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Object Substitution Masking: When does Mask Preview work?

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Abstract

When a target is surrounded by a four-dot mask pattern that persists after the target disappears, target identification is worse than when the mask terminates with the target. This masking effect has been attributed to Object Substitution Masking (OSM). Previewing the four-dot mask attenuated OSM. This study investigated specific situations in which mask preview was (or was not) effective in attenuating masking. In Experiment 1, the interstimulus interval (ISI) between previewed mask offset and target presentation was manipulated. The basic preview effect was replicated; neither ISI nor preview duration influenced target discrimination performance. In Experiment 2, mask configurations were manipulated. When the configuration of the mask at preview matched the configuration at target presentation, the preview effect was replicated. New evidence of ineffective mask preview was found: when the two configurations did not match, performance declined. Yet, when the ISI between previewed mask offset and target presentation was removed, such that the mask underwent apparent motion, preview was effective despite the configuration mismatch. The object-token interpretation provides an excellent account to this data. This study enabled a new understanding of when preview exactly attenuates OSM.

Keywords: object substitution masking; mask preview; ISI; mask configuration; object token

Introduction

Visual backward masking refers to the reduction in visibility of an earlier stimulus (the target) by a later stimulus (the mask) that is presented within close spatial and temporal proximity of the target. Traditionally, these masking situations investigated low-level mechanisms (Breitmeyer, 1984). Di Lollo, Enns and Rensink (2000; Enns & Di Lollo, 1997) recently reported a hitherto unrecognized form of visual backward masking, called object substitution masking (OSM), that appears to involve high-level attentional and object-recognition mechanisms. In a typical OSM task, the observer is presented with a brief visual display of geometric shapes. An object (the target) is flanked by four dots (the mask) that corresponded to the corners of an imaginary square surrounding the target. The observer is to report the shape of the target as accurately as possible. The dots appear simultaneously with the target. If their offset is also simultaneous with the target (simultaneous-offset condition), there is little impairment of target visibility. However, if their offset is delayed relative to the target offset (delayed-offset condition), target visibility is significantly impaired.

Di Lollo, Enns and Rensink (2000) emphasized a causal role of reentrant processes to explain OSM. The target and mask information is initially processed at feature-level when the target and mask appear. At the early stages, only partial information about the target and mask is routed to higher levels of the visual system which initiate object recognition. However, the specification of the object is incomplete from the initial information. Thus, the visual system needs to sample the input again to obtain more information. This process of sampling, construction and resampling proceeds in cycles.

Consider the scenario where the target is removed, but the mask persists. When the visual system continues to sample information from the display which now contains only the mask, the durable representation that is eventually established is that of the mask and not the target. As a result, target information is unrepresented (or at least under-represented). Under this view, OSM occurs only when the target disappears before a durable representation of it has been established, or some visual information such as the mask alone persists in the display after the target terminates.

Neill, Hutchison and Graves (2002) argued that OSM involves relatively high-level attentional mechanisms. More recently, Tata and Giaschi (2004) proposed that OSM occurs when attention is selectively deployed to the masking object. The visual system fundamentally assigns priority tags to objects in a scene (Yantis & Jonides, 1984), and attention is selectively deployed to high-priority objects (new items in the display) before low-priority objects (older items) (Yantis & Johnson, 1990). Under this view, OSM occurs when the novel masking object appears simultaneously with the target. Since both the target and the mask are high-priority objects, they compete to capture attention and the representation of the target is possibly disrupted. Logically, previewing the mask, such that it is made no longer "new", may prevent such attentional capture and thus perceptual interference.

Extant literature appears to suggest that in an OSM paradigm, so long as the mask is previewed, the masking effect is always attenuated. However, such a hypothesis has not been directly tested. Of particular interest is that previewing the mask might be ineffective under certain scenarios, where, for instance, the mask remains novel despite the preview. These scenarios can shed light onto the underlying visual cognitive processes which determine whether a visual object is "old" or "new" and therefore its capacity to capture attention.

Experiment 1

Previewing the mask pattern attenuated OSM (e.g., Neill, Hutchison & Graves, 2002), and the duration, per se, of mask preview was in fact not critical in influencing preview effectiveness (Tata & Giaschi, 2004; Neill, Hutchison & Graves, 2002). Masking was reduced so long as the masks were briefly (133 ms) previewed.

