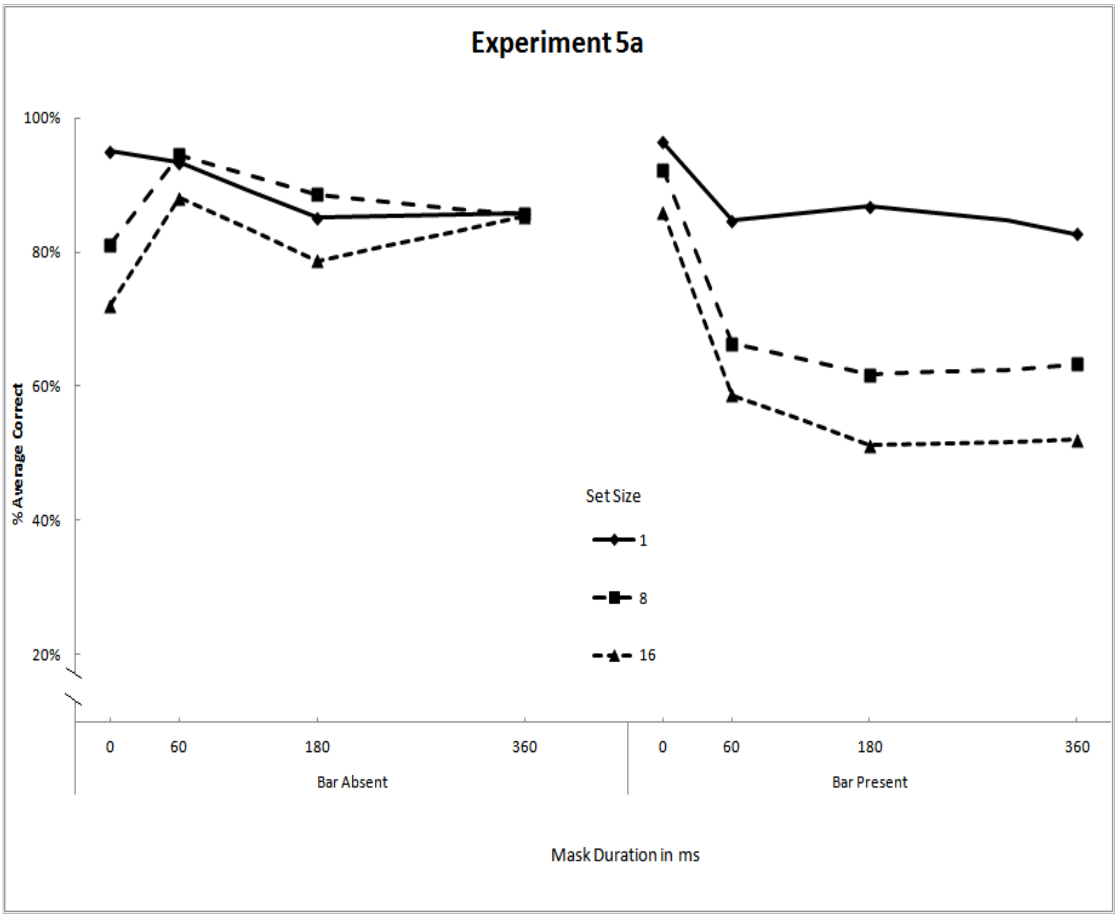

Figure 10. Mean percentage correct detection of the presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided into scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and to scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.

