## Research Article

# EVIDENCE FOR TWO COMPONENTS OF OBJECT-BASED SELECTION

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**Abstract**—*A wealth of research has shown that observers can bias visual processing toward specific locations, but the role of object-based selection is less clear. In support of object-based selection, previous research has shown that when two objects are presented simultaneously, observers are better at reporting two attributes from one of the objects than one attribute from each object. However, there has been controversy over whether this effect is best explained by object-based selection or spatial selection. Our work suggests that there are two separate components of selection in this task: (a) a spatial component that is observed when the relevant targets are cued for observers before the onset of the stimulus display and (b) an object-based component that can still be observed when the first component has been eliminated. The latter effect replicates the initial evidence in favor of object-based selection, and can be demonstrated even when the relevant targets are cued after the offset of the target stimuli.*

The ability to focus attention on a subset of the information in a visual scene is a crucial means for observers to compensate for their limited ability to process a complex visual world. For instance, observers can focus attention on a specific spatial position, causing stimuli at the attended location to be processed with greater speed and better quality than stimuli at other locations. However, although there is general agreement that visual selection can occur via space, the role of other visual features in selection remains controversial. An influential study by Duncan (1984) provided the best evidence for object-based selection. Observers were required to discriminate the visual properties of two briefly presented objects that were superimposed in space (see Fig. 1). In one condition (hereafter referred to as the *within* condition), observers reported two properties of a single object (e.g., the texture and orientation of the line); in the other condition (hereafter referred to as the *between* condition), observers reported one property from each target object (e.g., the orientation of the line and the height of the box). The accuracy of these reports was better when only one object's properties were reported (the *within-object advantage*), even though the spatial separation between the judged features and the number of discriminations made were equivalent in the within and between conditions. Duncan argued that the limits of visual processing are best defined in terms of the number of objects to be discriminated.

In line with Duncan's findings, subsequent studies have shown that in some cases the selection of a visual feature is better predicted by the object that contains the feature than by the spatial position of that feature (e.g., Baylis & Driver, 1992; Egly, Driver, & Rafal, 1994; Humphreys & Riddoch, 1993; Kramer & Jacobson, 1991; Moore, Yantis, & Vaughan, 1998). However, these studies have not ruled out the view that object-based selection is inherently spatial. This possibility was elucidated by Vecera and Farah (1994), who described a *grouped-array* model of spatial selection. According to this view, information is selected on the basis of spatial position, but the positions selected are those that are occupied by a particular object. Thus, although object representations have a direct effect on the selected information, the grouped-array model holds that the final result of object-based attention is location-based filtering.

Kramer, Weber, and Watson (1997) provided support for the grouped-array model with a modified version of Duncan's (1984) paradigm. Their experiment also included within and between conditions, but the spatial separation of the targets was manipulated (following the design of Vecera & Farah, 1994). Half of the time, the stimuli were superimposed (as they were in Duncan's study), and half of the time the stimuli were separated (i.e., presented on either side of fixation). In addition, a postdisplay probe was included on a subset of the trials, and observers were instructed to press a key as quickly as possible when it was detected. Two aspects of their data implicated spatial selection: First, observers were faster to detect the postdisplay probe when it appeared in the same position as the target than when it appeared on the opposite side of fixation. This suggested that spatial attention was indeed attracted to the position of the target. Second, a larger within-object advantage was observed in the separated condition than in the superimposed condition, suggesting that this advantage is mediated by spatial selection.[1]

A recent study by Davis, Driver, Pavani, and Shepherd (2000) also suggests spatial selection in this paradigm. They found a within-object advantage that was restricted to cases in which the two objects occupied a larger spatial extent than the relevant target in the within-object condition. They suggested that the within-object advantage was due to a wider distribution of spatial attention when the parts of two objects had to be discriminated.

