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Object Features, Object Locations, and Object Files: Which Does Selective Attention Activate and When?

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The representation within which attention operates was investigated in 3 experiments. The task was similar to that of R. Egly, J. Driver, and R. D. Rafal (1994). Participants had to detect the presence of a target at 1 of 4 ends of 2 shapes, differing in color and form. A precue appeared at 1 of the 4 possible corners. The 2 shapes occupied either the same or different locations in the cuing and target displays. The results showed that the cued object location was attended whether or not space was task relevant, whereas the cued object features (color and form) were attended only when these were task relevant. Moreover, when object file continuity was maintained through continuous movement, attention was found to follow the cued object file as it moved while also accruing to the cued location.

Selective attention is the mechanism that enables an organism to select part of the information that is registered by the senses for further processing and action. Attention can select only a limited amount of information, and its ability to reject irrelevant information is imperfect. Over the past decade, much research has been devoted to the question of how the information selected by attention is represented.

Space-Based and Object-Based Views on Attention

Two different types of answers to this question are usually distinguished. According to the space-based view, attention selects from relatively early, spatial representations, and attending to an object entails attending to its location. Metaphors such as spotlights (e.g., Broadbent, 1982; Eriksen & Hoffman, 1973; Posner, Snyder, & Davidson, 1980), zoom lenses (e.g., Eriksen & St.-James, 1986; Eriksen & Yeh, 1985), and gradients (Downing & Pinker, 1985; LaBerge & Brown, 1989) are often invoked in order to describe how space constrains the distribution of attention. Although they differ on a number of aspects, all three models propose that attention can be allocated only to a continuous, unparsed area of the field.

In contrast to the space-based view, object-based models propose that selection operates on later representations, in which the visual field is already segmented into candidate objects on the basis of Gestalt principles. Such candidate objects (or perceptual groups) rather than pieces of space are the units selected by attention for further processing (e.g., Bundesen, 1990; Duncan, 1984; Duncan & Humphreys, 1989; Kahneman & Treisman, 1984; Neisser, 1967; Treisman, Kahneman, & Burkell, 1983).

An increasing number of findings have provided support for the object-based view (e.g., Baylis & Driver, 1992, 1993; Driver & Baylis, 1989; Duncan, 1984; Harms & Bundesen, 1983). For instance, Baylis and Driver (1992) presented participants with five-letter arrays in which the central letter was designated as the target. They found that response competition from distant incompatible distractor letters that were grouped with the target by common color or by good continuation was larger than from incompatible distractors that were closer to the target but were not otherwise grouped with it.

However, proponents of the space-based view continue to provide evidence in favor of the idea that space plays a unique role in attentive selection (e.g., Cave & Pashler, 1995; Kim & Cave, 1995; Luck, Fan, & Hillyard, 1993; Tsal & Lavie, 1988, 1993). For example, Tsal and Lavie (1993, Experiment 4) presented their participants with a cuing display consisting of one black dot and one colored dot, which was either blue or pink. It was immediately followed by a probe display. Participants were required to respond to a target letter that appeared in the probe display only if the colored dot was pink. Although spatial factors were task irrelevant, the probe was detected faster when it appeared in the location previously occupied by the attended colored dot than in the alternative location.

It is important to recognize that these apparently conflicting sets of findings concern distinct issues. On the one hand, studies supporting the object-based view investigated whether all Gestalt principles of perceptual grouping rather than just proximity constrain the distribution of attention. On the other hand, studies supporting the space-based view investigated whether attending to an object entails attending to its location. Thus, the reviewed findings may be reconciled by assuming that attention selects from representations that code grouping, in keeping with the object-based view, but are not space invariant, in keeping with the space-based view (see Lamy & Tsal, in press, for a broader discussion).

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Recently, this hypothesis has been tested by investigators who measured grouping effects and spatial effects within the same paradigm (e.g., Kim & Cave, 1996; Kramer & Jacobson, 1991; Vecera, 1994; Vecera & Farah, 1994). In an elegant demonstration, Kim and Cave (1996) presented their participants with three letters, the central letter being the target. One of the distractors was of the same color as the target (grouped distractor), whereas the other was of another color (nongrouped distractor). Participants had to identify the target and then respond as fast as possible to the onset of a probe that immediately followed the target display. Detection times were faster when the probe appeared in the location previously occupied by the grouped distractor rather than by the nongrouped distractor.