Lleras and Moore (2003) argued that two different components must contribute to the total interference in OSM: low-level backward masking and interference at higher-, object-level representations. A critical differentiation between a lower-level and a higher-level representation is whether the representation is tied to a specific location: the exact location will not be crucial if the underlying mechanisms are high-level. For instance, the object could move to a new location. They considered this higher representation an "object token" (p. 107).

To test whether interference actually takes place at this object-token level of representation in OSM, Lleras and Moore (2003) manipulated the location of the mask and created object-token representations with apparent motion. The task was to identify and report the black target among the seven other grey distractors (see Figure 1). In the two critical conditions, the masks terminated with the target and distractors, thus supposedly appearing to be simultaneous-offset conditions. However, at a variable interstimulus interval (ISI) later, identical versions of the masks were presented at positions slightly removed from the original positions, on the circumference of a larger imaginary circle. In the condition where the ISI was short (17 – 34 ms), the masks were perceived to move from their original locations to their new locations. In terms of object tokens, this condition constitutes a delayed-offset condition rather than a simultaneous-offset condition. If object tokens are the relevant level of representation for some component of OSM, OSM should occur. The control was a long ISI (216 – 233 ms) so that the masks would be perceived as terminating at their original locations, and a set of new objects would seem to appear at the new locations (i.e., no apparent motion). This condition constitutes a simultaneous-offset condition. If object tokens are the relevant level of representation, OSM should not occur.

Indeed, masking was observed only in the short-ISI condition. The researchers proposed that the apparent motion in this condition maintained the original object-token representation from the target location to the final mask location, which interfered with target report. This interpretation asserts that at least some mechanisms underlying OSM must be object-token-level representations (i.e., the masking is not purely "sensory").

The ISI variable modulates the nature of the object-token representation in visual short term memory (cf. Lleras & Moore, 2003), which in turn determines whether an object is perceived by the visual system as "new" or "old". By manipulating the duration of the ISI between previewed mask offset and target-with-mask onset, the original object-token representation of the mask may or may not be maintained: when the ISI is zero or very short, the mask representation can possibly be maintained in visual short term memory, and OSM in all likelihood would be attenuated. On the other hand, if ISI is long, the object-token of the mask established during its preview may degrade over time. When the mask appears again simultaneously with the target, the representation of the previewed mask may no longer remain in visual short term memory. As such, this later mask cannot be associated with the previewed version, and is perceived as a new instantiation (new object) that is capable of interfering with target identification.

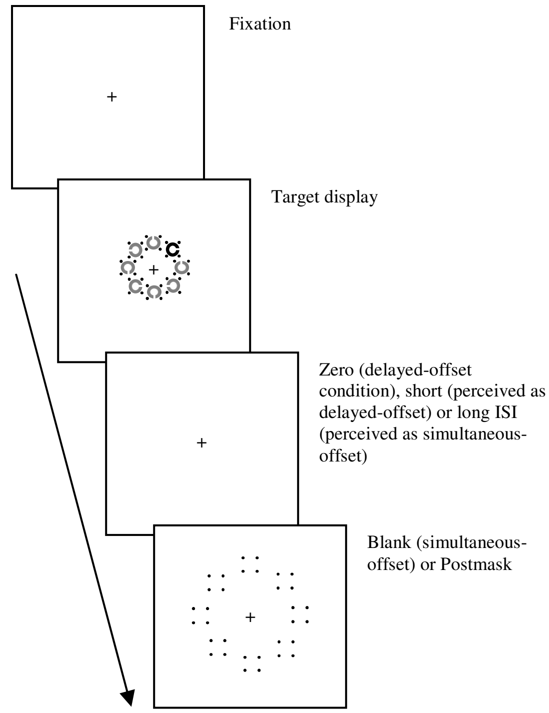

Figure 1: Schematic of the sequence in Experiment 2 of Lleras and Moore (2003).

Experiment 1 had three goals. The first and second were to replicate the basic findings that previewing the masks attenuates OSM, and that duration, per se, of mask preview does not influence its effectiveness to attenuate OSM (Tata & Giaschi, 2004; Neill, Hutchison & Graves, 2002). The third was to influence the nature of representation in visual short term memory with ISI. The critical hypothesis was that, to the extent that the delay between previewed mask offset and final mask onset affects its representation, ISI should modulate performance (e.g., if ISI is long, target identification would be poor).

