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Long-Term Memory Representations Influence Perception Before Edges Are Assigned to Objects

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One way to prioritize limited mental resources for perception is to take into account the familiarity of an object to the perceiver. But does an objects' familiarity influence perception only after an object's shape has been determined, or does it influence the decision of which edges are considered part of that object? Here we compare the influence of target familiarity on whole-object masking (object-substitution masking) with its influence on edge-based masking. Two new aspects of edge-based masking are reported. First, we demonstrate that mask and target edges do not only compete (object trimming) but that mask and target edges can also cooperate (object binding), confirming that these masking effects are indeed occurring during the process of object formation and not after object shape has been determined. Second, we find that object trimming and binding are each less likely if the target is linked with a representation already present in long-term memory. Since trimming and binding effects arise very early in visual perception, these data indicate that existing long term memory representations influence the earliest stages of object assembly, before the system has even decided which edges to include in the object.

Keywords: object-substitution masking, object trimming, object binding, reentrant processing

It is axiomatic that the perception of an object is strongly influenced by whether it can be readily linked to a long-term memory representation. Such objects are often referred to as *denotative*, because they can be readily associated, in a direct and explicit way, with a simple label or name. Evidence of the importance of denotation in perception range from demonstrations that perceptual judgments of sameness or difference are affected by conceptual categories (Lupyan, Thompson-Schill, & Swingley, 2010), that figure-ground segmentation is influenced by long-term memory representations (Peterson & Gibson, 1991, 1993, 1994), that search times for shapes that are grouped by color are faster when those shapes were previously learned as associated pairs than when they were not (Vickery & Jiang, 2009), that the grouping of shapes and object-based attentional benefits are influenced by prior experience (Zemel, Behrmann, Mozer, & Bavelier, 2002), that the perceptual binding of color and feature information is affected by stimulus familiarity (Prinzmetal & Millis-Wright, 1984), that words and familiar images are less susceptible to backward masking than less familiar letter strings and images (Elze, Song, Stollhoff, & Jost, 2011; Reicher, 1969; Shelley-Tremblay & Mack, 1999; Weisstein & Harris, 1974; Wheeler, 1970), that the apparent felt size of a coin is greater when its relative value is increased (Bruner & Goodman, 1947), and that automobile drivers are more likely to notice vehicles on the road that are similar to those they are familiar with (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005).

The focus of the present study is on whether denotation exerts its influence on perception only *after* an object representation has been formed, or whether this influence can be measured *before* early perceptual processes have determined which parts of the image belong to the candidate object. What makes this question tractable is the recent discovery of a form of visual masking that has its influence on the edge-assembly stage of perception, rather than the whole-object level (Kahan & Mathis, 2002; Kahan & Enns, 2010).

Masking at the whole-object level is often studied by presenting two objects briefly in nearby locations, with one of the objects terminating early (e.g., a target) and the other persisting for a longer period (e.g., four surrounding dots). *Object-substitution masking* refers to the finding that the object that persists often replaces the briefer object in the consciousness of the observer, with the brief object not being seen (Di Lollo, Enns, & Rensink, 2000). Evidence that this masking occurs at the whole-object level comes from studies showing that masking often decreases when observers perceive the mask and target as representing different objects and, conversely, is stronger when mask and target are seen as the same object transforming over time (Enns, Lleras, & Moore, 2010; Lleras & Moore, 2003; Moore & Lleras, 2005).

Against this background, Kahan and Mathis (2002) reported that when two dots flank one edge of the target rather than four surrounding it, the masking effect is limited to the local region of the dots. For example, if the digital letter A shown in Figure 1 is presented with a vertically arrayed dot-pair flanking its lower right side, it may incorrectly be reported as the letter P.

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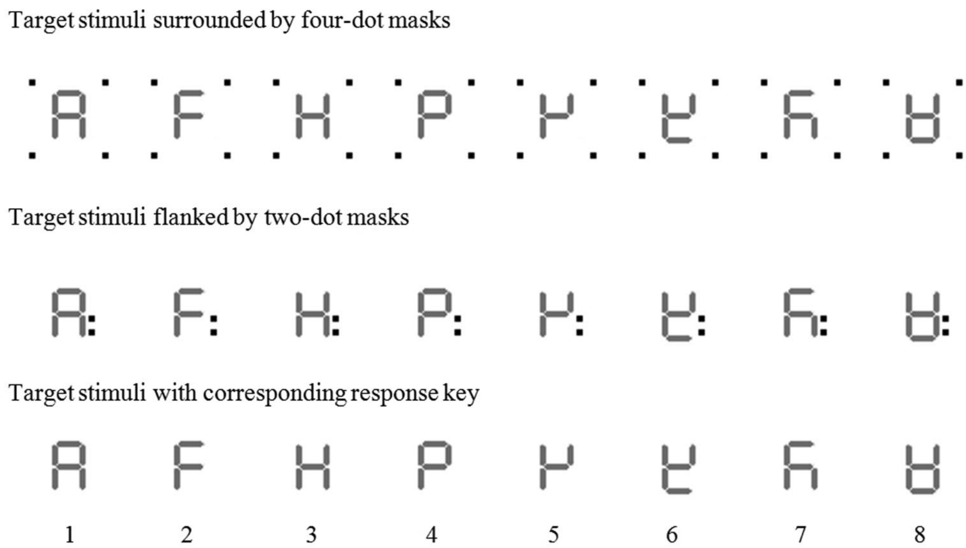

Figure 1. Examples of target stimuli surrounded by four-dot masks (top) or flanked by two-dot masks (middle). The mapping of targets to response keys is shown at the bottom. Four familiar targets that are easily named are displayed on the left; four unfamiliar targets are shown on the right.