Kim and Cave (1996) concluded that "spatial attention selects the group of locations occupied by visual objects that share the same features." The same conclusion was reached by Vecera (1994; but see Vecera & Farah, 1994). He proposed that attentional selection occurs from a grouped location-based (grouped array format) representation. Such formulations imply that the representational substrate of attention describes the visual field as featureless clusters of grouped locations, and does not contain other features of the object (such as its color, for instance). A very similar idea is implemented within Treisman's feature integration theory (FIT) theory (e.g., Treisman & Gormican, 1988). According to this account, "the medium in which attention operates is a master map of locations that specifies *where* in the display things are, but not *what* they are. It indicates the number of elements or filled locations, but not which features occupy which locations" (p. 17).

However, the reviewed studies have not provided any empirical test for that claim. They showed that attending to an object entails selecting the locations it occupies, but this finding is equally consistent with the idea that the selection medium codes either (a) the locations and other features associated with a certain object or (b) only the group of locations that object occupies, and not its other features. For instance, in Kim and Cave's (1996) study, the probe appeared in the location previously occupied either by the grouped distractor or by the nongrouped distractor, that is, the manipulation concerned the probe location. The probe was always a black dot, so it never shared the target's color or form. Therefore, whereas the experiment showed that attention selects from a spatial representation that codes grouping, it could say nothing about whether that representation also contains information about other features, such as color or form. This issue has been overlooked in the literature, and Experiment 1 of the present study was designed to investigate it.

The only experiment that incidentally touched upon the question of whether attention operates on a representation that codes object physical properties other than location was conducted by Tsal and Lavie (1993, Experiment 4), discussed above. In that experiment, the authors also manipulated the probe's color. Reaction times (RTs) were found to be faster when the probe letter had the same color as the cuing dot rather than the alternative color. Note, however, that in Tsal and Lavie's study, only one of the two colors present in the target display was also present in the cuing display. Therefore, one may argue that the facilitation obtained was due to simple perceptual priming rather than indicating that attentional activation lingered on a representation that codes color. Indeed, it is possible that the mere fact that the target color was present in the cuing display gave rise to faster RTs, rather than the fact it was attended.

Task Demands and the Representational Substrate of Selection

Vecera and Farah (1994) recently suggested that attention may operate on different representations depending on task demands. Although many authors recognize the contribution of this proposition to the study of attention (e.g., Baylis & Driver, 1993), it has received very little investigation. Vecera and Farah used a variant of Duncan's (1984) task. Duncan presented his participants with two superimposed objects, each object possessing two attributes. Participants more accurately reported two attributes when these attributes belonged to the same object rather than to two different objects. Vecera and Farah added a condition in which the two objects were spatially separated. They found the cost of shifting attention from one object to the other to be the same when the objects were superimposed and when they were distant from each other (Experiments 1 and 2). In Experiments 3 and 4 the same stimuli were used, but participants had to detect a target that was most likely to appear on the object that was precued. Validity effects of object cuing were found only in the separate condition. The authors suggested that identification tasks may elicit object-based selection, whereas simple detection tasks may involve space-based selection. However, Kramer, Weber, and Watson (1997) proposed an alternative account to Vecera and Farah's finding (Experiments 1 and 2), questioning the fact that it demonstrated attentional selection from a spatially invariant object representation (but see Vecera, 1997).

Another study tested the idea that different types of stimulus representation may be inhibited, depending on the task at hand, with a negative priming task. Negative priming experiments demonstrate that people are slower to respond to an item if they have just ignored it (e.g., Tipper, 1985). Tipper, Weaver, and Houghton (1994) showed that those internal representations of the distractor that are most associated with the action to be directed toward the target are inhibited. However, as some authors disputed the idea that negative priming operates at the level of attentional selection (e.g., May, Kane, & Hasher, 1995), this finding is not necessarily relevant to the question at issue.

Thus, the few studies that specifically tested the idea that attention may activate different object representations depending on task characteristics did not yield conclusive findings. However, one does find indirect support for this hypothesis in the literature. In the studies that showed that attention selects from grouped arrays of locations, participants were typically required to attend to a certain location. For instance, in Kim and Cave's (1996) as well as in Kramer and Jacobson's (1991) experiments, the target was designated as the element occupying the central location in the display. In Vecera's (1994) experiment, participants were required to attend to the location of the cue. Thus, when space was task relevant, attention was shown to operate on spatial representations. Similarly, in the only experiment showing that attention may activate the color of the attended object, attention was directed by a color cue (Tsal & Lavie, 1993, Experiment 4). Thus, when color was task relevant, attention was shown to operate on a representation that codes color.