Method

Participants Participants were 27 undergraduates (15 females and 12 males) from the National University of Singapore who participated to fulfill an experiment requirement for an introductory psychology course. All participants had normal or corrected-to-normal visual acuity.

Apparatus and setting Each participant undertook the experiment in a designated cubicle. The participant sat in front of a 19-in. (48-cm) colour monitor controlled by a Macintosh G4 computer. Viewing distance between the eyes and the monitor screen was set at approximately 50 cm.

Responses were gathered on a standard keyboard. Throughout the experiment, the monitor provided the only source of luminance.

Stimuli The visual display comprised a background light grey in colour (luminance = 80 cd/m^2). All other stimuli presented were of a darker shade of grey (luminance = 40 cd/m^2). A fixation cross (subtending 0.6° x 0.6° of visual angle) was presented, followed by four identical masks (see Figure 2). Each mask comprised four circular dots (each 0.5° of visual angle in diameter) presented on the four corners of an imaginary square (subtending 3.4° of visual angle), surrounding either a distractor or the target. These distractors or the target were Landolt C stimuli (each 1.6° of visual angle in diameter), evenly distributed in a circular array (8° of visual angle in radius) which surrounded the fixation cross. Each of the four Landolt C stimuli had a small gap (0.2° of visual angle in width) which faced north, south, east, or west. On each trial, all four Landolt C's were presented. One would be designated the target, so that guess rate was 25%. The target was indicated by an arrow stimulus (subtending 1.6° of visual angle) which appeared at the fixation position simultaneously with the target and distractors, replacing the fixation cross. The arrow stimulus could point to any one of the four possible target locations. The target was presented equally often on all four locations on the search array.

Task The task was to report the orientation of the target stimulus' gap. Participants used the arrow keys of a standard keyboard to respond; the up-, down-, right- and left- arrows were used to report gaps facing north, south, east, and west respectively.

Design A single factor, within-subject design was used. The independent variable was preview condition with five levels: (1) no preview, (2) long preview (1000 ms) with ISI = 0 ms, (3) long preview (980 ms) with short ISI (20 ms), (4) short preview (100 ms) with long ISI (900 ms), and (5) short preview (100 ms) with short ISI (20 ms). ISI was defined to be the period between the offset of the previewed masks, and the simultaneous onset of the Landolt C stimuli (i.e., target and distractors) and masks.

The target or each distractor could appear randomly at any of the four possible locations in the circular array. The dependent variable was response accuracy, measured in terms of proportion of correct responses. Each participant completed six experimental blocks of 20 trials each. All five types of preview conditions occurred equally often, resulting in a total of 24 observations for each type of preview condition in the six blocks. The duration of each trial, defined as the point of onset of the fixation cross to the final offset of the mask patterns (postmasks), was held constant (1620 ms) across all five conditions to control for total trial duration, per se, as a possible cause of interference with target discrimination performance.

Procedure Each participant engaged in a 25-min-long session. The participants were first shown an illustration of the standard visual display of the experiment. They completed one 20-trial practice block followed by the six experimental blocks. The trials were self-paced, allowing the participants to rest in between trials whenever they deemed it necessary.

The sequence of trial events is illustrated in Figure 2. Each trial began with the presentation of the fixation cross, which stayed on the display until the arrow stimulus replaced it. In the *no preview* condition, the target and distractors appeared simultaneously with the mask patterns 1000 ms after the fixation cross onset. In the *long preview, ISI = 0 ms* condition, the mask patterns appeared simultaneously with the fixation and stayed on the display throughout the trial; the target and distractors appeared 1000 ms later following the masks.

In the *long preview, short ISI* condition, the mask patterns appeared with the fixation cross and extinguished after 980 ms; the same mask patterns appeared simultaneously with the target and distractors after an ISI of 20 ms. In the *short preview, long ISI* condition, the mask patterns appeared with the fixation cross and extinguished after 100 ms; 900 ms later, the same mask patterns appeared simultaneously with the target and distractors. In the *short preview, short ISI* condition, the mask patterns appeared 880 ms after fixation cross onset and extinguished after 100 ms; the same mask patterns appeared simultaneously with the target and distractors after an ISI of 20 ms.