The results of Kramer et al. (1997) and Davis et al. (2000) provide compelling support for a spatial component of selection in this paradigm. But the possibility remains that object-based selection also plays a role. As Kramer et al. (1997) acknowledged, there is substantial evidence that object-centered representations are important in visual analysis, and the specific responses required of observers in this task are conducive to an object-centered representation (Vecera, 1997). Thus, controversy remains over the representational formats that guide selection in this task. The experiments we report here clarify this issue by demonstrating that there are two distinct selection processes operating in this paradigm. First, there is an early process of spatial selection (i.e., the mechanism asserted by Kramer et al., 1997) that is sensitive to the distance between the target objects—larger distances

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1. These results differed from those of Vecera and Farah (1994), who did not observe a larger within-object effect in the separated condition. However, the stimulus displays were different in these two studies. In the superimposed condition of Kramer et al. (1997), the stimuli appeared either to the right or to the left of fixation (at the same eccentricity as the separated stimuli), whereas in Vecera and Farah's studies, the superimposed stimuli appeared directly at fixation. Kramer et al. suggested that differences in metacontrast masking in the periphery and the fovea might explain the discrepancy between the two studies.

  

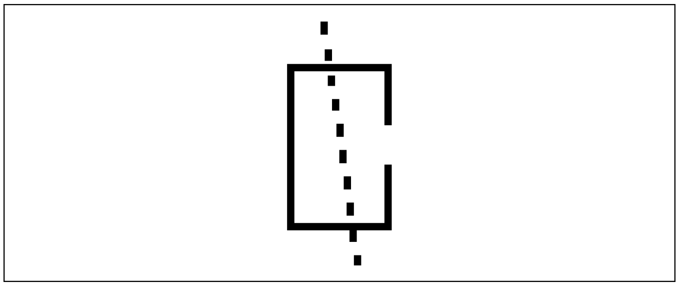

**Fig. 1.** Example of the stimuli used in Duncan's (1984) experiments.

cause a larger within-object advantage. The results of Experiment 1 show that this distance effect is equivalent for the first and the second attributes that are reported. Second, there is a selection process that operates at a later stage of visual analysis, after the stimuli have been masked. This mechanism also contributes to the within-object advantage—but only for the second-reported attribute.

When precues give observers advance information about which object attributes they will have to report, then both of these selection processes are active. However, Experiment 2 shows that when information about the to-be-reported attributes is withheld until after the target objects have been masked, only the second selection process affects performance. Under these conditions, a reliable within-object advantage was still observed, but only for the second-reported attribute. Thus, the data suggest two modes of selection that can be distinguished by their time course and by the specific responses that they affect.

The target objects in the experiments were colored lines that were tilted either to the right or to the left. The stimuli appeared two at a time, with one object on either side of fixation; this aspect of the design resembled the *separated* condition from previous versions of this paradigm (Kramer et al., 1997; Vecera & Farah, 1994). In addition, we manipulated the distance between the two target objects. Observers discriminated either two properties of a single line (the within condition) or one property from each line (the between condition). The goal of Experiment 1 was to replicate the within-object advantage that Duncan (1984) first observed, as well as the effect of the distance between targets that Kramer et al. (1997) observed.

## EXPERIMENT 1

### Method

#### *Observers*

Twelve University of Oregon students were paid for their participation. All observers had normal or corrected-to-normal vision.

#### *Stimuli*

Observers viewed the displays at a distance of approximately 40 cm. The target objects were lines that were 2.1° in length and differed in both color and orientation. One target line was red and was tilted 45° clockwise; the other target line was blue and was tilted 45° counterclockwise. The attributes that observers discriminated were texture (dotted or dashed) and gap position (top or bottom). All four attribute values are illustrated in Figure 2. The dotted lines were composed of eight separate rectangles (2 pixels high and 3 pixels wide). The dashed lines were composed of four separate rectangles (6 pixels high and 3 pixels wide). The gaps were 0.6° in length, and they appeared 0.2° either from the top or from the bottom of each line. Four square pattern masks (2.0° on each side) centered over the four possible target positions were presented after each target array.

#### *Display positions*

There were four possible target positions where the center of each target could be aligned. The positions fell along the corners of an imaginary rectangle that was 3° tall and 2.2° wide, centered around the fixation point. The center-to-center distance between the targets was either

