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Exogenous spatial pre-cueing reliably modulates object processing but not object substitution masking

Michael Pilling[1], Angus Gellatly[1,3], Yiannis Argyropoulos[1] & Paul Skarratt[2]

[1] Oxford Brookes University, UK

[2] University of Hull, UK

[3] A*STAR, Singapore

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Address for correspondence:

Dr. Michael Pilling,

Psychology,

Faculty of Health and Life Sciences,

Oxford Brookes University,

Oxford, OX3 8PE, United Kingdom

Email: mpilling@brookes.ac.uk

Tel. ++44 (0) 1865 483788

Fax. ++44 (0) 1865 483887

Abstract

Object substitution masking (OSM) is used in behavioural and imaging studies to investigate processes associated with the formation of a conscious percept. Reportedly, OSM occurs only when visual attention is diffusely spread over a search display or focused away from the target location. Indeed, the presumed role of spatial attention is central to theoretical accounts of OSM and of visual processing more generally (Di Lollo, et al, 2000). We report a series of five experiments in which valid spatial pre-cueing is shown to enhance the ability of participants to accurately report a target but, in most cases, without affecting OSM. In only one experiment (Exp. 5) was a significant effect of pre-cueing observed on masking. This is in contrast to the reliable effect shown across all five experiments in which pre-cueing improved overall performance. The results are convergent with recent findings from Argyropoulos et al. (2012) which show that OSM is independent of the number of distractor items in a display. Our results demonstrate that OSM can operate independently of focal attention. Previous claims of the strong interrelationship between OSM and spatial attention are likely to have arisen from ceiling or floor artifacts that restricted measurable performance.

Words: 197

Exogenous spatial pre-cueing reliably modulates object processing but not object substitution masking

Visual masking, as both tool and object of study, is a major component of visual cognitive neuroscience. It provides a principal method of studying the microgenesis of conscious visual perception (Breitmeyer & Öğmen, 2005; Bachmann, 2006). Object substitution masking (OSM) is a surprising new form of visual masking. First reported by Enns and Di Lollo (1997; Di Lollo, Enns & Rensink, 2000), it has prompted interest both as a means for studying the relationship between awareness and brain networks thought to be involved in its generation (Woodman & Luck, 2003; Bridgeman, 2006; Carlson, Rauschenberger,& Verstraten, 2007; Boehler, Schonfeld, Heinze & Hopf, 2008; Bouvier & Treisman, 2010; Dux, Visser, Goodhew & Lipp, 2010; Prime, Pluchino, Eimer, Dell'Acqua & Jolicoeur, 2011; Koivisto, 2012) and as a phenomenon to be explained in its own right (Di Lollo et al, 2000; Francis & Herrman, 2002; Lleras & Moore, 2003; Bridgeman, 2007; Reiss & Hoffman, 2006; Francis & Cho, 2007; Chen & Treisman, 2009; Koivisto & Silvanto, 2011; Goodhew, Dux, Lipp, & Visser, 2012; see Goodhew, Pratt, Dux & Ferber, 2013, for a recent review). In its simplest form, an array of items, such as Landolt Cs or digits, is briefly presented; the target item is indicated by four surrounding and simultaneously onsetting dots that offset either simultaneously with it (control condition) or a few hundred milliseconds later (trailing mask condition). The task might typically require participants to either discriminate the target (e.g. the orientation of a Landolt C) or identify it (e.g. digit identity). Performance is typically found to be maximal in the control condition and drops off with increasing mask duration. Thus OSM is measured as the decline in performance as the duration of the trailing mask increases.

Di Lollo et al. (2000) proposed a theoretical framework to explain OSM, drawing on the notion of bidirectional communication between hierarchically organised brain areas (Felleman & Van Essen, 1991). Onset of the target display activates low level cells that code only simple stimulus attributes and precise location information. A feed-forward sweep communicates this information to higher (extrastriate) visual areas which generate one or more perceptual hypotheses as to what the stimulus may be. The higher level cells have large receptive fields and the resultant hypotheses have poor spatial resolution. To resolve potential ambiguities in figural synthesis and stimulus location, hypothesis information is sent back to low level areas via re-entrant projections where a matching process occurs. If the unchanged display or its icon (target plus mask) persist throughout the duration of the re-entrant loop, one hypothesis from the extra-striate areas will match the current activity in lower visual areas, the system will lock onto this interpretation and a stable percept will be achieved. If, however, the display changes to mask alone during the iterative loop, 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. This second cycle of recurrent processing is likely to lead to perception of the mask alone or to perception of the mask with a partially and indistinctly seen target.

According to Di Lollo, Enns and colleagues (Di Lollo et al., 2000; Enns & Di Lollo, 1997, 2000; Enns, 2004; Lleras & Moore, 2003; Moore & Lleras, 2005), a signature feature of OSM is its modulation by spatial attention. OSM is claimed to occur only when attention cannot be rapidly focused, or pre-focused, upon the target location. A central assumption in support of the role of attention is that mask duration (after target offset) interacts with the set size of the search array, the effect of each being stronger as the other increases (e.g. Enns & Di Lollo, 1997; Di Lollo et al. 2000; Tata, 2002; Enns, 2004; Goodhew et al., 2012). According to Di Lollo et al. (2000) this is because set-size effectively determines the speed with which attention can be focused on the target within the search array. A target presented in isolation, for instance, can enjoy recurrent processing free of distractor interference. All available attentional resources can be directed to target processing, thereby ameliorating the effects of the trailing mask.

Argyropoulos, Gellatly Pilling & Carter (2012) reviewed the literature on set size and masking and commented that although an interaction between set size and mask duration is promoted as the hallmark of OSM (Di Lollo et al., 2000; Goodhew et al., 2011, 2012; Kotsoni et al., 2007), the actual evidence for it was surprisingly sparse. On the basis of their own experiments, Argyropoulos et al.showed that while set-size and mask duration independently influence the perceptibility of a target in OSM displays, the two factors do not interact. It was argued that the multiplicative relationship previously reported by Di Lollo and colleagues may have been artifactual. In forced-choice tasks, such as discriminating the orientation of a Landolt

C, it resulted from ceiling and/or floor effects present in the data which constrained the measurable range of performance. When these limiting effects were avoided, Argyropoulos et al. showed that no interaction ensued. Further evidence of set size influencing OSM had been reported by Di Lollo et al (2000) in the context of a present/absent task. Argyropoulos et al.showed that when performance on target absent trials was held sufficiently below ceiling such that a meaningful guessing correction could be applied to the target present data, the apparent interaction in those data was eliminated. As before, both set size and mask duration strongly affected performance but they did so only independently (see also Jannati, Spalek & Di Lollo, 2013, for further confirmatory evidence of the independence of set size and mask duration in OSM).

The lack of interaction between set size and mask duration found by Argyropoulos et al. (2012) is consistent with spatial attention having no effect on OSM. However it is not definitive evidence. In the first instance, it must be noted that even when a target was presented alone by Argyropoulos et al., there was spatial uncertainty as to its location in each array. This means that attention would have to be distributed across multiple locations prior to target onset, a point recently made by Goodhew and colleagues about the Argyropoulos et al. findings in their recent review of the OSM literature (Goodhew, Pratt, Dux & Ferber, 2013). Furthermore, though set size manipulations are generally considered to be a proxy for manipulations of the spatial distribution of attention, this assumed relationship is certainly not without challenge. It has been suggested that set size effects are often attributable to factors which are associated with other changes when item number is increased, such as in probable stimulus location, distractor proximity and the amount of visual information. Set size effects have been argued to be a consequence of low level factors such as changes in stimulus eccentricity (Carrasco, Evert, Chang, & Katz, 1995; cf. Wolfe, O'Neill & Bennett, 1998), increased lateral inhibition (Pöder, 2004), or other visual processes such as crowding (e.g. Palmer 1994; Pelli & Tillman, 2008), priming preparation (Zelinsky, 1999), or increases in the level of visual noise (Magyar, Van den Berg & Ma, 2012).

We will be reporting a set of experiments in which we unpack the effect of set size from other potential confounding factors in a separate forthcoming paper (Argyropoulos, Pilling & Gellatly, submitted). However, for now it is important to note that the relationship between set size and attention is rather less straightforward than might initially have been thought. It can therefore be stated that the absence of set size effects does not, by itself, rule out a role for attention in OSM in the manner described by Di Lollo et al. (2000).

More direct evidence in support of the role of attention in OSM has been presented from studies which manipulate attention through the introduction of a spatial cue prior to the onset of the target. In such work it has been claimed that OSM is substantially weakened or even abolished entirely when a cue allows attention to be pre-focused on the target (e.g. Di Lollo et al. 2000; Tata, 2002; Enns, 2004; Luiga and Bachmann, 2007; Germeys, Pomianowska, De Graef, Zaenen & Verfaillie, 2010). Argyropoulos et al. (2013) also reviewed the literature on the effect of spatial pre-cueing on OSM. It was noted that in all cases these earlier studies were either subject to ceiling artifacts or open to alternative interpretations. For instance, in Di Lollo et al. (2000, Exp 6) target location was pre-cued by having a four dot mask (FDM) onset prior to the target array which served both to indicate the target and to mask it. Di Lollo et al found for all set sizes tested that performance improved as pre-cue duration increased, with the two factors interacting. However, they did not vary mask duration, therefore their finding is only that cueing enhances performance with a particular mask duration, not that OSM is reduced by pre-cued attention. Furthermore, the near-ceiling level accuracy they observed for set size one for pre-cue durations beyond zero mean their interaction was most likely artifactual, an argument that applies also to the study by Germeys et al. (2010). Moreover, as Argyropoulos et al. noted, the introduction of an asynchrony between target and mask onsets is known to reduce OSM even where the asynchrony is uninformative as a spatial cue (Gellatly et al., 2010; Guest et al, 2012; Lim & Chua, 2008; Neill et al, 2002; Tata & Giaschi, 2004). Indeed this temporal asynchrony effect seems to occur because it prompts the visual system to individuate the target as a separate object independent from the mask, a finding consistent with the object updating hypothesis account of OSM (Lleras & Moore, 2003; Moore & Lleras, 2005).

Thus, current evidence about the role of spatial cueing on OSM is not conclusive and requires further examination. In the present paper we report five experiments which examine the effect upon OSM of direct manipulations of spatial attention using different kinds of pre-cue and different sorts of search display. There are several important reasons for conducting such a study. First, there is a clear theoretical basis for it. The claim that attention exerts a modulatory influence on

OSM is central to the recurrent processing theory of Di Lollo et al. (2000), which is implemented in a computer simulation, and has also been said (Oriet & Enns, 2010) to be crucial to the up-dating account of OSM. If no such modulatory influence is revealed by our data, this will indicate a need for theoretical revision. Second, there is the demand of empirical consistency. As just noted, the findings of Argyropoulos et al. are based on implicit manipulation of attention and so provide only indirect evidence that it does not modulate OSM. It is important to check whether evidence from an explicit manipulation of attentional focus will yield findings consistent with the indirect evidence. Thirdly, the assumption of a central role for attention has informed the interpretation not only of much behavioural data but also of most, if not all, brain imaging studies of OSM to date. Should that assumption be brought into question, the brain imaging results will in many cases require re-interpretation.

The experiments reported here were approved by the ethics committee of Oxford Brookes University (OBU). All participants reported normal or corrected-to-normal visual acuity; they gave informed consent and had been pre-warned that they should not take part if they had a medical history of epilepsy or visual migraine. Testing sessions lasted approximately 40 minutes.

