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

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ABSTRACT

30

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

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

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### Introduction

61 Object Substitution Masking (OSM) refers to the observation that the visibility of a target  
62 stimulus can be reduced by the presence of a second, spatially non-overlapping stimulus (the  
63 mask) with minimal contour. OSM is frequently observed for tasks in which the mask consists  
64 of just four dots that surround the target and onset along with it (common onset), and either the  
65 two stimuli vanish together (common offset, or control, condition) or the mask offsets after the  
66 termination of the target (trailing mask, or masking, condition). Reporting of the target is  
67 reduced when mask offset trails target offset, and the difference between the two conditions is  
68 typically reported as an index of OSM. It has been thought that to obtain the effect the target  
69 must appear as part of a display of several items (as in Figure 3) and that the observer must  
70 not have advance knowledge of the target location (Di Lollo, Enns, & Rensink, 2000; Enns,  
71 2004; Enns & Di Lollo, 1997; Enns & Di Lollo, 2000). In this paper, we will demonstrate that  
72 the first of these conditions does not apply and argue that, in fact, the second is not supported  
73 by the evidence.

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

79 Di Lollo et al. (2000) highlighted the contribution of these processes by proposing a  
80 theoretical framework premised on the assumption of bidirectionality between hierarchically  
81 organised brain areas (Felleman & Van Essen, 1991). Stimulus onset activates low level cells  
82 that code only simple stimulus attributes and location information. A feed-forward sweep  
83 progresses this information to higher (extrastriate) visual areas which generate one or more  
84 perceptual hypothesis as to what the stimulus comprises. The receptive fields of the cells in the  
85 extrastriate visual areas are, however, large in size and the resultant hypothesis has poor  
86 spatial resolution. To resolve potential perceptual and location ambiguities, hypothesis  
87 information is sent back to low level areas via re-entrant projections where a matching process

88 occurs. If the display remained the same (target plus mask) during the re-entrant loop, the  
89 hypothesis from the extrastriate areas will match the current activity in lower visual areas and a  
90 stable percept will be achieved. If, during the iterative loop, however, the displayed image  
91 changes (to mask alone) a mismatch is created between the re-entrant information and the  
92 current visual input and a new cycle of processing begins based only on the current sensory  
93 input activating lower level neurons.

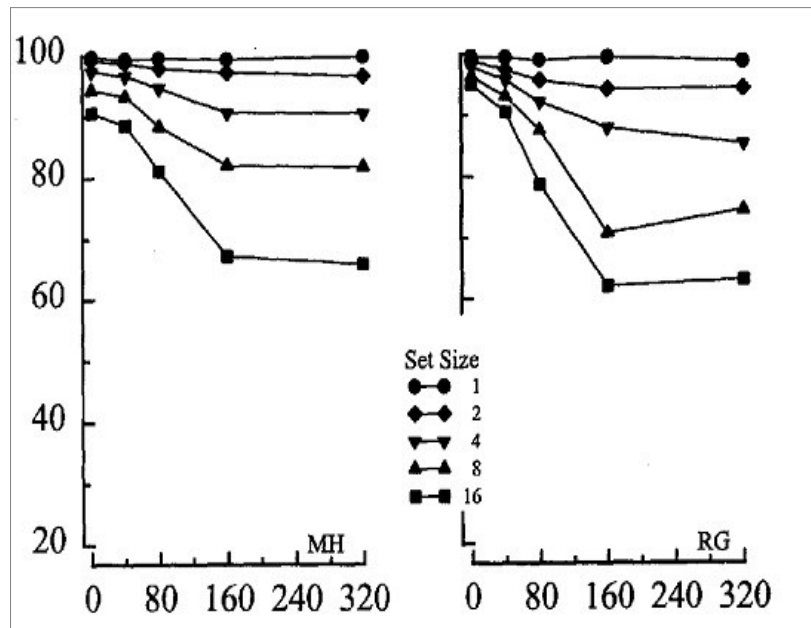
94 According to Di Lollo et al. (2000), key evidence in support of the re-entrant hypothesis  
95 account comes from the fact that large masking effects are observed only with multi-element  
96 displays and relatively prolonged mask durations. To explain this, they suggest that when a  
97 large number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

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

113

114 In their Experiment 3, the stimuli consisted of circles, each with a gap at the top, left,  
115 bottom or right. The target was cued by four dots which also served as a mask, and, the  
116 observers' task was to report the orientation of the gap of the target circle. The results showed

117 that set size and mask duration (after target offset) interacted such that OSM was maximal for  
 118 the largest set-size at relatively long mask durations (Figure 1)



119

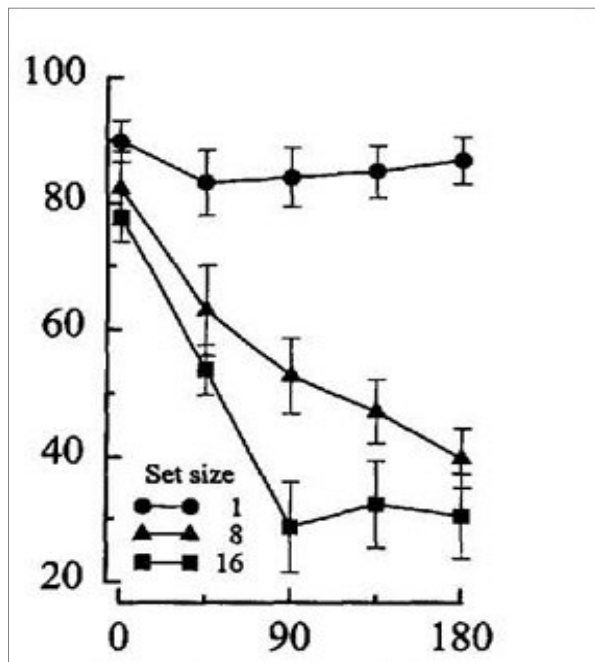
120 **Figure 1.** Mean percentage correct identification of the location of the gap in the  
 121 target as a function of set size and mask duration for two observers (Figure 1 Adapted  
 122 from "Competition for consciousness among visual events: The psychophysics of  
 123 reentrant visual processes",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

126

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

133 The claim that the magnitude of OSM is critically dependent on the joint effects of set size  
 134 and mask duration can be called into question on the grounds that ceiling effects were evident  
 135 in both experiments. For instance, in Experiment 3 performance for the small set sizes was  
 136 close to or at 100% for all levels of mask duration. In addition, performance in the common  
 137 offset condition was close to ceiling for all set sizes as indicated by the narrow vertical spread  
 138 of the data when mask duration was 0 ms. These features of the data suggest performance for

139 certain conditions may not have been fully revealed because it was compressed by the limits of  
 140 the response scale. Di Lollo et al. noted that crowding acts to reduce the detectability of the  
 141 target in larger set sizes. This means ceiling performance for larger set sizes could be less



142

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

149

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

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

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

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



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

194

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

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

208

209

### Experiment 1

210 Our first experiment employed a four alternative discrimination task and, in terms of the  
211 nature and size of the stimuli, was deliberately modeled on Experiments 1 to 3 of Di Lollo et al.  
212 (2000), although using squares with gaps rather than circles. However, whereas Di Lollo et al..  
213 displayed their stimuli in virtual square array, the stimuli in all our studies were presented in a  
214 virtual circle so distance of the target from fixation was constant. The initial aim was simply to  
215 validate our experimental method by replicating the effects of set size and mask duration and  
216 the interaction between them so that we could then go on to investigate other issues. The  
217 experiments we report all had the approval of the University Research Ethics Committee of  
218 Oxford Brookes University.

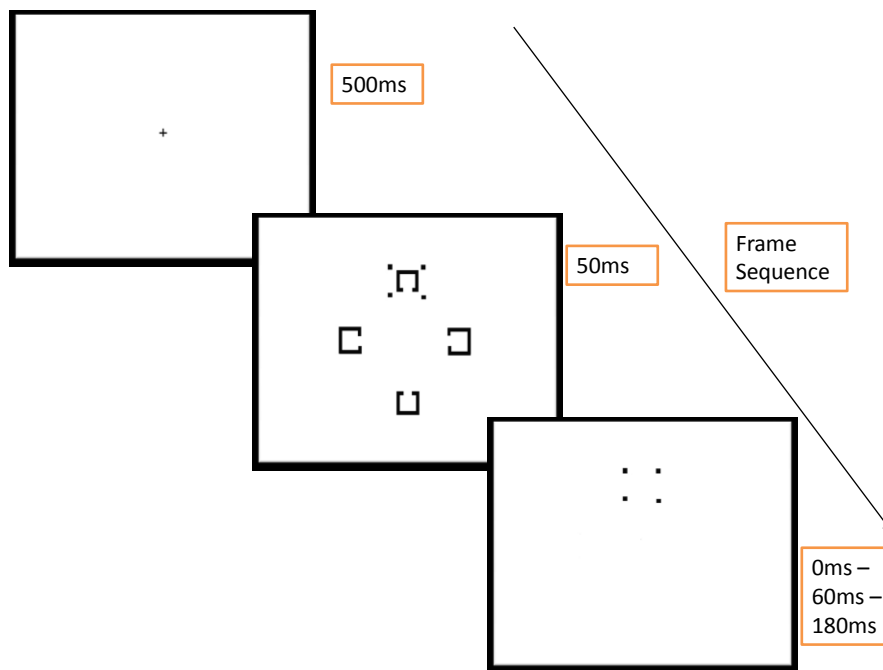
219 *Method*

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

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

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

237



238

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

242

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

246 Each participant underwent 240 trials which resulted from the factorial combination of 2 set  
 247 sizes x 3 mask durations x 40 trials per condition. 24 demonstration trials with extended frame  
 248 durations (to ensure participants fully understood the task) and 48 practice trials preceded the  
 249 main experiment. Every 60 trials the computer prompted the participants to have a brief break.  
 250 The total duration of the experiment was approximately 25 minutes. At the beginning of each  
 251 trial a fixation cross was presented for 500ms at the centre of the screen followed by a frame  
 252 that contained the target, the mask and the distractors for 50ms. A subsequent frame was  
 253 either blank – common offset condition - or contained only the trailing mask for 60 ms or 180  
 254 ms. Participants were instructed to press one of four arrow keys on a computer keyboard if

