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Object Substitution Masking and the Object Updating hypothesis

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Author note

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Abstract

The object updating hypothesis of Object Substitution Masking proposes that the phenomenon arises when the visual system fails to individuate target and mask at the level of object token representations. This hypothesis is tested in two experiments using modifications of the dot mask paradigm developed by Lleras and Moore (2003). Target-mask individuation is manipulated by the presentation of additional display items which influence the linking apparent motion seen between a target and a spatially separated mask (Experiment 1), and by the use of placeholders which maintain the target object's presence during mask presentation (Experiment 2). Results in both cases are consistent with the updating hypothesis in showing significantly reduced masking when the conditions promoted target-mask individuation. However, in both experiments some masking was still present under conditions of individuation, an effect we attribute to attentional capture by the mask.

Introduction

Object substitution masking (OSM) is a recently reported form of visual masking which does not depend on the factors that have been established as important in conventional masking (e.g. the degree of spatial overlap or abutting contour). In OSM a target can be rendered imperceptible by a mask comprising just four dots surrounding the target, or in some circumstances a single dot presented at a distance from the target location. For OSM to occur at least two conditions do need to be fulfilled: that the target is not the focus of attention and, that the mask remains present after target offset (Di Lollo, Enns, & Rensink, 2000).

Initial accounts of OSM argued that it arose as a consequence of iterative re-entrant exchanges in the cortex that occur as part of the normal processes of the visual system forming a stable representation based on current input. The presence of the trailing mask surrounding the target was argued to dramatically reduce the possibility that the stable representation that arises from the iterative exchanges will include the target as well as the mask (Di Lollo et al., 2000). In the original substitution account of OSM the assumption was that masking consisted of competition for consciousness between two separate object representations. The more recent *object updating* account of OSM (Lleras & Moore, 2003; Moore & Lleras, 2005; Enns et al., 2009) proposes that this competition occurs within a single object representation. This account focuses on the interactions which occur at the *object token* level of representation, hypothesised mid-level representations considered responsible for maintaining object integrity by linking together the different object attributes over changes in time and space (Kanwisher & Driver, 1992). In the object updating account OSM is viewed as a consequence of the visual system failing to *individuate* target and mask as distinct perceptual objects, meaning that the attributes of the target and of the mask are initially bound within the same object token representation. If under such circumstances the

mask lingers in the display after target offset, the representation will be updated so the joint target and mask features are overwritten by those of the mask alone, rendering the target features imperceptible.

Key evidence for the object updating account of OSM was presented by Lleras and Moore (2003). In a critical experiment a target search array was briefly presented around a fixation point. The array was replaced after a variable interstimulus interval (ISI) by a frame consisting of single dots (the masks) presented at locations eccentric from target array items (see the upper portion of Figure 1 for illustration): With a short (17-34 ms) ISI the onset of the mask frame generated a motion signal connecting the dots with the corresponding items in the search array; with the long (216-233 ms) ISI this connecting AM was not observed. Importantly masking was found in the short, but not the long, ISI condition when measured against a no mask control condition. The connecting AM was interpreted as being critical for masking to occur under these conditions. The presence of the AM suggested that, at the token level, the visual system was representing the target and mask items as a single object. The masking that was associated with this could accordingly be viewed as caused by the mask overwriting the attributes of the target associated with the same object token as it was seen to transform over time and space. The absence of the connecting AM with a long ISI conversely suggested that target and mask were represented as distinct objects at the token level, with the consequences that the mask no longer affected target perceptibility.

The data in Lleras and Moore indicate that OSM is influenced by target-mask ISI. Indeed, ISI is well established in the masking literature as an important variable across a range of stimulus conditions (e.g. Sekuler, 1965). However, the relevance of the perceived motion in masking is unclear as it was always confounded with ISI. This confound makes it difficult to determine whether the ISI alone or AM was the important factor in Lleras and

Moore's experiment. More recent work by Moore and Lleras (2005) has given further support for the object updating hypothesis in showing the importance of target-mask grouping in OSM under a number of circumstances. However, this paper focuses on the role of perceived object continuity in producing OSM under conditions similar to those of Lleras and Moore (2003). In two experiments displays are manipulated to influence target-mask individuation at the object token level of representation under circumstances in which the mask is composed of just a single dot presented after the offset of a target array. If the object updating hypothesis is correct then masking should be absent when target and mask can readily be individuated by the visual system.