Experiment 1

Previous studies of pre-cueing in OSM cued the target location on every trial and compared the effect of varying the relative onset times of cue and target object (pre-cueing, simultaneous cueing or post-cueing). In Experiment 1, by contrast, cue validity was manipulated (Posner, 1980). Performance was compared when either the target location was precued (i.e., a valid cue) and when a distractor location was precued (an invalid cue). Each item in the search display appeared inside an outline box, one of which 'flashed' briefly prior to onset of the display (see Figure 1), Because having attention directed away from the target location is supposedly a pre-requisite for obtaining OSM, it was expected masking would be obtained for invalid cue trials, with performance lower when FDM trailed target offset than when it offset simultaneously with the target. Of interest was whether OSM would be reduced, or even eliminated, for valid cue trials.

Pilot work suggested that if target and distractor items were drawn from the same conceptual category (e.g. all were digits), there was a tendency on invalid cue trials for observers to report the item that had been cued rather than the item inside the FDM. To obviate this confound, distractors in Experiment 1 were all 'X's whereas the target was one of the digits from 0 to 9. Participants were instructed simply to report the lone digit in the display; thus their attention was explicitly drawn neither to the flashing box nor the FDM in which the target digit appeared.

Method

Design and Participants

The experiment had a within-participants design with two factors, cue validity with 2 levels (valid, invalid), and trailing mask duration with 3 levels (zero [simultaneous offset of dots and display items], 60 ms, 180 ms). Twenty individuals from Oxford Brookes University (15 female) participated in part-fulfillment of a course requirement.

Stimuli and Apparatus

In this and the four following experiments, the stimuli were presented on a 20-inch *Sony Trinitron* CRT running at 100Hz, viewed from 113cms in a dimly lit and sound attenuated room. All stimuli were black (0.3 cd/m^2) on a white background (97 cd/m^2) apart from the outline boxes of Experiment 1 which were light grey (72 cd/m^2). Search display items for Experiments 1, 2, 4 and 5 were presented in Arial font. Experiments 1, 2, 3 and 5 were controlled by software routines written in *BlitzMax* (V. 1.44; Sibley, 2006).

Procedure

The trial sequence is shown in Figure 1. Trials began with a 900 ms blank screen followed by the fixation cross surrounded by four outline square boxes (subtending an angle of 3.65°) at the four cardinal positions for 350 ms. One grey box then briefly became black for 50 ms, followed by a 50 ms cue-target interval (CTI). The search display then appeared for 40 ms, followed by the dot mask alone for 0, 60 or 180 ms, then the fixation display until response. The search display consisted of 'X's in three boxes and a digit (0-9) surrounded by four dots in the fourth box. The distance from the centre of fixation to that of display items was 4.82°; the items were 0.51° in height; the four dots were 0.06° in diameter and created a notional square of side 1.01°; see Figure 1 for displays and trial sequence. The task was to report the identity of the digit by pressing the corresponding key on a standard keyboard. Error feedback in the form of an auditory tone followed each response. Responses initiated the next trial. For each mask duration there were 40 trials with a valid cue and 120 trials with an invalid cue. This gave a cue validity of 25% across the 480 randomly ordered trials. For all experiments, the experimental session was preceded by verbal instructions, demonstration trials with slowed display sequences, and 40 practice trials.

*****Insert Figure 1 about here*****

Results and Discussion

Mean scores are shown in Figure 2. No participant scored higher than 83% or lower than 37% in any condition, showing that the data are free of ceiling and floor effects (chance = 10%). Performance decreased with trailing mask duration and was lower for invalidly cued than for validly cued trials. A 2-way repeated measures ANOVA gave significant main effects for validity, $F(1, 19) = 9.99$, $MS_{error} = 33.10$, $p < .01$, partial $\eta^2=.345$ and mask duration, $F(2, 38) = 27.52$, $MS_{error} = 28.31$,$p < .001$, partial $\eta^2=.592$. Critically, – and in contrast to various previous reports of the effect of spatial attention on OSM– there was no interaction of the factors: $F(2,38) = 0.45$, $MS_{error} = 26.60$, $p = .641$. Post hoc analyses (Tukey's LSD) indicated performance with a 180 ms mask duration differed from both the 60 ms ($p<.01$), and zero ms conditions ($p<.001$), which also differed from each other ($p<.001$).

*****Insert Figure 2 about here*****

The results of Experiment 1 challenge the view that spatial attention modulates OSM. When attention was pre-cued to the target location performance was better than when it was invalidly pre-cued to a distractor, indicating that the pre-cueing procedure was sufficient to affect performance on the task. Yet there was no interaction with mask duration, showing that the modulatory effect of attention was equivalent for all mask durations. Directing spatial attention towards or away from the target affected overall performance but it did not modulate OSM. This result conflicts with results from a number of previous studies that manipulated spatial attention to the target. Why should this be so? Aside from the possibility that attention really does not modulate OSM, could our failure to find an interaction have resulted from something to do with the cueing procedure we used and the comparison we made between valid and invalid cue trials? Other investigators only ever cued the target location, either before or simultaneously with target onset. Although there seems to be no reason in principle why this method of pre-cueing should reveal effects of attention not obtainable with the valid/invalid procedure, it is true that the cue validity effect in Experiment 1 was quite small, producing an average difference in accuracy of less than 4%. Since cue validity was only 25%, it is possible observers may have tried (with only partial success) to ignore the cue. Perhaps the attentional cueing effect was simply not strong enough to interact with mask duration. We therefore tested for this possibility by conducting Experiment 2, which used similar stimuli to Experiment 1 but a different pre-cueing technique.

Experiment 2

Although Experiment 1 yielded clear-cut results, the cueing effect, though highly significant, was relatively small. This is not surprising given that some investigators have claimed Posner cueing does not affect target discrimination tasks (e.g. Prinzmetal, Park & Garrett, 2005), though others have reported a robust cue validity effect for such tasks (e.g. Liu, Pestilli, & Carrasco, 2005). We, therefore, conducted a second experiment in which attention was manipulated by cueing the target location either simultaneously with or shortly before target onset. There is a large literature reporting strong effects of this kind of cueing procedure (Eriksen & Hoffman, 1972, 1973; Colegate, Hoffman & Eriksen, 1973). The cue was a line from fixation to the target location and its onset preceded target onset by zero ms or 150 ms. The line was both an endogenous cue to the target location and, due to illusory line motion away from fixation (Hikosaka, Miyauchi & Shimojo, 1993), an exogenous cue.

In many studies of OSM, a FDM serves both to cue the target and to mask it. It is useful to separate these functions in the present context because we want to study the effect of the line cue as its onset time varies in relation to target onset without the complication of having the target also cued by an FDM that 'popped out' of the display. We, therefore, presented all search display items inside FDMs. This then raised the question of whether, on trailing mask trials, distractor FDMs should disappear along with the search display items or stay on for the same duration as did the target's FDM. In other words, should distractors as well as targets be masked or only the latter? Given that Argyropoulos et al. (2012) found that set size has no influence on the extent of OSM – OSM was the same with 15 distractors or none – there are a priori grounds for supposing that it should make no difference whether or not distractors are masked. To test whether or not this would prove to be the case, we ran separate blocks of trials in which FDMs surrounding distractors either always disappeared along with the search display or else always had the same duration as the FDM surrounding the target. The order of these trial blocks was counterbalanced across observers.

Method

Design and Participants

The experiment had a mixed design with four factors. The between participants factor was the order in which trials with or without distractor masking were presented (masked/unmasked, unmasked/masked). The three within-participant factors were distractor masking with two levels (distractors masked/unmasked) cue-target onset asynchrony (CTOA) with 2 levels (zero, 150 ms) and trailing mask duration with 2 levels (zero ms, 180 ms). Twenty four participants (14 female) as previously described, but including also authors AG, MP and YA, performed the experiment.

Stimuli

The search display contained one digit and seven Xs, the centre of each item positioned on a virtual circle of radius 4.82°. Each of these stimuli was surrounded by four dots (see Figure 3). Digits, Xs and the four dots were of the same dimensions as in Experiment 1. The straight line radial cue (3.20°) was one pixel in width. Target and cue locations were randomized within the constraints of the experimental design.

*****Insert Figure 3 about here*****

Procedure

Each trial began with a 900 ms blank screen followed by a fixation cross for 350 ms. On non-zero CTOA trials the cue then appeared for 150 ms before the search display was added; on zero CTOA trials cue and search display appeared simultaneously. The search display was presented for 40 ms, and followed by the dot masks for 0 ms or 180 ms, followed by the fixation display again until response (see Figure 3). Aural error feedback followed each response, which initiated the next trial. There were two blocks of 160 trials. Half of participants began with a block of trials with unmasked distractors, followed by a block with masked distractors; the other half underwent the opposite assignment of trial blocks. Trials within each block were in random order, 40 for each combination of mask duration and CTOA.

Results and Discussion

Mean scores are shown in Figure 4. No participants scored higher than 88% or lower than 25% in any condition. Performance was higher with a pre-cue (150 ms CTOA) than without (zero ms CTOA) and decreased as mask duration increased, but there was little difference between conditions with masked and unmasked distractors. The data were analysed using a 3-way repeated measures ANOVA. There was no main effect of *distractor masking condition* (masked, unmasked; F=0.26, p=.614),. but that there were significant main effects of CTOA, $F(1, 23) = 185.97$, $MS_{error} = 54.50$, $p < .001$, partial $\eta^2=.89$); and trailing mask duration, $F(1, 23) = 123.60$, $MS_{error} = 32.26$, $p <.001$, partial $\eta^2=.843$). Critically, as in Experiment 1, there was no hint of a CTOA ×mask duration interaction: $F(1,23) = 1.11$, $MS_{error} = 42.45$, $p= .30$). There was however, a significant *distractor masking condition* × *mask duration* interaction: $F(1,23)=6.31$, $p<.05$, partial $\eta^2=.215$). This reflected the fact that more masking resulted when the target alone had a trailing mask compared to trials when distractors also had a trailing mask. No other interactions were significant (max. $F=2.24$, $p=.148$)

*****Insert Figure 4 about here*****

The interaction between distractor masking condition and trailing mask shows that OSM was proportionally weaker when the trailing mask was given at all locations than when given only at the target location. This could point to an influence of distractor processing on masking; it is possible that perceptual interference from the ‘X’s present when only the target was masked was reduced when the ‘X’s themselves were being masked leading to less OSM. Another possibility, one consistent with the finding of Argyropoulos et al. (2012), is that the effect of having trailing masks at distractor locations has nothing to do with distractor interference, but with the salience of the trailing mask stimuli. Tata and Giaschi (2004, Experiment 1) similarly report reduced OSM when, in addition to the target, distractor items were also surrounded by a trailing mask. They argued, based on that and other findings, that the presence of a single trailing mask was more likely to capture attention from the target towards the mask in an involuntary manner than when several trailing masks were present at several display locations. The same process could explain the effect of distractor mask condition on OSM observed in our task.

However, the focus of our paper is not to explore attentional capture by the trailing mask object but if and how spatial attention, manipulated by spatial pre-cuing, influences OSM. Experiment 2, like Experiment 1, indicated no significant effect of pre-cueing on masking. Thus, the results of Experiment 2 suggest the lack of an interaction between cue validity and mask duration in Experiment 1 did not result from use of the valid/invalid cueing procedure rather than a pre-cue/simultaneous cue procedure. As with Experiment 1, the data of Experiment 2 militate against the idea that spatial attention modulates OSM. When attention was pre-cued to the target location, participants were much better able to report the identity of the digit target. But this was equally the case for both mask durations. Once again, spatial attention affected performance but not OSM.