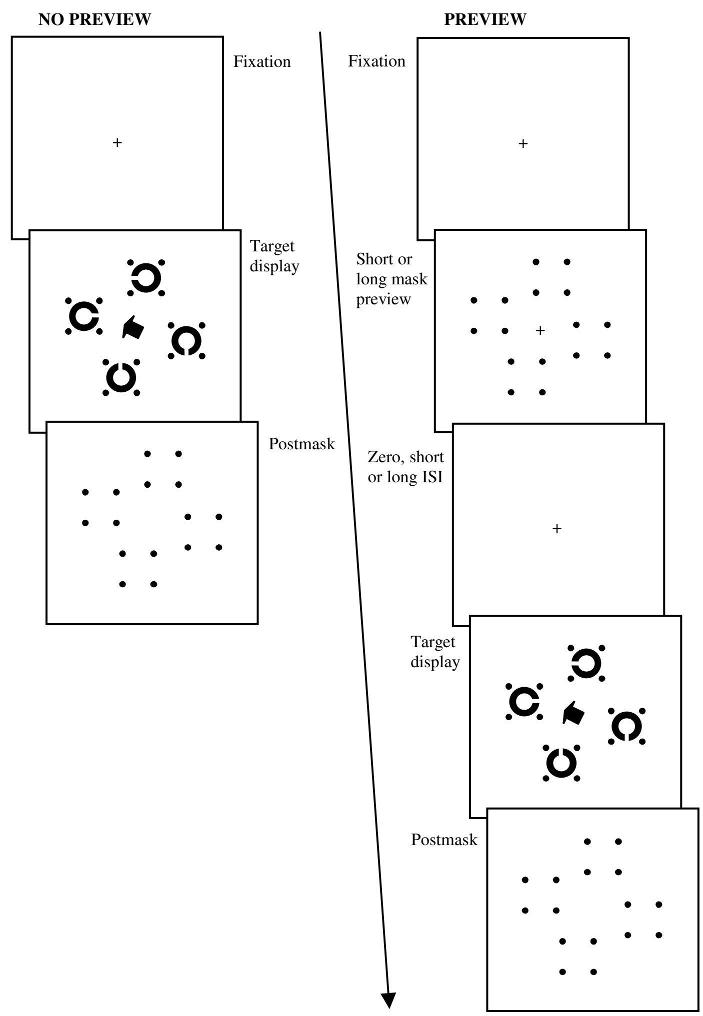

Figure 2: Schematic of the sequence in Experiment 1 of the present study.

Across all five conditions, the arrow stimulus appeared simultaneously with the target and distractors. The target and distractors were shown for 20 ms, following which they terminated simultaneously with the arrow stimulus; the mask patterns persisted for another 600 ms on the display (delayed-offset).

Results

Data were collapsed across target locations. Figure 3 shows the proportion of correct responses as a function of preview condition. The proportion of correct responses in each condition was calculated for each participant and submitted to a one-way repeated measures ANOVA. There was a significant main effect of preview condition, $F(4, 104) = 5.04$, $MSe = 0.008$, $p < .005$, $\eta^2 = 0.16$. To determine whether preview, per se, enhanced performance, the *no preview* condition was compared with the *long preview, ISI = 0 ms* condition: when the mask was previewed ($M = .66$, $SD = .16$), performance was significantly better than where the mask was not previewed ($M = .57$, $SD = .13$), $F(1, 26) = 14.95$, $MSe = 0.008$, $p < .005$, $\eta^2 = 0.37$. Previewing the mask enhanced performance.

To determine whether duration of mask preview influenced performance, the *long preview, short ISI* condition and *short preview, short ISI* condition were compared: performance in the *long preview, short ISI* condition ($M = .65$, $SD = .15$) was not reliably different from performance in the *short preview, short ISI* condition ($M = .64$, $SD = .17$), $F < 1$. Mask preview duration did not influence performance, replicating Neill, Hutchison and Graves' (2002) finding. To determine whether ISI modulated performance, the *short preview, long ISI* condition and *short preview, short ISI* condition were compared: performance in the *short preview, long ISI condition* ($M = .66$, $SD = .14$) did not differ reliably from performance in the *short preview, short ISI* condition ($M = .64$, $SD = .17$), $F < 1$. ISI did not modulate performance.

