Research Report

A DISSOCIATION BETWEEN ATTENTION AND SELECTION

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Abstract—*It is widely assumed that the allocation of spatial attention results in the "selection" of attended objects or regions of space. That is, once a stimulus is attended, all its feature dimensions are processed irrespective of their relevance to behavioral goals. This assumption is based in part on experiments showing significant interference for attended stimuli when the response to an irrelevant dimension conflicts with the response to the relevant dimension (e.g., the Stroop effect). Here we show that such interference is not due to attending per se. In two spatial cuing experiments, we found that it was possible to restrict processing of attended stimuli to task-relevant dimensions. This new evidence supports two novel conclusions: (a) Selection involves more than the focusing of attention per se; and (b) task expectations play a key role in determining the depth of processing of the elementary feature dimensions of attended stimuli.*

The ability to carry out goal-directed behavior relies on selective attention to filter irrelevant sensory input. In vision, for example, attending to locations (e.g., Posner, 1980) or objects (Duncan, 1984; Kahneman & Treisman, 1984) facilitates response time to attended items, and delays response time to unattended items. But what opportunities are there for further selection once an item is spatially attended? If a task requires judgment of only one of several feature dimensions of an attended stimulus, is it possible to restrict processing to only that dimension? Most current theories would say this is not possible. Indeed, there seems to be widespread agreement on two related assumptions common to both space-based and object-based selection: (a) The act of attending to a location or object, in and of itself, constitutes the act of selection; and (b) when a location or object has been attended, all features of the attended object are selected regardless of their relevance to the immediate task (Duncan, 1984; Kahneman & Treisman, 1984). Accordingly, it has been concluded that "the attention allocated to an object potentiates the processing of all aspects of that object and the instigation of all responses associated with it, whether or not these responses are relevant" (Kahneman & Chajczyk, 1983, p. 498).

A principal source of evidence for these assumptions comes from patterns of interference in responding to one dimension of a multidimensional stimulus: Response times are elevated when relevant and irrelevant dimensions are associated with competing responses. Interference from irrelevant feature dimensions, such as color or orientation, has been observed for attended stimuli in a variety of speeded tasks (e.g., Eriksen & Hoffman, 1973; Kramer & Jacobsen, 1991; Theeuwes, 1996), of which the best known example is the Stroop task (e.g., Proctor, 1978; Tzelgov, Henik, & Burger, 1992). Interference has also been observed in the rapid serial visual search paradigm (RSVP), in which spatial attention is focused for an entire trial sequence. Processing of items in the spatially attended RSVP stream cannot be restricted to only those with defined physical properties (Shih & Sperling, 1996; Sperling, Wurst, & Lu, 1992). In semantic priming experiments, interference is obtained from the meaning of words presented briefly at attended locations even though the meaning is irrelevant to the task (Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellog, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994; Smith, 1979; Smith, Theodor, & Franklin, 1983; Stoltz & Besner, 1996). The activation of responses associated with the irrelevant dimension reflects a failure or inability to further restrict processing once an item has been spatially attended.

Moreover, manipulations of visual attention can determine whether or not an irrelevant dimension interferes, strengthening the case for a causal link between attention and loss of dimensional sensitivity. When attention is focused on single letters rather than entire words, interference from the irrelevant word dimension is reduced in both Stroop and semantic priming (Stoltz & Besner, 1996). Interference from flanking characters can be reduced by moving the flankers outside the focus of attention (Eriksen & Hoffman, 1973), by focusing attention in advance on the target letter (Yantis & Jonides, 1990), or by increasing the number of cues, thereby altering the distribution of attention (Lavie, 1995; Lavie & Tsal, 1994).

These patterns of interference have been interpreted in ways consistent with the two assumptions referred to earlier. Attending allows an object or region access to response processes either by boosting activation levels for all the features of spatially attended stimuli (e.g., Cohen & Shoup, 1997) or by enabling established pathways between lower-level representations (e.g., object files) and response mechanisms (e.g., Cave & Wolfe, 1990; Kahneman, Treisman, & Gibbs, 1992). In either case, the assumption is that once attention has been allocated to an object or region, it has been selected, and the ability to selectively control which dimensions of that object or region gain access to response processes has been lost (see also Shih & Sperling, 1996; Sperling et al., 1992).