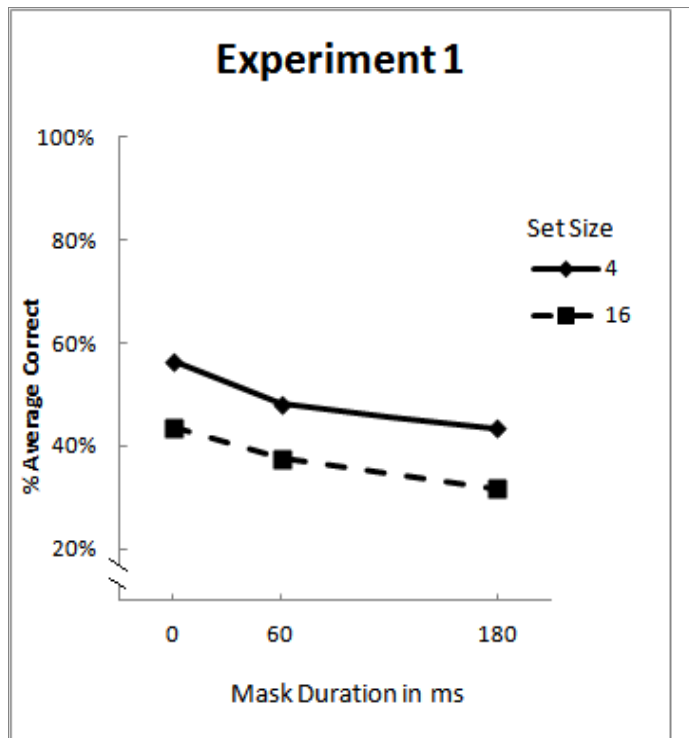
255 they thought that the gap was on the right, left, top or bottom side of the target-square.  
 256 Participants were informed that accuracy not speed of response was of importance.

257

## 258 *Results and Discussion*

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

267



268

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

272

273 A possible explanation for this lack of interaction could lie in the overall level of  
274 performance. In Di Lollo et al.'s (2000) study (Experiment 3) performance for all set sizes in  
275 the common offset condition was consistently high (on average above 90%), and even at  
276 longer mask durations performance for smaller set sizes varied between 70% and 100%. In  
277 our Experiment 1, however, performance for the common offset condition was much lower,  
278 56% for set size of four and 44% for set size of sixteen. Furthermore, performance for the  
279 larger set size and longest mask duration (32%) was not very far above the chance level of  
280 25%. Although the group mean was significantly different from chance ( $t(10) = 10.99, p <$   
281  $.001$ ), results for some participants may have been compressed by a floor effect. Certainly  
282 performance on our task was much lower than on Di Lollo et al.'s task, and it is possible that  
283 the relatively close to floor performance for the larger set size at the longest mask duration  
284 might have disguised the expected interaction.

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

289

290

## Experiment 2

291 *Method*

292 There were 10 psychology undergraduate participants (8 females) with an average age of  
293 30.8 years (s.d. = 13.2). They were recruited from the OBU Psychology Department  
294 Participants Panel and received course credits for taking part in the study. Stimuli were  
295 identical to those used in Experiment 1 except that instead of each square having a small gap  
296 in one of its sides, a whole side was missing. The procedure was identical to that in  
297 Experiment 1.

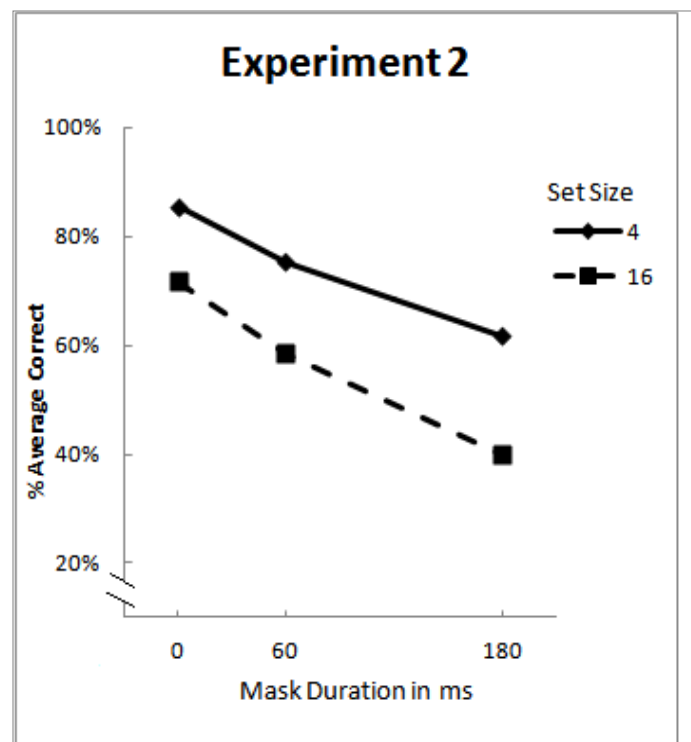
298

299

300 *Results and Discussion*

301 Figure 5 shows the mean percentage correct responses over set size and mask duration.  
 302 As expected, the replacement of the small gap with a missing side markedly improved  
 303 discrimination performance. A two way repeated measures ANOVA revealed a significant main  
 304 effect of set size [ $F(1,9) = 28.04, p < .001, \text{partial } \eta^2 = .76$ ] and of mask duration [ $F(2,18) =$   
 305  $26.29, p < .001, \text{partial } \eta^2 = .75$ ]. However, as in Experiment 1, there was no interaction  
 306 between these two factors [ $F(2,18) = .86, p > .05$ ]. Increasing the size of the target gap had  
 307 the desired effect of raising overall performance levels and also resulted in steeper masking  
 308 functions but did not otherwise alter the pattern of results from those of Experiment 1.  
 309 Although the difference in accuracy between set sizes 4 and 16 does increase slightly across  
 310 set sizes, the interaction does not even approach significance.

311



312

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

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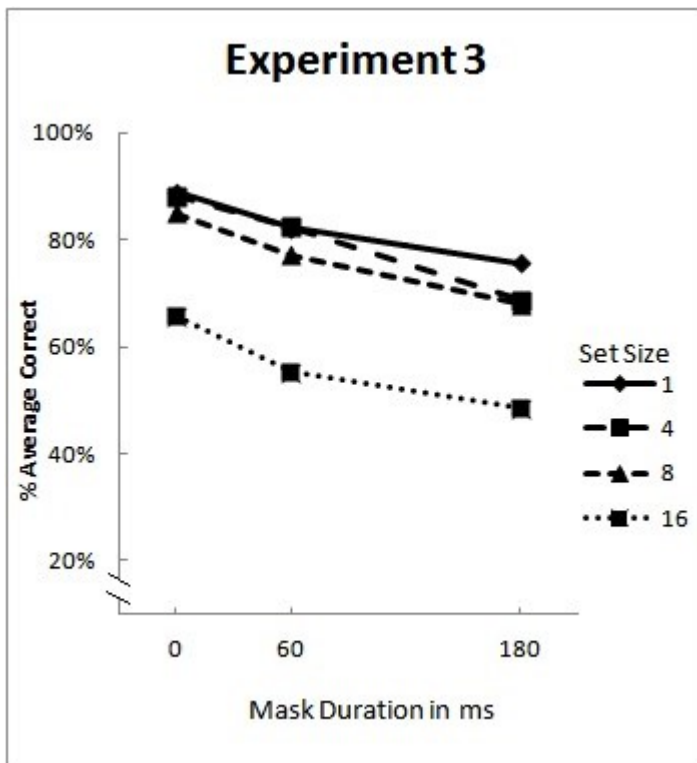
**Experiment 3**

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

335

336 *Method*

337 There were 10 psychology undergraduate participants (7 females) with an average age of  
338 22.7 years (SD = 5.17). They were recruited from the OBU Psychology Department  
339 Participants Panel for course credits. Stimuli were identical to those used in Experiment 1  
340 except for the two following changes; instead of a small gap ( $0.1^\circ$ ) there was now a larger gap  
341 of  $0.2^\circ$ . Also, two extra set sizes of 1 and 8 items were added. As a result, the total number of  
342 trials was increased from 240 to 480 (from the factorial combination of 4 set sizes X 3 mask  
343 durations X 40 trials per condition). The procedure was identical to that of Experiment 1.