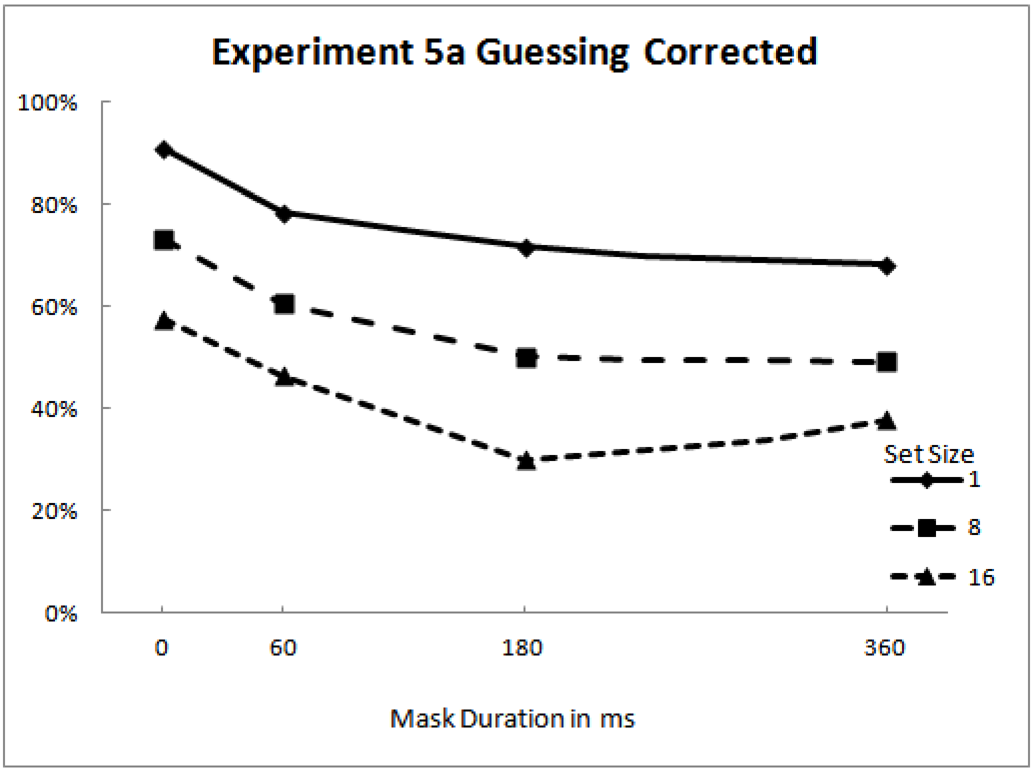

Figure 11. Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.

The data of Experiment 5b were similarly submitted to two separate repeated measures ANOVAs for the bar absent and bar present conditions. . For the bar absent trials, the ANOVA revealed a significant main effect of mask duration [$F(1.9, 28.7) = 5.45$, $p < .05$, partial $\eta^2 = .27$] but not one of set size [$F(2, 30) = 2.08$, $p>.05$, partial $\eta^2 = .12$] and nor an interaction between set size and mask duration [$F(3.5, 51.8) = 1.02$, $p>.05$, partial $\eta^2 = .06$]. For the bar present trials, there were significant main effects of set size [$F(1.3, 19.7) = 62.9$, $p < .0001$, partial $\eta^2 = .81$] and mask duration [$F(1.8, 26.6) = 39.65$, $p < .0001$, partial $\eta^2 = .73$. In addition, the interaction between mask duration and set size reached statistical significance [$F(6,90) = 7.07$, $p < .001$, partial $\eta^2 = .32$]. “

As for Experiment 4, the target present and target absent data of Experiment 5b were combined using a guessing correction procedure, the results of which are shown in Figure 13. An ANOVA confirmed the main effects of set size [$F(1.4, 20.8) = 88.88$, $p < .0001$, partial $\eta^2 = .86$] and of mask duration [$F(1.7, 25.8) = 32.54$, $p < .0001$, partial $\eta^2 = .69$] and also of the interaction between them ($F(6, 90) = 5.23$, $p<.0001$, partial $\eta^2 = .265$). Thus in Experiment 5b we finally replicated the elusive interaction between set size and mask duration, but only because a deliberately induced response bias lead to near ceiling performance on all target absent trials. Because of this near to ceiling performance, the guessing correction procedure could do little to modulate the the data pattern for target present trials.