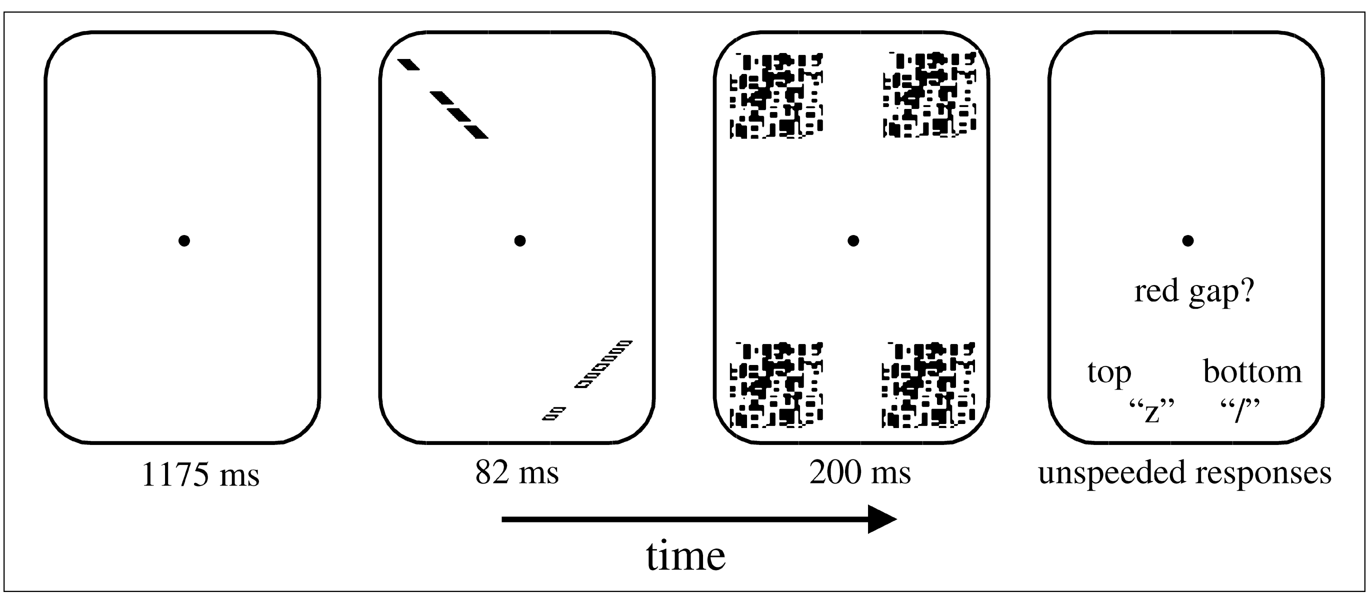


**Fig. 2.** Sequence of events in a single trial of the task. A far trial is depicted.

2.2° or 3.7° (*near* and *far* trials, respectively). During near trials, the targets were presented in either the top two or the bottom two positions of the imaginary rectangle. During far trials, one target was presented in one of the top locations and the other target was presented in the bottom position that was in the opposite hemifield (i.e., the targets were diagonally arrayed around the fixation point). Thus, there were two possible target configurations during near trials and two possible configurations during far trials; each of these four configurations occurred equally often. These configurations were chosen so that both targets would never appear within the same hemifield, because previous research had shown that people have more difficulty processing targets that fall within a single hemifield (e.g., Awh & Pashler, 2000; Sereno & Kosslyn, 1991).

### *Design and procedure*

At the beginning of each block, instructions displayed on the monitor informed the observers of the defining features of the target (or targets) and the attributes that would be reported during that block (e.g., in the between condition, "In the next block you will report the gap of the blue line and the texture of the red line"). When the observers had understood the instructions, they initiated the block with a key press. The sequence of events in a single trial (depicted in Fig. 2) was as follows: First, a central fixation dot (0.3° in diameter) appeared in the center of the screen for 1,175 ms. Then, the two target objects were presented for 82 ms. Immediately after target offset, the pattern masks were presented for 200 ms. Finally, immediately after mask offset, observers made two unspeeded responses, one for each of the two attributes that were to be reported. For each response, a visual cue reminded observers of the target color and the attribute to be reported (e.g., "blue gap?"), as well as which keys corresponded to the specific attribute values. Observers were instructed to respond as accurately as possible, without regard to speed. The next trial was initiated by the key press for the second response.

There were two main conditions, *within* and *between*. The order of these conditions was counterbalanced across observers and blocked within observer. Within each block, equal numbers of near and far trials were presented in random order. During a single block of the within condition, observers reported both the texture and the gap of either the red or the blue line. The order of report for texture and gap was held constant within a block. There were four types of blocks in the within condition, defined by the color of the target and the order of report: (a) red target lines with gap reported first, (b) red target lines with texture reported first, (c) blue target lines with gap reported first, and (d) blue target lines with texture reported first. The order of these block types was counterbalanced across observers. During the between condition, observers reported the texture of one line and the gap of the other line. There were four block types in the between condition, defined by which target was reported first and which attribute was reported: (a) gap of the red line and then texture of the blue line, (b) texture of the red line and then gap of the blue line, (c) gap of the blue line and then texture of the red line, and (d) texture of the blue line and then gap of the red line. The order of these block types was counterbalanced across observers. Before each condition (within and between), one block of 32 practice trials was administered. There were eight experimental blocks of 32 trials in each condition.