This is called *object trimming* because the edges of the mask and target compete for the consciousness of the observer, with the persisting dots defining the edge that is seen in place of the target edge. Direct tests of this interpretation, involving target-identification tasks, speeded-priming tasks, and judgments of ambiguous apparent motion, all indicated that object trimming is influenced by mechanisms of perceptual grouping that operate on target representations prior to conscious awareness (Kahan & Enns, 2010). In addition, *object trimming* is dissociable from *object-substitution masking.* Object trimming is robust when the dots terminate with the target and reflects edge-based competition occurring before object representations are established. In contrast, object-substitution masking requires delayed offset of the dots and is theorized to reflect reentrant processes that occur after object representations are formed.

In the present study, we demonstrate that the edge interactions involved in two-dot masking can be *cooperative* as well as competitive. For example, when the digital letter P in Figure 1 is presented with dots flanking its lower right side, it may be incorrectly reported as the letter A. A very practical benefit of studying cooperative edge interactions, which we hereafter refer to as *object-binding,* at the same time as studying competitive edge interactions (*object-trimming*), is that it allowed us to design an experiment that controlled the possibility of response bias stemming from the location of the implied mask edge (e.g., the tendency to report an edge is present if the two dots are also present at that location). That is, by making the existence of a target edge independent of the existence of a mask edge, and by using target shapes that were equally likely to have, or not have, a line segment in the bottom right, we could measure the tendency of the visual system to falsely trim an edge from, or to bind an edge to the target, independent of any possible biasing tendency of the mask.

The primary purpose of distinguishing between perceptual processes at the level of edges (through object trimming and binding) and at the level of the whole shape (through object substitution masking) is that it gives us the opportunity to determine where in the visual processing stream long-term memory representations influence shape perception. As mentioned earlier, numerous studies have reported that objects associated with long-term memory representations are identified more efficiently, more rapidly, and are less susceptible to interference from neighboring objects than less denotative objects (see Bruner & Goodman, 1947; Elze et al., 2011; Lupyan et al., 2010; Neale et al., 2005; Peterson & Gibson, 1991, 1993, 1994; Prinzmetal & Millis-Wright, 1984; Reicher, 1969; Shelley-Tremblay & Mack, 1999; Vickery & Jiang, 2009; Weisstein & Harris, 1974; Wheeler, 1970; Zemel et al., 2002, among others). Although these reports document that the perception of objects is affected by long-term memory representations, they do not establish where in the chain of visual processing the influence takes place.

Here we distinguish between two broad classes of possibility. One approach has been to adopt a late perspective, where long-term memory representations exert their influence at the highest level in the system, after the results of lower level edge-assembly processes have taken place and have been transferred to higher levels. Most feed-forward models of visual perception fall into this category (e.g., Riesenhuber & Poggio, 1999). As an alternative, it is possible that long-term memory representations exert their influence early on in visual processing. This can be accomplished in several ways. For example, in a feed-forward system well-practiced patterns may give rise to visual templates that facilitate the processing of familiar forms. However, since simple template-based models of perception have difficulty explaining (a) how familiar objects are recognized when viewed from perspectives that do not match a stored template or (b) how familiar patterns are perceived when the surface form is novel (e.g., novel fonts), reentrant theories may be more plausible[1]. Under this approach, long-term memory representations exert their influence on object recognition processes through the iterative exchanges of neural signals among levels (Ahissar & Hochstein, 2004; Di Lollo et al., 2000; Lamme, Zipser, & Spekreijse, 2002; Mumford, 1991; Mumford, 1992; Rao & Ballard, 1999). An initial wave of stimulation ascends rapidly through the system, followed by descending signals between levels. Together, ascending and descending pathways form an iterative-loop system, aimed at noise reduction and hypothesis verification, thereby establishing the most plausible interpretation of the incoming stimulus. In this view, the assembly of edges into a familiar shape is based on interactions among all levels. The ascending activity provides an initial hypothesis about edge length or orientation, but this activity is modified by descending activity, reflecting the history of this stimulus and its importance to the organism as a whole.

In this study we examined object identification when it is interfered with at both the whole-object level (through object substitution masking) and at the edge-assembly stage (through object trimming and binding). The objects to be identified consisted of eight target shapes constructed from digital clock-face letters (see Figure 1). Four of the targets were familiar letters from the English alphabet (A, F, H, P); the other four were relatively unfamiliar shapes that had the same number of segments and the possibility of lines and missing lines in the same locations as the familiar letters. The participants' task was to identify each target shape.