Discussion

The present experiment replicated the basic findings that previewing the masks attenuates masking, and duration of preview did not influence target discrimination performance. Most important, ISI did not seem to modulate target discrimination performance. It would appear that the visual system could effectively maintain the object-token representation of the mask, even when it was absent for as long as 900 ms.

When the same object was presented at two different instances in time, so long as the original object-token representation was effectively maintained across this temporal lag and *associated with* the later instance, these two instances would be perceived by the visual system as a single instantiation of the same object. The object would then be considered "old" during its later presentation, attenuating masking.

The fundamental motivation behind this study was to determine if previewing the mask could sometimes be ineffective in reducing masking. In order for OSM to occur despite a preview of the mask, the mask pattern during target onset must be considered by the visual system as a new instantiation. Experiment 2 was designed to test the distinction between an "old" and "new" object.

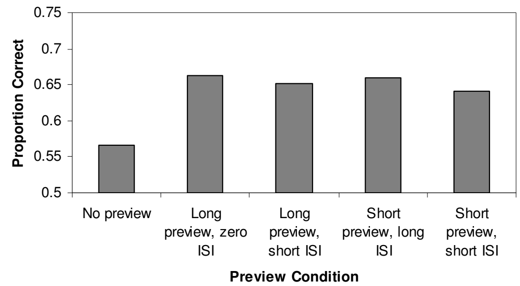

Figure 3: Proportion of correct responses in Experiment 1 of the present study as a function of preview condition. Error bars indicate standard errors.

Experiment 2

In Experiment 2, the configuration of the four-dot mask was manipulated. In the critical (configuration change) conditions, each previewed mask (e.g., square configuration) underwent a 45° rotation, so that the mask during target presentation was a different (diamond) configuration. The diamond configuration should be perceived as "novel", and previewing the mask should not help attenuate masking.

Yet, where there was no ISI between the previewed mask offset and the target presentation, the dots would likely be perceived by the visual system to have "rotated" from a square configuration to a diamond configuration at the same location. Through this apparent motion, the mask, configured as diamond, would not be perceived as a new instantiation from the previewed (square) mask. The later mask would therefore be perceived by the visual system as "old" and incapable of capturing attention.

Method

Participants were 23 undergraduates (13 females and 10 males) from the National University of Singapore who participated to fulfill an experiment requirement for an introductory psychology course. All participants had normal or corrected-to-normal visual acuity. None had participated in Experiment 1.

Apparatus, setting, task, and stimuli The apparatus, setting, task, and stimuli were the same as in Experiment 1, except for the following: each mask comprised four dots presented on the four corners of either an imaginary square or an imaginary diamond shape.

Design A 4 x 2 within-subjects design was used. The independent variable (IV) of primary interest was preview condition. This variable involved four levels: (1) no preview, (2) preview, with no change in configuration of mask pattern and an ISI (900 ms), (3) preview, with a change in configuration of mask pattern and a (long) ISI (900 ms), and (4) preview, with a change in configuration and no ISI. ISI, as in Experiment 1, was defined as the period between previewed mask offset and target-with-mask onset.

The second IV was the mask configuration at preview: (1) the diamond configuration was shown first, or (2) the square configuration was shown first.

All eight types of preview conditions occurred equally often, resulting in a total of 16 observations for each type of preview condition in the four blocks. The total duration of each trial was held constant at 1820 ms across all eight conditions.

Procedure The procedure was largely the same as in Experiment 1, except for the following: each participant completed one 16-trial practice block followed by the four 32-trial experimental blocks. The sequence of trial events is illustrated in Figure 4. In the *no preview* condition, the target and distractors appeared simultaneously with the mask patterns (either square or diamond configurations) 1200 ms after the fixation cross onset. In the *preview, no configuration change, ISI* condition, the mask patterns appeared simultaneously with the fixation and terminated after 300 ms; 900 ms later, the same mask patterns (in the same configurations) appeared simultaneously with the target and distractors. The sequence of the *preview, configuration change, ISI* condition was the same as that of the *preview, no configuration change, ISI* condition, except that the mask configuration during target presentation now differed from the previewed mask configuration. In the *preview, configuration change, ISI = 0 ms* condition, the mask patterns appeared 900 ms after fixation cross onset and persisted for 300 ms, after which the target and distractors appeared together with the altered mask configurations.