Experiments 1 and 3 of the present study were designed to test the idea that the object representations activated by attention vary with task demands. Specifically, we investigated whether attention operates on a representation that codes (a) grouped arrays of locations or space-invariant coordinates and (b) object features other than location (e.g., color), under conditions in which space on the one hand, and other object features on the other hand, are either relevant or irrelevant in order to perform the task. Task relevance is defined as the object property used to direct attention.

Moving Objects

In contrast to the reviewed studies, which used static objects, evidence from experiments with moving objects suggests that attention may access space-invariant representations rather than fixed spatial coordinates in the visual field. Tipper, Driver, and Weaver (1991), for instance, addressed this issue with an inhibition of return paradigm. Inhibition of return refers to participants' difficulty in returning their attention to a recently attended location (e.g., Posner & Cohen, 1984). Tipper et al. (1991) cued attention to a moving object and found subsequent inhibition at the locus the object later occupied (see Abrams & Dobkin, 1994; Tipper, Weaver, Jerreat, & Burak, 1994, for similar results). In the same vein, in a negative priming experiment, the inhibition associated with a distracting object was found to follow the object as it moved through space (Tipper, Brehaut, & Driver, 1990). However, these studies did not yield a clear picture as to whether space-based representations were simultaneously accessed. The relevant condition was usually not included in the design (e.g., Tipper et al., 1990) and when it was, conflicting results were obtained (for instance, Tipper et al., 1994, found inhibition of return effects at the location in which attention was initially engaged, whereas Tipper et al., 1991, did not).

Such results are often cited as showing that attention selects *object files* (see Kanwisher & Driver, 1992, for a review). This notion was introduced by Kahneman and his colleagues (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992). An object file is a temporary representation of an object that maintains that object's identity and continuity in spite of constant changes in its attributes. As was vividly illustrated by Kahneman et al., (1992), this notion explains how "onlookers in the movie can exclaim 'its a bird; it's a plane; it's Superman!' without any change of referrent for the pronoun" (p. 177). Object-file continuity is maintained if appropriate constraints of spatiotemporal continuity are observed, regardless of changes in location or physical properties (e.g., Gordon & Irwin, 1996; Henderson & Anes, 1994; Kolers & Pomerantz, 1971; Navon, 1976).

Surprisingly, the studies in which moving objects were used to examine whether object-file (or space-invariant) representations may be accessed by attention focused on the inhibitory component of attention. At best, such evidence cannot provide a complete answer on this issue, as it is usually recognized that different mechanisms underlie inhibitory and excitatory components of attention (e.g., Houghton, Tipper, Weaver, & Shore, 1996). Furthermore, some authors have suggested that negative priming and inhibition of return may not be attentional phenomena (e.g., May et al., 1995; Reuter-Lorenz, Jha & Rosenquist, 1996; Terry, Valdes, & Neill, 1994). Whether attending to an object file facilitates redirecting attention to the same object file has not been investigated to date. Experiment 2 of this study examined this issue.

Overview

To summarize, we note that the research on the representational substrate of attentional selection has yielded important findings. It has shown that attention selects perceptual groups defined by all Gestalt grouping principles, proximity playing no special role, but that the locations occupied by these perceptual groups rather than space-invariant representations are selected, which emphasizes the special role of location. The relative consensus that has recently crystallized around this view, sometimes termed the *grouped-array* view (e.g., Vecera, 1994), thus conciliates the space-based and object-based views on attention. However, a number of critical issues remain open.

First, the fact that attention selects from a representation that codes objects' spatial coordinates does not preclude the possibility that this representation may also code other object properties, such as color, for instance. This issue has not been addressed in the literature as yet. As object-based theories posit that attending to any aspect of an object entails that all its attributes are attended (e.g., Duncan, 1984), finding that the selection medium codes object features other than location would be consistent with object-based theories and argue against the idea that space is special.