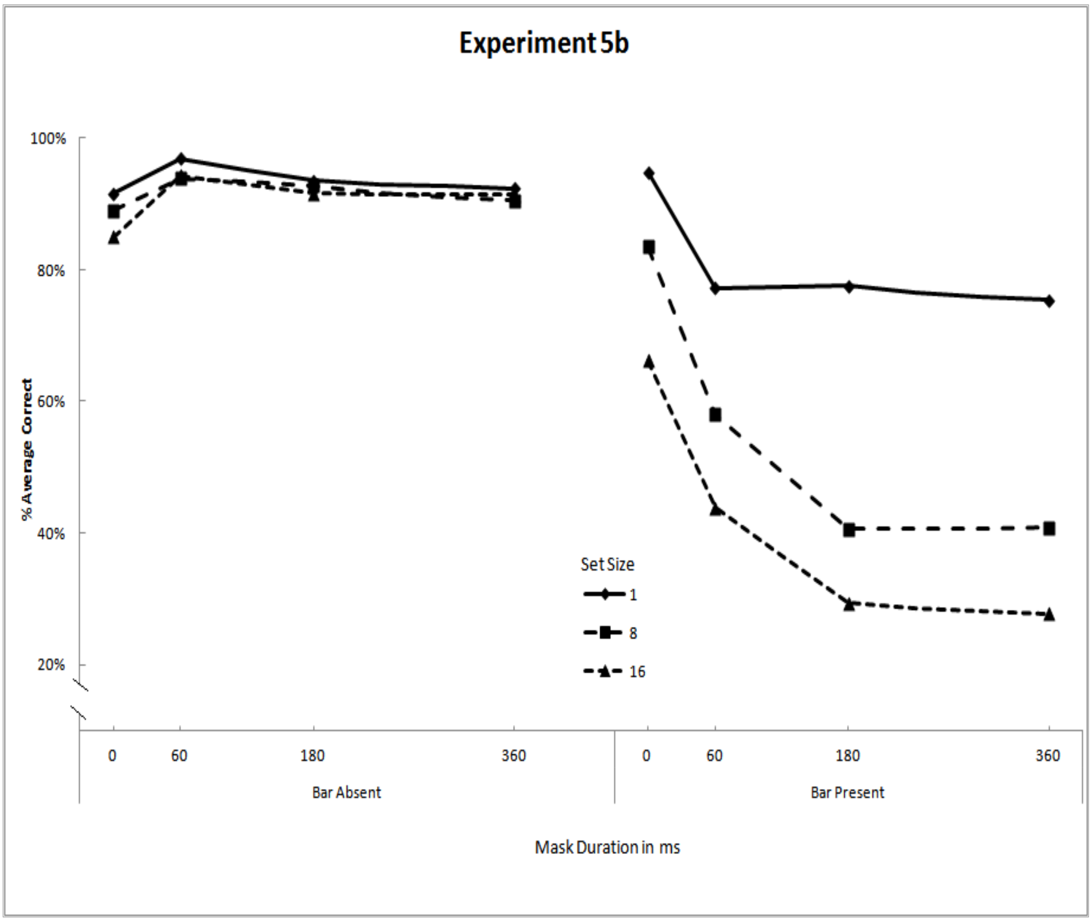

Figure 12. Mean percentage correct detection of the presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided to scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and to scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.

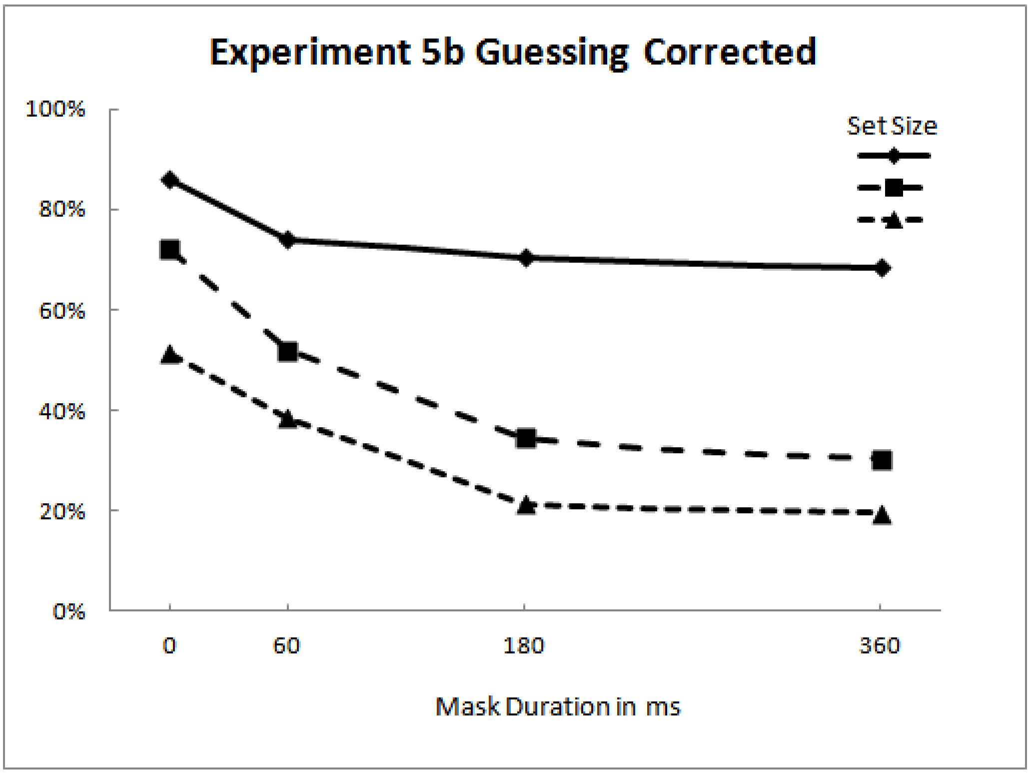

Figure 13. Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.

Discussion

We begin by comparing the results of Experiment 5a with those of Experiment 4, since the latter was a replication with extensions of the former. Reducing the eccentricity of the stimulus display in Experiment 5a had the desired effect of raising accuracy levels for both target absent and target present trials. However, the pattern of results is very similar in the two studies. For target absent trials, eight of the first nine data points (i.e. ignoring the 360 ms mask duration) are in the same configuration, with only the point for set size one and zero mask duration having markedly changed its relative position. For target present trials the same is true for all nine points that are common to both experiments, the only difference being a slight bunching of the zero mask duration points in Experiment 5a, which is attributable to the higher overall accuracy level bringing these points up against ceiling. Turning to the guessing corrected results (Figures 9 and 11) the similarity between the two sets of data is again striking despite the difference in absolute levels of accuracy. Furthermore, although in both graphs the spread of points is slightly greater for the 180 ms than for the zero trailing mask duration, the spread reduces again for the 360 ms duration in Experiment 5a. Lengthening mask duration does not cause an interaction to emerge.

If we now compare Experiments 5a and 5b, then, as expected, the contrasting instructions resulted in higher performance on target absent trials for the latter than the former and the reverse for target present trials. As intended, participants appear to have set a higher criterion for reporting a target segment in 5b than in 5a. The patterns of results are, however, very similar for target present trials in the two experiments, with both closely resembling the corresponding data of Experiment 4. All three studies show an interaction between set size and target duration when target present trials are viewed alone but for Experiments 4 and 5a the interaction vanishes when a guessing correction is undertaken. Only in Experiment 5b does the interaction survive guessing correction but that is clearly due to ceiling level performance on target absent trials rendering the procedure ineffective. The overall consistency across the three experiments can only increase confidence in conclusions drawn from them.