## Results and Discussion

The data for Experiment 1 are presented in Figure 3. A three-way analysis of variance was run, with condition (within vs. between), distance (near vs. far), and response (first vs. second) as within-subjects factors. A within-object advantage was confirmed by a main effect of condition; accuracy was higher for judgments of two attributes within a single object (86%) than for judgments of one attribute from each object (76%), $F(1, 11) = 40.2$, $p < .01$. In addition, accuracy was higher for first responses (83%) than for second responses (79%), $F(1, 11) = 14.0$, $p < .01$. The effect of response order was restricted to the between condition, resulting in a significant interaction of condition and response, $F(1, 11) = 10.5$, $p < .01$. Paired $t$ tests showed that although first responses were more accurate than second responses in the between condition, $t(11) = 4.6$, $p < .01$, there was no reliable difference between first and second responses in the within condition, $t(11) = 0.97$, $p = .35$. In other words, the within-object advantage was larger for second responses than for first responses.

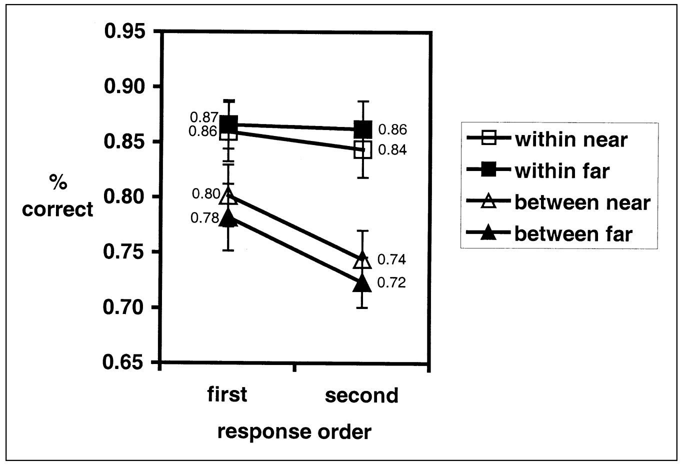


**Fig. 3.** Accuracy in the within and between conditions of Experiment 1 as a function of the order of response and the distance between the target stimuli.

It is also apparent from Figure 3 that there was a larger within-object advantage in the far condition (11%) than in the near condition (8%). This observation was confirmed by a significant interaction of condition and distance, $F(1, 11) = 8.8$, $p < .02$. The increased within-object advantage appears to result from a reduction in performance during the far trials of the between condition. Paired $t$ tests showed that accuracy in the between condition was higher in the near trials (77%) than in the far trials (75%), $t(11) = 2.9$, $p < .02$, but accuracy in the within condition showed a nonsignificant trend in the opposite direction (85% accuracy in near trials and 86% accuracy in far trials), $t(1, 11) = 1.7$, $p = .12$. The distance between targets had a reliable effect, but only in the between condition. The absence of a distance effect in the within condition suggests that observers were able to use their prior knowledge of the relevant target to select only the single object that was to be discriminated. The distance of the relevant target from the other object therefore had no effect on performance. But in the between condition, accurate responses demanded the selection of both objects, a process that is apparently more difficult when the objects are farther apart. This distance effect provides clear support for a spatial component of selection in this task.

Experiment 1 was modeled closely after Duncan's (1984), with the exception of the spatial separation of the stimuli. Accordingly, we replicated the key aspects of his findings. We observed a within-object advantage, and this effect was more pronounced for the second response than for the first response. However, although Duncan's original experiments showed a within-object advantage for only the second-judged attribute, we observed a significant within-object advantage for both first and second responses. We suggest that the first-response advantage for the within condition was a direct result of the spatial separation between targets—the most salient difference between the current procedure and the one employed by Duncan. Finally, spatial selection is clearly suggested by the larger within-object advantage found in far trials than in near trials. We emphasize two features of this distance effect. First, this effect was restricted to the between condition. Second, the distance effect was of equal size for the first and second responses of the between condition.