In what follows, we report the results of object substitution masking first, in order to establish the influence of long-term memory representations on masking at the whole-object level, before describing the results for object trimming and binding. We predicted that denotative targets—those with long-term memory representations—would be less susceptible to masking at the whole object stage since this is expected if long-term memory representations exert their influence at early or late-stages in the visual processing stream. Thus, the whole-object masking data were used to establish an important context of effect sizes, for comparison with any effects of long-term memory representations that we might observe at the edge-assembly stage of object identification. The truly novel question answered here is whether denotative shapes will be less susceptible to object trimming and binding effects, which arise early on in visual processing while edges are being assembled into objects. If denotation influences early, edge-based masking effects, then our data will firmly establish that familiarity influences perception before edges are assigned to objects.

To examine the influence of target denotation at different stages of visual processing, it is important to rule out the possibility that the data reflect some combination of response biases that include (a) "guess a familiar letter if unsure" and/or (b) "guess that the mask interfered with an edge at the same location." To control for these possible guessing biases, it was critical that our experimental design included (a) shapes that were equally likely to be familiar versus unfamiliar, and (b) that the presence of an edge and the absence of an edge at the masked location were equally likely. These two factors allowed us to separately measure decision biases at the response stage separately from the influence of denotation on perceptual stages of processing. As a further guard against questions of response bias arising from familiarity, we also report data from a control experiment where the target shapes were made difficult to see by reducing luminance contrast, rather than with masking. These control data provide a baseline for assessing whether object-level and edge-level perceptual effects can be differentiated from effects caused by mere uncertainty about the identity of a target.

Method

Participants

A total of 28 students from the University of British Columbia (Vancouver, British Columbia, Canada) and Bates College (Lewiston, Maine) participated for course credit in Introduction to Psychology classes. Fifteen of these students participated in the experimental task, where masking dots obscured target visibility, and 13 participated in a control experiment where target visibility was reduced by varying the target's contrast level. Participants from both colleges were between the ages of 17 and 22 and both samples were mostly composed of female participants. Eleven of the 15 participants from the University of British Columbia were female while 10 of the 13 participants from Bates College were female. We used sample sizes of 13 and 15 participants because in our prior work examining object trimming (Kahan & Enns, 2010) our effect sizes were extremely large (*d* values ranging from .88 in Experiment 3a to 2.8 in Experiment 1) and for this reason we calculated that we would have more than adequate power (i.e., power ranging from .80–.99) to detect similar-sized edge-based masking effects with samples as small as 13 participants (Faul, Erdfelder, Lang, & Buchner, 2007).

Experimental Group: Masking

Displays. Stimuli were presented and responses were recorded using E-Prime software. Participants were seated approximately 60 cm from a display of 1,024 × 768 pixels. Targets were randomly chosen from eight possibilities shown in Figure 1. All of the stimuli appeared in a digital-clock-type font and half were English letters (left-hand side of Figure 1) while the other half were not (right-hand side of Figure 1). Stimuli were either surrounded by four dots (top of Figure 1) or were flanked on the lower right by two dots (middle of Figure 1); this created 16 combinations. Dots measured 0.13° in diameter and targets measured 1.04° in height and 0.73° in width and appeared in one of four randomly chosen quadrants, 5.71° from fixation; in the other three quadrants the letter O appeared in this same digital-clock-type font.

Procedure. Each trial began with a fixation (+) at the center of the screen for 1,000 ms. This was replaced with a display containing four shapes, one in each quadrant, for 33 ms; three

[1] Although simple template-based models of perception, which require an exact match between the incoming visual stimulus and the stored template, have difficulty explaining the flexibility of the visual system to identify objects seen under a wide-array of different viewing conditions, more-sophisticated template-based models may fare better if they allow for nonexact matches. However, as feed-forward template-based models become more flexible, it may become increasingly difficult to distinguish between these models and interactive feature-based models of perception.

shapes were the letter O, and the other was the target-plus-masking-dots. On half of the trials, the masking dots terminated with the target and on the other half the masking dots had a delayed offset of 1,000 ms. After this a response key appeared at the bottom of the screen (bottom of Figure 1). Participants indicated the target shape as accurately as possible using the 1–8 keys on the computer's keyboard. Participants were told that all stimuli were equally likely as was the likelihood that they would either be surrounded by four dots or flanked by two dots. Each of the 16 stimulus types shown in Figure 1 was presented 40 times. Participants completed eight practice trials and 640 experimental trials with a self-paced break after every 80 trials.

Control Group: Contrast Reduction

The displays and procedure in the control group were identical to the experimental group with the following exceptions.

Displays. Targets appeared alone on the screen, in a randomly chosen quadrant, unaccompanied by any dots. Target contrast was manipulated by varying the opacity level in Adobe Photoshop in increments of 5%. Images with 100% opacity (i.e., unaltered images) were clearly visible and as the opacity level decreased from 95% down to 5% the images became harder to see.