344

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

348

### 349 *Results and Discussion*

350 Figure 6 shows the mean percentage correct responses over the 4 set sizes and the 3  
 351 mask durations. Similar to Experiments 1 & 2, there were significant effects of set size [ $F(1.5,$   
 352  $13.4) = 35.12, p < .001, \text{partial } \eta^2 = .79$  and mask duration [ $F(2,18) = 34.02, p < .001, \text{partial}$   
 353  $\eta^2 = .79]$  but not an interaction between these two factors [ $F(6,54) = .92, p > 0.05]$ . The results  
 354 of Experiment 3 are entirely consistent with those of Experiments 1 and 2. Increasing the  
 355 number and range of set sizes did nothing to promote an interaction with mask duration.

356 That OSM in Experiment 3 was just as strong for set size 1 as for the larger set sizes is a  
 357 theoretically important finding. It shows that, contrary to what has been thought previously, it is  
 358 not necessary for the target to be part of a multi-element display in order for OSM to be  
 359 obtained (see also Dux, Visser, Goodhew, & Lipp, 2010). In contrast to the data of Di Lollo et  
 360 al., the spread of the functions for set sizes 1, 4 and 8 is very small, with the main difference  
 361 being between 8 and 16 items. Di Lollo et al. remarked on the role crowding plays in reducing



362 performance for larger set sizes and a likely explanation for why such a large difference was  
363 found between set sizes 8 and 16 of Experiment 3 is that in our circular displays of equally  
364 spaced items crowding may have come into play only for the latter displays. We will be  
365 reporting investigations of the relationships between set size, mask duration and crowding  
366 effects in another paper (Argyropoulos, Gellatly, & Pilling, 2012).

367 An argument that might be made about our first three experiments is that each of them  
368 employed a relatively small number of participants, and that perhaps an interaction would have  
369 emerged if larger number of participants had been employed. Because, despite the  
370 differences in gap size in each experiment, all three studies were very similar and all included  
371 set sizes 4 and 16, we entered the relevant data into a single 3 x 3 x 2 mixed ANOVA, with one  
372 between participants factor (experiment) and two within participant factors (mask duration and  
373 set size). There were main effects of Experiment [ $F(2, 28) = 15.03, p < 0.001, \text{partial } \eta^2 = .52$ ],  
374 mask duration [ $F(2, 56) = 63.21, p < .001, \text{partial } \eta^2 = .69$ ] and set size [ $F(1, 28) = 99.86, p <$   
375  $.001, \text{partial } \eta^2 = .78$ ]. Experiment interacted significantly with set size [ $F(2, 28) = 3.96, p < .05,$   
376  $\text{partial } \eta^2 = .22$ ], and its interaction with mask duration was approaching significance [ $F(4, 56) =$   
377  $2.27, p < .1, \text{partial } \eta^2 = .14$ ]. Most importantly, there was not an interaction between set size  
378 and mask duration [ $F(2, 56) = .63, p > 0.05, \text{partial } \eta^2 = .02$ ], nor a 3-way interaction [ $F(4, 56)$   
379  $= .85, p > 0.05, \text{partial } \eta^2 = .06$ ]. Thus even with a total of 31 participants, there was no hint of  
380 an interaction between set size and mask duration.

381

382

#### Experiment 4

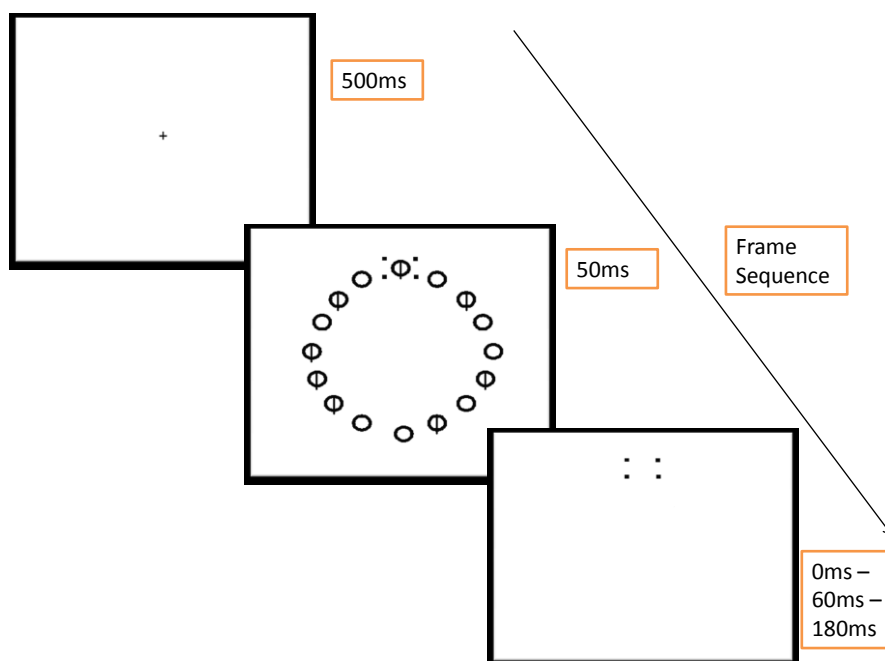
383 In all three experiments reported so far the target and the distractors were squares and  
384 observers had to report the orientation either of a gap or a missing side. In some of Di Lollo et  
385 al.'s experiments and in Kotsoni et al.'s studies, however, the stimuli consisted of circles, and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

389

390 *Method*

391 There were 18 psychology undergraduate participants (15 females) with an average age of  
 392 19.5 years (s.d. = 1.3). They were recruited from the OBU Psychology Department Participants  
 393 Panel for course credits.

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



405

406

407

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

412

413 In units of visual angle, the radius of the annular array was  $2.98^\circ$  and of each circle was  
414  $0.15^\circ$ . The bisecting vertical bar subtended for  $0.38^\circ$  and its thickness was 1.5 min arc. The  
415 distance between the dots was  $0.5^\circ$  and each dot had a thickness of 3 min arc. Luminance  
416 values of stimuli and background were as in the previous experiments.

417 Each participant contributed to 540 trials resulting from the factorial combination of 2 bar  
418 present/absent conditions x 3 set sizes x 3 mask durations x 30 trials per condition. Every 60  
419 trials the programme prompted observers to have a brief break. The total duration of the  
420 experiment was approximately 45 minutes. Similarly to the previous experiments, a session of  
421 12 demonstration trials with extended frame durations and 36 practice trials preceded the main  
422 experiment.

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

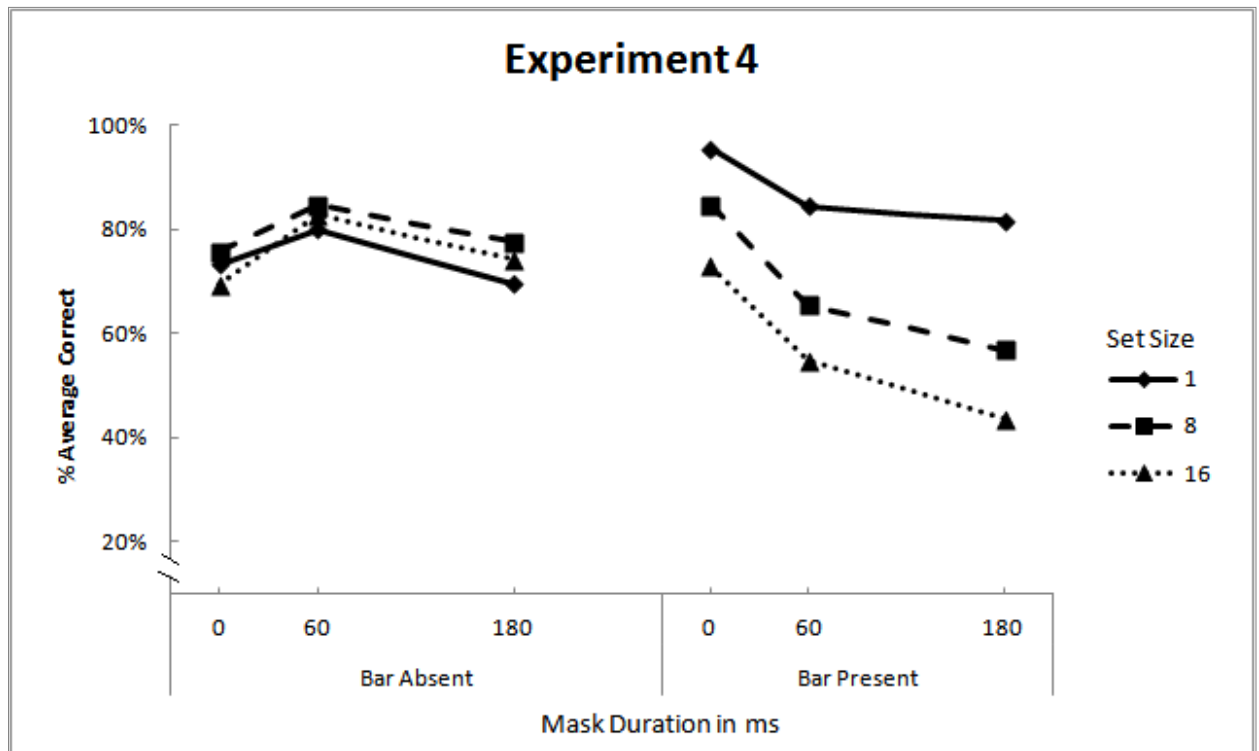
431

#### 432 *Results and Discussion*

433 Illustrated in Figure 8 are mean percent correct responses as a function of set size and  
434 mask duration. For target present trials (right side of the graph) a two-way repeated measures  
435 ANOVA showed significant main effects of both set size,  $[F(2,34) = 39.24, p < .001, \text{partial } \eta^2 =$   
436  $0.69]$  and mask duration  $[F(2,34) = 46.43, p < .001, \text{partial } \eta^2 = 0.73]$  and, most importantly, a

437 significant interaction between the two factors [ $F(4,68) = 2.82, p < .05, \text{partial } \eta^2 = 0.14$ ]. The  
 438 effect of set size was stronger for longer mask durations and, conversely, mask duration had  
 439 its greatest effect at larger set sizes.