The results from Experiments 4, 5a and 5b are consistent not only with each other but also with the studies of Di Lollo et al.(2000). For Experiments 5a and 5b the effect of mask duration reaches a plateau by 180 ms, just as observed in the Di Lollo et al.'s Experiments 1, 2 and 3. Such similar patterns of temporal dynamics across two sets of studies, undertaken in different laboratories more than ten years apart and with different target durations, is impressive. For target present trials in Experiments 4, 5a and 5b and for Di Lollo et al,'s Experiment 4, set size and mask duration significantly affect performance accuracy and also interact with each other. However, as we have already seen, these interactions disappear for Experiments 4 and 5a when a guessing correction is applied.

General Discussion

According to Di Lollo et al. (2000, p488), accounting for the interaction between set size and mask duration in terms of the time needed for spatial attention to focus on the target location is "…an essential part of the re-entrant-processing account that we favour…" for explaining OSM. The present paper has reported a series of experiments that question the reality of that interaction. Experiment 1 employed a 4AFC task, deliberately modelled in certain respects on the task used by Di Lollo et al. for their first 3 experiments, but designed to hold performance below ceiling in all conditions. With set sizes of 4 and 16 items, there was no sign of an interaction with mask duration, although both main effects were significant. Experiment 2 replicated Experiment 1 but with the critical feature increased in salience to avoid possible floor effects in some conditions. Although performance level was raised, the interaction was still absent. Experiment 3 was a further replication with the ranges of both set size and mask duration increased, and with the critical feature midway in size between those of Experiments 1 and 2, but once again there was no evidence of an interaction. Even when the power of the analysis was increased by combining the data of all three experiments for set sizes 4 and 16, and ignoring the difference in critical feature sizes, there was no evidence of an interaction. Experiment 4 then employed a present/absent decision based closely on the task in Experiment 4 of Di Lollo et al., but with performance calibrated to be below ceiling in all conditions. An interaction was present for target present trials but disappeared when target absent trials were taken into account by means of a guessing correction. Experiments 5a and 5b were then conducted with stimuli presented at a reduced eccentricity and with instructions that encouraged a higher or lower criterion for reporting the discriminatory target feature. The instructional manipulation yielded differing levels of performance but the pattern of results for target present trials in the two studies was highly similar in each case and to that of Experiment 4. For Experiment 5A, the interaction was abolished by a guessing correction. This was not the case for Experiment 5B because ceiling level accuracy on target absent trials rendered the guessing correction nugatory. In summary, across 6 studies on two different tasks we found no evidence for an interaction between set size and mask duration if performance levels were constrained below ceiling, even though each of these variables always produced an independent significant effect. It is, of course, possible that under conditions different from those tested by us an interaction between these two factors can be found, but our results indicate that the interaction is certainly not a hallmark of OSM and, therefore, that explaining it need not be an essential part of any theoretical account of how OSM is produced.

At this juncture it is worth commenting on a study that shows an interaction between set size and the asynchrony between target and mask onsets. In their Experiment 3, Enns & Di Lollo (1997) presented for 30 ms one or three diamond shapes that lacked either a left or right corner. Appearing around the target shape for 30 ms – and designating it as the target - were four dots that could onset between 300 ms before or after target onset. The dots had relatively little effect when only a single shape was presented. However, when three shapes were presented the dots interfered with reporting of the target at even the longest stimulus onset asynchronies (SOAs) for parafoveal locations and also impaired reporting of a centrally located target at intermediate SOAs. This result amounts to an interaction between set size and SOA because SOA affects performance with three shapes but not with one. However, the variable SOA of a brief 30 ms mask is not the same as the variable duration of a mask which onsets simultaneously with the target, as in the present studies and those of Di Lollo et al. (2000) and many other investigators (e.g. Kotsoni et al., 2007; Goodhew et al., 2011, 2012). In the SOA case, the dots may cause processing of the target to be terminated by capturing attention towards themselves. Indeed, Enns & Di Lollo (1997) offer just such an 'attentional capture' interpretation of their data, which is somewhat different to the re-entrant processing account proposed by Di Lollo et al. (2000). Other authors have also argued that four dot masking can result from attentional capture by the mask (Neill, Hutchison, & Graves, 2002; M. S. Tata & Giaschi, 2004), or that attentional capture may be one of several mechanisms by which four dot masking may come about (Bischof & Di Lollo, 1995; Guest, Gellatly, & Pilling, 2012; Kahan & Lichtman, 2006; Tsotsos, 1990). Although previous discussions have not made this point explicit, we wish to argue here that the attention that is captured in such conditions is object-based attention rather than spatial attention. Since the four dot mask (hereafter 4DM) surrounds the target, its onset may slightly broaden the focus of spatial attention but it is probable the main effect will be to cause the dots to become foregrounded as 'figure' in place of the target, which becomes relegated to 'ground'. Of course, object-based attention and spatial attention cannot be totally distinct from one another. Even though object-based attention has been defined in terms of objects occupying overlapping spatial positions in two dimensions (Kahneman, 1967), it refers to the perceptual representation of varying depth planes in the third dimension of space i.e. even for a two dimensional stimulus, one of the overlapping objects is represented as partially occluding the other. However, with the exceptions of Kahan & Lichtman (2006) and Guest et al. (2012), previous discussions of the effect of spatial attention on OSM have been concerned with attention deployed within a single two dimensional plane. This is mainly true also of the present paper, which is deals for the most part with studies of OSM in which target and mask onset simultaneously (what Di Lollo et al. termed ‘common onset masking’). We assume that in these conditions the target and mask elements are all represented as parts of a flat pattern, or object, lying in a single depth plane. This contrasts with the case of delayed mask onset, in which the effect of the mask may be attributed to it capturing attention as a singleton abrupt onset (Kastner & Ungerleider, 2000; Muhlenen, Rempel, & Enns, 2005; Yantis & Jonides, 1984), with the result that it is perceived to occupy a figural depth plane in front of the ground plane in which the target comes to be perceptually located.