Procedure. Targets were always displayed for 33 ms, but their contrast was adaptively manipulated on a trial-by-trial basis. When the participant's overall accuracy rate exceeded 57%, target contrast was reduced by 5%. When the participant's overall accuracy rate fell below 55%, target contrast was increased by 5%. This procedure kept participant accuracy rates in the control task equivalent to the experimental task, but it did so unaffected by any influences of object-level or edge-level masking.

Results

Targets with a vertical edge on the bottom right (Figure 2A) were analyzed separately from stimuli with no vertical edge (Figure 2B), because the former were susceptible to edge-based trimming (Kahan & Enns, 2010), while the latter were susceptible to edge-based binding. For both trimming and binding effects, we also first compare masking at the whole-object level (object substitution using four dot masks) to edge-based masking effects (trimming and binding using two dot masks). This was done to provide a context against which to compare the effects of edge-based trimming and binding. For example, when errors were made on targets that shared an edge with the competing two-dot mask (see Figure 2A) or to targets that did not share an edge with the two-dot mask (see Figure 2B) we examined the likelihood that a response consistent with object trimming or binding was made, respectively. Since participants were given eight choices on each trial, when errors were made (seven possible error responses) a response consistent with object trimming or binding is expected by chance 14% of the time. To help guard against the possibility that trimming and binding rates were caused by some form of guessing bias that might increases these rates, perhaps even higher than chance levels, we also compared the types of errors that were made when two dots obscured the target with the types of errors made for these same targets in the control condition where target contrast was reduced. This increased our confidence that the results reflect the influence of the mask on target performance rather than response biases that emerge when participants are uncertain, since overall accuracy rates were equivalent in the experimental

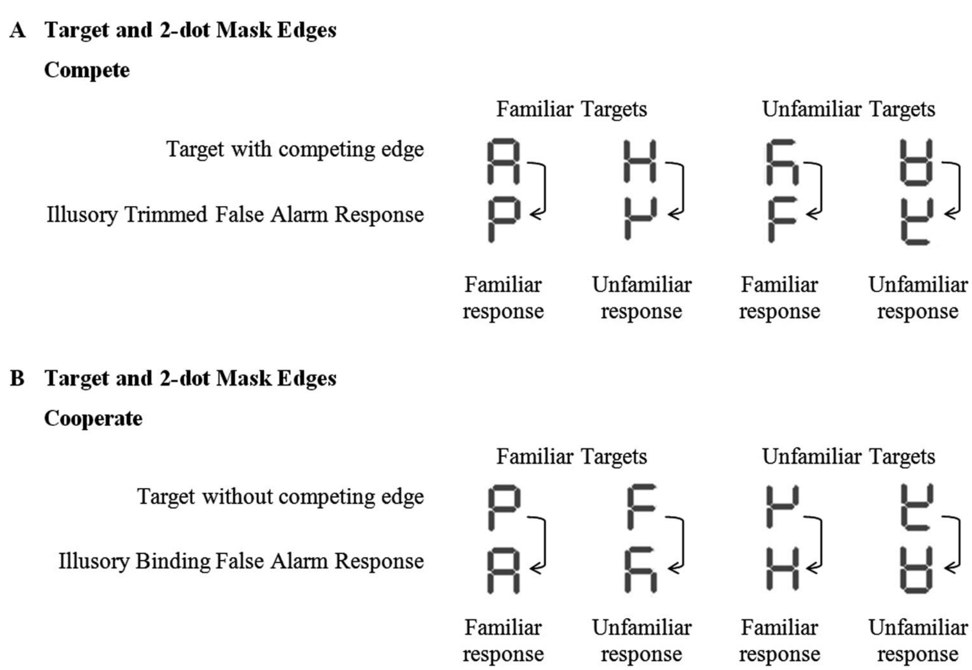

Figure 2. Examples of targets and possible false alarm responses. A. Targets that share a competing edge with two-dot masks flanking the lower right along with trimmed false alarm responses. B. Target stimuli that did not share a competing edge with two-dot masks flanking the lower right, along with illusory binding false alarm responses.

(M = .56) and control (M = .55) groups, $t(26) = 0.257$, $p = .80$.

Object trimming (when targets and masks share a competing edge). Figure 3 shows the effects of masking on target accuracy, separately for four-dot and two-dot masks. These data show that denotative targets were less susceptible to both object-level and edge-level masking than nondenotative targets, with the effect of familiarity being even *stronger* for two-dot than for four-dot masking.

These conclusions were based on a 2 × 2 × 2 repeated-measures analysis of variance (ANOVA), involving mask type (four-dot vs. two-dot), mask offset (immediate vs. delayed), and target denotation (familiar vs. unfamiliar). Masking dots reduced target accuracy more when their termination was delayed (M = .42) than simultaneous (M = .48), $F(1, 14) = 13.17$, $p < .05$; $h_p^2 = .49$; replicating Enns and Di Lollo (1997). Accuracy was higher for denotative targets (M = .58) than nondenotative targets (M = .31), $F(1, 14) = 42.23$, $p < .05$; $h_p^2 = .75$, indicating that denotative targets were more difficult to mask. There was also an interaction between mask type and target denotation, $F(1, 14) = 106.93$, $p < .05$; $h_p^2 = .88$, which indicates that the influence of denotation was *stronger* for two-dot than four-dot masks.