Second, the grouped-array view has been demonstrated only under very specific conditions. The finding that attention selects from a spatial representation has been obtained only with static objects. With moving objects, attention was always found to "follow" the attended object (or object file), and it remains unclear whether or not attentional effects are also found at the location where attention was initially engaged. The comparison between studies using static versus moving objects is complicated by the fact that the latter investigated only the inhibitory component of attention. Moreover, in studies supporting the grouped-array view with static objects (e.g., Kim & Cave, 1996; Kramer & Jacobson, 1991; Vecera, 1994), attention was always directed to a spatial location, so that space was always task relevant. When space is not relevant, attention may select from a representation that is not spatial.

Thus, the current literature offers only a fragmented description of the representation that mediates attentional selection. The objective of the present research was to provide a more unified picture by exploring the unresolved issues just mentioned using the same basic paradigm and set of stimuli.

We used a variation of Egly et al.'s (1994) paradigm. In their study, participants had to detect a luminance change in one of the four corners of two outline rectangles. One corner was precued. On valid cue trials, the target appeared in the cued corner of the cued rectangle, whereas on invalid cue trials, it appeared either in the noncued corner of the cued rectangle or in the uncued rectangle. The distance between the cued location and the location where the target actually appeared was identical in both invalid cue conditions. The authors found the cost of redirecting attention to an invalid location to be greater for targets in the noncued than in the cued rectangle, indicating the presence of grouping effects. The results of this study do not allow one to determine (a) whether the representation within which selection occurred coded object features other than location (e.g., its color or form), because the displays consisted of two identical rectangles that were differentiated only by the locations they occupied, or (b) whether selection occurred from a grouped-array representation or a space-invariant representation, because the location of the objects was not manipulated (Vecera, 1994).

In our experiments, each display consisted of two colored shapes, which differed in form and color, and occupied different locations in the cuing and target displays on half of the trials. This manipulation allowed dissociating an object's location from its other features (color and form). In the cuing display, attention was summoned by an abrupt onset cue, which appeared in one of the two colored shapes, and indicated the location (Experiments 1 and 2) or the physical features of the object (Experiment 3) in which the target would most probably occur. In Experiments 1 and 3, static displays were used, and the colored shapes changed their locations in an abrupt manner between the cuing and target displays. In Experiment 2, they exchanged locations by moving smoothly to their new locations.

In the remainder of this article, the term *grouped location* refers to the invalid location grouped with the valid location. *Cued object location* refers to the group of spatial locations in which the cue appears, and *uncued object location* refers to the alternative group of locations. *Cued object features* or *cued set of features* refers to the features of the colored shape in which the cue appears and *uncued object features* or *uncued set of features* refers to the features of the other colored shape.

If the representation in which attention operates is spatio-topic, then a target should be detected faster when it appears within the cued object location. Following the same logic, finding that performance is better when the target appears in the cued set of features would suggest that selection occurs within a representation that codes object features other than location, namely, color and/or form. Moreover, if the partial picture that emerges from the reviewed literature is correct, attention should follow the cued colored shape as it moves, whereas with static displays, object-location effects should be found. Finally, if the type of object representations activated by attention depends on whether these representations are task relevant, then one should expect object-location effects when attention is directed toward the location of the cue, and object-features effects when attention is directed toward the color and form of the object in which the cue appears.

Experiment 1

Experiment 1 was similar to that of Egly et al. (1994). In their study, participants had to detect the onset of a filled square at one of the four ends of two outline shapes. The outline shapes appeared either above and below fixation, or to the left and right of fixation. Before the target appeared, a cue was flashed at the location where the target would later appear (valid cue trials) or at a different location (invalid cue trials). On invalid cue trials, the target could appear in one of two locations, equidistant from the cued location, one within the cued rectangle and the other within the uncued rectangle.

In the present experiment, the displays were designed so as to dissociate the location occupied by an object (*object location*) and the color and form of that object (*object features*), which were confounded in Egly et al.'s experiments (1994). First, instead of two identical rectangles, our study used two objects that differed in form and in color. Furthermore, a new condition was added, in which the colored shapes occupied different locations in the cuing and the target displays (swap condition). This manipulation allowed us to dissociate the location of the cued object from its other features, because the features of the object occupying the cued object location in the target display were equally likely to be the same as in the cuing display, or to be the alternative set of features. Unlike Egly et al. (1994) who used large displays (11.4° × 11.4°), we used small displays (2° × 2°) in order to disconfound attentional effects and potential acuity effects due to eye movements.