A few studies have found that selective processing of feature dimensions can be maintained even when attention is focused. Interference from flanking characters appears to be restricted to only the relevant dimension of the flanker (Cohen & Shoup, 1997; Maruff, Danckert, Camplin, & Currie, 1999; Paquet, 1992; Paquet & Merikle, 1988). In search, the singleton dimension on which an item "pops out" is reported more accurately than the nonsingleton dimension of the same object (Mounts & Melara, 1999). However, neither the flankers task (see, e.g., Lavie, 1995; Lavie & Tsal, 1994) nor the pop-out task (see, e.g., Yantis & Egeth, 1999) provides strong constraints on where attention is allocated, making it difficult to determine whether the stimuli were attended in these experiments. When the allocation of spatial attention has been well controlled in visual search (Theeuwes, 1996) and in spatial cuing (Remington, Folk, & McLean, 2001), interference from irrelevant stimulus dimensions has not been tested. Given the importance of understanding the role of attention in stimulus processing, it is critical to examine the influence of both relevant and irrelevant dimensions under conditions in which the allocation of spatial attention is precisely controlled.

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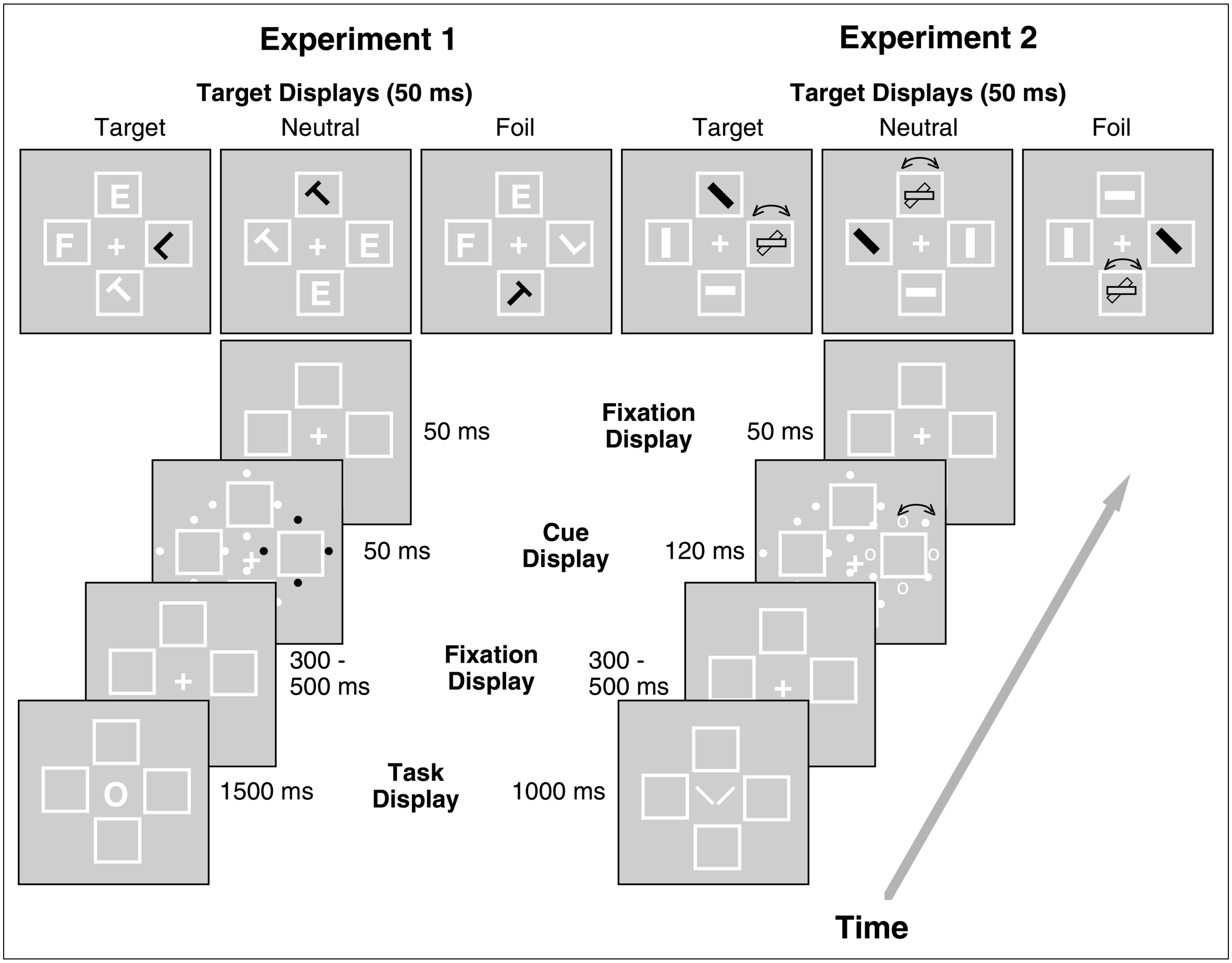