It is usual in studies of OSM for targets and distractors to be drawn from a single conceptual category, the members of which share the same limited set of physical features. We elected to break with this tradition (digit target, 'X' distractors) for the reason given in the introduction to Experiment 1. However, it could be argued that this decision was influential in determining the pattern of results obtained in both our first two experiments. In a series of papers, Ghorashi and colleagues (Ghorashi, Enns, Spalek & Di Lollo, 2009; Ghorashi, Spalek, Enns & Di Lollo, 2009; Ghorashi, Enns, Klein & Di Lollo, 2010 have argued that in rapid serial visual presentation tasks uncertainty as to target location and uncertainty as to target identity are resolved by different forms of attention, *where* and *what* systems Similar to this proposal is that stated by Argyropoulos et al. regarding why Gellatly et al. (2006) found that pop-out on a task irrelevant dimension does not reduce OSM whereas pop-out of a task relevant dimension does. The former could be said to engage spatial (where) but not identity (what) attention, with the latter engaging the identity system and possibly also the spatial system. There may be circumstances in which the two may share resources or else operate independently of one another (Ghorashi et al, 2009: Visser, 2011). It is possible that in Experiments 1 and 2 target and distractors were sufficiently distinct that target identification was achieved very easily, without calling upon resources that would have to have been shared with spatial attention.

One way in which this might have happened is if distractor suppression based on physical features played a greater role in Experiments 1 and 2 than is usual in OSM studies. Potentially, observers could have inhibited processing of diagonals at a featural level, so freeing resources for processing of the only search display item not (usually) containing any, i.e. the target. Since OSM seems to occur after the processing of physical features (Binsted et al, 2007; Woodman &Luck, 2003) but before processing at a category level (Chen & Treisman, 2009) this could be consistent with the absence of any effect of distractor masking. According to Di Lollo et al., focused attention reduces OSM by reducing distractor interference with target processing. But if in Experiments 1 and 2 distractor processing was already being suppressed, due to a top down strategy adopted by participants, then there may no longer have been a means by which attentional focus could modulate the extent of OSM. Therefore, in order to test the generality of our finding of no interaction between attentional cueing and mask duration, we next conducted an experiment using the kinds of cueing and target-distractor relations more typically employed in

OSM studies. We also included extra levels of the pre-cue and mask duration factors, similar to in Experiment 1, in case this would increase the probability of finding some evidence of an interaction.

Experiment 3

Targets and distractors in Experiment 3 were all digits. As in Experiment 2, we wanted to study the effect of the line cue as its onset time varied in relation to target onset without the complication of having the target also cued by an FDM that 'popped out' of the display. We, therefore, presented all search display items inside a FDM. Either all FDMs offset with the search display items or else they all stayed on for a given duration.

Method

Design and Participants

The experiment had a within-participants design with two factors, cue-target asynchrony (CTOA) with 3 levels (zero, 50 ms, 150 ms) and trailing mask duration with 3 levels (zero, 60 ms and 180 ms). Twenty participants (17 female) as previously described performed the experiment.

Stimuli

The search display contained eight digits in a virtual circle of radius 4.82°, each surrounded by four dots (see Figure 5). Digits and the four dots were of the same dimensions as Experiment 1. The straight line radial cue (3.20°) was one pixel in width.

Procedure

Each trial began with a 900 ms blank screen followed by a fixation cross for 350 ms. On non-zero CTOA trials the cue then appeared for 50 or 150 ms before the search display was added; on zero CTOA trials, cue and search display appeared simultaneously. The search display was presented for 40 ms, and followed by the dot masks for 0, 60 or 180 ms, followed by the fixation display again until response (see

Figure 5). Aural error feedback followed each response, which initiated the next trial. There were 360 trials in random order, 40 for each combination of mask duration and CTOA.

*****Insert Figure 5 about here*****

Results and Discussion

Mean scores are shown in Figure 6. No participants scored higher than 92% or lower than 25% in any condition. Performance decreased with decreasing CTOA and increasing mask duration. A 2-way repeated measures ANOVA showed both main effects were significant: CTOA, $F(2, 38) = 43.54$, $MS_{error} = 81.01$, $p < .001$, partial $\eta^2 = .696$); trailing mask duration, $F(2, 38) = 14.96$, $MS_{error} = 95.33$, $p < .001$, partial $\eta^2 = .441$). But as in Experiments 1 and 2, there was no hint of an interaction between these two factors: $F(4,76) = 0.77$, $MS_{error} = 44.15$, $p = .548$. Post hoc analyses (Tukey's) indicated that overall the zero pre-cue condition differed from both the 50 and 150 ms conditions (both $p<.001$), which also differed from each other, ($p<.01$); the 180 ms mask duration condition differed from both the 60 ms ($p<.05$) and zero ms conditions ($p<.001$), which also differed from each other ($p<.01$).

*****Insert Figures 6 about here*****

As with Experiments 1 and 2, the data of Experiment 3 question the idea that spatial attention modulates OSM. When attention was pre-cued to the target location, participants were more able to report the identity of the target. This was equally the case for all mask durations. Once again, spatial attention affected only overall performance and not OSM. This result contradicts those of a number of previous investigators, and we will consider later on what reasons there might be for such conflictingly different results. For the moment, it is worth noting that the data of Experiment 3 might be taken to show that it makes little difference whether distractors differ from the target on simple physical characteristics ('X' distractors versus a digit target in Experiment 2) or only in terms of categorical identity (all items are digits as in Experiment 3). However, it might also be argued that on masking trials in Experiments 2 and 3 there were effectively no distractors as the distractors were either being masked along with the target (Experiment 3, Experiment 2 masked distractors block) or else inhibited at a featural level (Experiment 2 unmasked distractor block). On this view, distractor interference from unmasked distractors on control trials could have been as great as or greater than interference from masked or inhibited distractors on masking trials. The relatively shallow slope of the masking (that is, mask duration) functions in Figures 4 and 6 are consistent with this possibility. Perhaps there was not enough variation in performance levels across mask durations and pre-cue conditions for an interaction to emerge. This seems an unlikely possibility given that the slope of the functions in Experiments 1 and 2 was similar to the slope in Experiment 3 and that, though modest by comparison with some examples of OSM (e.g. Di Lollo et al. 2000; Enns, 2004; Gellatly et al., 2010), these are not out of line with some other reports (e.g. Reiss & Hoffmann, 2006; Guest et al., 2012; Goodhew et al., 2012). However, to guard against this possibility we conducted a fourth experiment using a task we already knew to produce a larger OSM effect.

Experiment 4

Targets and distractors in Experiment 4 were Landolt squares with a gap in one side (Argyropoulos et al, 2013). Participants reported the side of the gap in the target square by pressing the corresponding arrow key on a standard keyboard. Once again, a radial line cue signaled the target location either simultaneously with target onset or shortly beforehand. Also, as in Experiments 2 and 3, search display items all appeared inside FDMs, all of which either offset with the search display items or else stayed on for a given duration, so that on masking trials not only the target but also the distractors could have been subject to the masking effect of a FDM. Experiment 4, therefore, closely resembled Experiment 3 in its design.

Method

Design and Participants

The experiment had within-participants design with 2 factors, CTOA with 4 levels (zero, 50 ms, 100 ms, 150 ms) and trailing mask duration with 3 levels (zero, 60 ms and 180 ms). Twenty-two participants (17 female) as previously described participated; the 3 authors also participated.

Stimuli and Apparatus

Stimuli were eight outline squares with lines of 1.5 min arc thickness. Each side of a square was 0.3^{o}, with a 0.1^{o} gap in one side. The thickness of each masking dot was 3 min arc and the distance between them was 0.5^{o}. The cue line was 1.6^{o} in length and had the same thickness as the dots. The experiment was written in and controlled by Matlab using the Psychophysics Toolbox [PTB-3] extension (Brainard, 1997; Pelli, 1997)

Procedure

The stimulus sequence was essentially as it was for Experiment 3 (see Figure 7 for schematic of sequence). Each trial began with a 1000ms blank screen followed by a 500 ms fixation cross. The target search display, preceded by 0, 50, 100 or 150 ms by the cue line, then appeared for 50 ms. It was followed by a dot mask for 0, 60 or 180 ms. This was followed by a blank display until response, which initiated the next trial. Accuracy feedback was not provided. There were 480 trials in random order, 40 for each combination of mask duration and CTOA.

******Insert Figure 7 about here******

Results and Discussion

Mean scores are shown in Figure 8. Performance decreased markedly with increasing mask duration and was lower for the simultaneous onset cue than for any other CTOA. A 2-way repeated measures ANOVA gave significant main effects of mask duration and CTOA, respectively $F(2, 48) = 247.55$, $MS_{error} = 83.15$, $p < .001$, partial $\eta^2 = .912$ and $F(3, 72) = 17.9$, $MS_{error} = 70.18$, $p < .001$, partial $\eta^2 = .43$). As in Experiments 1 to 3, there was not a significant interaction between the factors, $F(6, 144) = 1.73$, $MS_{error} = 51.30$, $p=.118$. Although the group means for all conditions are substantially below 100% and above chance (25%), there was great variability in the individual data. To ensure the results were not distorted by ceiling or floor effects, we separately analyzed the data of 11 participants who did not score above 90% or below 33% in any condition. This subset showed results very similar to the whole group - $F(2, 20) = 156.51$, $MS_{error} = 63.35$, $p < .001$ partial $\eta^2 = .94$ for CTOA, $F(3, 30) = 13.50$, $p < .001$, $MS_{error} = 51.94$, partial $\eta^2 = .57$) for mask duration, and $F(6,60) = .64$, $MS_{error} = 39.08$, $p=.695$ for the interaction. Post hoc analyses of the complete data set indicated that the zero pre-cue condition differed from all other pre-cue conditions, ($p<.001$), which did not differ from each other, (min. $p = .135$)[1]; and that performance with a 180 ms mask duration differed from both the 60 ms and zero ms conditions, (both $p<.001$), which also differed from each other ($p<.001$). Consistent with our expectation, Experiment 4 yielded a large OSM effect, as seen in the steep slope of the functions in Figure 8. But though the effect of mask duration is much greater than in the preceding two experiments and while pre-cueing once again has a highly reliable effect on performance, the two factors still do not interact. Once again, a manipulation of spatial attention did not modulate OSM.

*****Insert Figure 8 about here*****

If obtaining a strong OSM effect requires that there is a high level of interference from distractor items, then the use of masked distractors in Experiment 4 should have made it impossible to obtain strong OSM. In fact, however, the OSM effect is actually stronger than in comparable experiments by Argyropoulos et al (2013) which used identical displays except for the line cue and FDMs surrounding distractors. However, because it still might be argued that masking all display items on masking trials is not usual in OSM experiments, we conducted one further

[1] It is curious that, though there was an effect of cueing on performance, the non-zero cueing conditions did not differ from one another while in Experiment 3 there was a clear difference between the 50 and 150 ms cueing conditions. This difference in cue effectiveness may reflect something about the task differences between Experiments 3 and 4 (identification vs discrimination) or about the nature of the stimuli (overlearned digits vs. geometric shapes). However further speculations are beyond the scope of this paper. The important point is that both experiments produced a cueing effect which while affecting overall performance did not interact with masking.

experiment. In the final experiment, we employed only digits as display items, and distractors were never masked.