Experiment 1

In Experiment 1 the AM signal between target and mask is controlled by the presence or absence of additional display elements. A standard masking condition is given in which a target array is presented, followed after a short ISI by dot masks presented in the periphery. Under these conditions AM was perceived to link the target to the spatially separate mask. This condition is intended to replicate the corresponding condition in Lleras & Moore (2003, Exp. 5). On other trials additional display items were added which affected the perceived motion between target and mask. The additional items consisted of dots identical to the mask dots but presented before them and located even further in the periphery (see Figure 1). The presence of these 'outer dots', which offset at the same time as the target, had the effect of suppressing the linking motion between the target and mask display items. AM was perceptible on such trials but its origin and direction was changed: It now radiated inwards from the outer dots, rather than outwards from the target array items.

If the object updating hypothesis is correct then the level of masking produced will depend on the presence or absence of these outer dots because of their effect on the origin of the perceived motion. If the spatially separated mask and target are no longer connected by AM then they should be represented by the visual system as distinct objects and masking should be severely reduced, if not abolished.

Method

Participants. Sixteen observers drawn from staff and students at the Open University participated. All had normal/corrected-to-normal vision and were paid for their time. Research was conducted in accordance with University ethical procedures.

Stimuli and apparatus. Stimuli were presented on a 15" CRT monitor controlled by a Pentium PC and viewed at an approximate distance of 570 mm. Stimuli were presented on a black background. The target array consisted of four small triangles (each 0.3° in size) arranged at a distance of 1.9° around a central fixation point. Triangles either pointed left (\blacktriangleleft) or right (\blacktriangleright). The distractors were light grey (RGB: 42, 42, 42), and the target a darker grey (RGB: 21, 21, 21). The target triangle appeared with equal frequency in each of the four positions. The masks were dots (each 0.2° in size) positioned 1.9° eccentrically from the centre of each triangle in the target array. The outer dots were identical to the mask dots but positioned 1.9° further into the periphery. The mask and outer dots were both white (RGB: 64, 64, 64). The identical shape and luminance of the mask and outer dots gave the outer dots a stronger motion correspondence strength with the masks than produced by the target array items.

Procedure. Trials began with the fixation cross for 1000 ms followed by a 17 ms presentation of the target array. No mask trials served as the baseline from which the amount of masking could be measured. On mask trials masks were presented after a 17 ms ISI from

target array offset. Trials were given in one of two conditions: outer dots absent (hereafter, Outer-), and outer dots present, (hereafter, Outer+). Figure 1 shows a schematic depiction of the Outer- and Outer+ mask conditions. Participants were instructed to make an unspeeded key-press response according to the direction in which the target pointed. The key-press instigated the next trial after a 500 ms inter-trial delay. Participants were first given a demonstration and 32 practice trials followed by 320 main trials. Equal numbers of each trial type were given.

Insert Figure 1 about here

Results and Discussion

Figure 2 (a) gives the percentage of correct responses by condition; Figure 2 (b) shows the level of masking in the two main conditions expressed as a percentage difference calculated by subtracting performance in each mask condition from the appropriate non-mask condition. Responses were analysed using a repeated measures ANOVA with two factors: Mask (present, absent), Outer-dots (Outer+, Outer-). A main effect of Mask ($F[1,15]=45.74, MSE=53.84, p<.0001$), but not of Outer-dots ($F[1,15]=0.75, MSE=28.46, p<.05$) was found. Importantly the interaction was significant ($F[1,15]=16.23, MSE=6.32, p<.01$); inspection of Fig. 2 clearly shows that this interaction resulted from the masking effect being smaller in the outer dots condition than in the inner dots condition. Additionally, a planned t-test comparison, showed that the masking effect, though diminished, was still significant in the Outer+ condition ($p<.0001$).