440



441

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

448

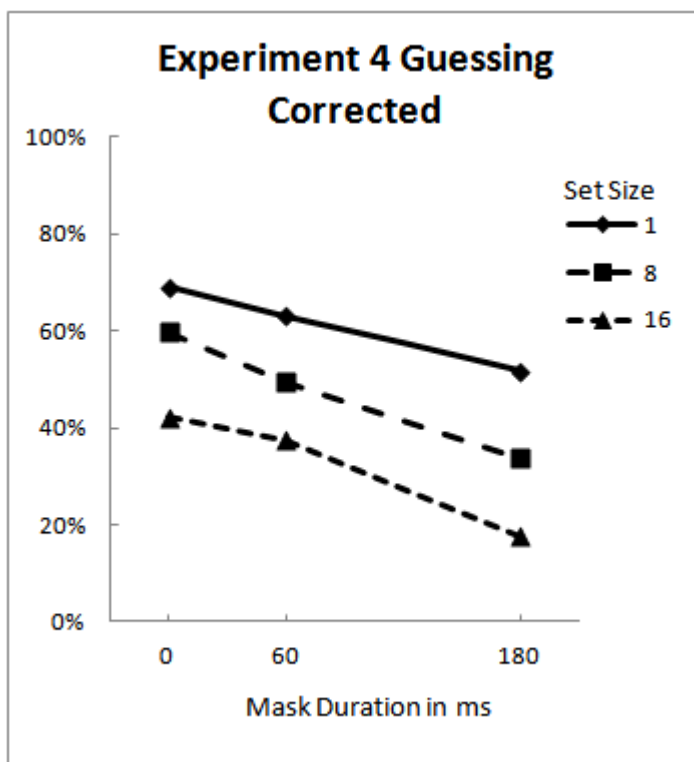
449 For target absent trials (left side of the graph) mask duration had a significant effect [ $F(1.4,$   
 450  $20.7) = 12.87, p < .005, \text{partial } \eta^2 = .46$ ] but neither set size [ $F(1.3, 20.12) = .55, p > 0.05$ ] nor  
 451 the interaction between these two factors [ $F(4, 60) = 1.2, p > 0.05$ ] were significant.

452 A rather surprising finding is that for target absent trials observers' accuracy in the common  
 453 offset conditions was worse than or comparable to in the extended mask duration conditions. A  
 454 similar finding was also reported by Di Lollo et al. and shows that observers are as likely or  
 455 more likely to commit false alarms (i.e. report that there was a vertical bar in the target when

456 there was not) in the control condition than in the delayed mask conditions. The main point,  
 457 however, is that unlike in Di Lollo et al.'s results, performance in the bar absent conditions was  
 458 not at ceiling; there were appreciable false alarm rates for all conditions. There are a number  
 459 of ways in which the data can be considered in the light of this finding. The simplest treatment  
 460 is to perform a guessing correction by subtracting false alarms in the bar absent condition from  
 461 correct detections in the bar present condition. Figure 9 illustrates the results of this  
 462 procedure. When the data were entered into an 3 (set size) by 3 (mask duration) ANOVA,  
 463 there was a main effect of set size [ $F(1.45, 21.9, 14) = 24.99, p < .0001, \text{partial } \eta^2 = .63$ ] and of  
 464 mask duration [ $F(2,30) = 32.48, p < .001, \text{partial } \eta^2 = 0.68$ ] but the interaction was not  
 465 significant [ $F(4,60) = .74, p > 0.05$ ]

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

467



468

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

471

472 A first feature of these results to note is that the finding of OSM for set size 1 displays is  
473 replicated in the guessing corrected data. In comparing the present results to those of Di Lollo  
474 et al., two main points warrant discussion. First, the pattern of results for the bar present trials  
475 resembles that found in Di Lollo et al.'s study (Figure 2 above), in that there was an interaction  
476 between mask duration and set size. However, when bar absent trials are taken into account,  
477 this joint effect vanishes as shown in the analysis of guessing corrected data. As mentioned in  
478 the introduction of the present paper, Di Lollo et al. reported that "On trials in which the target  
479 did not contain the vertical segment [...], accuracy was at ceiling except at mask duration of  
480 zero..." (p. 493). This statement indicates that the accuracy data for the bar absent conditions  
481 were constrained by a ceiling effect. This was not the case in our experiment where relatively  
482 high rates of false alarms were obtained, which when taken account of by guessing correction  
483 resulted in the complete lack of a significant interaction. Second, the failure to find a significant  
484 interaction cannot readily be attributed to stimulus presentation differences (a square matrix in  
485 Di Lollo et al. versus an annular array in the present study). When Di Lollo et al. analyzed their  
486 results based on the degree of eccentricity (Experiment 1) they found that although a stronger  
487 masking effect was present at greater eccentricities, the pattern of results remained similar  
488 across eccentricities. Moreover, the eccentricity of the annular array of the present experiment  
489 was deliberately very similar ( $3^\circ$ ) to that of the outer positions of their matrix ( $2.8^\circ$ ). However,  
490 the size of the circles differed considerably between the two studies ( $0.15^\circ$  in our experiment,  
491  $0.4^\circ$  in Di Lollo et al.). Conceivably, this might have resulted in higher false alarms rates. For  
492 this reason, and to ensure the reliability of our findings, we conducted a further experiment.

493

494

### Experiment 5

495 The present experiment was identical to Experiment 4 apart from the following changes.  
496 First, the eccentricity of the annular array was decreased from  $2.98^\circ$  to  $1.77^\circ$ . This change was  
497 expected to produce an improvement in overall discrimination performance and so eliminate  
498 concerns about possible floor effects. Secondly, an additional mask duration of 360 ms was  
499 employed. Although Di Lollo et al. found that the effect of mask duration reached a plateau by  
500 180 ms or sooner, it is possible that in the conditions of our experiments the main effect might  
501 operate over a longer duration. Similarly, although we have failed to obtain an interaction with

502 set size in any of our first four experiments, it is possible that one might emerge at a mask  
503 duration longer than those we used previously.

504 A further twist to Experiment 5 is that we ran two versions of it. In discussing the results of  
505 their Experiment 4 (see Figure 2), Di Lollo et al. noted that "...the lower limit of accuracy in  
506 Figure 9 is more properly regarded as being zero rather than the 50% chance level. This is  
507 because the observers indicated whether they had seen the vertical segment in the target.  
508 Thus, a score below 50% would indicate that the vertical segment, although present, was not  
509 seen because it had been masked. On trials on which the target did not contain the vertical  
510 segment ....accuracy was at ceiling except at a mask duration of zero....Ceiling effects for  
511 accuracy on target absent trials are commonly found in visual search experiments because  
512 observers are reluctant to guess that a feature they did not see was actually present".  
513 Another way of expressing the last point is to say that observers set a high criterion for  
514 reporting target presence. Although Di Lollo et al. do not report the precise instructions given  
515 to their participants, the ceiling level performance on target absent trials indicates that  
516 participants so interpreted the instructions that they did indeed set a high criterion for reporting  
517 having seen a line segment in the target circle. This contrasts with the results of the present  
518 Experiment 4 (see Figure 8) in which false alarms on target absent trials averaged around  
519 25%. We therefore ran two versions of Experiment 5 with different experimental instructions.  
520 For Experiment 5a, the instructions were exactly as for Experiment 4, making Experiment 5a a  
521 replication and extension of Experiment 4. For Experiment 5b, participants were instructed to  
522 press *yes* only if they were certain that the target contained the bisecting vertical bar, otherwise  
523 to press *no*. Our intention was to see whether the different instructions would influence  
524 performance level by changing participants' criterion, and how this might affect the appearance  
525 of an interaction between set size and trailing mask duration

526

#### 527 *Method*

528 For Experiment 5a there were 16 psychology undergraduate and postgraduate students  
529 and members of staff (11 females) with an average age of 30.43 years (SD = 9.85). For  
530 Experiment 5b there were 13 psychology undergraduate participants (all females) with an

531 average age of 19.61 years (SD = 1.75). Participants were either unpaid volunteers or were  
 532 recruited from the OBU Psychology Department Participants Panel for course credits. The  
 533 stimuli were the same to those in Experiment 4 except for the differences described above.  
 534 Additionally, in order to retain an analogous spatial relationship between the target-circle and  
 535 the masking dots, the distance between the dots decreased from  $0.5^\circ$  to  $0.4^\circ$ . An additional  
 536 mask duration of 360ms was added and the number of trials remained at 30 per condition. As  
 537 a result each participant contributed a total of 720 trials.