Experiment 5

Experiment 5 was similar in many respects to Experiment 3. All search display items were digits, two of the same CTOAs and two of the same mask durations were used as in Experiment 3. Each digit was initially surrounded by a FDM, for the reason given in the introduction to Experiment 2, but distractor FDMs always offset with search display items so that distractors were not subject to OSM. A further issue investigated in Experiment 5 was whether distractor homogeneity plays a part in determining the extent of OSM. If distractor interference with target processing is an important factor in OSM, then it might be expected that heterogeneous distractors could lead to greater OSM than homogeneous distractors. The distractors in Experiment 2 were all Xs, and so homogeneous as well differing from the target digit physically and conceptually. By contrast, distractors in Experiment 3 were heterogeneous digits that did not differ either physically or conceptually from the target. Both these experiments yielded a modest OSM effect. Experiment 4, however, produced a strong OSM effect with distractors that were certainly not conceptually different from the target. Whether they were heterogeneous or homogenous, and whether or not they should be considered to differ physically from the target depends on the emphasis one gives either to their essential squareness or to the varied orientations of the gaps they contained. In other words, comparing results across Experiments 2, 3 and 4, cannot tell us how distractor heterogeneity/homogeneity affects OSM. To investigate this issue, Experiment 5 included a distractor-type factor: Distractors were either random digits (heterogeneous distractors) or all 7s (homogeneous distractors).

Method

Design and Participants

The experiment had a within-participants design with three factors, distractor type with 2 levels (heterogeneous, homogeneous), cue-target onset asynchrony (CTOA) with 2 levels (zero, 150 ms) and trailing mask duration with 2 levels (zero, 180 ms). Twenty four participants (18 female) as previously described performed the experiment.

Stimuli

Stimulus and display parameters were as described for Experiment 3. The search display contained eight digits, each surrounded by four dots. The dots around distractor items always disappeared with the search items (see Figure 9).

*****Insert Figure 9 about here*****

Procedure

The trial sequence was as described for Experiment 3. There were 320 trials in random order, 40 for each combination of mask duration, CTOA and distractor type (i.e. heterogeneous and homogeneous distractors were not blocked).

Results and Discussion

Mean scores are shown in Figure 10. No participant scored higher than 95% correct or lower than 17% correct in any condition. Performance was better with a pre-cue than a simultaneous cue and decreased with a trailing mask. The effect of the trailing mask was somewhat less for the homogeneous distractors than for the heterogeneous distractors. A 3-way repeated measures ANOVA showed that all three main effects were significant: distractor type ($F[1,23]=7.47$, $MSE=41.84$, $p<.05$, partial $\eta^2 = .245$), CTOA, ($F[1,23]=176.4$, $MSE=87.86$, $p<.001$, partial $\eta^2 = .885$), mask duration ($F[1,23)=161.08$, $MSE=50.52$, $p<.001$, partial $\eta^2 = .875$). Significant two way interactions were found for distractor type × mask duration ($F[1,23]=17.34$, $MSE=27.04$, $p<.001$, partial $\eta^2 = .43$), and CTOA × mask duration ($F[1,24]=4.82$, $MSE=67.51$, $p<.05$, partial $\eta^2 =.173$). No other interactions approached significance (Max. $F=0.16$, $p=.69$).

*****Insert Figure 10 about here*****

The analysis was repeated but with participant accuracy in each condition calculated for trials on which the presented target was not the digit ‘7’. This limited the analysis to trials on which the target ‘popped out’ from (digit 7) distractors on homogeneous trials. In order to maintain parity the same exclusion criteria was applied for both heterogeneous as well as homogeneous trials (note that it meant that the number of trials per data point was reduced from 40 to 36). This reanalysis found essentially the same basic pattern of results. All three main effects were significant distractor type ($F[1,23]=5.55$, $MSE=51.07$, $p<.05$, partial $\eta^2 = .194$), CTOA, ($F[1,23]=139.88$, $MSE=104.81$, $p<.001$, partial $\eta^2 = .859$), mask duration ($F[1,23)=144.66$, $MSE=52.81$, $p<.001$, partial $\eta^2 = .863$). A significant two way interactions was found for distractor type × mask duration ($F[1,23]=20.77$, $MSE=35.79$, $p<.001$, partial $\eta^2 = .475$). The CTOA × mask duration interaction no longer reached significance ($F[1,23]=3.84$, $MSE=80.91$, $p=.062$, partial $\eta^2 = .143$). No other interaction approached significance (Max. $F= 0.59$, $p=.452$).

Unlike in the previous four experiments we did find an interaction between pre-cueing and masking. Thus with the stimulus conditions of Experiment 5 (all items digits, trailing masks around only the target) there is a small but statistically significant reduction in masking when the target is pre-cued. This suggests that attention does play some role when the target is presented in competition with other distractors of the same stimulus category (digits) which themselves are not surrounded by trailing masks. However even then, as can be seen from Figure 10, the effect on OSM is modest, particularly when taken in contrast with the more prominent main effect of pre-cueing across both unmasked and masked trials.

Interestingly distractor type may also have some effect on OSM. OSM was greater when distractors were a heterogeneous rather than a homogenous set of digits. This suggests that having the target pop-out from the display reduced its susceptibility to masking. Others have reported similar findings. Di Lollo et al. (2000, Exp. 5) reported that OSM was greatly reduced when the target was a pop out item amongst homogeneous distractors –a target circle with a vertical line segment in an array of items which only consisted of circles– though interpretation of their finding is hindered by the presence of ceiling effects and the fact that only data for target present trials is given. Tata (2002, Experiment 3) also reports, similar to our Experiment 5, that masking was affected by distractor homogeneity: a target Landolt C presented in an array with other distractor Landolt Cs in different orientations resulted in greater masking than when distractors consisted of completed circles. Similarly Gellatly, et al. (2006) found that a target consisting of a colour or orientation singleton in a display was far less susceptible to OSM than a target which was non-unique within a display, though this factor was found to be important only for judgments made for the pop out dimension. The findings of Gellatly and colleagues suggest that pop out effects on OSM are fundamentally different to spatial cueing effects of the type identified in Experiment 5 in being specific to judgments on the pop out dimension. What this suggests is that pop out serves to increase the salience of the report feature by increasing feature contrast, rather than through drawing attention to the target object in the manner of a spatial cue. Interestingly our data found no hint of a three-way interaction, suggesting that pre-cueing had a similar reductive effect on masking irrespective of whether or not the target was a pop out item within the display. Thus, though pop-out does modulate OSM it is more likely to do so via feature salience than via spatial attention, and its effects seem orthogonal to those of spatial cueing. The weakness of the pre-cuing interaction in comparison with that of feature salience (in terms of relative effect size) seems to further downplay the role of focused attention in OSM

General Discussion

In four of our experiments, using two kinds of cueing and a range of different stimulus items and presentation conditions, we found no evidence that exogenous spatial attention (as manipulated by spatial pre-cueing) modulates OSM. In Experiment 1, a valid but informative pre-cue improved reporting of a digit target among distractor Xs relative to an invalid and uninformative pre-cue but did not modulate the effect of mask duration. In Experiment 2, pre-cueing of the target location enhanced reporting of a digit target among ‘X’s relative to a simultaneous cue but did not modulate the effect of mask duration, whether or not the ‘X’ distractors were also subject to masking. The same benefit of pre-cueing was found in Experiment 3 for reporting a target digit among masked digit distractors, but there was again no interaction with OSM. Experiment 4 used squares with a gap in one side as display items but was otherwise almost identical to Experiment 3; it yielded essentially identical results but with a much stronger OSM effect. Only in Experiment 5 was any statistical relationship found between pre-cueing and masking, and even here the interactions was significant in only one of the two ANOVAs we conducted. However, we now need to consider whether our treatment of our data has been appropriate.

Should accuracy data be log transformed?

While a few authors have reported OSM in terms of values derived from signal detection analysis (e.g. Koivisto, 2012), the vast majority of studies of the topic have calculated the magnitude of OSM from raw accuracy scores. By doing the same here, we have followed the convention in the field. However, Schweickert (1985) has presented a convincing argument that accuracy data should be log- transformed before testing for interactive effects between factors.[2] We, therefore, re-analyzed all our experiments in the same manner as previously but having log transformed the data. For Experiments 1-4, the log transformation did not change the significance level of any interaction term - they all remained non-significant - although in some cases the F-values did show an increase. For Experiment 5, ANOVA of the overall log-transformed scores resulted in increased F-value and significance level for the CTOA × mask duration interaction ($F=15.96$, $p<.01$, partial $\eta2=.41$) as compared to the untransformed data. Additionally, and unlike for the untransformed scores, the interaction was also significant when the analysis was repeated on the data in which '7' trials were excluded ($F=13.03$, $p<.01$, partial $\eta2=.362$). Significance was not changed for any other interactions in either analysis.

The small effect, and in other cases total absence of an effect, of pre-cueing cannot be explained by the spatial cue being ineffective. On the contrary, in many of our five experiments pre-cueing as a factor accounted for a similar, or even greater, proportion of variance as the mask duration itself. Nor is the absence of influence of pre-cueing on masking in some of our experiments (Experiment 1, Experiment 2) explained as a consequence of the target somehow being a 'pop-out' stimulus within the array. In Experiment 5 the 'pop-out' status of the target was manipulated directly and was shown to influence masking but independently of spatial cueing.

Thus pre-cuing *can* influence OSM, but in many cases it has no measurable effect. This is contrasted with the reliable and substantial effect pre-cueing has on overall target processing across all our experiments. This result is consistent with

[2] We thank an anonymous reviewer for drawing this argument to our attention.

recent work looking at how set size affects OSM. Argyropoulos and colleagues found that though the overall perceptibility of the target was reduced when set size was increased, the amount of OSM was always the same. If distractor number does not influence OSM it is, perhaps, no surprise that spatial pre-cuing has only a limited effect.

According to the original re-entrant account of Di Lollo et al. (2000), focusing attention on the target location reduces the number of recurrent processing iterations needed to bind target features into a unified representation because interference from distractors (crowding) is minimized relative to when attention is initially diffused over the display (cf. Di Lollo, 2012). Similarly, with small rather than large set-sizes attention supposedly can be more rapidly focused upon the target, so distractor interference is minimized and target identification enhanced (Di Lollo et al., 2000; cf. Argyropoulos et al., 2012). Processing of a brief target may continue after target offset using a fading memorial representation which, in the trailing mask condition, must compete with information about the presence of mask dots around a blank space. The fewer target processing iterations completed before offset, the longer the period of this competition. Consequently, the more likely it is the representation of the mask alone will either replace that of the target plus mask or else be perceived as a transformation of it - substituting for it in VSTM (Di Lollo et., 2000; Lleras & Moore, 2003; Pilling & Gellatly, 2010; Oriet & Enns, 2010). So focused attention is supposed to reduce OSM by speeding up target identification and thereby shortening the period of competition between processing of the target plus mask memory trace and processing of information that only the mask is present. Our results can be said to strongly support the first part of this prediction but offer only limited support to the second. Attention clearly increases iterative target processing, shown by increased accuracy of reporting the target, but the probability of substitution seems mostly independent of that process.