Insert Figure 2 about here

The data in the standard (Outer-) condition replicates the finding that a single dot can produce masking even when spatially separated from a target. Consistent with the updating hypothesis, when the display configuration was changed to suppress the motion signal between target and mask (Outer+ condition), masking was significantly reduced. However though masking was reduced in this condition it was not eliminated. The persistence of masking in this condition can easily be explained within the object updating framework if we assume that our display manipulation did not entirely abolish AM between target and mask. This is certainly feasible, but subjective evidence suggests otherwise — participants were uniform in declaring that no motion was perceived from the target in the Outer+ displays. A further possibility which accommodates the introspective reports is that the mask may still have been having an effect by capturing attention away from the target at a time when processing of the target was incomplete. Attentional capturing effects of task-irrelevant objects are well established under conditions of diffuse attention (e.g. Forster & Lavie, 2008)¹. Experiment 2 was performed to determine whether the object updating effect could solely account for masking, or whether a subsidiary process of attentional capture was also occurring.

Experiment 2

In Experiment 2 a mode of stimulus presentation was given on some trials which should remove the possibility that object updating could occur between target and mask. This involved introducing placeholders to maintain the presence of the target objects on screen

during mask presentation. Placeholders were the same as the target objects other than in lacking the critical discriminative feature. The assumption was that if the target object persists in the display while the mask is presented then target and mask should always be individuated from one another at the object token level. Performance on such trials (hereafter referred to as *Persisting* array trials) is compared against performance in a standard condition (hereafter referred to here as *Transitory* array trials), in which the search array objects offset before the masks were presented.

The search array stimuli were chosen to accommodate the introduction of placeholder trials. The target array consisted of four hollow boxes each with a missing segment (left or right). The placeholders were complete boxes. The target was luminance cued in the same way as in Experiment 1. Four mask conditions were given; these were the same mask conditions used by Lleras and Moore (2003, Experiments 5): a no mask condition, a *short ISI* mask condition (masks appear in the periphery 17 ms after the target array disappeared, or in the case of the *Persisting* array 17 ms after the target array turned to placeholders), a *long ISI* mask condition (masks appear in the periphery 217 ms after the peripheral dot masks were presented), and, a *location mask* condition (mask dots appear in the same locations as the target display items 17 ms after they offset). With the *Transitory* array the target and mask are connected by motion in the short, but not the long ISI mask condition. With the *Persisting* array, AM is absent for all mask conditions.

The inclusion of the location- and long-ISI mask conditions allows a more complete picture to be made of the susceptibility of the target to masking by a later presented dot across the two arrays (*Transitory*, *Persisting*). The *Transitory* array should produce the same pattern of results observed by Lleras and Moore (2003) — masking present with the location and short ISI masks and absent with the long ISI mask. The critical question concerns the

Persisting array. When the array 'objects' remain in the display as the masks are shown, it is highly probable that target and mask will be individuated at the token level. According to the updating hypothesis, masking should not occur on such trials; if it does, this will implicate a second source of masking such as attentional capture in OSM.

Method

Participants. Sixteen observers participated. These were selected in the same manner and treated in accordance with the same ethical procedures as described for Experiment 1.

Stimuli. The stimulus array consisted of four squares (0.4°) positioned around the fixation point at a visual angle of 1.9° . The missing segment of each square was 0.2° . The side of the missing segment (left/right) was random with the constraint that it was on each side equally often. Target location was randomised within the array as in Experiment 1. The same luminance values as Experiment 1 were used to define the target and distractors. Masks were the same as Experiment 1. In the location mask condition masks were at the centre of each hollow array item, in the short and long ISI conditions the masks were 1.0° from the centre of each array item.

Procedure. The four mask conditions (no mask, location mask, short ISI and long ISI) were factorially combined for each array: Transitory and Persisting. A schematic diagram of each array is given in Figure 3. All trials began with a 1000 ms fixation cross followed by the stimulus array. In the Transitory array the search items offset after 17 ms. In the Persisting array search items were presented for 85 ms then replaced by placeholders which remained until mask offset. A longer duration search display was necessary with the Persisting array because onset of the placeholders made discriminating the target feature more difficult. For both the Transitory and Persisting arrays, masks onset 17 ms after offset of the search items in the location and short ISI mask conditions, and after 216 ms in the long ISI condition. A

demonstration and 32 practice trials was given before the 384 Experimental trials. Equal numbers of each trial type were given.