To inspect edge-level masking effects (two-dot masking) in greater detail we examined the types of errors that were made. Figure 4 shows the probability of making a response consistent with object trimming (Figure 2A). This analysis shows that participants were more likely to make trimmed false alarm responses when the target item was unfamiliar than when it was familiar, and this was especially likely in the delayed-offset condition when the response was also a familiar item. Thus, the influence of denotation on object trimming went well beyond any general tendency to guess a familiar response when uncertain, as evidenced by the large differences in trimmed responses between familiar and unfamiliar targets, over and above the effects of familiarity on the responses in general.

These conclusions were based on a 2 × 2 × 2 repeated-measures ANOVA, involving target denotation (familiar vs. unfamiliar), response denotation (familiar vs. unfamiliar), and offset duration (immediate vs. delayed). There was a main effect of target denotation, $F(1, 14) = 44.00$, $p < .05$; $h_p^2 = .76$; trimmed false alarms were more likely when the target was unfamiliar (M = .80) relative to familiar (M = .43). There was also a main effect of response denotation, $F(1, 14) = 15.06$, $p < .05$; $h_p^2 = .52$; participants were more likely to make a trimmed false alarm when their response referred to a familiar (M = .71) versus unfamiliar target (M = .51). Finally, there were interactions between target denotation and response denotation, $F(1, 14) = 6.14$, $p < .05$; $h_p^2 = .31$; between response denotation and dot duration, $F(1, 14) = 12.73$, $p < .05$; $h_p^2 = .48$; and a three-way interaction of dot duration, target denotation and response denotation, $F(1, 14) = 18.37$, $p < .05$; $h_p^2 = .57$. These interactions indicate that the effects of target denotation and response denotation were synergistic in the delayed-offset, but not the immediate-offset, condition. This is evidenced by a two-way interaction between target denotation and response denotation, $F(1, 14) = 35.48$, $p < .05$; $h_p^2 = .72$, when the delayed-offset data are analyzed separately from the immediate-offset data (right-side of Figure 4), and no such interaction when the immediate-offset data are analyzed separately (left side of Figure 4), $F(1, 14) = 0.10$, $p > .05$; $h_p^2 = .01$. Critically, target denotation affected object trimming beyond any bias to guess a familiar response.

To further bolster our confidence that response biases were not responsible for these denotation effects on object trimming, we compared the types of errors that were made to these same targets (Figure 2A) for participants in the experimental masking group (collapsing across dot duration) with participants in the control contrast-reduction group in a 2 × 2 × 2 mixed ANOVA, involving target denotation (familiar vs. unfamiliar), response denotation (familiar vs. unfamiliar), and group (experimental vs. control). Critically, this analysis resulted in a significant three-way interac-

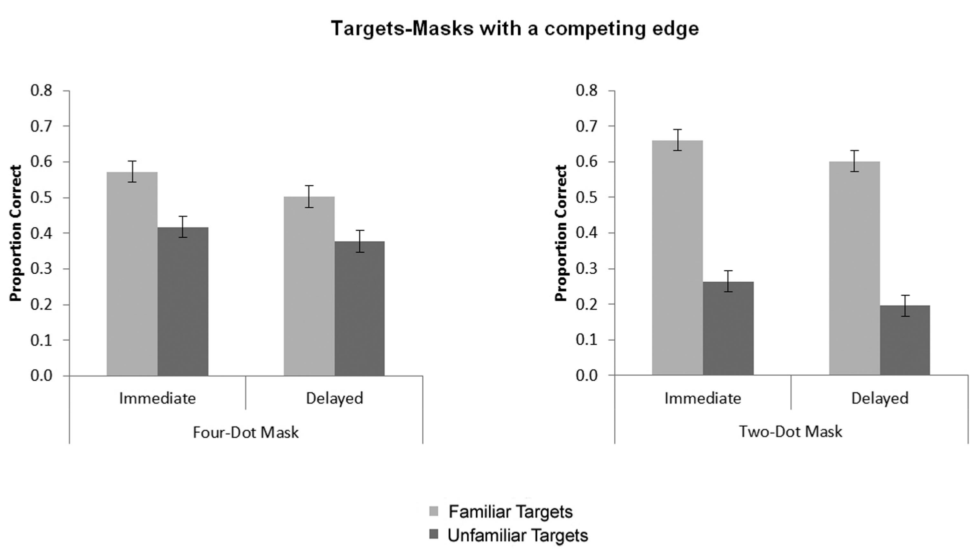

Figure 3. Proportion of correct responses to targets with a competing edge as a function of mask type, target familiarity, and dot offset duration. Data from four-dot surrounding masks are depicted in the left-hand panel and data from two-dot flanking masks are depicted in the right-hand panel. Error bars depict 95% confidence intervals for within-subject effects (Loftus & Masson, 1994).