In the no-swap condition, in which the colored shapes do not change their positions, detection performance should be better when a shift of attention is required within the cued set of features or within the cued object location (the two being confounded), whether attention selects an object's location, its other features, or both. In the swap condition, object location and object features are decoupled. If attention activates object features, performance should be better when the target appears in the cued rather than in the uncued set of features. If attention activates an object's location, performance should be better when the target appears within the cued object location. Note that in all the subsequent analyses, object-location effects will be defined as faster performance at the grouped location relative to the alternative invalid location. Although the valid location always belongs to the cued object location, performance at the valid location will not be incorporated in the measure of object-location effects, because an advantage at this location is likely to reflect top-down effects rather than purely representational effects. Thus, the object-location effect reported here reflects a pure grouped array of locations effect. Cue validity effects are analyzed separately.

Method

Participants. Participants were 16 Tel Aviv University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected-to-normal vision.

Stimuli and apparatus. The stimuli were presented on an IBM PC compatible computer attached to a VGA color monitor. The displays used in this experiment were similar to those used by Egly et al. (1994). The fixation display was a white 0.1° × 0.1° plus sign (+), which was presented in the center of a black background. The stimulus display consisted of two shapes, one rectangle and one hourglass, both subtending 2° in height and 0.4° in width. The overall display subtended 2° × 2°. The shapes were equally distant from fixation and their center-to-center distance was 1.6°, so that the distance between each pair of corners (belonging to the same or to different shapes) was the same. One shape was green and the other was red (CIE chromaticity coordinates and luminance values: x = .284, y = .580, lum = 19.9 cd/m^2, and x = .582, y = .336, lum = 12.3 cd/m^2, respectively). In the cuing display, the cue was superimposed on the stimulus display. The cue was a thick white outline 0.4° × 0.4° square, which overlapped one end of one of the two shapes, that is, it could appear in one of four possible locations.[1] In the target display, the target was superimposed on the stimulus display, in one of the same four possible locations. The target was a filled white square, each side of which subtended 0.4°. No target appeared on catch trials, in which the target display was therefore identical to the fixation display.

The colored shapes always had the same orientation in the cuing and target displays. They either remained in the same locations or swapped

[1] In Egly et al.'s experiment, the cue consisted of the thickening of three sides of an imaginary square. The fact that the open side of the cue always *pointed to* the invalid location within the cued object location possibly introduced a bias toward attending to it. In order to eliminate this potential problem, we used a square instead of the original three-sided cue. We thank Yonathan Goshen-Gottstein for this suggestion.

locations, one with another. All the figures were drawn on a black background.

Procedure. Participants sat approximately 60 cm from the monitor. Each trial began with a fixation display containing the fixation cross and the two shapes. The shapes appeared randomly and equally often vertically oriented, to the left and right of fixation, or horizontally oriented, above and below fixation. For each orientation, each of the two colored shapes appeared in each of the two possible locations equally often and in random order. For half the participants, the red shape was the hourglass, whereas for the other half, it was the rectangle.

The course of events that took place on each trial is illustrated in Figure 1. The fixation display was presented for 1,000 ms. The cue appeared for 50 ms, equally often in each of the four corners, after which the screen went blank for an interstimulus interval (ISI) of 150 ms. Immediately afterwards, the target display was presented and remained visible until the participant responded. The screen went blank for 500 ms before the next trial began.

The participants' task was to press one key "1" (on the numeric keypad for right-handed participants and on the number strip above the "q-w-e-r-t-y" keypad for left-handed participants) with their dominant hand as rapidly as possible whenever a target was detected at any of the four corners, and another key "3" (on the number strip above the "q-w-e-r-t-y" keypad for right-handed participants and on the numeric keypad for left-handed participants) with the other hand on catch trials with no target. They were asked to pay attention to the cue, because it specified the location where the target was most likely to appear. They were also told that on a small proportion of the trials, the target would appear in an uncued location and that on other trials, no target would appear (catch trials). They were told to respond as fast as possible, because response latency was recorded, and also to minimize the number of errors. A 500-ms feedback beep was sounded if a participant made an anticipated response (RT $<$ 150 ms), a miss, or a false alarm. Participants were asked to maintain fixation throughout each trial.

After the participants heard the instructions, they were given 40 practice trials randomly selected from the experimental trials. The order of the trials was randomized by computer for each participant. There were two blocks of 200 experimental trials (160 target-present and 40 catch trials per block that were randomly intermixed). Participants were allowed a rest period between them.