Fig. 1. Sequence of events within a trial for Experiment 1 (left) and Experiment 2 (right) for the three cue conditions: target (.25), foil (.25), and neutral (.50). In Experiment 1, the target was a red *T* or *L* (shown here in black) tilted right or left, the foil was a white *T* or *L* tilted right or left, and the neutral characters were an upright *E* and *F*. The center of the task display indicated whether subjects should respond to the target's orientation ("O") or identity ("$^{T}_{L}$"). In Experiment 2, the target was a rotating left or right diagonal that was green (bar with dark outline) or red (solid black bar), the foil was a stationary left or right diagonal that was green or red, and the neutral characters were stationary white vertical and horizontal line segments. The center of the task display indicated whether subjects should respond to the target's orientation ("\ /") or color (a small green square and red square side by side).

In the study we report here, we conducted a critical test of the link between spatial attention and the loss of selective processing of stimulus dimensions that satisfies the aforementioned constraints. A spatial cue presented prior to a target stimulus oriented attention to one of four possible target locations. Targets and nontargets comprised two possible reporting dimensions (letter identity and orientation in Experiment 1, orientation and color in Experiment 2). The response compatibility of relevant and irrelevant dimensions of stimuli was varied. We reasoned that if all features of attended stimuli have access to response mechanisms, then compatibility effects should be observed from both relevant and irrelevant dimensions of a "nontarget" stimulus to which attention has been briefly drawn. In contrast to this prediction, the results showed that only the relevant dimension of attended nontargets affected response times—evidence for selective dimensional processing of attended stimuli.

METHOD

Experiment 1: Identity and Orientation

Forty-one participants from the NASA Ames subject pool were tested in a single 1-hr session. Participants were students at local colleges and universities who received credit toward a course requirement in exchange for their participation.

Subjects made speeded manual responses to either the identity or the orientation of a target character. The target character was a red *T* or

L rotated 45° left- or rightward from upright. A task symbol at the beginning of each trial indicated to which dimension, identity or orientation, subjects should respond. This determined the relevant and irrelevant dimension for that trial. On orientation trials, subjects were instructed to ignore the letter identity (irrelevant dimension) and respond to the orientation (relevant dimension). The converse was true for identity trials. In addition to the red target character, each target display contained three nontarget characters presented in white: the neutral characters *E* and *F* and one foil character, *T* or *L*. The foils were also rotated so that they were distinguishable from targets in color only. Thus, both target and foil characters contained values on the relevant and irrelevant dimensions.

Control of spatial attention was achieved by presenting a cue, prior to target onset, that would draw attention to one of the four potential target locations (Fig. 1). Cue and target locations were chosen randomly with the constraint that on 25% of the trials the character at the cue location was the target, on 25% of the trials the character at the cue location was a foil, and on 50% of the trials the character at the cue location was a neutral stimulus. Thus, on target-cued trials, the cue location contained the target (red *T* or *L*); on neutral-cued trials, this location contained one of two neutral characters (white *E* or *F*); and on foil-cued trials, this location contained the foil character (white *T* or *L*). The absence of a correlation between cue and target locations removed any overt incentive to voluntarily attend to the cue.