What are we to make of our failure to find an interaction of set size and mask duration with common onset four dot masking? In the original re-entrant processing account of Di Lollo et al., the crucial factor in determining OSM is held to be the speed with which two dimensional spatial attention can be focused on the target. When the target can be rapidly located because it is the one of very few items, or even the only item, in the display, there is said to be little interference from involuntary processing of distractors. Because spatial attention focuses more rapidly on the target, processing of it will be more advanced by the time it offsets, so the representation of it will be more developed and less likely to be substituted by a representation of the mask object in the course of continuing iterative re-entrant processing. The probability of substitution is also increased by the duration of the trailing mask up to a limit in the region of 160 to 200 ms – see Figures 1, 2, 10 and 12. The two factors supposedly have multiplicative effects on the probability of substitution during this period, so causing an interaction. The present evidence that set size and mask duration do not, in fact, interact statistically except when performance is compressed by a ceiling (or floor) effect suggests something is incorrect in the re-entrant processing account of OSM.

One simple way around the difficulty is to assume that rather than have a multiplicative effect on OSM, set size and mask duration have additive effects – as indicated by the present data. It could be that the set size effect does not reflect time for attention to locate the target but is, in fact, solely a function of crowding (Bachmann, 2006; Sibley, 2011),the effect of which might well be additive with the effect of mask duration (Argyropoulos et al., 2012). Di Lollo et al. considered that the spread of set size points at zero trailing mask duration (see Figures 1 and 2) was due to crowding but argued that the increase in spread as mask duration was made longer indexed the interaction of mask duration with the delayed arrival of attention at the target for larger set sizes. However, if, as seems likely, the spread at zero mask duration is compressed by a ceiling effect, then the statistical interaction they obtained is an artefact. Assuming additive effects of set size (mediating crowding) and mask duration would seriously undermine the re-entrant processing account, and particularly its computer model instantiation, CMOS, which dictates an interaction between the two factors. The crucial points for the re-entrant account are that the set size manipulation is a proxy for the speed with which spatial attention contacts the target and that attention interacts with mask duration to determine the extent of OSM.

Supporting the idea that attention interacts with mask duration to determine the extent of OSM, and counting against the assumption of additivity, are reports that OSM is absent or greatly reduced when, as the result of a local cue, spatial attention can be pre-focussed in a spotlight like fashion on the location of the target (Di Lollo, et al., 2000, Exp 6; Enns, 2004, Exp 3; Luiga & Bachmann, 2007, Exps 1 & 2; Matthew S. Tata, 2002, Exps 1 & 2). Similarly, OSM is reported to be reduced if the target ‘pops out’ from distractors due to it containing a unique and to-be-reported feature (Di Lollo et al., 2000, Exp 5). It is, therefore, important to assess the validity of these reports at some length, a task to which we now turn.

As part of a large experiment comparing several different forms of masking, Enns (2004, Exp 3) cued the location of the target in a display of letters with a dot presented 100 ms prior to target display onset. This caused ceiling level performance for all SOAs between the 30 ms target and a 30 ms 4DM. Even if we were to suppose that four dot masking with a non-zero SOA produces the same sort of OSM as four dot masking with common onset (see above), these results do not demonstrate that pre-focussed spatial attention reduces OSM. What they show is that in this study pre-focussing attention at the target location moved performance out of the measurable range for four dot masking. Tata (2002, Exp 2) conducted a very similar experiment using circles with gaps, as in the squares of the present experiments. An eight item array was presented for 10 ms followed after an 80 ms SOA by a circular mask for 10 ms around the target. The mask cued the target but in addition a dot pre-cue was presented at the centre of the target circle location between zero and 200 ms before onset of the target array. With non-zero cue lead times performance was increased relative to a no cue baseline, although ceiling performance was never reached. However, since target and mask did not have a common onset and mask duration was not varied, the results show only that pre-focussing attention to the target location enhances performance; it cannot say anything about the effect of pre-cueing on OSM. Di Lollo et al. (2000) and Luiga & Bachmann (2007) pre-cued the target location by presenting the 4DM ahead of the target it would then mask. Di Lollo et al found that performance improved for all set sizes tested as the duration of the pre-cue increased, and that the two factors interacted. However, because they did not manipulate mask duration, their results also show only that cueing improves performance for a particular mask duration but not that pre-cued attention reduces OSM. Moreover, the interaction they observed may well have reflected the ceiling level accuracy obtained for the smallest set size (of one) for all but the zero cue duration. Contrastingly, Luiga and Bachmann (2007) did vary the duration of a common onset mask for a single set size of four items. They found that a local 4DM pre-cue both raised performance for all trailing mask durations (including zero) and greatly reduced the effect of mask duration on accuracy levels, i.e. the pre-cue reduced OSM. Although Luiga and Bachmann interpreted their results in terms of sensory facilitation, they could seem to offer support for the re-entrant processing account of OSM according to which OSM is reduced or abolished by rapid, or prior, deployment of attention to the target location. However, this is not necessarily the case because, as we will argue in the next section, an alternative interpretation of the Luiga and Bachmann findings is possible.