Our results are largely comparable with findings by Ghorashi and colleagues found in the context of the attentional blink paradigm (Ghorashi, Di Lollo, & Klein, 2007; Ghorashi, Enns, Klein, & Di Lollo, 2010; Ghorashi, Enns, Spalek, &Di Lollo, 2009; Ghorashi, Spalek, Enns, & Di Lollo, 2009; cf. Visser, 2011). What the authors have found was that focusing attention on the target (T2 in the attentional blink) by means of a spatial cue facilitated stimulus identification, however this occurred in a manner additive with the AB effect itself (as manipulated by the T1-T2 inter-target lag). Our results show a similar pattern on stimulus identification, performance is improved by pre-cueing almost irrespective of whether or not a target is masked through OSM. Ghorashi and colleagues argue on the basis of their findings that the spatial selection of a stimulus and the identification of the stimulus should be thought of as functionally separate cognitive processes analogous to the functional separation between 'what' and 'where' associated respectively with the anatomically distinct ventral and dorsal visual pathways (Mishkin, Ungerleider, & Macko, 1983; Milner, Goodale & Vingrys, 2006). One could arguably use the same framework to understand our results. The utilization of spatial cue information to select the target location can be understood to be processed along the dorsal ('where') pathway, the processing of target digit identity being processed along the ventral ('what') pathway. In such a model OSM could be conceived to operate within the ventral stream, rendering masking largely insensitive to spatial attentional manipulations though with overall performance still being affected. What this model does not explicitly formulate, however, is how spatial attention actually operates to modulate processing of a target. A frequent suggestion is that a spatial pre-cue produces enhancement at the indicated display location amplifying the target signal (e.g. Posner, 1980; Carrasco, Williams, Yeshurun, 2009), thus improving the quality of the stimulus representation (Dosher & Lu, 2000; Carrasco, Penpeci-Talgar & Eckstein, 2000). Others argue that spatial attention improves distractor inhibition (Eriksen & Eriksen, 1974; Shiu & Pashler, 1994), reducing the noise in the decision process in which the target is identified (Gould, Wolfgang, & Smith, 2007; Smith & Radcliffe, 2009). We did not specifically seek to tease apart these possibilities; however our data give some indications. Seen across our experiments the effect of spatial cueing seemed broadly similar irrespective of whether distractors were confusable with the target (random digits) or different to the target (e.g. 'X's), and whether distractors were heterogeneous or homogeneous. This seems to indicate that pre-cueing had a fairly limited role in inhibiting distractors or in reducing decision noise associated with distractors.

Perhaps what determines substitution is less the extent to which the target is processed prior to offset but the probability that, subsequently, the trailing mask rather than the target memory trace is attended.[3] If attention remains focused on the target (plus mask) memory trace, it consolidates the target into visual short term memory (VSTM), and/or conscious experience; but if attention switches to the developing representation of the mask alone, it consolidates that into VSTM instead. In our studies, spatial attention may have become focused on the target location by the time of target offset even on invalidly cued trials (Experiment 1) or zero pre-cue trials (Experiments 1 and 2). Hence the probability of attention being directed to the mask alone would be equal for all trial types and, consequently, so would the likelihood of substitution. On this account, spatial attention is a single mechanism that facilitates recurrent object processing, its effects being determined by which object is selected (target or mask). A rather different account of the role of attention in masking has recently been proposed by Smith, Ellis, Sewell & Wolfgang (2010). They posit two mechanisms of attention, an early selection mechanism that enhances processing of a selected stimulus, and a late selection mechanism that increases the rate of transfer of information about that stimulus to VSTM. Imaging studies of the kind already being used to study OSM (Woodman & Luck, 2003; Carlson et al., 2007; Boehler et al, 2008; Prime et al, 2011) offer the best means of distinguishing between our proposal and that of Smith et al. (2010).

Finally, one might ask whether there are conditions in which pre-cueing effects on OSM might be amplified. We think this is a possibility. In all our experiments target and mask occupied the same position and onset in the same frame. It may be that spatial pre-cueing is more effective in ameliorating OSM in displays in which target and mask are in separate locations (Yiang & Chun, 2001) or when the target proceeds the mask in time (e.g. Gellatly, et al. 2010). Here the spatial pre-cue may be more effective at directing attention to the target alone rather, than, as is possibly the case in the current experiments, to a location which contains both the target and mask. If spatial attention can be brought more effectively towards the target this may facilitate the ease with which the target is individuated from the mask as a separate perceptual object, leading – according to the object updating account of OSM (e.g. Moore & Lleras, 2005) - to release from masking. Such questions could be a focus of future research.

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[3] Enns & Di Lollo (1997) allude to a similar point in suggesting that when OSM occurs "..the mask itself appears to be the new focus of object recognition mechanisms." The position in Di Lollo et al. (2000) is also broadly consistent in conceiving of OSM as a competitive process between the emerging representations of the target and mask.

Conclusion

OSM, as initially reported by Enns and Di Lollo (1997) and Di Lollo et al. (2000), remains an intriguing and counter-intuitive type of visual masking and an important tool for investigating the implementation of re-entrant processing in brain networks. There is still much to be learnt from it about how the early stages of processing do or do not result in visual consciousness of a target object and its features. In this paper, we sharpen understanding of OSM regarding the influence of directed spatial attention. We demonstrate that, counter to previous claims, spatial attention often has no influence on OSM. Where an effect was produced it was small. This presents a rather different picture from other claims in the literature where it has been suggested that prior attention entirely abolishes the OSM effect (e.g. Di Lollo et al. 2000; Neill et al., 2002; Enns, 2004). Pre-cueing seems to produce, at best, mild attenuation of OSM, and in many cases has no effect at all.

Our findings are convergent with recent work which, contrary to earlier claims, has indicated that the number of display items does not influence OSM when ceiling and floor effects are avoided (Agryropoulos et al., 2012; Jannati, et al., 2013). Given these combined results, one must acknowledge that attention has a far less privileged role in OSM than was claimed in the original description of the phenomenon (Enns & Di Lollo, 1997; Di Lollo et al. 2000), and in much of the OSM literature to date.

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Figure headings

Figure 1. Stimulus sequence in Experiment 1 showing valid and invalid trials.

Figure 2. Mean accuracy in Experiment 1 for valid and invalid trials with a trailing mask duration of 0, 60 or 180 ms.

Figure 3. Stimulus sequence in Experiment 2 for trials in which the distractors were masked and ones in which the distractors were unmasked (i.e. a trailing mask is present only at the target location).

Figure 4. Mean accuracy in Experiment 2 for trials when the target is spatially pre-cued (150 ms CTOA) or no pre-cued (0 ms CTOA) when the distractors are masked or unmasked. On masked trials the mask(s) trailed for 180 ms.

Figure 5. Stimulus sequence in Experiment 3.

Figure 6. Mean accuracy in Experiment 3 with a spatial pre-cue of 0, 50 or 150 ms (CTOA 0-150) for the three trailing mask durations

Figure 7. Stimulus sequence in Experiment 4.

Figure 8. Mean accuracy in Experiment 4 with a spatial pre-cue of 0, 50, 100 or 150 ms for the three trailing mask durations (0, 60 or 180 ms).

Figure 9. Stimulus sequence in Experiment 5 for trials in which the distractors are homogeneous (all ‘7’s) or heterogeneous (random digits).

Figure 10. Means accuracy in Experiment 5 with a spatial pre-cue of 0 or 150 ms, for trials in which distractors were homogeneous or heterogeneous for masked (180 ms trailing mask duration) and unmasked (0 ms trailing mask duration) trials.

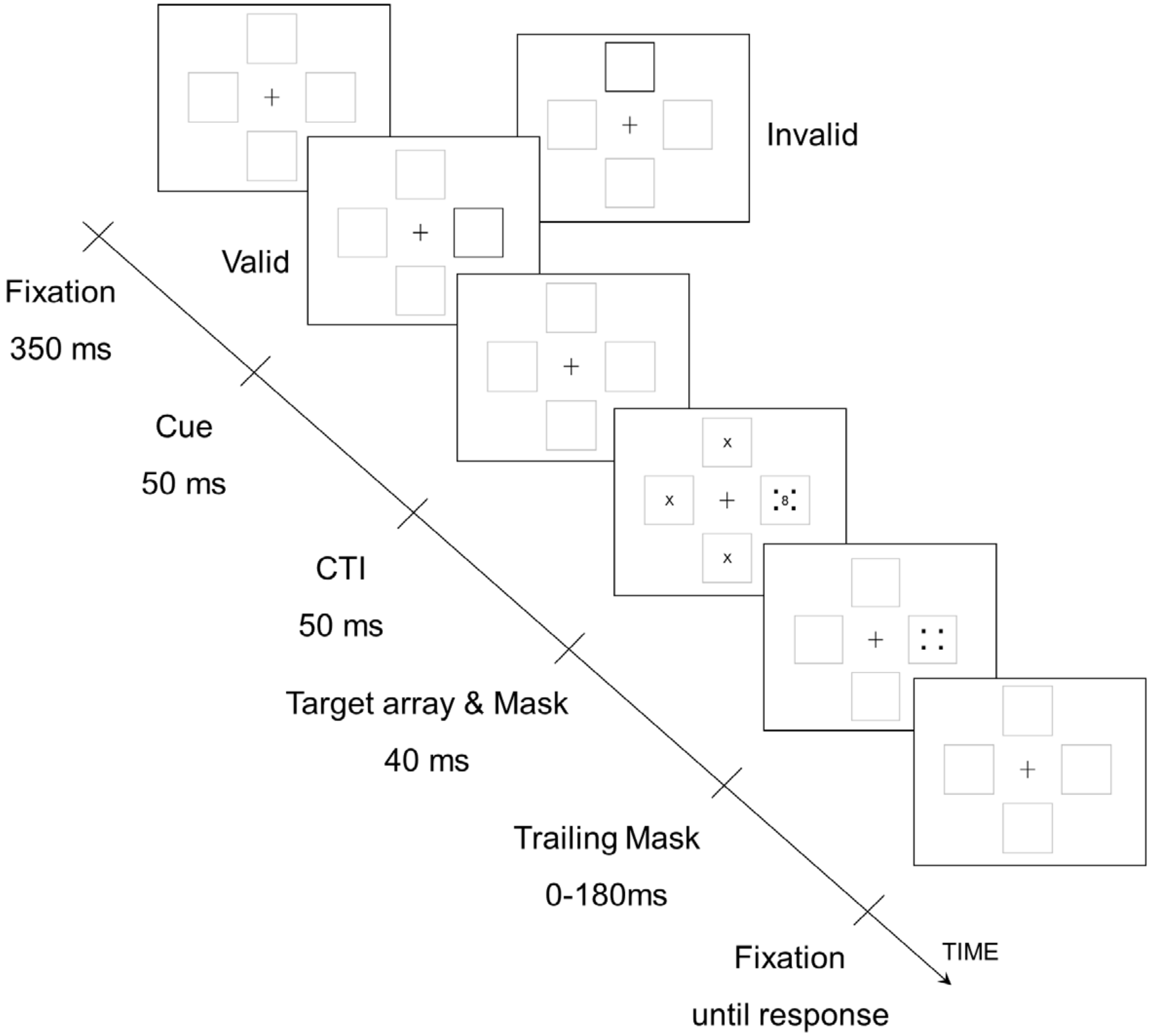
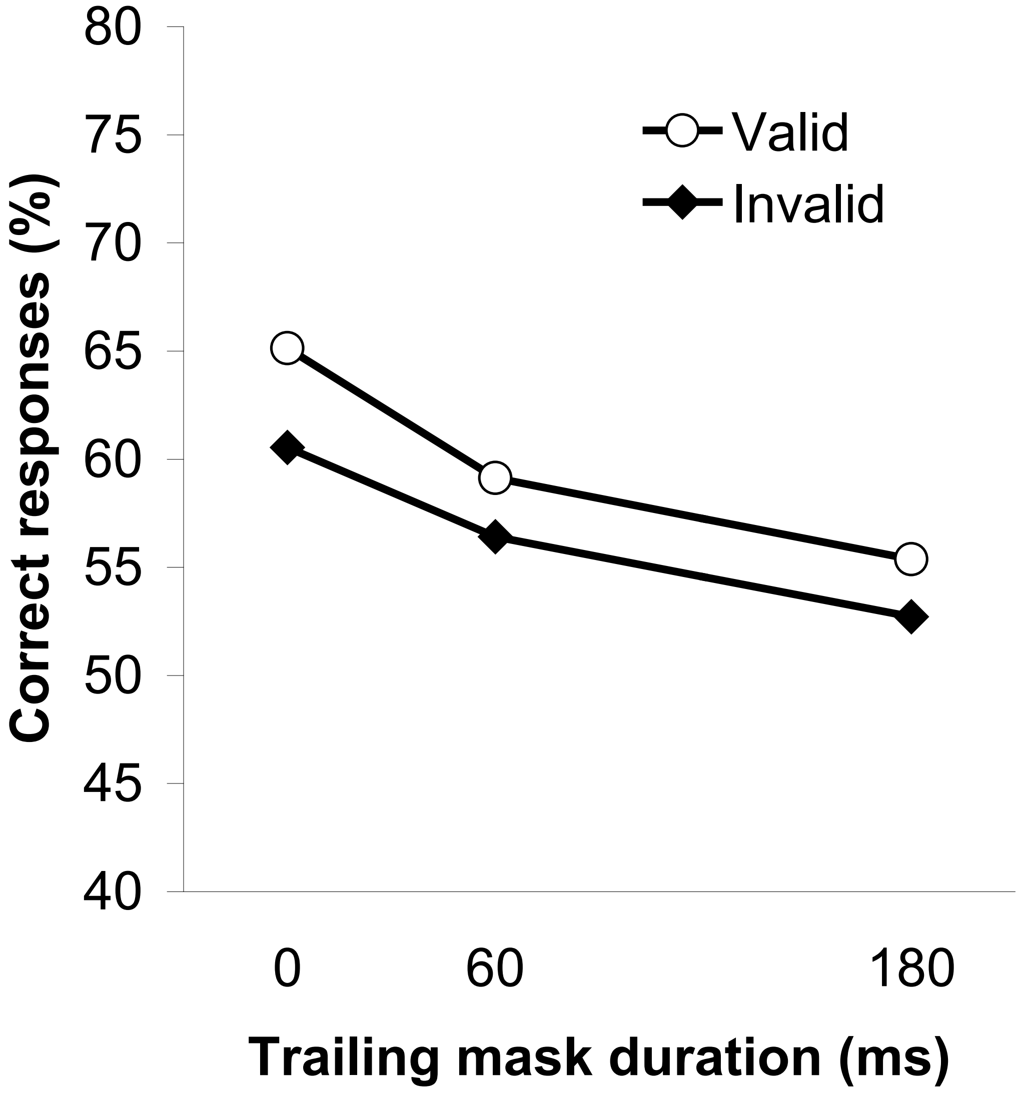