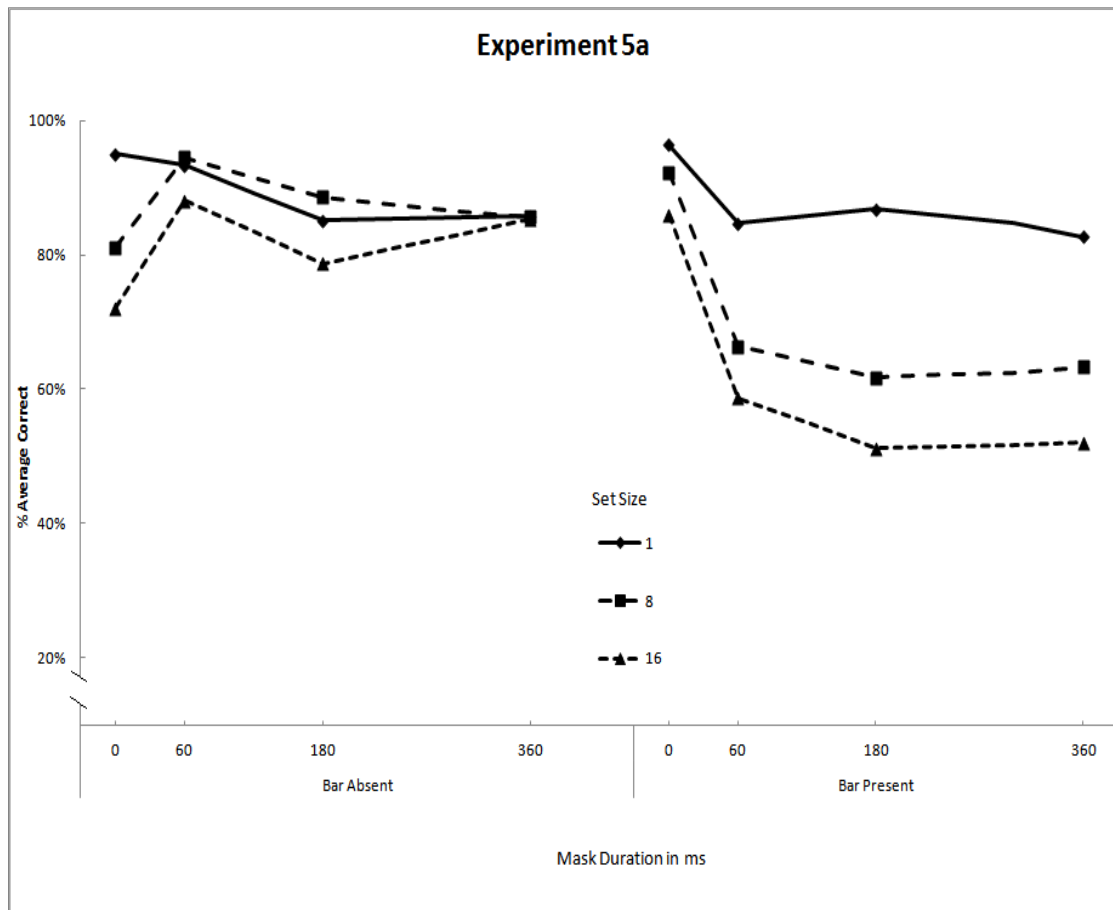
538

### 539 *Results*

540 The results for Experiments 5a and 5b are shown in Figure 10 and 11, and Figures 12 and  
 541 13 respectively. Figure 10 illustrates the average percent correct as a function of bar  
 542 absent/bar present conditions, set size and mask duration in Experiment 5a. The data of 5a  
 543 were submitted to two separate repeated measures ANOVAs for the bar absent and bar  
 544 present conditions. For the former conditions, there were main effects of set size [ $F(2,24) =$   
 545  $5.62, p < .05, \text{partial } \eta^2 = .31]$  and mask duration [ $F(1.4, 1.7) = 7.66, p < .05, \text{partial } \eta^2 = .39]$   
 546 and a significant interaction between them [ $F(6, 72) = 5.48, p < .005, \text{partial } \eta^2 = .31]$ . For trials  
 547 when the target included a bar, there were again main effects of set size [ $F(2, 24) = 21.26, p <$   
 548  $.0001, \text{partial } \eta^2 = .64]$  and mask duration [ $F(1.8, 22) = 27.27, p < .0001, \text{partial } \eta^2 = .69]$  and  
 549 also a significant interaction between them [ $F(6,72) = 6.17, p < .005, \text{partial } \eta^2 = .34]$ .

550 As for Experiment 4, the target present and target absent data of Experiment 5a were  
 551 combined using a guessing correction procedure, the results of which are shown in Figure 11.  
 552 The individual scores were entered into an ANOVA, which yielded significant main effects of  
 553 set size [ $F(2,24) = 36.74, p < .001, \eta^2 = .75]$  and mask duration [ $F(3,36) = 53.60, p < .001, \eta^2 =$   
 554  $.81]$  but no interaction between these factors [ $F(6,72) = .71, p = \text{n.s.}, \eta^2 = .05]$ . Once again d-  
 555 prime and A-prime analyses gave the same result.