Before making that argument, we need to consider the pop-out study of Di Lollo et al. (2000, Exp 5). This experiment employed circles as display items, the target circle being surrounded by a 4DM. The task was to report whether or not the target contained a vertical line segment. Unlike in some of their other experiments, none of the distractors contained such a line segment (see Introduction to Experiment 4 above), so the target was said to ‘pop-out’ on this feature. The results were similar to when half of distractors contained a line segment (see Figure 2), in that for target present trials there was an interaction of set size and mask duration, but with higher overall levels of performance and shallower slopes for the functions of set size against mask duration. The reduction in slopes was taken as evidence that rapid deployment of attention to the target location – in this case as a consequence of pop-out - reduces OSM. However, the overall increased level of accuracy due to pop-out resulted in ceiling level performance for all set sizes at the zero mask duration and near to ceiling levels for some set sizes at some mask durations (despite a bias to respond 'target absent' shown by ceiling level performance on target absent trials for all conditions). Thus the reduced slopes for the set size functions – relative to the non-pop-out conditions of their Experiment 4 - may have been due to compression of the set size points at shorter mask durations and not to a reduction in OSM due to pop-out. This interpretation becomes more persuasive when one considers that in the standard 4DM procedure the target should always pop-out by virtue of being the only item (or location) surrounded by four dots. If rapid deployment of attention to the target eliminates or greatly reduces OSM, then the phenomenon of four dot masking should be almost impossible to demonstrate in the first place, whereas in fact demonstrations of it are often quantitatively impressive (Enns & Di Lollo, 1997; Di Lollo et al., 2000; Enns, 2004). A possible means for resolving this apparent paradox comes from a finding by Gellatly, Pilling, Cole & Skarratt (1993), who observed that pop-out on a task relevant dimension reduced OSM but that pop-out on a task irrelevant dimension did not do so. If the task was to report target colour, then colour pop-out of the target reduced OSM but orientation pop-out of the target did not, and vice-versa when the task was to report target orientation. With this in mind, we can see that the pop-out caused by four surrounding dots may not eliminate OSM because what is to be reported is some other feature of the target, the presence of a line segment or the orientation of a gap or the identity of a target letter. More broadly, what this seems to indicate is that, contrary to the re-entrant processing account, spatial attention to the target is not in itself incompatible with OSM but may be so if it also involves attention to the task relevant feature dimension. It should be emphasised that we are talking here about the case when target and mask have a common onset so that they are likely to be processed as a single object. In other words, the dots will be perceived as a feature of the composite target/mask object (see next subsection).

The object updating account

An alternative to the original re-entrant processing account of OSM by Di Lollo et al (2000) is the object updating account first proposed by Lleras & Moore (Lleras & Moore, 2003; Moore, Alej, & Lleras, 2005) and since supported by a range of other findings (Bischof & Di Lollo, 1995; Guest, et al., 2012; Pashler, 1988; Tsotsos, 1990). According to the updating account, masking in OSM-like situations occurs because the trailing mask is perceived as a transformation, or updating, of the target rather than as a new and different object that replaces it. Under common onset conditions, the mask and target are not initially individuated as separate objects but are represented as a single object because of their close temporal and spatial proximity. The disappearance of the target is treated as a transformation of this single object, as when an animal changes its orientation to the viewer so that its visible shape changes and some of its features become obscured while others come into view. The longer the mask remains present after target offset, the more likely it is that the features of the original target-plus-mask will be overwritten by those of the mask alone. The updating, or individuation, account is certainly not incompatible with a re-entrant processing framework since, like the original re-entrant account, it emphasises the dynamic nature of visual representations. Transient and ambiguous activity at lower levels of the system is fed forward to higher levels, where it is either integrated into an already activated object/event representation schema or, if sufficiently discrepant with that, triggers activation of an alternative representation. Neisser (1976) referred to these representations as schemata, and Most, Scholl, Clifford & Simons (2005) have discussed the relationship of such schemata to bottom-up driven attention and top-down driven attention. However, the emphasis in updating is somewhat different from in the original account, and although spatial attention has been held to modulate the process of updating (Oriet and Enns, 2010), this may not necessitate commitment to an interaction between set size and mask duration. A finding of relevance to the present argument is that pre-view of the search display before the target item is indicated by onset of the 4DM (or square mask) reduces OSM (Guest, et al., 2012; Tsotsos, 1990). The same is true for pre-view of the mask (Mishkin & Ungerleider, 1982; Neill, et al., 2002; M. S. Tata & Giaschi, 2004) These findings can be accommodated by the updating account in that a temporal disparity between target onset and mask onset increases the probability the target and mask will be individuated, and so represented as separate objects rather than as a single object. This in turn means that offset of the target will not be processed as a transformation of a single continuing object, and the target features will not be subject to over-writing by features of the mask. With this explanation in mind, we can now also explain the finding by Luiga & Bachmann (2007) that having the 4DM serve as a local pre-cue reduced masking (see above). Since their 4DM onset ahead of the target it subsequently served to mask, the 4DM was more likely to have been represented as a separate object from the target than in the standard condition in which the two onset simultaneously. This explanation is supported by the results of another manipulation introduced by Luiga & Bachmann. In their second experiment, the 4DM pre-cue appeared either for 150 ms or 250 ms ahead of the target or else came on for 33 ms and disappeared for 117 ms or 217 ms. Relative to a no cue control condition, accuracy was higher and OSM weaker for all the pre-cue conditions but more so for the uninterrupted than for the interrupted cues. Our explanation for this is that in the former case the cue/mask was very likely to be individuated as a separate object from the target because of their asynchronous onsets, whereas in the latter, interrupted case the 4DM, because it reappeared after an absence and simultaneously with the target, was likely sometimes to be represented with the target as a single object, which is precisely the condition that gives rise to OSM by updating.