Insert Figure 3 about here

Results and Discussion

The average percent correct responses in each condition is shown in Figure 4 (a) and the difference between corresponding mask and no mask conditions shown in Figure 4 (b). Performance with the Transitory and Persisting arrays did not differ statistically in the no mask conditions, ($p = .129$), showing that the difference in target frame duration balanced the baseline perceptibility of the search array across the two trial types. One-way ANOVAs were used to analyse percent correct responses across the four mask conditions, these were calculated separately for the Persisting and Transitory array trials. Both ANOVAs were significant: Transitory, $F(1, 15) = 53.81$, $MSE = 88.03$, $p < .0001$; Persisting $F(1, 15) = 24.46$, $MSE = 23.08$, $p < .0001$. Tukey's LSD post-hoc comparisons explored these main effects in both ANOVAs. For both Transitory and Persisting arrays, there was significant masking in both the location and short ISI conditions (max. $p < .01$), but not in the long ISI mask conditions (min. $p = .16$) [see Fig 4b]. However, accuracy was significantly lower with a location mask than with a short ISI mask for Transitory arrays ($p < .001$) but not for the Persisting arrays ($p = .26$). T-tests compared the amount of masking across the two array types for each masking condition. Masking was significantly greater for Transitory than for Persisting arrays with the location mask ($p < .001$) but not with the short ISI or the long ISI masks (min $p = .423$).

Insert Figure 4 about here

The pattern of data for Transitory arrays reproduces the findings of Lleras and Moore (2003): most masking was seen with the location mask, the short ISI producing weaker, but still highly significant, masking, while no significant masking at all was produced with the long ISI mask. A somewhat different pattern of masking was seen with the Persisting arrays: significant masking was seen with the location mask and short ISI mask, but importantly there was no statistical difference between the two, and, again, the long ISI mask produced no significant masking.

Target persistence had a large and significant effect on masking in the location mask condition but no effect in the other conditions: The substantial reduction in the effect of the location mask is easily explained by the object updating hypothesis. When the target disappears before the mask onsets at the same location, the visual system is highly likely to treat the mask as a transformation of the target object so the target's features are substituted by those of the mask. This is object updating (Lleras & Moore, 2003. Moore & Lleras, 2005). Having the target persist as a placeholder makes it unlikely that the mask will be treated as a continuation of the target; under these circumstances the mask should be always assigned a separate object token, so that updating, and therefore masking, does not occur. The lack of such an effect for the Short ISI mask is more problematic for the object updating account: the persistence of the target object resulting in an absence of linking AM should also have led to the target being reliably individuated from the spatially separated mask, and a similar substantial decline in masking should have resulted. Yet here masking strength did not differ statistically across Transitory and Persisting arrays. Similarly, though the presence of target

placeholders heavily reduced the effect of the location mask they did not eliminate it: significant masking was still observed even here. These facts we interpret as evidence for a role for attentional capture, as well as object updating, in OSM.

General Discussion

Consistent with Lleras and Moore (2003), both experiments found OSM to be most evident when the display conditions favoured the perception of the mask as a continuation of the target object, either because the mask was linked to the target across space by connecting AM, or by the mask appearing in the location of the target after its disappearance. These results are also largely consistent with the more recent work of Moore and Lleras (2005) who found OSM was wholly or largely absent when target and mask were ungrouped in a display, for instance because the target failed to move concordantly with a sliding mask, failed to share common fate with a moving mask or was different in colour to the mask. Our results principally differ from Moore and Lleras in showing only reduced OSM rather than abolition of OSM in display conditions which strongly favour target-mask individuation. This enduring masking we attribute to attentional capture effects. This suggestion is not a new one. Certainly the importance of the distribution of attention in OSM is well established as indicated by the fact that having more distractor items in a display increases masking, presumably by drawing attention away from the target (DiLollo et al., 2000). More directly Neill, Hutchensen & Graves (2002) and Tata & Geaschi (2004), on the basis of different evidence, have also suggested a role for mask attentional capture.