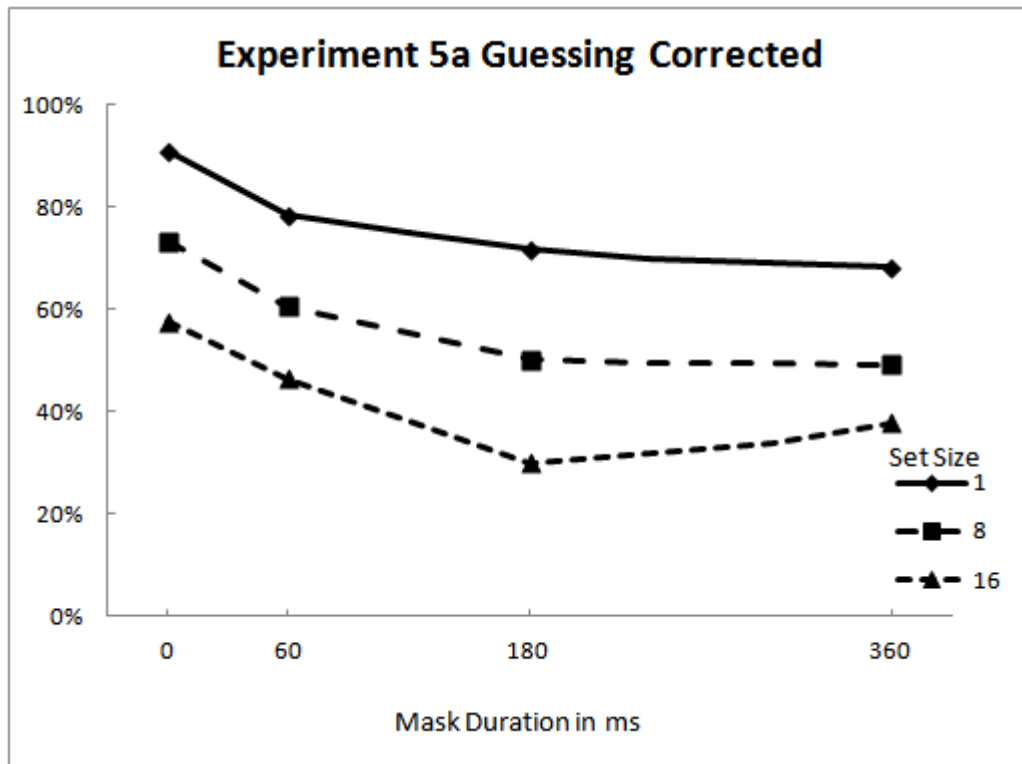




556

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

563



564

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

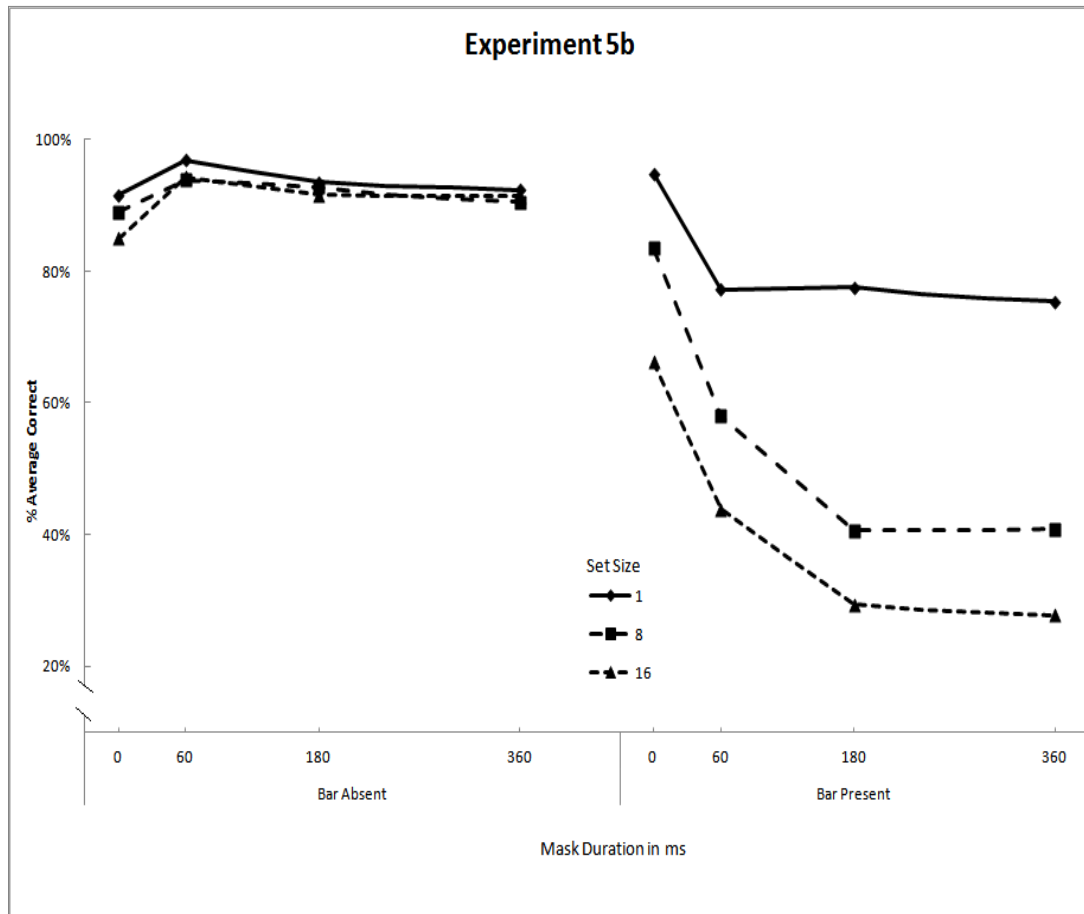
567

568 The data of Experiment 5b were similarly submitted to two separate repeated measures  
 569 ANOVAs for the bar absent and bar present conditions. For the bar absent trials, the ANOVA  
 570 revealed a significant main effect of mask duration [ $F(1.9, 28.7) = 5.45, p < .05, \text{partial } \eta^2 =$   
 571  $.27]$  but not one of set size [ $F(2, 30) = 2.08, p > .05, \text{partial } \eta^2 = .12]$  and nor an interaction  
 572 between set size and mask duration [ $F(3.5, 51.8) = 1.02, p > .05, \text{partial } \eta^2 = .06]$ . For the bar  
 573 present trials, there were significant main effects of set size [ $F(1.3, 19.7) = 62.9, p < .0001,$   
 574  $\text{partial } \eta^2 = .81]$  and mask duration [ $F(1.8, 26.6) = 39.65, p < .0001, \text{partial } \eta^2 = .73]$ . In  
 575 addition, the interaction between mask duration and set size reached statistical significance  
 576 [ $F(6,90) = 7.07, p < .001, \text{partial } \eta^2 = .32]$ . “

577 As for Experiment 4, the target present and target absent data of Experiment 5b were  
 578 combined using a guessing correction procedure, the results of which are shown in Figure 13.  
 579 An ANOVA confirmed the main effects of set size [ $F(1.4, 20.8) = 88.88, p < .0001, \text{partial } \eta^2 =$   
 580  $.86]$  and of mask duration [ $F(1.7, 25.8) = 32.54, p < .0001, \text{partial } \eta^2 = .69]$  and also of the

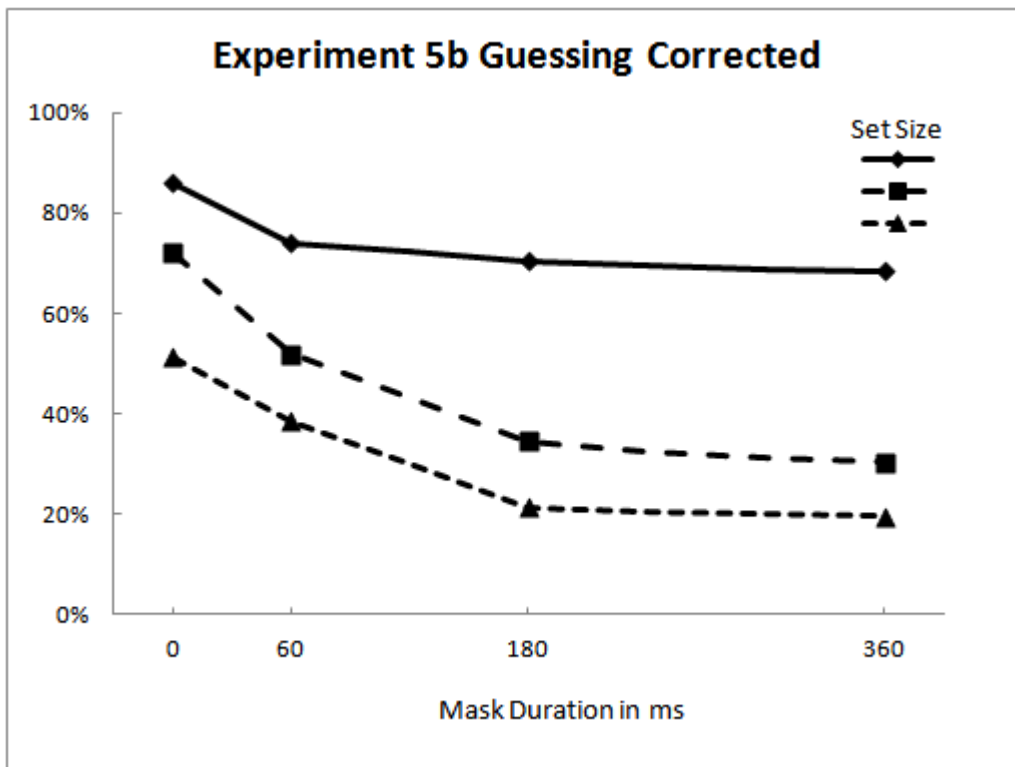
581 interaction between them ( $F(6, 90) = 5.23, p < .0001, \text{partial } \eta^2 = .265$ ). Thus in Experiment 5b  
 582 we finally replicated the elusive interaction between set size and mask duration, but only  
 583 because a deliberately induced response bias lead to near ceiling performance on all target  
 584 absent trials. Because of this near to ceiling performance, the guessing correction procedure  
 585 could do little to modulate the the data pattern for target present trials.

586



587

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



594

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

597

598 Discussion

599 We begin by comparing the results of Experiment 5a with those of Experiment 4, since the  
 600 latter was a replication with extensions of the former. Reducing the eccentricity of the stimulus  
 601 display in Experiment 5a had the desired effect of raising accuracy levels for both target absent  
 602 and target present trials. However, the pattern of results is very similar in the two studies. For  
 603 target absent trials, eight of the first nine data points (i.e. ignoring the 360 ms mask duration)  
 604 are in the same configuration, with only the point for set size one and zero mask duration  
 605 having markedly changed its relative position. For target present trials the same is true for all  
 606 nine points that are common to both experiments, the only difference being a slight bunching of  
 607 the zero mask duration points in Experiment 5a, which is attributable to the higher overall  
 608 accuracy level bringing these points up against ceiling. Turning to the guessing corrected  
 609 results (Figures 9 and 11) the similarity between the two sets of data is again striking despite  
 610 the difference in absolute levels of accuracy. Furthermore, although in both graphs the spread  
 611 of points is slightly greater for the 180 ms than for the zero trailing mask duration, the spread

612 reduces again for the 360 ms duration in Experiment 5a. Lengthening mask duration does not  
613 cause an interaction to emerge.

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

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

635

636

### **General Discussion**

637 According to Di Lollo et al. (2000, p488), accounting for the interaction between set size  
638 and mask duration in terms of the time needed for spatial attention to focus on the target  
639 location is "...an essential part of the re-entrant-processing account that we favour..." for  
640 explaining OSM. The present paper has reported a series of experiments that question the

641 reality of that interaction. Experiment 1 employed a 4AFC task, deliberately modelled in  
642 certain respects on the task used by Di Lollo et al. for their first 3 experiments, but designed to  
643 hold performance below ceiling in all conditions. With set sizes of 4 and 16 items, there was  
644 no sign of an interaction with mask duration, although both main effects were significant.  
645 Experiment 2 replicated Experiment 1 but with the critical feature increased in salience to avoid  
646 possible floor effects in some conditions. Although performance level was raised, the  
647 interaction was still absent. Experiment 3 was a further replication with the ranges of both set  
648 size and mask duration increased, and with the critical feature midway in size between those of  
649 Experiments 1 and 2, but once again there was no evidence of an interaction. Even when the  
650 power of the analysis was increased by combining the data of all three experiments for set  
651 sizes 4 and 16, and ignoring the difference in critical feature sizes, there was no evidence of an  
652 interaction. Experiment 4 then employed a present/absent decision based closely on the task  
653 in Experiment 4 of Di Lollo et al., but with performance calibrated to be below ceiling in all  
654 conditions. An interaction was present for target present trials but disappeared when target  
655 absent trials were taken into account by means of a guessing correction. Experiments 5a and  
656 5b were then conducted with stimuli presented at a reduced eccentricity and with instructions  
657 that encouraged a higher or lower criterion for reporting the discriminatory target feature. The  
658 instructional manipulation yielded differing levels of performance but the pattern of results for  
659 target present trials in the two studies was highly similar in each case and to that of Experiment  
660 4. For Experiment 5A, the interaction was abolished by a guessing correction. This was not  
661 the case for Experiment 5B because ceiling level accuracy on target absent trials rendered the  
662 guessing correction nugatory. In summary, across 6 studies on two different tasks we found  
663 no evidence for an interaction between set size and mask duration if performance levels were  
664 constrained below ceiling, even though each of these variables always produced an  
665 independent significant effect. It is, of course, possible that under conditions different from  
666 those tested by us an interaction between these two factors can be found, but our results  
667 indicate that the interaction is certainly not a hallmark of OSM and, therefore, that explaining it  
668 need not be an essential part of any theoretical account of how OSM is produced.