We ensured that the cue would involuntarily capture attention by making it, like the target, a color singleton. This condition has been shown to produce reliable attentional capture (see, e.g., Folk, Remington, & Johnston, 1992). The cue display consisted of four small circles surrounding each of the four potential target boxes. Three of these sets of circles were white, and one set of circles (i.e., the cue) was red.

Compatible and incompatible conditions for the irrelevant target, relevant foil, and irrelevant foil dimensions were defined with respect to the response on the relevant target dimension. The responses to *T* and to a leftward tilt were compatible, as both responses were made by pressing the right index finger. The responses to *L* and to a rightward tilt were compatible, as both responses were made by pressing the right middle finger. For example, consider a trial in which subjects were instructed to respond to the orientation of the red letter in the target frame (orientation relevant, identity irrelevant). If the target were a left-tilted *L*, the response to the relevant target dimension (orientation) would be made with the index finger. The irrelevant dimension, identity (*L*), would be incompatible because it was associated with a middle-finger response. If the foil were a right-tilted *T*, the relevant foil dimension (orientation) would be incompatible (middle-finger response), whereas the irrelevant foil dimension (identity) would be compatible (index-finger response). Values on the relevant and irrelevant dimensions of both the foil and the target were fully crossed with compatibility (compatible, incompatible) and task (identity, orientation).

Experiment 2: Color and Orientation

To ensure that results were not due to the specific reporting dimensions (identity and orientation), we ran a subsequent additional 15 subjects using the color and orientation of line segments as the reporting dimensions. The stimuli and sequence of events within a trial are illustrated in Figure 1. The defining feature of the target was a 40-ms 45° rotation of the target line segment that began 40 ms after the onset of the target frame. To capture attention, the cue element at one of the four target locations underwent a similar rotation. This motion-cue/motion-target condition has been shown to produce reliable capture (Folk, Remington, & Wright, 1994). In all other respects, the design was identical to that of Experiment 1.

RESULTS

Figure 2 plots target response times for each cue location for compatible and incompatible values separately for the three stimulus dimensions of interest: the irrelevant target dimension, and the relevant and irrelevant dimensions of the foil. The results of the two experiments were qualitatively identical. For all three dimensions, response times were significantly faster when the cue was at the target location (valid) than when the cue was at the other two locations (invalid), regardless of compatibility. Compatibility effects were observed for both the irrelevant target dimension and the relevant foil dimension, but not for the irrelevant foil dimension. There was an interaction between cue location and compatibility only for the relevant foil dimension. Substantially greater interference was observed for incompatible values of the relevant foil dimension when the foil location was cued (i.e., when the foil was attended) than when another location was cued. In both experiments, this pattern of results was obtained regardless of the relevant reported dimension (orientation or identity in Experiment 1, orientation or color in Experiment 2).[1]

DISCUSSION

The results of these two experiments challenge assumptions about the processing of attended stimuli by showing that access to response mechanisms can be restricted to an individual task-relevant dimension of a visually attended object. This finding is inconsistent with the assumption that all dimensions and associated responses of an attended object are potentiated, whether relevant or not. In our experiments, interference from attended nontarget items (foils) was observed only for the task-relevant dimension. For example, when the task called for identity judgments, the identity, but not the orientation, of an attended nontarget foil was processed sufficiently to influence response mechanisms. This was true for all dimensions examined (identity, orientation, color). The selectivity found in Experiment 2 is especially compelling because both color and orientation are simple features assumed to be encoded automatically.