In addition to studies with local pre-cues, the effect of spatial attention on OSM has been investigated with central pre-cues indicating the location of the target item. In both their experiments, Luiga & Bachmann (2007)included conditions in which onset of the target display was preceded for 150 ms or 250 ms by a small, centrally presented arrow cue pointing to the location of the target. Relative to the no-cue control condition, the central cues produced neither increased accuracy nor reduced OSM. These results possibly provide a first indication that spatial attention plays little part in the phenomenon of OSM but since there was no main effect on accuracy, they perhaps show only that for some reason the central cue was ineffective in directing attention to the target location. A central simultaneous line cue pointing at the target was also used by Tata (2002, Exp 1) in a study that varied both set size and the SOA between target display and mask; but since mask duration was constant at 10 ms, the relevance of these data to common onset OSM are unclear. In summary, these few studies using central cuing of the target do not show that endogenous spatial attention does *not* modulate OSM but, on the other hand, they certainly do not provide any evidence that it *does* do so.

A final study of relevance to the issue of how attention does or does not affect OSM, and one which incidentally demonstrates the possibility of obtaining OSM with a set size of one item, was reported by Dux et al. (2010). Their experiment was concerned with whether engaging anterior brain regions, thought to play a role in re-entrant processing, would impact on the extent of OSM. Participants saw a sequence of four digits presented at fixation for 500 ms each, with an inter-stimulus interval of 500 ms. After a further 100 ms or 600 ms, a circle with a gap surrounded by four dots also appeared at fixation for 10 ms, and the dots either offset simultaneously with the single circle or trailed it for 200 ms. In blocked trials, participants either did an arithmetic calculation on the digits before reporting the orientation of the target gap or reported only the latter. Relative to simultaneous mask offset, delayed mask offset reduced performance in all conditions, an OSM effect, even though only a single target was presented, and that at fixation. The slopes of the two-point masking functions varied considerably but since the data of at least some of the conditions are likely to have been affected by ceiling level performance on the part of some participants (for simultaneous mask offset, accuracy varied between 88% and 97%) the differences in slopes must be treated with caution since some of those slopes will have been reduced by the ceiling on performance. The conclusion the authors drew from the slope differences must be open to question. However, for present purposes, the significant finding was that OSM was reliably obtained for a single item presented at the focus of fixation and spatial attention. Thus pre-focussing attention at the target location certainly does not abolish OSM under all circumstances. We will shortly be reporting the results of experiments intended to clarify the role attention may or may not play in generating OSM (Pilling, Gellatly, & Argyropoulos, 2012).

Conclusion

Across six experiments, we have presented evidence that set size and mask duration do not interact to produce OSM. We suggest that previously reported interactions of these two factors have resulted from ceiling level accuracy having compressed the data for some conditions. If the effect of set size indexes the speed with which attention reaches the target location, then the absence of an interaction with mask duration suggests that speed of attention to the target is not a critical factor in determining OSM, as supposed in the original re-entrant processing account of Di Lollo et al. (2000). Although it is often thought that the literature on OSM provides evidence for the importance of speed of attention to the target, our detailed review of the relevant literature reveals that evidence to be either weak or open to alternative interpretation. Since an important role for attention has been thought to distinguish OSM from other forms of visual masking (Di Lollo et al., 2000; Enns & Di Lollo, 1997; Enns, 2004), the present paper brings into question just how different it truly is. More generally, our analysis of the literature and our experimental findings demonstrate how important it is to take ceiling effects into account when interpreting data on visual cognition.

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References

Argyropoulos, I. (6th-8th September, 2011). *The elusive interaction of set size and mask duration in object substitution masking.* Paper presented at the British Psychological Society Cognitive Section.