669 At this juncture it is worth commenting on a study that shows an interaction between set  
670 size and the asynchrony between target and mask onsets. In their Experiment 3, Enns & Di  
671 Lollo (1997) presented for 30 ms one or three diamond shapes that lacked either a left or right

672 corner. Appearing around the target shape for 30 ms – and designating it as the target - were  
673 four dots that could onset between 300 ms before or after target onset. The dots had relatively  
674 little effect when only a single shape was presented. However, when three shapes were  
675 presented the dots interfered with reporting of the target at even the longest stimulus onset  
676 asynchronies (SOAs) for parafoveal locations and also impaired reporting of a centrally located  
677 target at intermediate SOAs. This result amounts to an interaction between set size and SOA  
678 because SOA affects performance with three shapes but not with one. However, the variable  
679 SOA of a brief 30 ms mask is not the same as the variable duration of a mask which onsets  
680 simultaneously with the target, as in the present studies and those of Di Lollo et al. (2000) and  
681 many other investigators (e.g. Kotsoni et al., 2007; Goodhew et al., 2011, 2012 ). In the SOA  
682 case, the dots may cause processing of the target to be terminated by capturing attention  
683 towards themselves. Indeed, Enns & Di Lollo (1997) offer just such an ‘attentional capture’  
684 interpretation of their data, which is somewhat different to the re-entrant processing account  
685 proposed by Di Lollo et al. (2000). Other authors have also argued that four dot masking can  
686 result from attentional capture by the mask (Neill, Hutchison, & Graves, 2002; M. S. Tata &  
687 Giaschi, 2004), or that attentional capture may be one of several mechanisms by which four  
688 dot masking may come about (Bischof & Di Lollo, 1995; Guest, Gellatly, & Pilling, 2012; Kahan  
689 & Lichtman, 2006; Tsotsos, 1990). Although previous discussions have not made this point  
690 explicit, we wish to argue here that the attention that is captured in such conditions is object-  
691 based attention rather than spatial attention. Since the four dot mask (hereafter 4DM)  
692 surrounds the target, its onset may slightly broaden the focus of spatial attention but it is  
693 probable the main effect will be to cause the dots to become foregrounded as ‘figure’ in place  
694 of the target, which becomes relegated to ‘ground’. Of course, object-based attention and  
695 spatial attention cannot be totally distinct from one another. Even though object-based  
696 attention has been defined in terms of objects occupying overlapping spatial positions in two  
697 dimensions (Kahneman, 1967), it refers to the perceptual representation of varying depth  
698 planes in the third dimension of space i.e. even for a two dimensional stimulus, one of the  
699 overlapping objects is represented as partially occluding the other. However, with the  
700 exceptions of Kahan & Lichtman (2006) and Guest et al. (2012), previous discussions of the  
701 effect of spatial attention on OSM have been concerned with attention deployed within a single  
702 two dimensional plane. This is mainly true also of the present paper, which is deals for the

703 most part with studies of OSM in which target and mask onset simultaneously (what Di Lollo et  
704 al. termed 'common onset masking'). We assume that in these conditions the target and mask  
705 elements are all represented as parts of a flat pattern, or object, lying in a single depth plane.  
706 This contrasts with the case of delayed mask onset, in which the effect of the mask may be  
707 attributed to it capturing attention as a singleton abrupt onset (Kastner & Ungerleider, 2000;  
708 Muhlenen, Rempel, & Enns, 2005; Yantis & Jonides, 1984), with the result that it is perceived  
709 to occupy a figural depth plane in front of the ground plane in which the target comes to be  
710 perceptually located.

711       What are we to make of our failure to find an interaction of set size and mask duration with  
712 common onset four dot masking? In the original re-entrant processing account of Di Lollo et  
713 al., the crucial factor in determining OSM is held to be the speed with which two dimensional  
714 spatial attention can be focused on the target. When the target can be rapidly located because  
715 it is the one of very few items, or even the only item, in the display, there is said to be little  
716 interference from involuntary processing of distractors. Because spatial attention focuses  
717 more rapidly on the target, processing of it will be more advanced by the time it offsets, so the  
718 representation of it will be more developed and less likely to be substituted by a representation  
719 of the mask object in the course of continuing iterative re-entrant processing. The probability  
720 of substitution is also increased by the duration of the trailing mask up to a limit in the region of  
721 160 to 200 ms – see Figures 1, 2, 10 and 12. The two factors supposedly have multiplicative  
722 effects on the probability of substitution during this period, so causing an interaction. The  
723 present evidence that set size and mask duration do not, in fact, interact statistically except  
724 when performance is compressed by a ceiling (or floor) effect suggests something is incorrect  
725 in the re-entrant processing account of OSM.

726       One simple way around the difficulty is to assume that rather than have a multiplicative  
727 effect on OSM, set size and mask duration have additive effects – as indicated by the present  
728 data. It could be that the set size effect does not reflect time for attention to locate the target  
729 but is, in fact, solely a function of crowding (Bachmann, 2006; Sibley, 2011), the effect of which  
730 might well be additive with the effect of mask duration (Argyropoulos et al., 2012). Di Lollo et  
731 al. considered that the spread of set size points at zero trailing mask duration (see Figures 1  
732 and 2) was due to crowding but argued that the increase in spread as mask duration was



733 made longer indexed the interaction of mask duration with the delayed arrival of attention at  
734 the target for larger set sizes. However, if, as seems likely, the spread at zero mask duration is  
735 compressed by a ceiling effect, then the statistical interaction they obtained is an artefact.  
736 Assuming additive effects of set size (mediating crowding) and mask duration would seriously  
737 undermine the re-entrant processing account, and particularly its computer model instantiation,  
738 CMOS, which dictates an interaction between the two factors. The crucial points for the re-  
739 entrant account are that the set size manipulation is a proxy for the speed with which spatial  
740 attention contacts the target and that attention interacts with mask duration to determine the  
741 extent of OSM.

742 Supporting the idea that attention interacts with mask duration to determine the extent of  
743 OSM, and counting against the assumption of additivity, are reports that OSM is absent or  
744 greatly reduced when, as the result of a local cue, spatial attention can be pre-focussed in a  
745 spotlight like fashion on the location of the target (Di Lollo, et al., 2000, Exp 6; Enns, 2004, Exp  
746 3; Luiga & Bachmann, 2007, Exps 1 & 2; Matthew S. Tata, 2002, Exps 1 & 2). Similarly, OSM  
747 is reported to be reduced if the target 'pops out' from distractors due to it containing a unique  
748 and to-be-reported feature (Di Lollo et al., 2000, Exp 5). It is, therefore, important to assess  
749 the validity of these reports at some length, a task to which we now turn.

750 As part of a large experiment comparing several different forms of masking, Enns (2004,  
751 Exp 3) cued the location of the target in a display of letters with a dot presented 100 ms prior to  
752 target display onset. This caused ceiling level performance for all SOAs between the 30 ms  
753 target and a 30 ms 4DM. Even if we were to suppose that four dot masking with a non-zero  
754 SOA produces the same sort of OSM as four dot masking with common onset (see above),  
755 these results do not demonstrate that pre-focussed spatial attention reduces OSM. What they  
756 show is that in this study pre-focussing attention at the target location moved performance out  
757 of the measurable range for four dot masking. Tata (2002, Exp 2) conducted a very similar  
758 experiment using circles with gaps, as in the squares of the present experiments. An eight  
759 item array was presented for 10 ms followed after an 80 ms SOA by a circular mask for 10 ms  
760 around the target. The mask cued the target but in addition a dot pre-cue was presented at the  
761 centre of the target circle location between zero and 200 ms before onset of the target array.  
762 With non-zero cue lead times performance was increased relative to a no cue baseline,

763 although ceiling performance was never reached. However, since target and mask did not  
764 have a common onset and mask duration was not varied, the results show only that pre-  
765 focussing attention to the target location enhances performance; it cannot say anything about  
766 the effect of pre-cueing on OSM. Di Lollo et al. (2000) and Luiga & Bachmann (2007) pre-cued  
767 the target location by presenting the 4DM ahead of the target it would then mask. Di Lollo et al  
768 found that performance improved for all set sizes tested as the duration of the pre-cue  
769 increased, and that the two factors interacted. However, because they did not manipulate  
770 mask duration, their results also show only that cueing improves performance for a particular  
771 mask duration but not that pre-cued attention reduces OSM. Moreover, the interaction they  
772 observed may well have reflected the ceiling level accuracy obtained for the smallest set size  
773 (of one) for all but the zero cue duration. Contrastingly, Luiga and Bachmann (2007) did vary  
774 the duration of a common onset mask for a single set size of four items. They found that a  
775 local 4DM pre-cue both raised performance for all trailing mask durations (including zero) and  
776 greatly reduced the effect of mask duration on accuracy levels, i.e. the pre-cue reduced OSM.  
777 Although Luiga and Bachmann interpreted their results in terms of sensory facilitation, they  
778 could seem to offer support for the re-entrant processing account of OSM according to which  
779 OSM is reduced or abolished by rapid, or prior, deployment of attention to the target location.  
780 However, this is not necessarily the case because, as we will argue in the next section, an  
781 alternative interpretation of the Luiga and Bachmann findings is possible.