Design. The experiment was a within-subject design. The target appeared at the cued corner on 80% of the trials (valid cue condition) and at an uncued corner on 20% of the trials (invalid cue condition). In the latter condition, it appeared equally often at the uncued end of the cued colored shape and at the equidistant end of the uncued colored shape. In order to keep cue-to-target distance constant across invalid-cue conditions, the target never appeared at the location diagonal to the cued location.

The critical manipulation was that the colored shapes either remained in the same location (no-swap condition) or swapped locations with each other between the cuing and target displays (swap condition). In the swap condition, the location and features of the colored shape in which the cue appeared were dissociated, because in the target display, the cued object location was occupied by the uncued object features, and the uncued object location was occupied by the cued object features. Thus, there were six target conditions: (a) valid cue, cued object location, cued object features; (b) invalid cue, cued object location, cued object features; (c) invalid cue, uncued object location, uncued object features; (d) valid cue, cued object location, uncued object features; (e) invalid cue, cued object location, uncued object features; and (f) invalid cue, uncued object location, cued object features. An example for each condition is shown in Figure 2, and the distribution of target-present trials across the six conditions is described in Table 1. Shape orientation was not included as a factor in the experimental design, because in previous studies that used similar stimuli and procedures (Egly et al., 1994; Vecera, 1994), this variable was found not to be a significant source of variance. All conditions were randomly intermixed.

Results and Discussion

Error trials were removed from analysis (1.6% of all trials) as were trials with RTs faster than 150 ms (0.1% of all trials) or exceeding the mean RT on correct trials by more than three standard deviations for each subject (1.9% of all trials). The mean hit rate on target-present trials was 98.8%, and the mean false alarm rate on catch trials was 3.0%.

The effect of cuing (valid vs. invalid) was analyzed with a simple *t* test. As shown in Figure 3A, RTs were significantly faster on valid-cue trials than on invalid-cue trials, 481 ms vs. 574 ms; $t(15) = 18.81$ ($p < .0001$).

In order to measure separately the effects of redirecting attention to the cued versus uncued object location and the effects of redirecting attention to the cued versus uncued object features, participants' mean RTs on invalid cue trials were then analyzed in a two-way, within-subject analysis of variance (ANOVA) with cued versus uncued object location and cued versus uncued object features as factors (see Figure 3B).

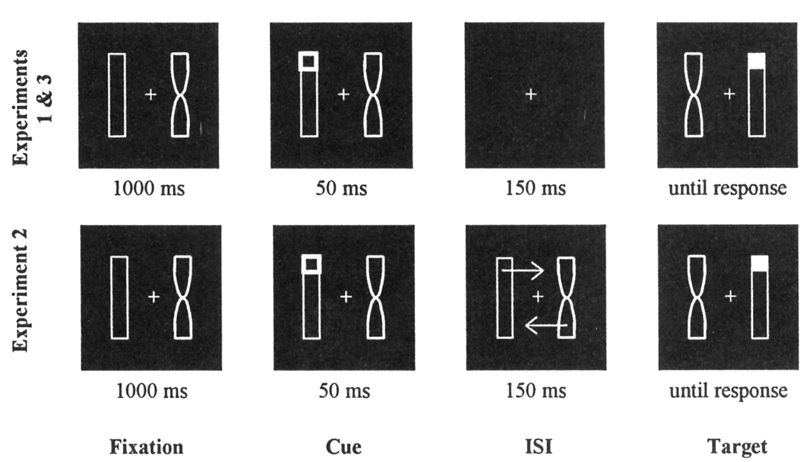

Figure 1. Stimuli and exposure times. The examples correspond to the invalid cue location/cued object features/swap condition. ISI = interstimulus interval.