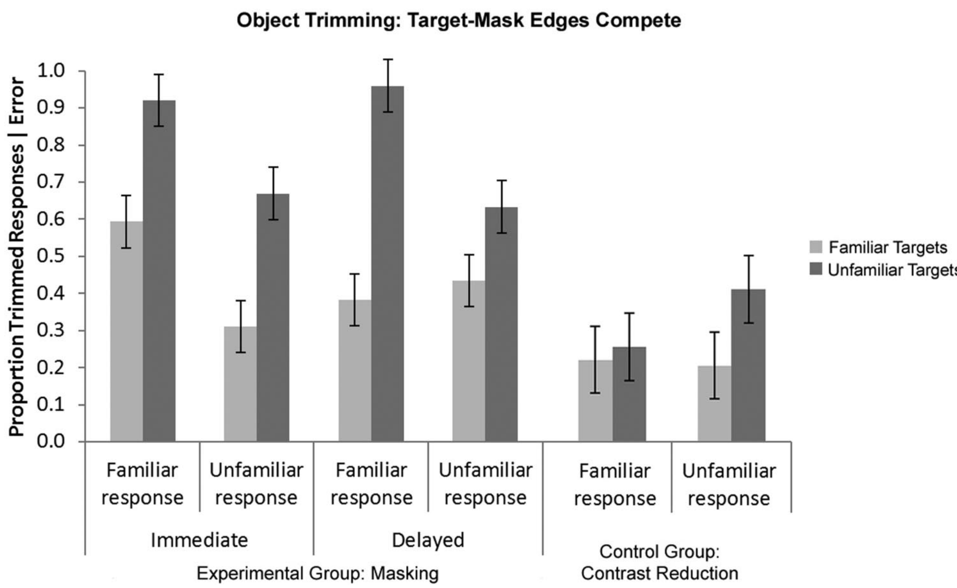

Figure 4. Proportion trimmed responses given an error for targets that were flanked by dots along a competing edge, as a function of dot offset duration, response familiarity, target familiarity, and group. Error bars depict 95% confidence intervals for within-subject effects (Loftus & Masson, 1994) and are computed separately for the experimental and control groups.

tion, $F(1, 26) = 8.75$, $p < .05$; $h_p^2 = .25$, and an examination of Figure 4 makes it clear that that the trimming effects we observe are caused by edge-based competition rather than guessing strategies that emerge when participants are uncertain.

Object binding (when targets and masks combine edges). Figure 5 shows the effects of masking on target accuracy, separately for four-dot and two-dot masks. These data show that targets with long-term memory representations were again much less susceptible to masking than unfamiliar targets, but here the effect of the simultaneous versus delayed offset was different for four and two-dot masking. In particular, four-dot masks reduced target accuracy more when their termination was delayed than when it was simultaneous, whereas two-dot masks were equally effective whether they had simultaneous or delayed offsets. This is consistent with masking at the whole-object level for four-dot masks, where an object with a delayed offset can win the competition for

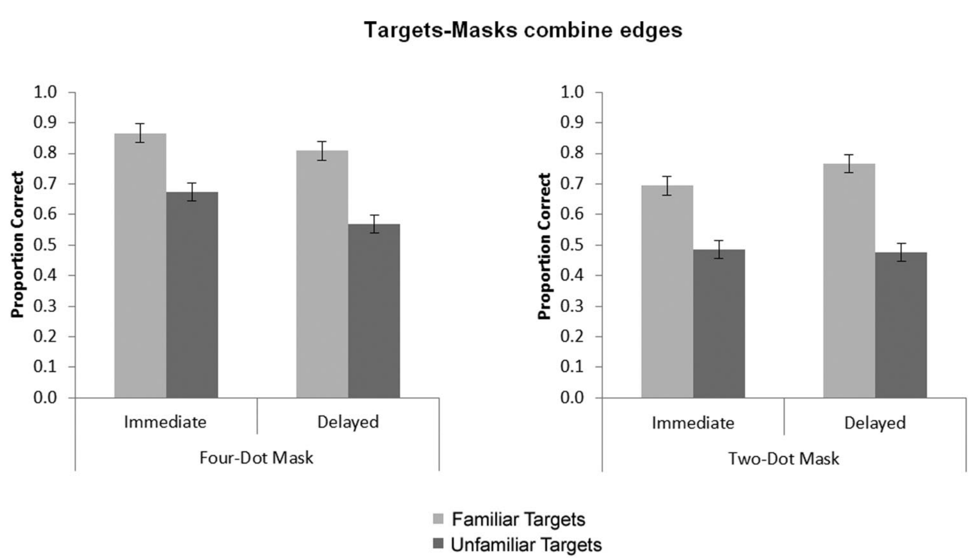

Figure 5. Proportion of correct responses to targets without a competing edge as a function of mask type, target familiarity, and dot offset duration. Data from four-dot surrounding masks are depicted in the left-hand panel and data from two-dot flanking masks are depicted in the right-hand panel. Error bars depict 95% confidence intervals for within-subject effects (Loftus & Masson, 1994).

consciousness, and edge-level masking for two-dot masks, which involves a local cooperative interaction among neighboring edges.