Why do the results of Moore and Lleras (2005) not indicate effects consistent with attentional capture as ours did? In the current experiments (and in Lleras & Moore, 2003) masking was measured as a difference between a no mask baseline and conditions in which a

mask was presented after target offset. In Moore and Lleras (2005), by contrast, masking was measured as a difference between a common onset and common offset condition and corresponding conditions in which the same common onset mask trailed target offset. Such variations in procedure and in the comparison being made may explain the differences in results. Indeed, the importance of attentional capture may have been amplified in the present studies by following Lleras & Moore's choice of a no mask baseline and a delayed onset mask. The possibility of attentional capture effects do not, however, diminish the importance of object updating as a mechanism of OSM: it must be noted that even in the current experiments masking was always lower when display conditions favoured target-mask individuation. Further research is needed to explore the specific conditions under which attentional capture also contributes to OSM.

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Figure captions

Figure 1. Display sequence on mask trials in Experiment 1 (The Outer- condition is shown in the upper portion of the figure, the Outer+ condition shown in the lower portion).

Figure 2. Mean percentage correct responses in Outer- and Outer + conditions for no mask and mask trials (a). Mean difference in percentage between no mask and mask conditions for the two conditions (b).

Figure 3. Display sequence on mask trials in Experiment 2 for Transitory (upper portion of figure) and Persisting (lower portion of figure) arrays. Note that the target array frame lasted 17 ms on Transitory array trials and 85 ms on Persisting array trials. In the location mask condition the mask dots appeared inside each of the four squares. In the short and long ISI conditions the mask dots appeared in the periphery of the display as illustrated here.

Figure 4. Mean percentage correct responses in the no mask and three mask conditions (a). Mean difference in percentage between no mask and the corresponding mask conditions for Transitory and Persisting arrays (b).