Invalid
Valid
Fixation
350 ms
Cue
50 ms
CTI
50 ms
Target array & Mask
40 ms
Trailing Mask
0-180ms
Fixation
until response
TIME

Figure 1.



80
75
70
65
60
55
50
45
40
Correct responses (%)
Valid
Invalid
0
60
180
Trailing mask duration (ms)

Figure 2.

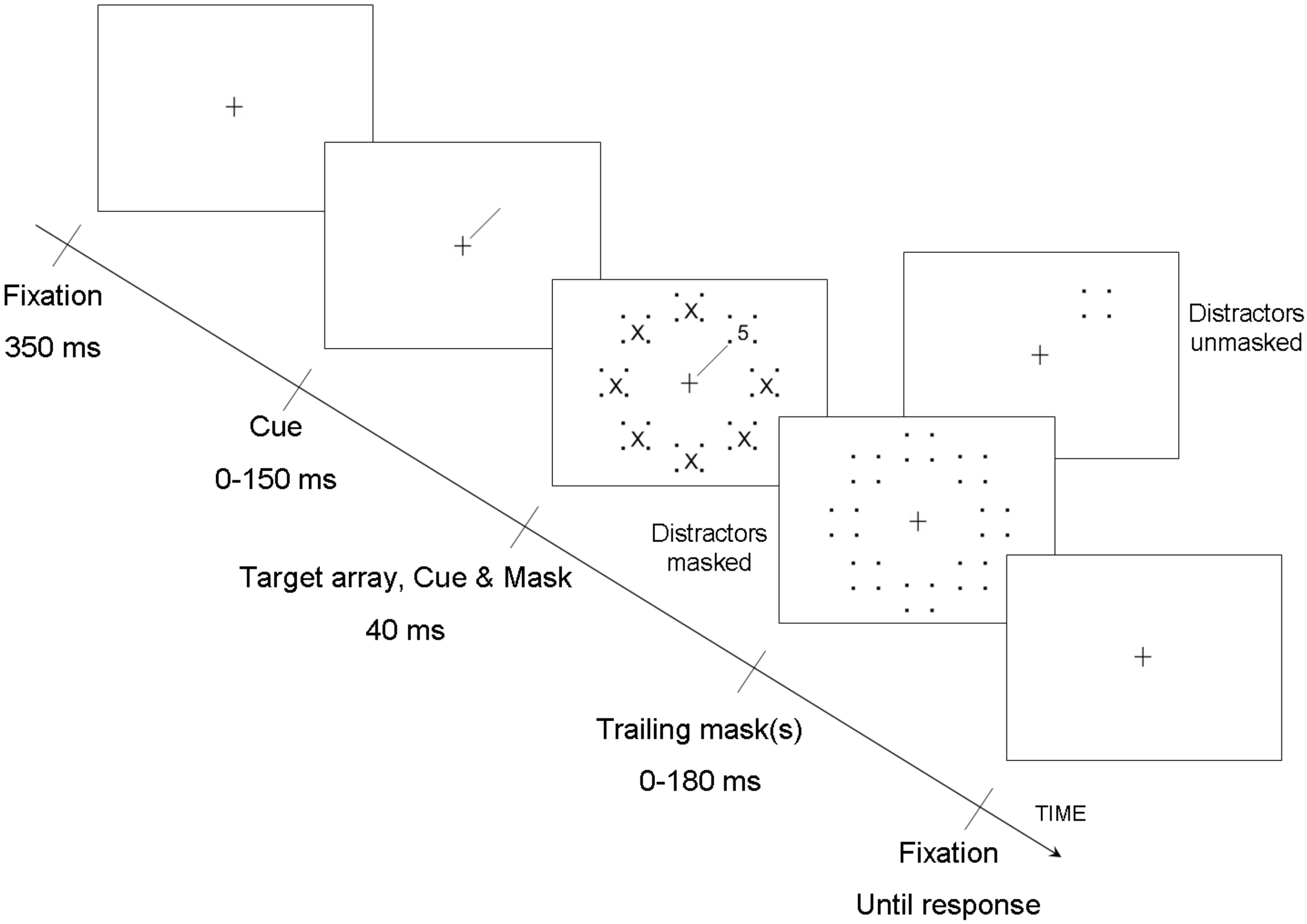

Fixation
350 ms
Cue
0-150 ms
Target array, Cue & Mask
40 ms
Distractors masked
Trailing mask(s)
0-180 ms
Distractors unmasked
Fixation
Until response
TIME
X
5

Figure 3.

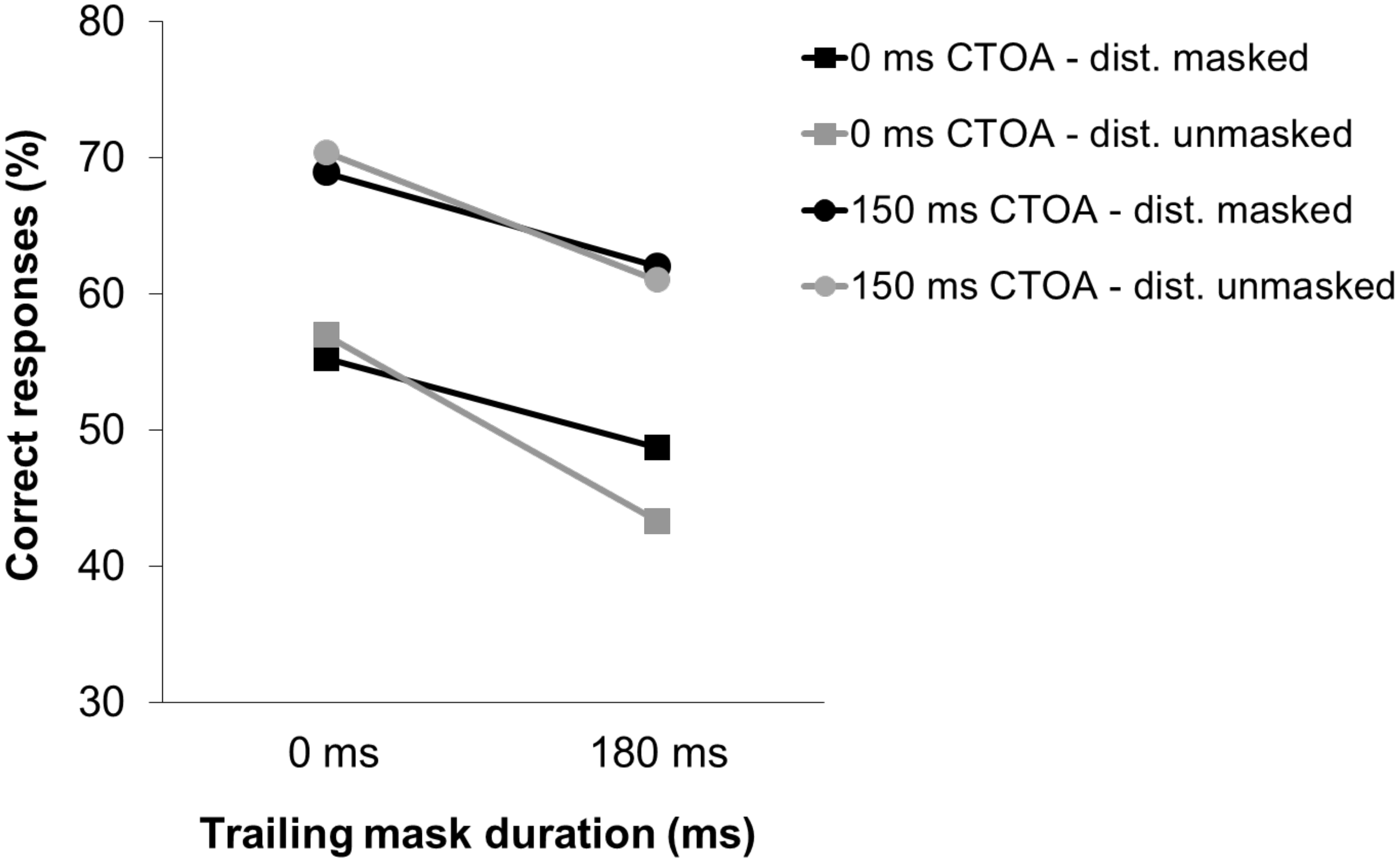
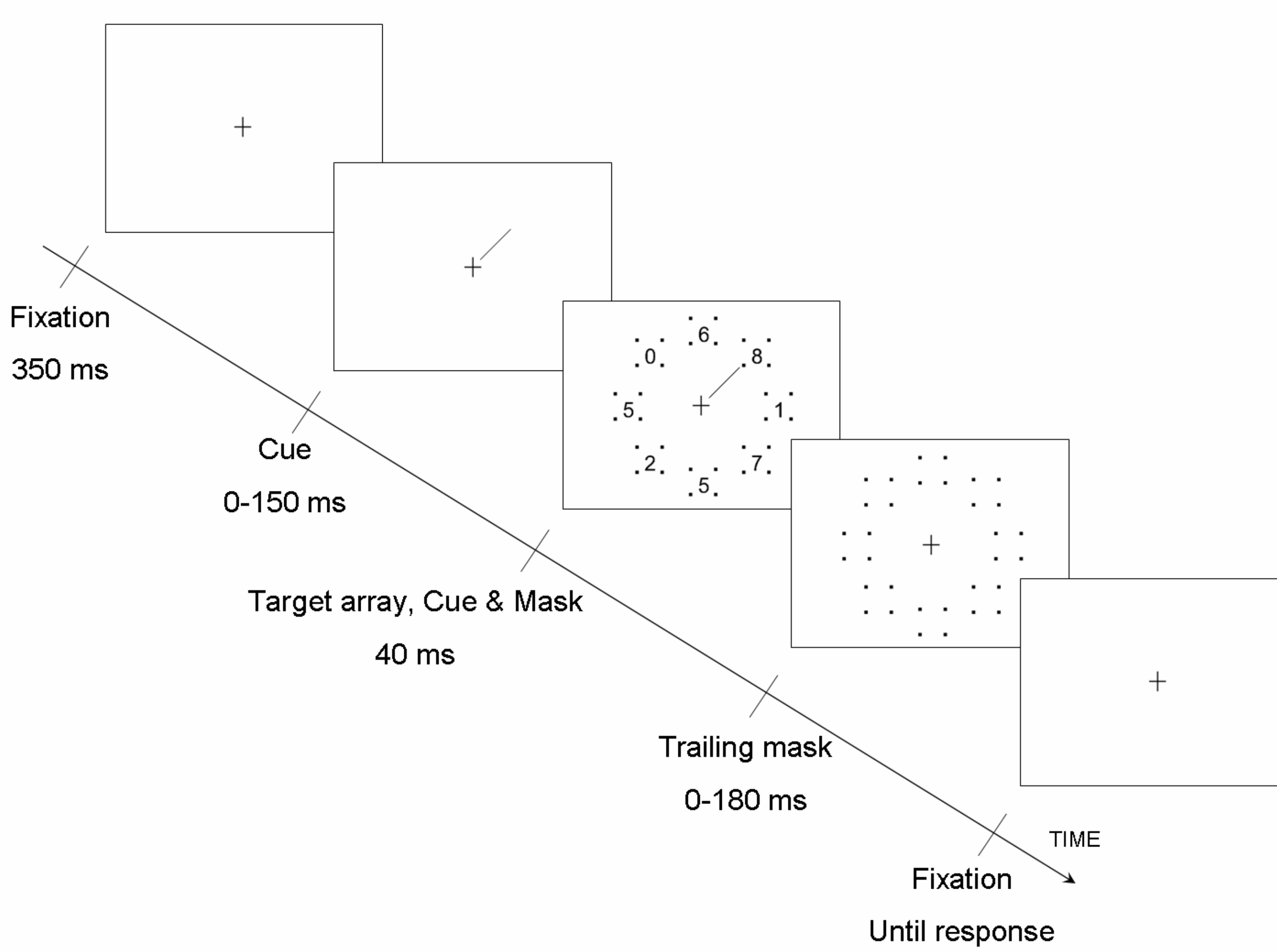