It is important to note that the selective processing observed in these experiments cannot be simply a function of the brief duration of

1. Analysis of variance on mean correct response times was performed separately for each of the three stimulus dimensions. Results for Experiment 1 were as follows: For the irrelevant target dimension, significant effects were obtained for cue location, $F(2, 80) = 132.44$, $p < .001$, and compatibility, $F(1, 40) = 90.04$, $p < .001$. For the relevant foil dimension, significant effects were obtained for cue location, $F(2, 80) = 137.06$, $p < .001$; compatibility, $F(1, 40) = 139.75$, $p < .001$; and the Cue Location × Compatibility interaction, $F(2, 80) = 42.99$, $p < .001$. For the irrelevant foil dimension, significant effects were obtained only for cue location, $F(2, 80) = 135.92$, $p < .001$. Results for Experiment 2 were similar: For the irrelevant target dimension, significant effects were obtained for cue location, $F(2, 28) = 7.78$, $p < .01$, and compatibility, $F(1, 14) = 35.47$, $p < .000$. For the relevant foil dimension, significant effects were obtained for cue location, $F(2, 28) = 10.70$, $p <. 001$; compatibility, $F(1, 14) = 50.88$, $p < .000$; and the Cue Location × Compatibility interaction, $F(2, 28) = 3.47$, $p < .05$. For the irrelevant foil dimension, significant effects were obtained only for cue location, $F(2, 28) = 9.90$, $p < .001$.