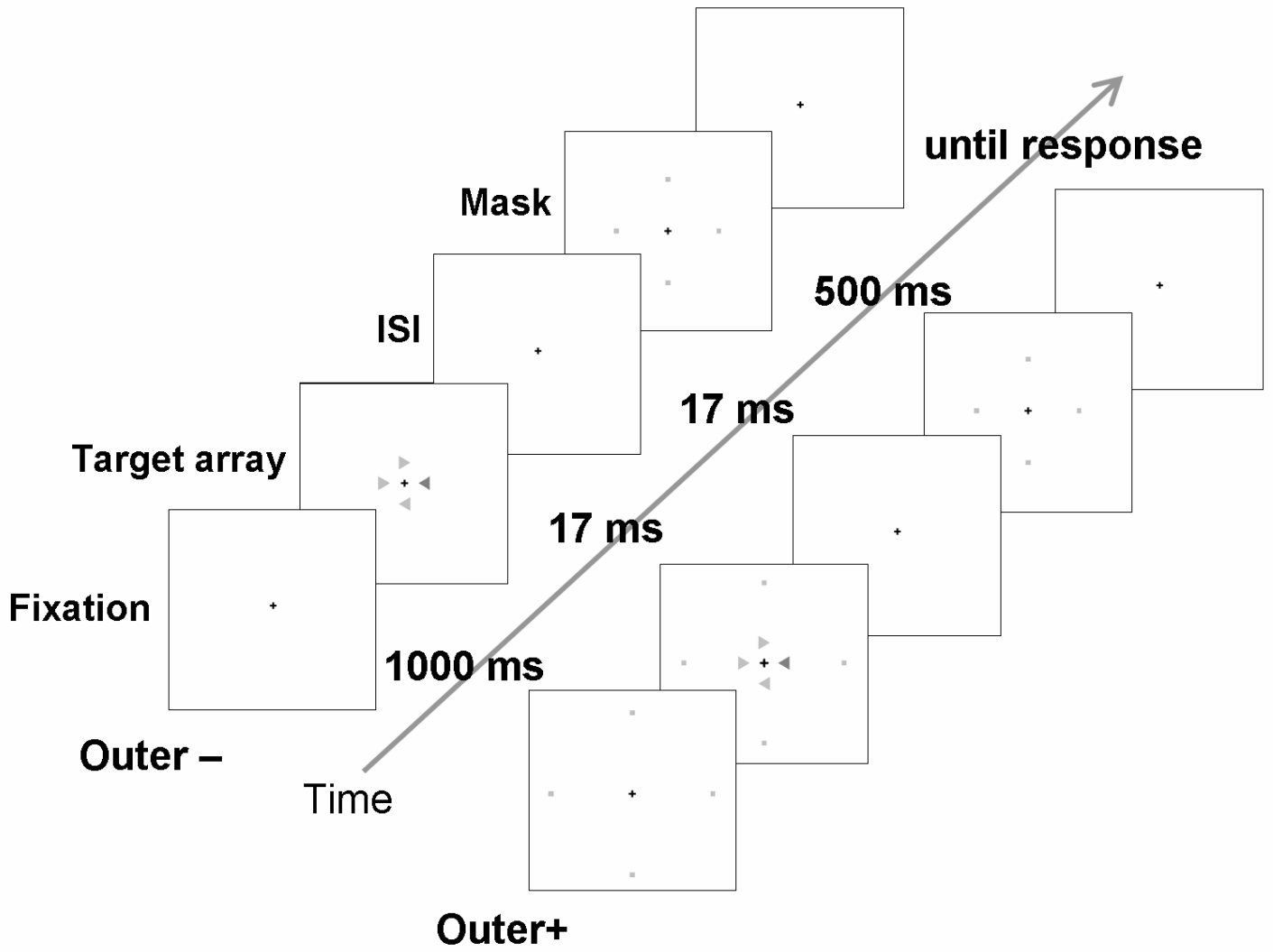


Figure 1.

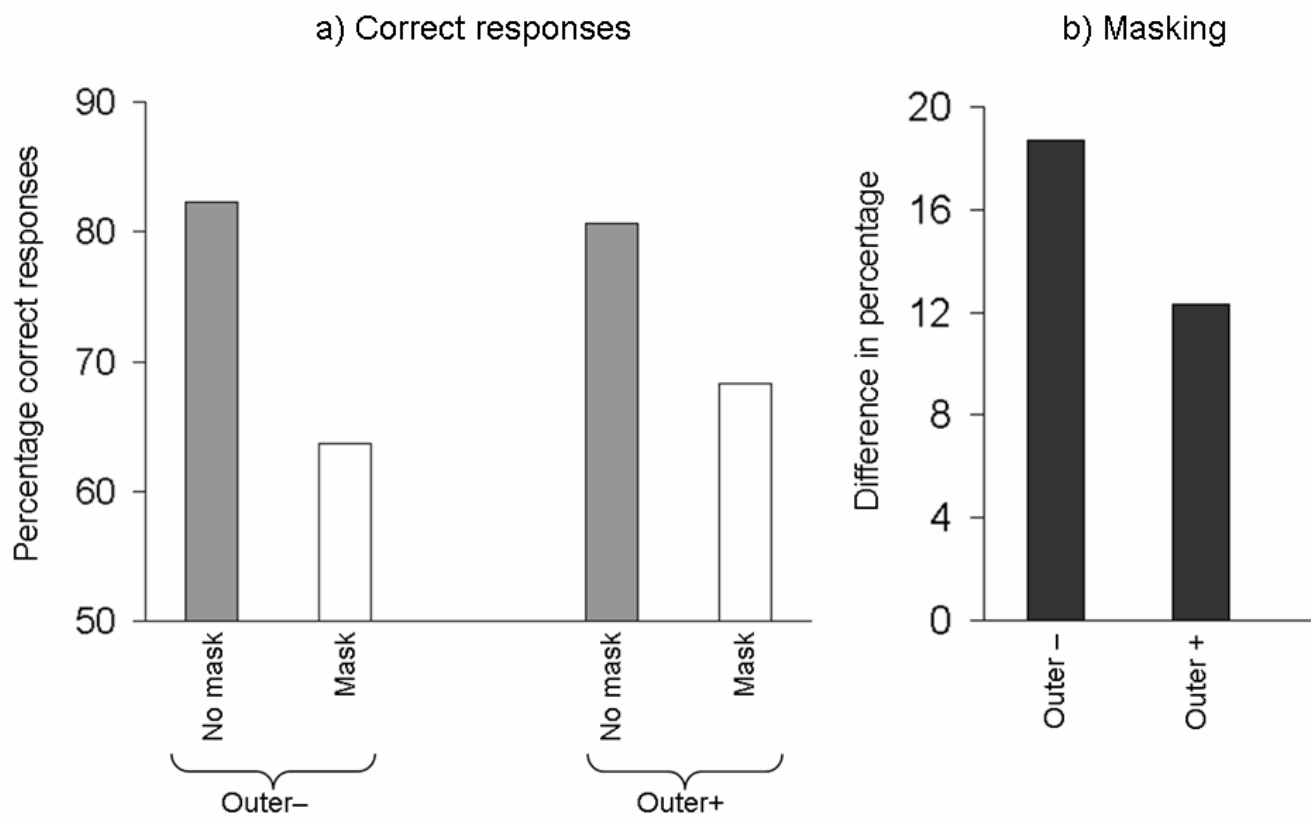


Figure 2.