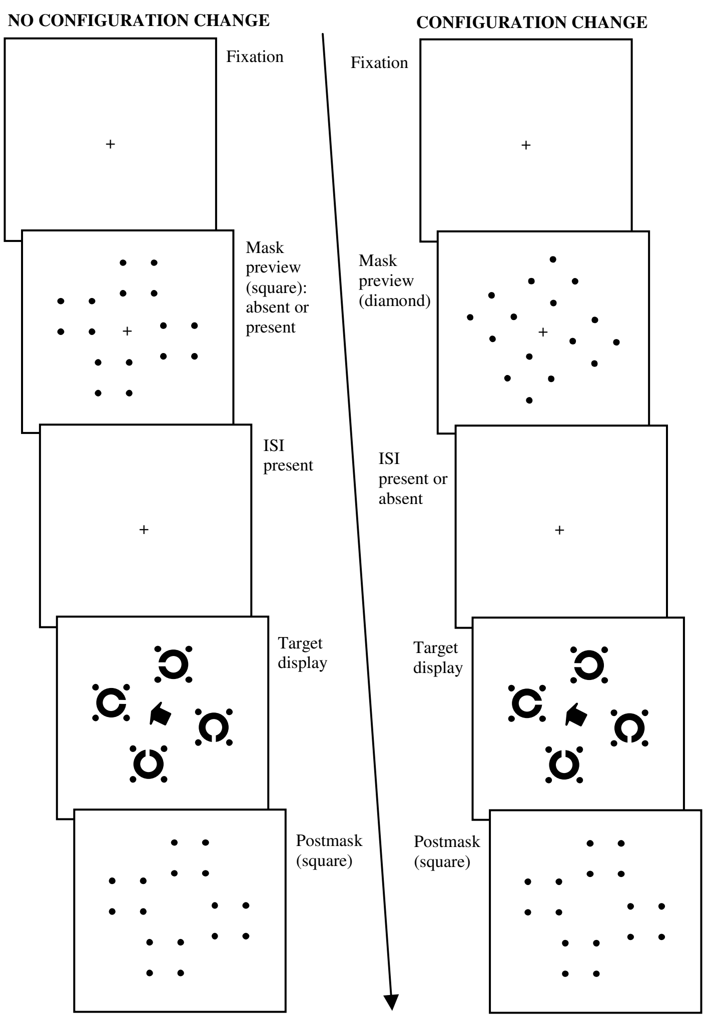

Figure 4: Schematic of the sequence in Experiment 2 of the present study.

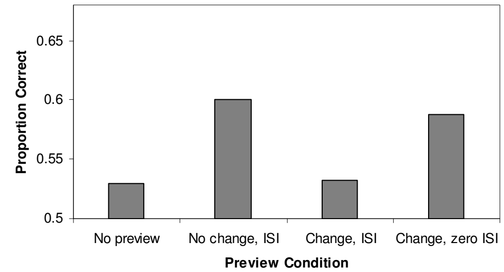

Figure 5: Proportion of correct responses in Experiment 2 of the present study as a function of preview condition. Error bars indicate standard errors.

Results

Data were collapsed across target locations. Figure 5 shows the proportion of correct responses as a function of preview condition. The proportion of correct responses in each condition was calculated for each participant and submitted to a 4 (preview condition) x 2 (order of previewed mask configuration) repeated measures ANOVA. There was a significant main effect of preview condition, $F(3, 66) = 3.36$, $MSe = 0.009$, $p < .05$, $\eta^2 = 0.12$. Neither the main effect of order of previewed mask configuration nor the interaction between order of previewed mask configuration and preview condition was significant, $F < 1$.

To determine whether preview, per se, enhanced performance, the *no preview* condition was compared with the *preview, no configuration change, ISI* condition: when the mask was previewed ($M = .60$, $SD = .14$), performance was significantly better than where the mask was not previewed, ($M = .52$, $SD = .15$), $F(1, 22) = 5.90$, $MSe = 0.001$, $p < .05$, $\eta^2 = 0.28$. Previewing the mask enhanced performance. To determine the effects of configuration change, per se, on performance, the *preview, no configuration change, ISI* condition and the *preview, configuration change, ISI* condition were compared: where there was configuration change ($M = .53$, $SD = .12$), performance was significantly impaired compared to where there was no change ($M = .60$, $SD = .14$), $F(1, 22) = 7.78$, $MSe = 0.007$, $p < .05$, $\eta^2 = 0.29$. A change in mask configuration, with a delay of 900 ms between previewed mask offset and target presentation, impeded target discrimination performance. To investigate the effects of the ISI variable on performance, the *preview, configuration change, ISI* condition and the *preview, configuration change, ISI = 0 ms* condition were compared: given a change in mask configuration, performance was significantly better when ISI = 0 ms ($M = .59$, $SD = .14$) than when the ISI was present ($M = .53$, $SD = .12$), $F(1, 22) = 4.64$, $MSe = 0.008$, $p < .05$, $\eta^2 = 0.26$. Apparent motion nullified the effects of configuration change.