These conclusions were based on a 2 × 2 × 2 repeated-measures ANOVA, involving masking type (four-dot vs. two-dot), mask offset (immediate vs. delayed), and target denotation (familiar vs. unfamiliar). Accuracy was higher when the target was familiar (*M* = .79) than unfamiliar (*M* = .55), $F(1, 14) = 52.77$, $p < .05$; $h_p^2 = .79$. A main effect of mask type, $F(1, 14) = 29.93$, $p < .05$; $h_p^2 = .63$, indicated that accuracy was higher with four-dot masks (*M* = .73) than two-dot masks (*M* = .61). Four dots reduced target accuracy more when their termination was delayed (*M* = .69) than simultaneous (*M* = .77), $t(14) = 4.02$, $p < .05$; $h_p^2 = .54$, whereas the masking effects of the two flanking dots were the same whether they terminated with the target (*M* = .59) or were delayed (*M* = .63),$t(14) = 1.59$, $p > .05$; $h_p^2 = .15$. The interaction of mask type by mask offset was significant, $F(1, 14) = 14.40$, $p < .05$; $h_p^2 = .51$.

To inspect edge-level masking (two-dot masks) in greater detail we examined the types of errors that were made. Figure 6 shows the probability of making a response consistent with object binding (Figure 2B). This analysis shows that participants were more likely to make binding false alarms when the target was unfamiliar than when it was familiar, indicating that a target is less susceptible to edge-level interactions if it can be linked to a long-term memory representation. This analysis also shows a bias for participants to respond with a familiar over an unfamiliar item, though this bias interacts with whether the target was unfamiliar to begin with. Finally, binding false alarms were more likely when target and mask edges began and ended together (simultaneous offset), than when the mask edges persisted (delayed offset), a finding that again supports the claim that this binding effect is edge-based, rather than object-based, because edge binding was supported by temporal coincidence.

These conclusions were based on a 2 × 2 × 2 repeated-measures ANOVA, involving target denotation (familiar vs. unfamiliar), response denotation (familiar vs. unfamiliar), and offset duration (immediate vs. delayed). There was a main effect of target denotation; object binding responses were more likely when the target was unfamiliar (*M* = .31) than familiar (*M* = .13), $F(1, 14) = 28.07$, $p < .05$; $h_p^2 = .67$. They also more frequently involved making familiar (*M* = .36) than unfamiliar (*M* = .08) responses, $F(1, 14) = 52.90$, $p < .05$; $h_p^2 = .79$. The interaction between target denotation and response denotation was significant, $F(1, 14) = 4.60$, $p < .05$; $h_p^2 = .25$, indicating that these effects were synergistic, i.e., the tendency to report a familiar item was greater when that target was unfamiliar to begin with than when it was familiar. Finally, object binding was more likely when termination of the dots was simultaneous (*M* = .26), rather than delayed (*M* = .18), $F(1, 14) = 17.42$, $p < .05$; $h_p^2 = .55$, and this effect was larger when the response was familiar rather than unfamiliar, $F(1, 14) = 11.71$, $p < .05$; $h_p^2 = .46$.

To further examine whether response biases were responsible for these effects of denotation on object binding we compared the types of errors that were made to these targets (Figure 2B) for participants in the experimental masking group (collapsing across dot duration) with participants in the control contrast-reduction group in a 2 × 2 × 2 mixed ANOVA, involving target denotation (familiar vs. unfamiliar), response denotation (familiar vs. unfamiliar), and group (experimental vs. control). Critically, this analysis resulted in a significant interaction between target denotation and group, $F(1, 26) = 22.10$, $p < .05$; $h_p^2 = .46$, where familiar targets were less susceptible to binding errors than were unfamiliar targets in the experimental group, $t(14) = 5.27$, $p < .05$. This interaction was not significant for participants in the control group, $t(12) = 1.32$, $p > .05$, and an examination of Figure 6 makes it clear that that the binding effects we observe are caused by early