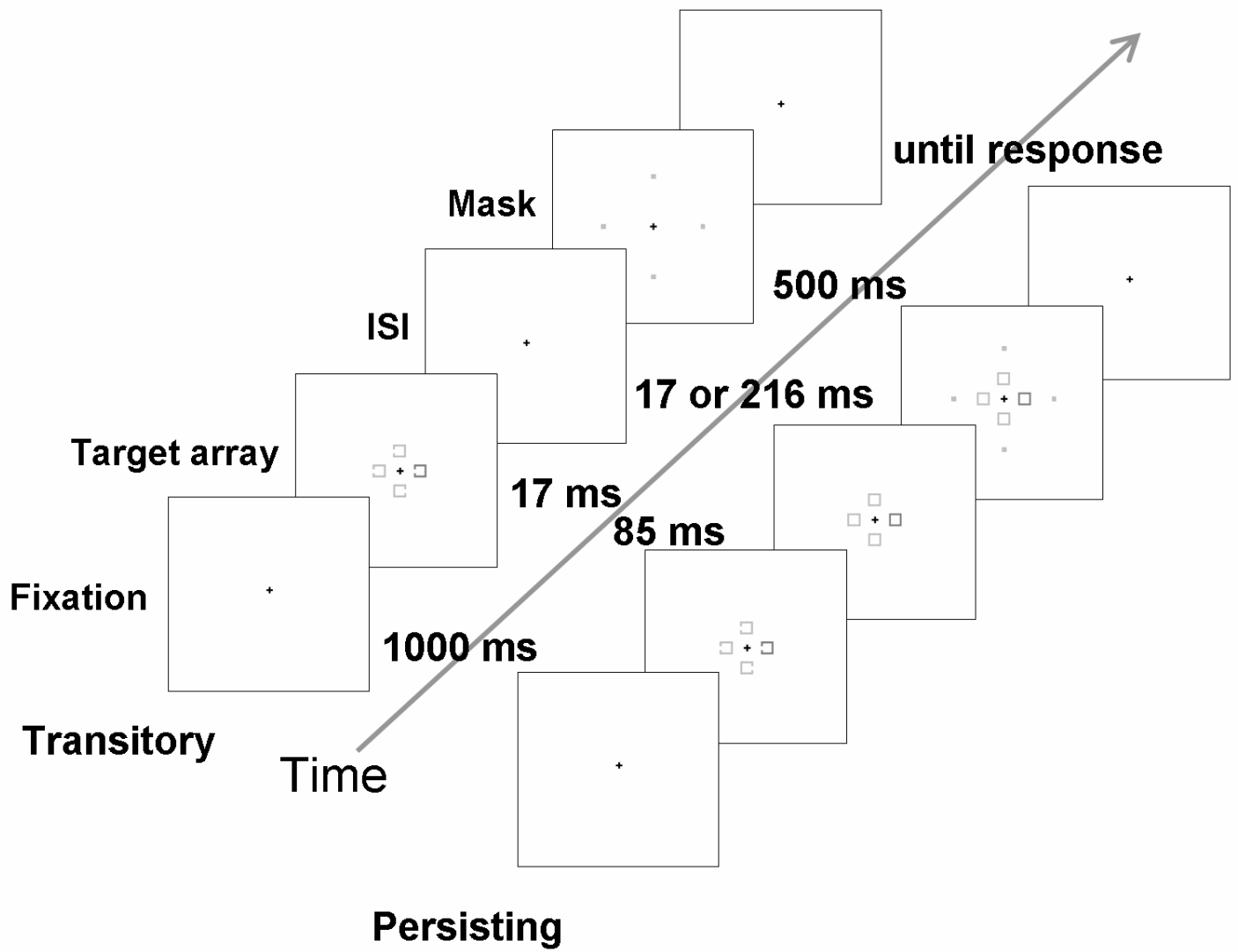


Figure 3.