80
70
60
50
40
30
Correct responses (%)
0 ms
180 ms
Trailing mask duration (ms)
0 ms CTOA - dist. masked
0 ms CTOA - dist. unmasked
150 ms CTOA - dist. masked
150 ms CTOA - dist. unmasked

Figure 4.



Fixation
350 ms
Cue
0-150 ms
Target array, Cue & Mask
40 ms
Trailing mask
0-180 ms
Fixation
Until response
TIME
0
6
8
5
1
2
7
5

Figure 5.

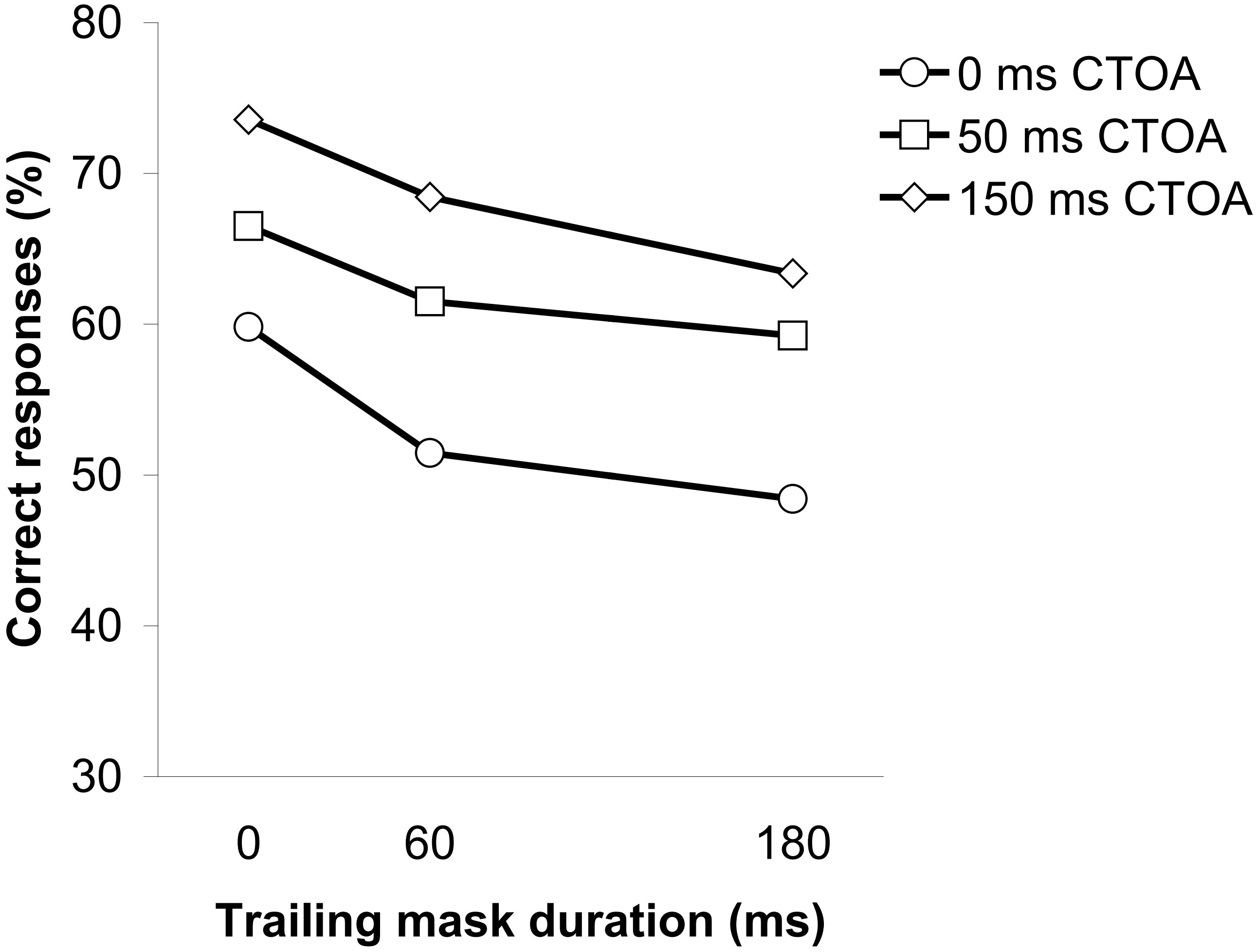

80
70
60
50
40
30
Correct responses (%)
0
60
180
Trailing mask duration (ms)
0 ms CTOA
50 ms CTOA
150 ms CTOA

Figure 6.

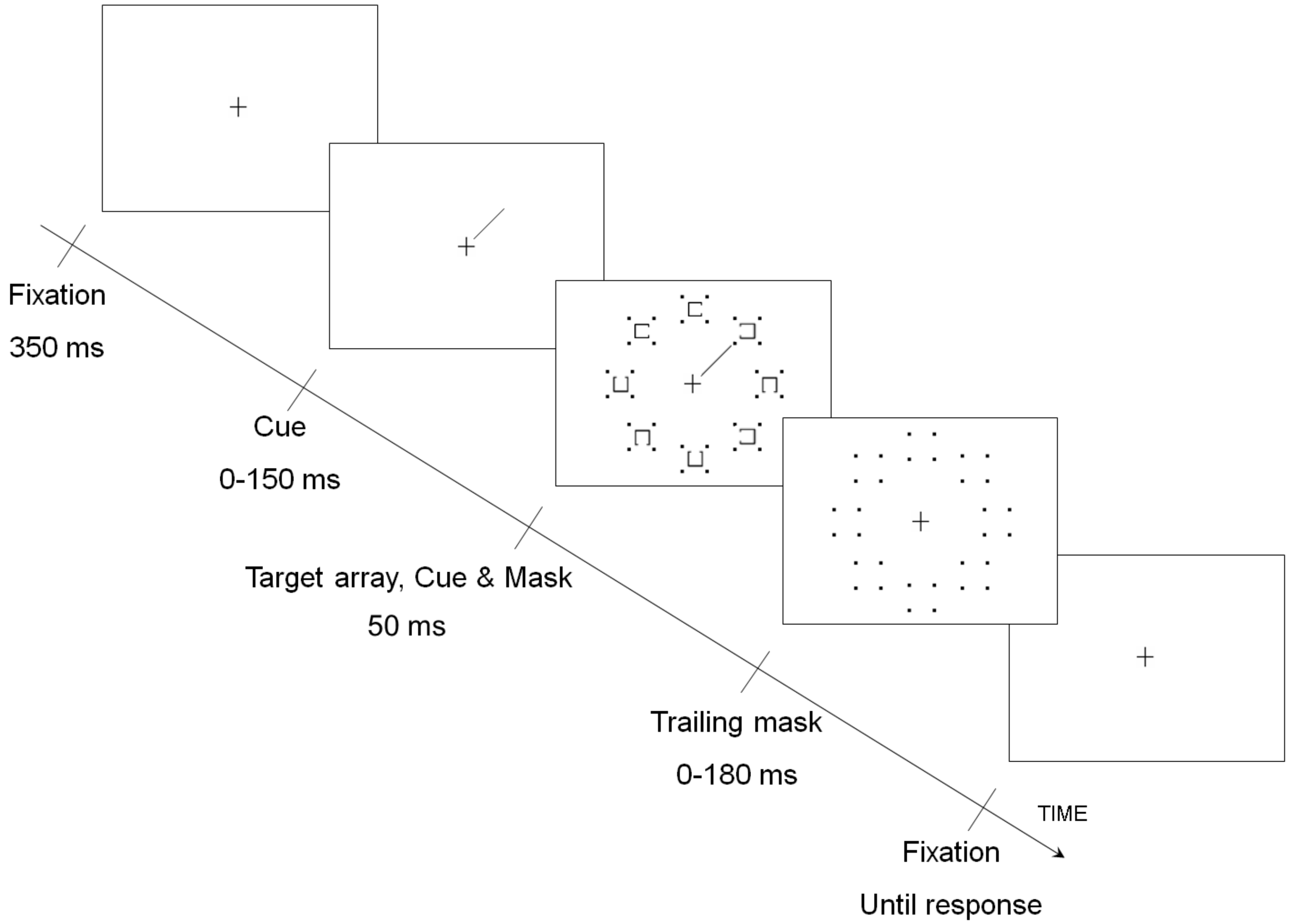

Fixation
350 ms
Cue
0-150 ms
Target array, Cue & Mask
50 ms
Trailing mask
0-180 ms
Fixation
Until response
TIME

Figure 7.