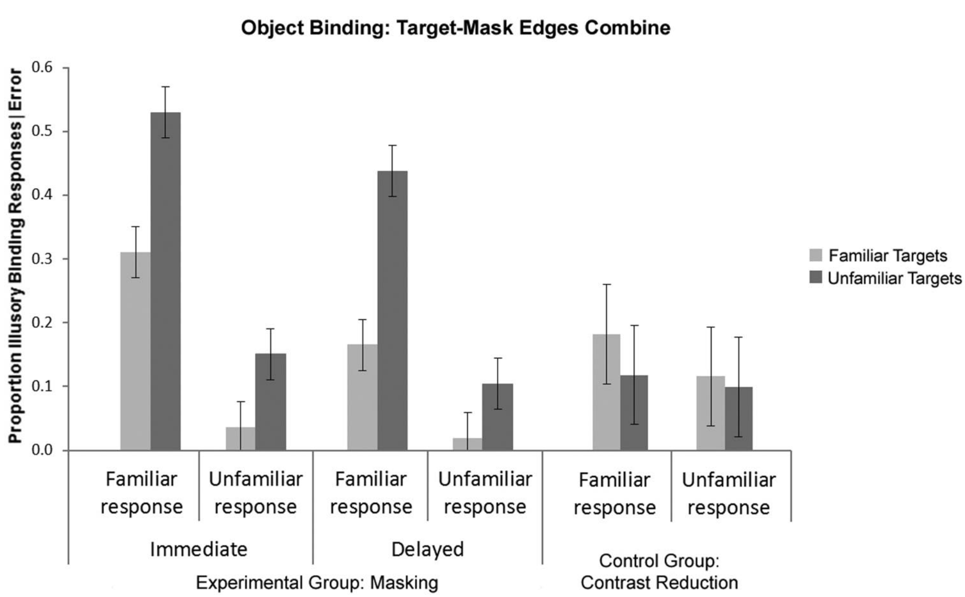

Figure 6. Proportion illusory binding responses, given an error, for targets that were flanked by dots along a missing side (i.e., no competing edge) as a function of response familiarity, target familiarity, and group. Error bars depict 95% confidence intervals for within-subject effects (Loftus & Masson, 1994) and are computed separately for the experimental and control groups.

level edge-assembly processes rather than guessing strategies that emerge when participants are uncertain.

Discussion

When one of several briefly presented shapes is surrounded by four dots that linger on view, the visibility of the surrounded shape is impaired, an effect referred to as object-substitution masking (Di Lollo et al., 2000). This effect arises from object-level competition when the target and surrounding dots are perceived as one object transforming over time (Enns et al., 2010; Lleras & Moore, 2003; Moore & Lleras, 2005) and requires that the masking dots have a delayed offset. When one of the briefly presented shapes is flanked by only two dots, then target visibility is influenced by edge-based competition between masking dots and targets, a phenomenon referred to as *object-trimming* (Kahan & Mathis, 2002). The present study demonstrated that two-dot masking can also result in the illusory *addition* of a target line, a phenomenon we refer to as *object binding*. Both of these effects (trimming and binding) arise before object representations have been established (Kahan & Enns, 2010), as evidenced by the finding that these effects do not require delayed offset of the masking dots.

These three masking phenomena, one at the level of object competition (object-substitution), and two at the level of edge assembly (object-trimming and object-binding), allowed us to ask a unique question about the role of long-term memory representations in the visibility of a briefly presented shape. Does the existence of a long-term memory representation for a shape influence its visibility only *after* its relevant edges have been assembled into an object candidate? Or, do long-term memory representations exert their influences during the edge-assembly phase itself? The data were clear: targets linked to long-term memory representations were less vulnerable to edge-based interference.

These data cannot be accounted for by a guessing strategy, where participants are simply biased to generate familiar rather than unfamiliar responses when they are uncertain. This is because the data revealed large effects of target denotation that were above and beyond the effects of denotation in the response. In some analyses the effects of target denotation even interacted with the denotation of the response, implying that any response biases favoring familiarity were not simply tagged on to the end of an uncertain perceptual process. As further confirmation of this conclusion, comparisons of these masking effects with the effects of contrast reduction in a control group, made it clear that participants' errors generated in the context of two dot masking were caused by early level perceptual processes rather than guessing strategies that are added in at some later decision stage.

Having come to this conclusion, it is worth noting that the traditional dichotomy between a perceptual stage and a decision-making stage applies only to a linear, feed-forward, model of perception. If perception is dynamic and iterative, as proposed by current reentrant theories of perception (Ahissar & Hochstein, 2004; Di Lollo et al., 2000; Lamme et al., 2002; Mumford, 1991, 1992; Rao & Ballard, 1999) then perception and decision making are no longer dichotomous. Instead, each level in the visual hierarchy will be extracting information from both lower and higher levels in order to register its most up-to-date *guess* about the world. Indeed, if this is what is meant by *guessing*, then guessing is inseparable from seeing. What our experimental design rules out is that a simple model of guessing based on stimulus familiarity can account for the effects of masking on target perception.

The question of whether objects with preexisting long-term memory representations are afforded a processing advantage in early stages of vision has, to date, remained elusive. The present study contributes to this debate by making it clear that this processing advantage occurs before the component edges of an object have been assembled into a coherent object. Whether these early effects on edge assembly are better modeled within a feed-forward architecture (e.g., using templates formed with experience) or a reentrant one (e.g., through strong predictions to low-level units based on the activation of higher level ones) cannot be determined by the present findings. It is our view that reentrant accounts, which assume iterative exchanges of neural signals among levels to account for these results, will ultimately fare better, since these accounts do not require there to be a perfect match between a template and a stimulus (but see footnote 1). Moreover, reentrant theories can easily explain the effects of familiarity that have recently been observed with other visual phenomenon, including visual search (Malinowski & Hubner, 2001), figure-ground segmentation (Peterson & Gibson, 1991, 1993, 1994), and backward masking effects (Elze et al., 2011; Reicher, 1969; Shelley-Tremblay & Mack, 1999; Weisstein & Harris, 1974; Wheeler, 1970), to name just a few, since reentrant theories propose that long term memory representations will percolate their influence to the very earliest stages of visual perception. This is consistent with the present data.

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