782 Before making that argument, we need to consider the pop-out study of Di Lollo et al.  
783 (2000, Exp 5). This experiment employed circles as display items, the target circle being  
784 surrounded by a 4DM. The task was to report whether or not the target contained a vertical  
785 line segment. Unlike in some of their other experiments, none of the distractors contained  
786 such a line segment (see Introduction to Experiment 4 above), so the target was said to 'pop-  
787 out' on this feature. The results were similar to when half of distractors contained a line  
788 segment (see Figure 2), in that for target present trials there was an interaction of set size and  
789 mask duration, but with higher overall levels of performance and shallower slopes for the  
790 functions of set size against mask duration. The reduction in slopes was taken as evidence  
791 that rapid deployment of attention to the target location – in this case as a consequence of  
792 pop-out - reduces OSM. However, the overall increased level of accuracy due to pop-out  
793 resulted in ceiling level performance for all set sizes at the zero mask duration and near to

794 ceiling levels for some set sizes at some mask durations (despite a bias to respond ‘target  
795 absent’ shown by ceiling level performance on target absent trials for all conditions). Thus the  
796 reduced slopes for the set size functions – relative to the non-pop-out conditions of their  
797 Experiment 4 - may have been due to compression of the set size points at shorter mask  
798 durations and not to a reduction in OSM due to pop-out. This interpretation becomes more  
799 persuasive when one considers that in the standard 4DM procedure the target should always  
800 pop-out by virtue of being the only item (or location) surrounded by four dots. If rapid  
801 deployment of attention to the target eliminates or greatly reduces OSM, then the phenomenon  
802 of four dot masking should be almost impossible to demonstrate in the first place, whereas in  
803 fact demonstrations of it are often quantitatively impressive (Enns & Di Lollo, 1997; Di Lollo et  
804 al., 2000; Enns, 2004). A possible means for resolving this apparent paradox comes from a  
805 finding by Gellatly, Pilling, Cole & Skarratt (1993), who observed that pop-out on a task  
806 relevant dimension reduced OSM but that pop-out on a task irrelevant dimension did not do so.  
807 If the task was to report target colour, then colour pop-out of the target reduced OSM but  
808 orientation pop-out of the target did not, and vice-versa when the task was to report target  
809 orientation. With this in mind, we can see that the pop-out caused by four surrounding dots  
810 may not eliminate OSM because what is to be reported is some other feature of the target, the  
811 presence of a line segment or the orientation of a gap or the identity of a target letter. More  
812 broadly, what this seems to indicate is that, contrary to the re-entrant processing account,  
813 spatial attention to the target is not in itself incompatible with OSM but may be so if it also  
814 involves attention to the task relevant feature dimension. It should be emphasised that we are  
815 talking here about the case when target and mask have a common onset so that they are likely  
816 to be processed as a single object. In other words, the dots will be perceived as a feature of  
817 the composite target/mask object (see next subsection).

818

### 819 *The object updating account*

820 An alternative to the original re-entrant processing account of OSM by Di Lollo et al (2000)  
821 is the object updating account first proposed by Lleras & Moore (Lleras & Moore, 2003;  
822 Moore, Alej, & Lleras, 2005) and since supported by a range of other findings (Bischof & Di  
823 Lollo, 1995; Guest, et al., 2012; Pashler, 1988; Tsotsos, 1990). According to the updating

824 account, masking in OSM-like situations occurs because the trailing mask is perceived as a  
825 transformation, or updating, of the target rather than as a new and different object that replaces  
826 it. Under common onset conditions, the mask and target are not initially individuated as  
827 separate objects but are represented as a single object because of their close temporal and  
828 spatial proximity. The disappearance of the target is treated as a transformation of this single  
829 object, as when an animal changes its orientation to the viewer so that its visible shape  
830 changes and some of its features become obscured while others come into view. The longer  
831 the mask remains present after target offset, the more likely it is that the features of the original  
832 target-plus-mask will be overwritten by those of the mask alone. The updating, or  
833 individuation, account is certainly not incompatible with a re-entrant processing framework  
834 since, like the original re-entrant account, it emphasises the dynamic nature of visual  
835 representations. Transient and ambiguous activity at lower levels of the system is fed forward  
836 to higher levels, where it is either integrated into an already activated object/event  
837 representation schema or, if sufficiently discrepant with that, triggers activation of an alternative  
838 representation. Neisser (1976) referred to these representations as schemata, and Most,  
839 Scholl, Clifford & Simons (2005) have discussed the relationship of such schemata to bottom-  
840 up driven attention and top-down driven attention. However, the emphasis in updating is  
841 somewhat different from in the original account, and although spatial attention has been held to  
842 modulate the process of updating (Oriet and Enns, 2010), this may not necessitate  
843 commitment to an interaction between set size and mask duration. A finding of relevance to  
844 the present argument is that pre-view of the search display before the target item is indicated  
845 by onset of the 4DM (or square mask) reduces OSM (Guest, et al., 2012; Tsotsos, 1990). The  
846 same is true for pre-view of the mask (Mishkin & Ungerleider, 1982; Neill, et al., 2002; M. S.  
847 Tata & Giaschi, 2004) These findings can be accommodated by the updating account in that a  
848 temporal disparity between target onset and mask onset increases the probability the target  
849 and mask will be individuated, and so represented as separate objects rather than as a single  
850 object. This in turn means that offset of the target will not be processed as a transformation of  
851 a single continuing object, and the target features will not be subject to over-writing by features  
852 of the mask. With this explanation in mind, we can now also explain the finding by Luiga &  
853 Bachmann (2007) that having the 4DM serve as a local pre-cue reduced masking (see above).  
854 Since their 4DM onset ahead of the target it subsequently served to mask, the 4DM was more

855 likely to have been represented as a separate object from the target than in the standard  
856 condition in which the two onset simultaneously. This explanation is supported by the results  
857 of another manipulation introduced by Luiga & Bachmann. In their second experiment, the  
858 4DM pre-cue appeared either for 150 ms or 250 ms ahead of the target or else came on for 33  
859 ms and disappeared for 117 ms or 217 ms. Relative to a no cue control condition, accuracy  
860 was higher and OSM weaker for all the pre-cue conditions but more so for the uninterrupted  
861 than for the interrupted cues. Our explanation for this is that in the former case the cue/mask  
862 was very likely to be individuated as a separate object from the target because of their  
863 asynchronous onsets, whereas in the latter, interrupted case the 4DM, because it reappeared  
864 after an absence and simultaneously with the target, was likely sometimes to be represented  
865 with the target as a single object, which is precisely the condition that gives rise to OSM by  
866 updating.

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

882 A final study of relevance to the issue of how attention does or does not affect OSM, and  
883 one which incidentally demonstrates the possibility of obtaining OSM with a set size of one  
884 item, was reported by Dux et al. (2010). Their experiment was concerned with whether

885 engaging anterior brain regions, thought to play a role in re-entrant processing, would impact  
886 on the extent of OSM. Participants saw a sequence of four digits presented at fixation for 500  
887 ms each, with an inter-stimulus interval of 500 ms. After a further 100 ms or 600 ms, a circle  
888 with a gap surrounded by four dots also appeared at fixation for 10 ms, and the dots either  
889 offset simultaneously with the single circle or trailed it for 200 ms. In blocked trials, participants  
890 either did an arithmetic calculation on the digits before reporting the orientation of the target  
891 gap or reported only the latter. Relative to simultaneous mask offset, delayed mask offset  
892 reduced performance in all conditions, an OSM effect, even though only a single target was  
893 presented, and that at fixation. The slopes of the two-point masking functions varied  
894 considerably but since the data of at least some of the conditions are likely to have been  
895 affected by ceiling level performance on the part of some participants (for simultaneous mask  
896 offset, accuracy varied between 88% and 97%) the differences in slopes must be treated with  
897 caution since some of those slopes will have been reduced by the ceiling on performance. The  
898 conclusion the authors drew from the slope differences must be open to question. However,  
899 for present purposes, the significant finding was that OSM was reliably obtained for a single  
900 item presented at the focus of fixation and spatial attention. Thus pre-focussing attention at  
901 the target location certainly does not abolish OSM under all circumstances. We will shortly be  
902 reporting the results of experiments intended to clarify the role attention may or may not play in  
903 generating OSM (Pilling, Gellatly, & Argyropoulos, 2012).

904

#### 905 *Conclusion*

906 Across six experiments, we have presented evidence that set size and mask duration do not  
907 interact to produce OSM. We suggest that previously reported interactions of these two factors  
908 have resulted from ceiling level accuracy having compressed the data for some conditions. If  
909 the effect of set size indexes the speed with which attention reaches the target location, then  
910 the absence of an interaction with mask duration suggests that speed of attention to the target  
911 is not a critical factor in determining OSM, as supposed in the original re-entrant processing  
912 account of Di Lollo et al. (2000). Although it is often thought that the literature on OSM  
913 provides evidence for the importance of speed of attention to the target, our detailed review of  
914 the relevant literature reveals that evidence to be either weak or open to alternative

915 interpretation. Since an important role for attention has been thought to distinguish OSM from  
 916 other forms of visual masking (Di Lollo et al., 2000; Enns & Di Lollo, 1997; Enns, 2004), the  
 917 present paper brings into question just how different it truly is. More generally, our analysis of  
 918 the literature and our experimental findings demonstrate how important it is to take ceiling  
 919 effects into account when interpreting data on visual cognition.

920

921

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