Argyropoulos, I., Gellatly, A., & Pilling, M. (2012). The effects of crowding, setsize and mask duration on four dot masking. *In preparation*.

Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *Bell System Technical Journal, 40*, 309-328.

Bachmann, T. (2006). Microgenesis of Perception: Conceptual, Psychophysical, and Neurobiological Aspects. In H. Öğmen & B. G. Breitmeyer (Eds.), *The first half second: The microgenesis and temporal dynamics of unconscious and conscious visual processes* (pp. 11-33). Cambridge, MA, US: MIT Press.

Bischof, W. F., & Di Lollo, V. (1995). Motion and metacontrast with simultaneous onset of stimuli. *J Opt Soc Am A Opt Image Sci Vis, 12*(8), 1623-1636.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*, 433-436.

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*(4), 481-507.

Dux, P. E., Visser, T. A., Goodhew, S. C., & Lipp, O. V. (2010). Delayed reentrant processing impairs visual awareness: an object-substitution-masking study. *Psychol Sci, 21*(9), 1242-1247.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research, 44*(12), 1321-1331.

Enns, J. T., & Di Lollo, V. (1997). Object Substitution: A New Form of Masking in Unattended Visual Locations. *Psychological Science, 8*(2), 135-139.

Enns, J. T., & Di Lollo, V. D. (2000). What's new in visual masking? *Trends in Cognitive Sciences, 4*(9), 345-352.

Felleman, D. J., & Van Essen, D. C. (1991). Distributed Hierarchical Processing in the Primate Cerebral Cortex (Vol. 1, pp. 1-a-47).

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

Goodhew, S. C., Visser, T. A. W., 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*(2), 588.

Guest, D., Gellatly, A., & Pilling, M. (2012). Reduced OSM for long duration targets: Individuation or items loaded into VSTM? *Journal of Experimental Psychology: Human Perception and Performance, In Press*.

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research, 33*(9), 1219-1240.

Kahan, T. A., & Lichtman, A. S. (2006). Looking at object-substitution masking in depth and motion: toward a two-object theory of object substitution. *Perception & Psychophysics, 68*(3), 437-446.

Kahneman, D. (1967). An onset-onset law for one case of apparent motion and metacontrast. *Attention, Perception, & Psychophysics, 2*(12), 577-584.

Kastner, S., & Ungerleider, S. K. L. G. (2000). Mechanisms of visual attention in the human cortex. *Annual review of neuroscience, 23*(1), 315-341.

Kotsoni, E., Csibra, G., Mareschal, D., & Johnson, M. H. (2007). Electrophysiological correlates of common-onset visual masking. *Neuropsychologia, 45*(10), 2285-2293.

Lleras, A., & Moore, C. M. (2003). When the target becomes the mask: using apparent motion to isolate the object-level component of object substitution masking. *Journal of Experimental Psychology. Human Perception and Performance, 29*(1), 106-120.

Luiga, I., & Bachmann, T. (2007). Different effects of the two types of spatial pre-cueing: what precisely is “attention” in Di Lollo’s and Enns’ substitution masking theory? *Psychological Research, 71*(6), 634-640.

Mishkin, M., & Ungerleider, L. G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioural brain research, 6*(1), 57-77.

Moore, C. M., Alej, & Lleras, r. (2005). On the Role of Object Representations in Substitution Masking. *Journal of Experimental Psychology : Human Perception and Performance, 31*(6), 1171-1180.

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see is what you set: sustained inattentional blindness and the capture of awareness. *Psychological Review, 112*(1), 217.

Muhlenen, A., Rempel, M. I., & Enns, J. T. (2005). Unique temporal change is the key to attentional capture. *Psychological Science, 16*(12), 979-986.

Neill, W. T., Hutchison, K. A., & Graves, D. F. (2002). Masking by object substitution: dissociation of masking and cuing effects. *Journal of Experimental Psychology. Human Perception and Performance, 28*(3), 682-694.

Neisser, U. (1976). *Cognition and Reality*. San Francisco: Freeman.

Pashler, H. (1988). Familiarity and visual change detection. *Attention, Perception, & Psychophysics, 44*(4), 369-378.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(437-442).

Pilling, M., Gellatly, A., & Argyropoulos, I. (2012). Visual spatial attention does not affect common onset four dot masking. *Paper submitted for publication*.

Ramachandran, V. S., & Cobb, S. (1995). Visual attention modulates metacontrast masking. *Nature, 373*(6509), 66-68.

Sibley, M. (2011). BlitzMax [Version 1.44]. Auckland, New Zealand: Blitz Research Ltd.

Tata, M. S. (2002). Attend to it now or lose it forever: selective attention, metacontrast masking, and object substitution. *Perception & Psychophysics, 64*(7), 1028-1038.

Tata, M. S., & Giaschi, D. E. (2004). Warning: Attending to a mask may be hazardous to your perception. *Psychonomic Bulletin & Review, 11*(2), 262-268.

Tsotsos, J. K. (1990). Analyzing vision at the complexity level. *Behavioral and Brain Sciences, 13*(3), 423-469.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10*(5), 601-621.