Given that the distance effect—a marker of spatial selection—was equivalent for the first and second responses, the possibility arises that a different selection process was responsible for the significantly larger within-object advantage that was observed for second than for first responses. Experiment 2 provides direct support for this hypothesis. The procedure was almost identical to that of Experiment 1, but observers were given no prior information regarding which target (or targets) they would be reporting about or which attributes they would be reporting. Instead, observers responded on the basis of postmask cues that specified the relevant target object (or objects) and the attributes that should be reported. Because these postmask cues did not appear until 200 ms after the offset of the target stimuli, spatial selection during the presentation of the stimulus display was not possible. This procedure eliminated the component of the within-object advantage that was sensitive to distance, and no within-object advantage remained for the first responses. What did remain was a robust within-object advantage for second responses, much like the one observed by Duncan (1984).

## EXPERIMENT 2

### Method

#### *Observers*

Twelve people from the University of Oregon community were paid for their participation. All observers had normal or corrected-to-normal vision.

#### *Stimuli, design, and procedure*

All aspects of the stimulus displays and procedure were identical to those of Experiment 1 with three exceptions: First, observers were not given advance information about the targets or the attributes that they would be reporting. Thus, in the within condition, observers were aware that they would be reporting two attributes of a single object, but they did not know which target object they would be reporting about. Likewise, in the between condition, observers were not told in advance which attribute would be reported for each object. Second, in order to prevent observers from anticipating the relevant targets, we randomized the relevant target objects and the properties that were judged across trials. Condition (within vs. between) was still blocked. Third, target exposure duration was increased to 106 ms so that accuracy would be comparable to that of Experiment 1.

Immediately after the offset of the target mask, visual cues informed observers of the target and attribute they were to report first. When the first target and attribute were revealed, the second target and attribute were predictable for that trial. That is, the second-reported attribute was always the attribute that had not yet been reported (i.e., gap or texture) in either the same object (in the within condition) or the other object (in the between condition).

### Results and Discussion

Accuracy data as a function of condition, response, and distance are displayed in Table 1. The data were analyzed by a three-way analysis of variance with condition (within vs. between), response (first vs. second), and distance (near vs. far) as within-subjects factors. There was a significant effect of distance, with higher accuracy for near trials (79%) than far trials (77%), $F(1, 11) = 22.7$, $p < .01$. However, there was no interaction between condition and distance, $F = 0.6$, $p = .4$, or between condition, distance, and response, $F = 1.9$, $p = .19$. Recall that the interaction of condition and distance was a key part of the results in Experiment 1; there was a significant advantage for near trials in the between condition, but the within condition showed no trace of this effect. We have argued that observers in Experiment 1 used their prior knowledge of the relevant target object to restrict processing to a single object in the within condition; under these conditions, the distance between the relevant and irrelevant objects had no reliable effect. By contrast, in Experiment 2, observers did not have prior knowledge of which target object was relevant in the within condition. Thus, it is likely that both target objects were selected during the initial presentation of the targets (in both the within and the between conditions). Just as in the between condition of Experiment 1, it was more difficult to select both objects when they were farther apart. This would explain the reliable advantage for near trials over far trials in both the within and the between blocks of Experiment 2, $t(11) = 2.35$, $p < .05$, and $t(11) = 3.7$, $p < .01$, respectively.

The data from Experiment 2 are graphed as a function of condition and response in Figure 4. As this graph illustrates, Experiment 2 produced a within-object advantage remarkably similar to the one first observed by Duncan (1984). The advantage in the within condition was restricted to the second response, leading to a significant interaction of condition and response, $F(1, 11) = 8.7$, $p < .02$. Paired $t$ tests confirmed that although there was no reliable difference between accuracy in the within (80%) and between (81%) conditions for first responses, $t(11) = 0.37$, $p = .7$, there was a significant advantage for the within (78%) over the between (73%) condition for second responses, $t(11) = 3.1$, $p < .01$. A main effect of response showed that first responses were more accurate than second responses, $F(1, 11) = 31.6$, $p < .01$. Figure 4 illustrates that this effect was more pronounced in the between condition than in the within condition, and paired $t$ tests confirmed that the difference between first and second responses was larger in the between condition (8%) than in the within condition (2%), $t(11) = 2.9$,