Discussion

Findings supported all predictions. The basic preview effect in Experiment 1 was replicated. When the same mask configuration was used throughout, previewing the mask attenuated masking despite a long ISI of 900 ms. The important finding was that given the same ISI, previewing a mask that had a configuration that was *different* from the configuration at test did not attenuate masking. Yet, where the ISI in this particular case was removed, masking was attenuated.

When a diamond configuration was previewed, an object-token of this diamond mask was represented in visual short term memory. However, when the mask appeared with the target in a square configuration (cf. *preview, configuration change, ISI* condition), the original (diamond) object-token representation, albeit maintained (recall from Experiment 1 that an object token can be maintained in visual short term memory for as long as 900 ms), was not effectively associated with this new configuration. Represented as a separate object-token, the square mask was therefore perceived as a novel stimulus that could capture selective attention, resulting in OSM.

Yet, where ISI = 0 ms, an apparent motion effect was attained which nullified the effects of mask configuration change. The visual system perceived the mask to have moved (rotated) directly from its original (diamond) orientation into its final (square) orientation at the same location. The mask in its (new) square orientation was therefore represented as a mere extension of the "old" stimulus which cannot capture attention. OSM is therefore attenuated.

General Discussion

The present study showed that previewing the mask pattern effectively attenuated masking and enhanced target discrimination performance under most situations; neither preview duration nor ISI, per se, modulated performance (Experiment 1). Consider where the previewed mask configuration (e.g., diamond) differed from the mask configuration during target presentation (e.g., square). When there was a delay of 900 ms between previewed mask offset and target presentation, previewing was found to be ineffective. Yet, when this delay was removed (i.e., ISI = 0 ms), preview attenuated masking.

Taken together, these findings seem to converge on one critical point: how the masks are represented in visual short term memory, and whether these initial representations are maintained and associated with the masks during target onset later determine whether preview is effective in attenuating substitution. An account based on object-token representations seems to provide an excellent fit to the data.

Durable representations of the target and mask occur at the object-token level. By previewing the mask, an object-token representation of the mask can be established, as it is the only object during preview. This representation is maintained in visual short term memory even after the mask disappears from view. By the time the same mask appears again (with the target), the specification of the mask is already completed (during the preview stage). At this point, the original object-token is effectively associated with the (same) mask that reappears, which marks it as an "old" stimulus. The visual system continues to sample information from the display which now also includes the new target object. As the only new stimulus in the display, the target gets processed. After several cycles of information sampling, an object-token-level representation of the target is established. As this is the most recent object-token representation to be established and maintained in visual short term memory, the target can be represented in a form for later report.

When the configuration of the previewed mask (e.g., a diamond configuration) differs from that of the mask during target presentation (a square configuration) (Experiment 2), the diamond mask may be fully specified at preview, its cycles and object-token representation established. But when the configuration during target presentation is different (square), the latter would yield a separate object-token representation, making it "new". Presented simultaneously with the target, this square configuration would be processed concurrently with the target. The specification of the target may be incomplete due to competition from the square mask for selective attention. As the target terminates first while the square mask persists (delayed-offset), the visual system continues to sample information from the mask. As a result, the mask "object substitutes" the target. An object-token of the mask is established and last represented in visual short term memory. Target report is hampered and OSM occurs as if there has been no previewing of the mask.

Conclusion

We report new evidence of ineffective mask preview under the scenario where the original object-token representation, albeit maintained, cannot be effectively associated with the mask that reinstates, after a temporal lag, during target presentation. This later mask is perceived by the visual system as "new" and is capable of capturing attention and causing OSM. A new understanding of when mask preview can exactly attenuate substitution masking is initiated.

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