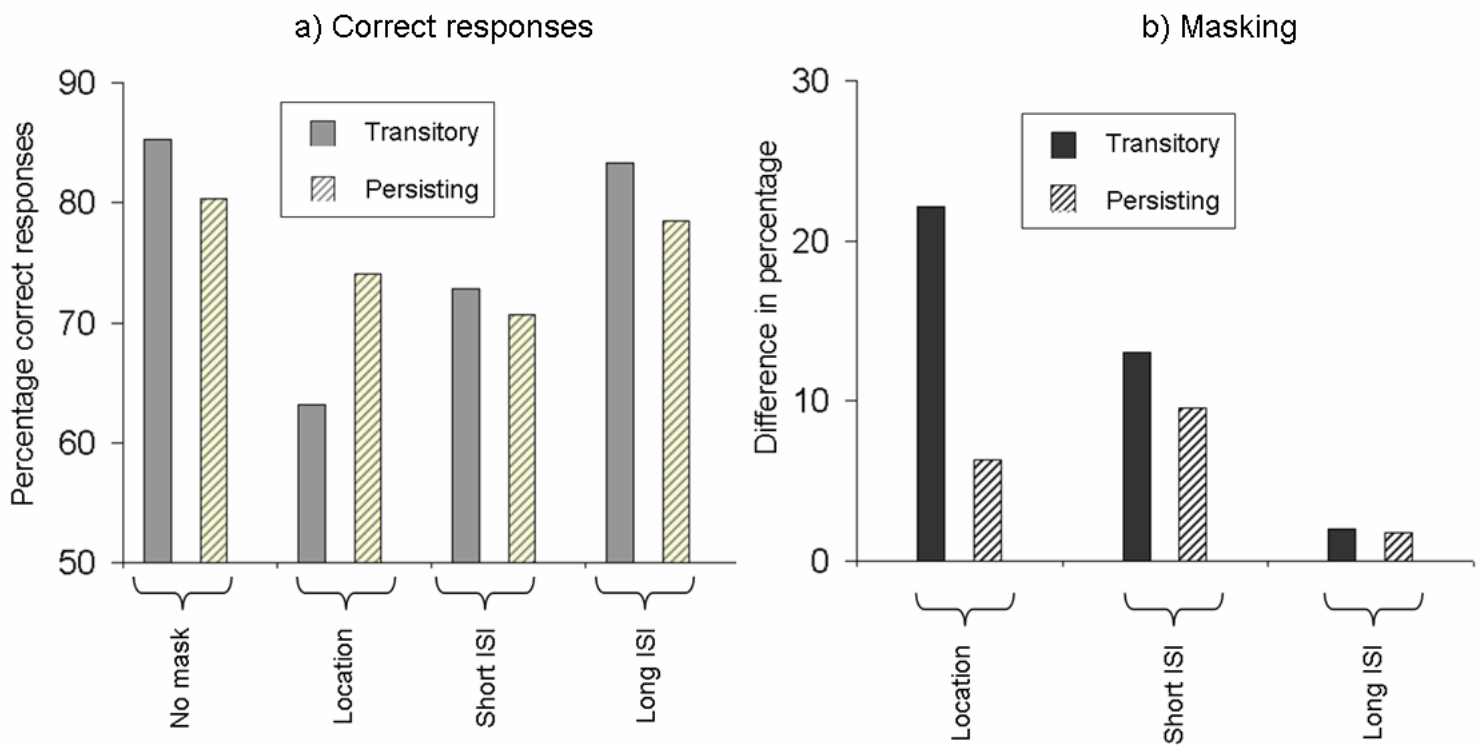


Figure 4.

Footnote

ⁱ Attentional capture has similarities as an explanatory concept in masking with that of interruption (e.g. Kolars, 1968). The basic assumption in both is that the target draws visual processing mechanisms away from the target towards the mask, limiting target processing. However there are differences between the two: interruption is generally conceived as a process when the target was the focus of visual attention while attentional capture is one which occurs under diffuse attention.