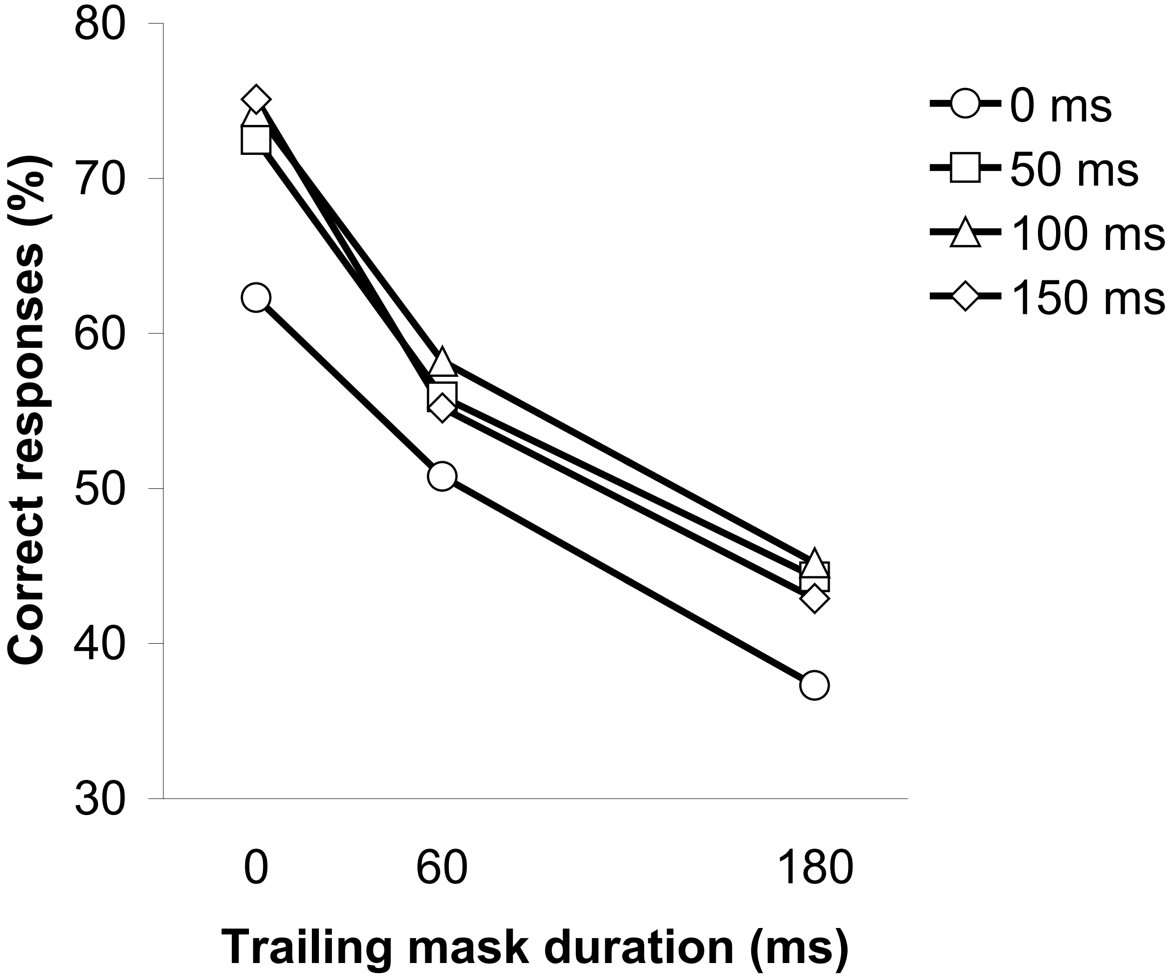

80
70
60
50
40
30
Correct responses (%)
0
60
180
Trailing mask duration (ms)
0 ms
50 ms
100 ms
150 ms

Figure 8.

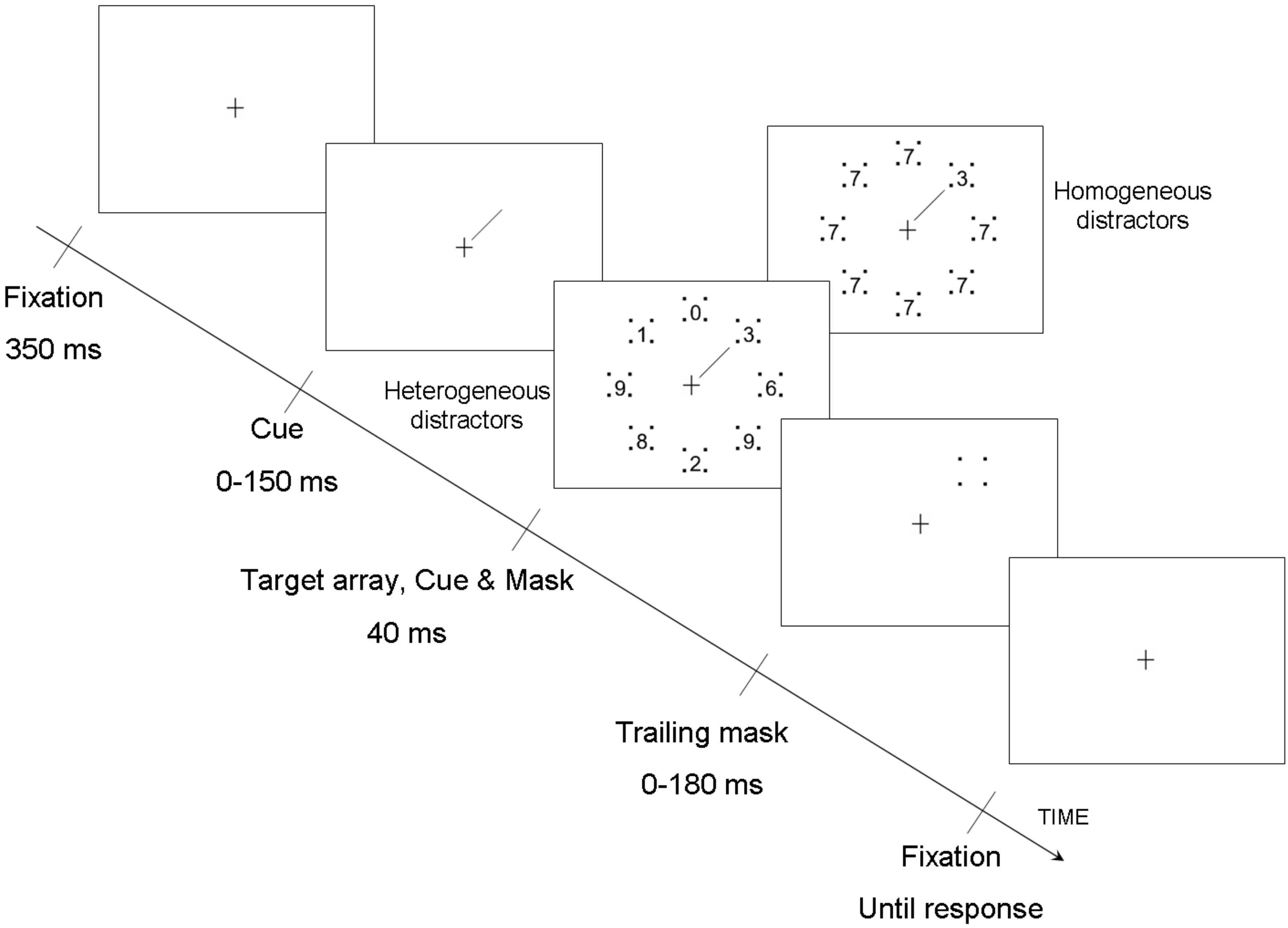

Fixation
350 ms
Cue
0-150 ms
Heterogeneous
distractors
Homogeneous
distractors
Target array, Cue & Mask
40 ms
Trailing mask
0-180 ms
Fixation
Until response
TIME

Figure 9.

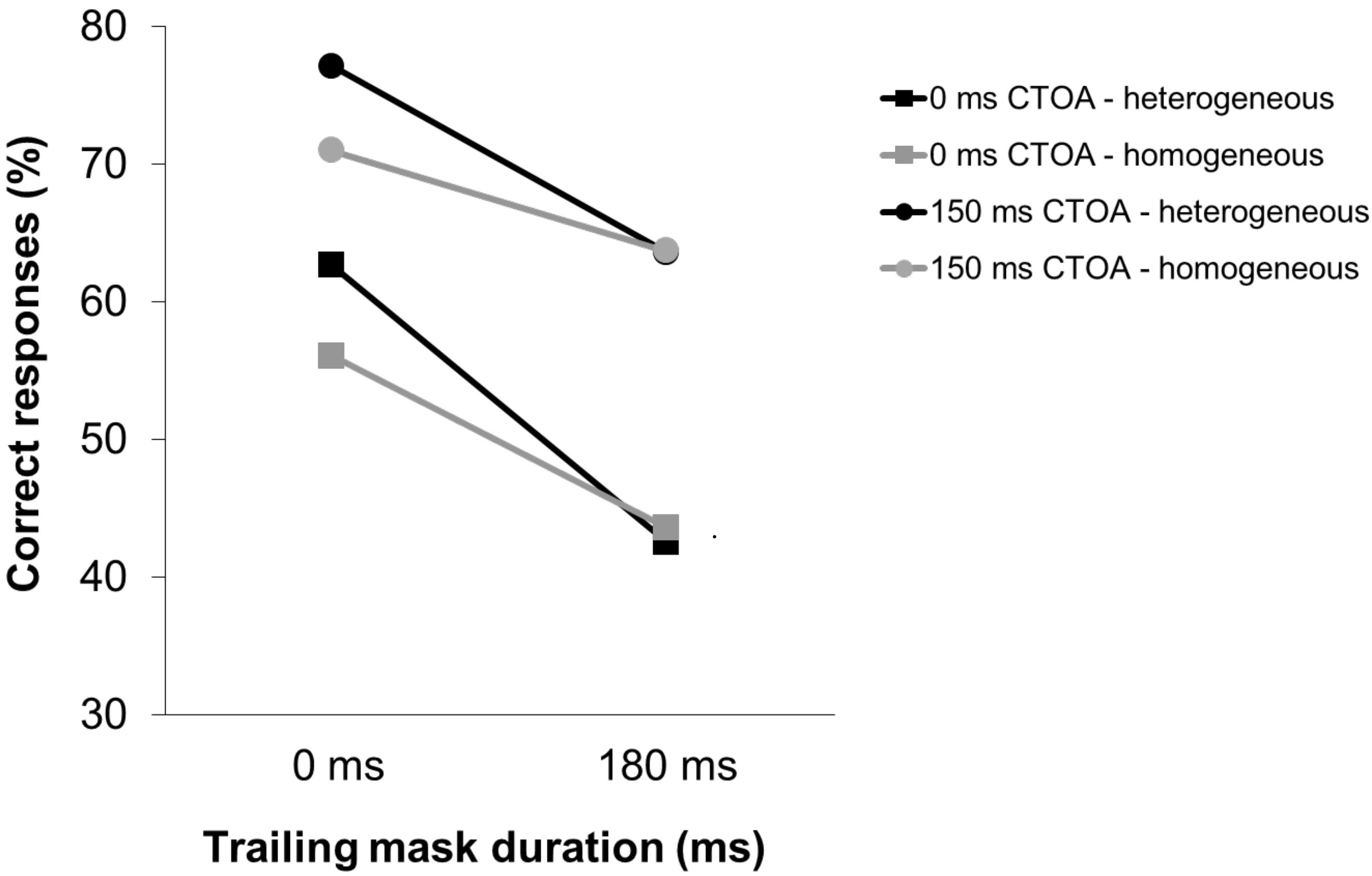

80
70
60
50
40
30
Correct responses (%)
0 ms
180 ms
Trailing mask duration (ms)
0 ms CTOA - heterogeneous
0 ms CTOA - homogeneous
150 ms CTOA - heterogeneous
150 ms CTOA - homogeneous

Figure 10.