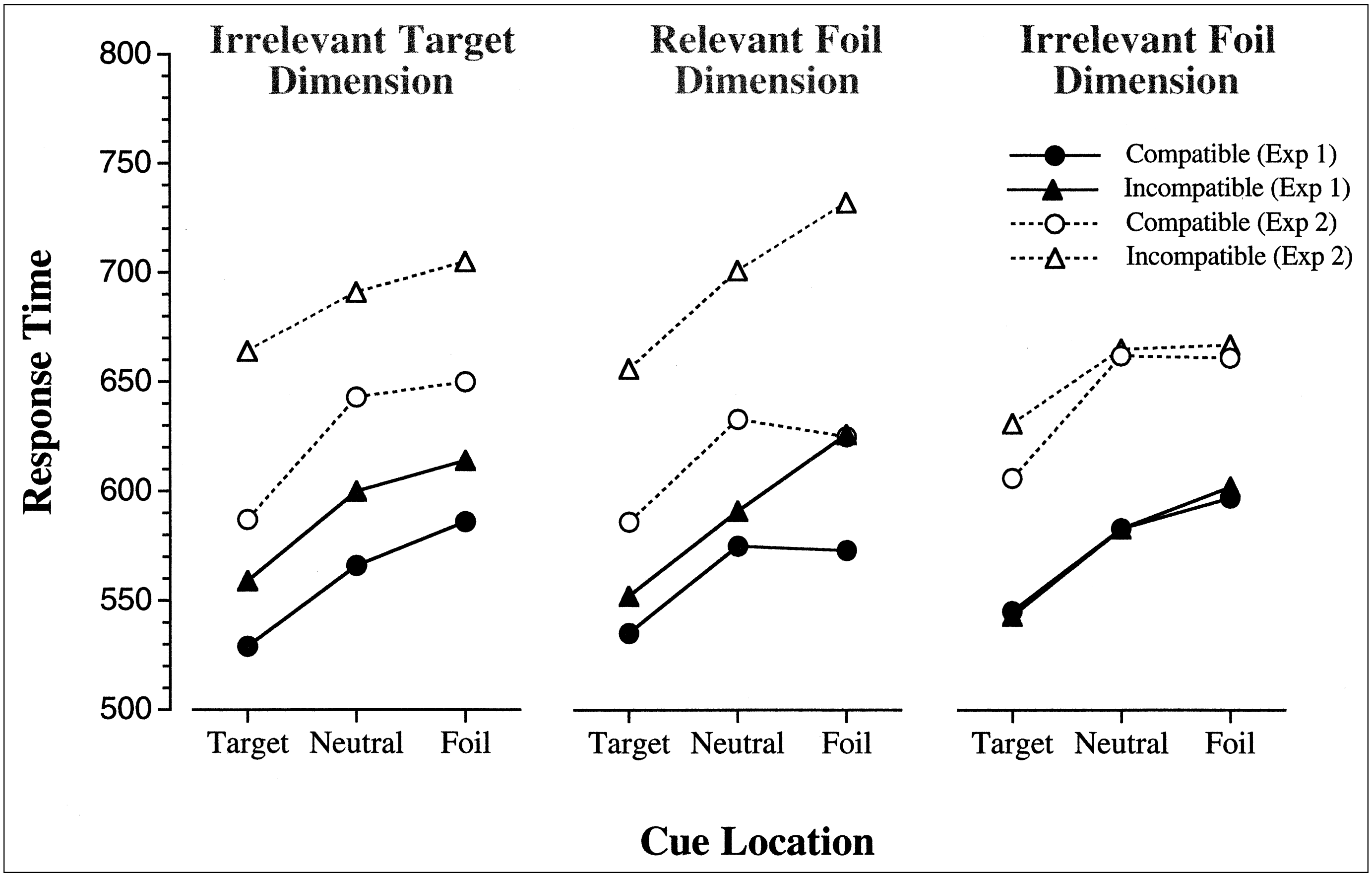

Fig. 2. The effects of compatibility as a function of cue location (target, neutral, foil) for the irrelevant target dimension, the relevant foil dimension, and the irrelevant foil dimension. Results for Experiment 1 and Experiment 2 are shown separately.

the attentional fixation. If relevant and irrelevant dimensions were processed equally, then equal interference, or lack of it, would have been obtained. Instead, processing of the attended item must entail preferential treatment of the goal-relevant feature dimension that affords this dimension access to response mechanisms.

Because of the attentional capture afforded by the spatial cue, we were able to expose differences in the processing of attended targets and attended nontargets. Incompatibility on the irrelevant dimension of the foil had no effect on target response time, whereas incompatibility on the irrelevant target dimension produced substantial interference. This difference cannot be accounted for by attention alone because both the target and the foil were presumably attended prior to responding. The results are thus inconsistent with models in which interference from irrelevant dimensions occurs because spatial attention has boosted the activation of all dimensions of the attended stimulus (e.g., Cohen & Shoup, 1997). Rather, it appears that a stimulus that conforms to target specifications ("red" in Experiment 1, "rotational motion" in Experiment 2) seems to undergo qualitatively different processing than attended nontargets; it is treated not as a set of individual features, but as an object or object file (Kahneman et al., 1992) with properties bound to it. Specialized processing of targets, as opposed to nontargets, is consistent with recent neuroimaging data showing enhanced frontal activity during target processing (Jiang, Haxby, Martin, Ungerleider, & Parasuraman, 2000). Evidence that top-down settings can affect selection in conjunction with spatial attention provides further confirmation that selective attention can act at multiple distinct stages in processing (Johnston, McCann, & Remington, 1995; Posner & Petersen, 1990).

The idea that selection is a process that spans multiple levels suggests a distinction between forms of selection associated with visual spatial attention and those associated with target "registration" (i.e., determining whether a given stimulus matches top-down target specifications). Whereas target registration selects an entire object with all its features, spatial attention seems to facilitate the representation of task-relevant features of an object. This explains why the relevant dimension of an attended foil produced more interference than the same dimension of an unattended foil. How the relevant dimension of the foil comes to affect responses is not yet clear. Our results are consistent with the hypothesis that spatial attention and task set act jointly at the feature level to determine which features have access to response mechanisms.

The results of these experiments provide further confirmation that operations of attention that were once thought to be automatic are subject to top-down mediation. In earlier work, we showed that top-down factors affected the orienting of attention when involuntarily captured by an external object (e.g., Folk et al., 1992). In the present experiments, we showed that processing of attended items is likewise mediated by behavioral goals.

CONCLUSIONS

We have extended the evidence for top-down control to include not only the orienting of attention, but the subsequent processing of attended stimuli as well. The orienting of spatial attention itself does not provide all dimensions of the stimulus access to response mechanisms. Such access is a property of stimuli matching target specification. Our results indicate that the automatic extraction of identity, color, and orientation of an object is mediated by top-down goals so long as that object has not been selected as a target.

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