**Table 1.** *Experiment 2: Accuracy as a function of condition, response, and distance*

| | | Distance between objects | |
|---|---|---|---|
| Condition | Response | Near | Far |
| Within | First | .80 | .80 |
| | Second | .79 | .76 |
| Between | First | .82 | .80 |
| | Second | .74 | .71 |

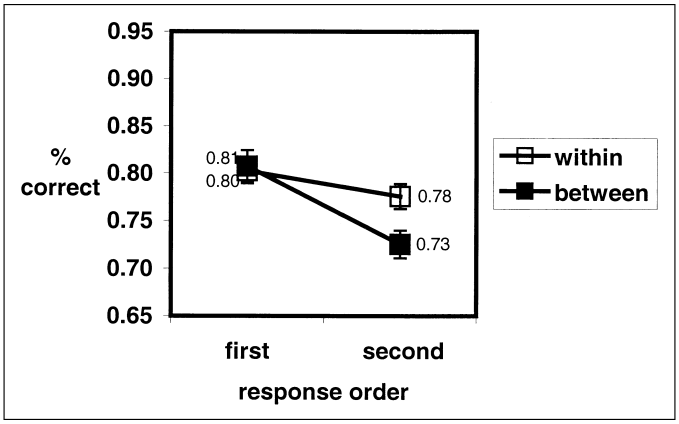


**Fig. 4.** Accuracy in the within and between conditions of Experiment 2 as a function of the order of response.

$p < .02$. To summarize, even though spatial selection was eliminated during the initial presentation of the target objects, Experiment 2 replicated the within-object advantage first observed by Duncan (1984).

## CONCLUSIONS

These experiments reveal two distinct selection processes in this paradigm. There is a within-object advantage for both first and second responses that is sensitive to the distance between the target objects. The distance effect, first observed by Kramer et al. (1997), suggests a component of spatial selection that benefits both the first and the second responses in the within condition. Furthermore, it is apparent that this spatial selection effect is dependent on foreknowledge of the relevant target object. When the cues that identified the targets were withheld until after the mask, only a second-response advantage remained. The within-object advantage observed in Experiment 2 is inconsistent with some of the known properties of spatial selection. The effect was generated more than 200 ms after the offset of the targets—much later than the early perceptual effects that have been demonstrated in many electrophysiological studies of spatial attention (e.g., Mangun, Hansen, & Hillyard, 1987).[2] The within-object advantage in Experiment 2 was no greater when the targets were farther apart than when they were closer together; but this interaction of condition and distance was a primary indicator of spatial selection in Experiment 1. Finally, although the effect of target distance was equal for first and second responses in both experiments, the within-object advantage was absent for first responses in Experiment 2. We therefore suggest that the within-object advantage in Experiment 2 may result from spatially invariant selection.

We favor an account of this postmask effect that is consistent with Duncan's (1984) original interpretation of object-based selection. Observers may have consulted an internal representation that specified the structural properties of the target objects without regard to location. In the within condition, only a single object representation had to be consulted in order to respond accurately. However, in the between condition, observers were forced to redirect attention between two objects in order to report both attributes. Apparently, the information about the second target object is lost when attention is directed toward the first object. Thus, the information processing load in this paradigm is defined in terms of the number of object files that must be consulted, rather than the number of features that are reported (Duncan, 1984).[3]

An attractive hypothesis is that the postmask selection process operates on representations in object working memory. Luck and Vogel (1997) have provided evidence that the capacity of object working memory is best defined in terms of the number of object files rather than the number of features that must be retained. A process of postperceptual selection from these object files provides an appealing account of the data that we observed in Experiment 2. Observers might discriminate the target attributes from representations that are maintained in object working memory. While attention is directed toward the object file for the first target, the quality of the memory representation for the second target declines. Accuracy in the within condition is unaffected by this decline because only the first object file is relevant in that condition. However, the second responses in the between condition would suffer—precisely the effect we observed in Experiment 2.

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2. It is tempting to conclude that this object-based effect is entirely postperceptual. However, we have not ruled out the possibility that some degree of perceptual processing occurs after the offset of the target masks. Thus, these experiments leave open the possibility that postmask selection affects perceptual processing.

3. The information about the second target could be lost through interference (e.g., because of processing of the first target) or through passive decay in the absence of attentional selection. Either mechanism could account for the present data, and there is evidence to support the participation of both processes in forgetting (e.g., Cowan, Wood, Nugent, & Treisman, 1997; Dosher, 1999).

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