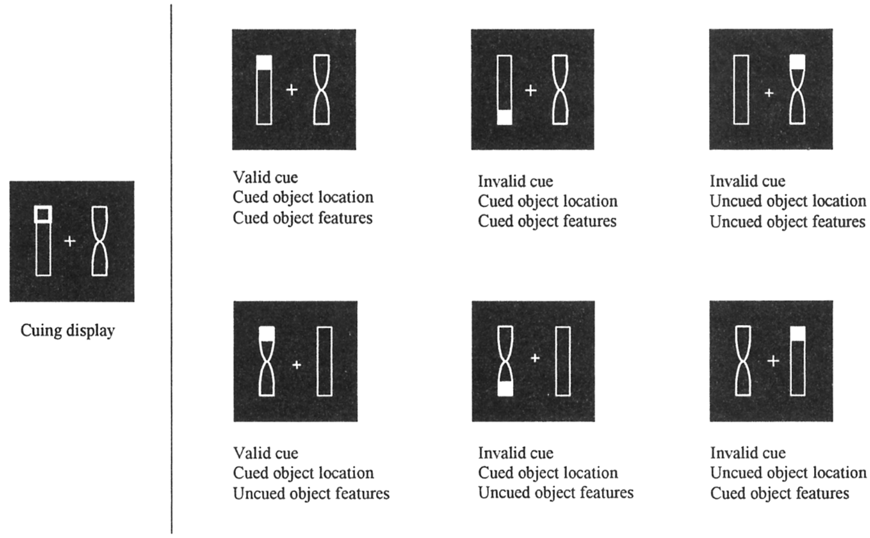

Figure 2. Experiment 1: Target display conditions (example corresponds to the cue appearing in the upper-left corner in the cuing display).

There was a significant effect of object location. RTs were significantly faster when the target appeared within the cued object location than when it appeared within the uncued object location, 556 ms vs. 593 ms, respectively; $F(1, 15) = 13.37$, $p < .003$. There was no effect of object features, 575 ms on cued object-features trials, and 573 ms on uncued object-features trials, $F(1, 15) = 0.41$, $p > .5$. The interaction between the two factors was also nonsignificant, $F(1, 15) = .00$, $p > .9$.

The results of this experiment support the idea that attention selects object locations and does not select objects' other properties such as color or form. Note however, that such a conclusion rests on the assumption that participants perceived the two colored shapes present in the cuing display to swap locations on half of the trials (Interpretation A). However, there is another possible interpretation for the sequence of events in this experiment. Participants may have perceived the two colored shapes to remain at the same locations, having exchanged their color and form on half of the trials, that is, the green rectangle having become a red hourglass and vice versa (Interpretation B). In this case, one may argue that the object-location effect obtained in this experiment in fact indicated that attention selected an object, the color and form of which changed between the cuing and target displays, rather than selecting the location this object occupied.

Thus, participants may have perceived the same objects to disappear during the ISI and reappear in the target display, having sometimes exchanged their locations or features (Interpretations A or B, respectively). Alternatively, however, they may have perceived the objects in the cuing display to disappear and new objects with the same color and form, to replace them, with the same features occupying different locations in the cuing and target displays on half of the trials (Interpretation C). Put differently, the 150-ms blank ISI may or may not have disrupted object-file continuity. This distinction is important for the interpretation of the results. In Experiment 1, if new object files were created in the target display, then the results indicate that attention selects object locations and not other object features—but this finding may pertain only to the particular situation of disrupted object file continuity. As such, it falls into the category of findings such as Kim and Cave (1996) or Kramer et al. (1997), showing that attention selects the groups of locations occupied by objects and provides the first empirical test for the claim that object features are not activated under such conditions. If, in contrast, the blank ISI did not disrupt object file continuity, then the results of Experiment 1 support the idea that attention selects object locations and does not select object files.

Table 1
Distribution of Target-Present Trials by Condition in Experiments 1 and 2

	Valid location		Invalid location		
Object features	No-swap	Swap	No-swap	Swap	All
Cued	40%		5%	5%	50%
Uncued		40%	5%	5%	50%
All	40%	40%	10%	10%	

To summarize, we note that the results of the first experiment suggest that attention does not select object features, but they are ambiguous as to whether attention selects object locations or object files, depending on how subjects construed the displays.

In order to assess how the displays were perceived, we ran 10 new participants on 10 randomly sampled trials of Experiment 1. After that, we first asked them to describe what they saw and then to choose between Interpretations A, B, and C of the displays. The order in which the three options were presented was counterbalanced across participants. We used a free report procedure before the forced-choice procedure lest participants come up with a novel interpretation of the displays. As this did not happen, we report only the data from the forced-choice procedure. Seven participants opted for Interpretation C (i.e., they reported seeing new objects in the target display), and three participants opted for Interpretation A (i.e., they reported seeing the same objects in the cuing and target

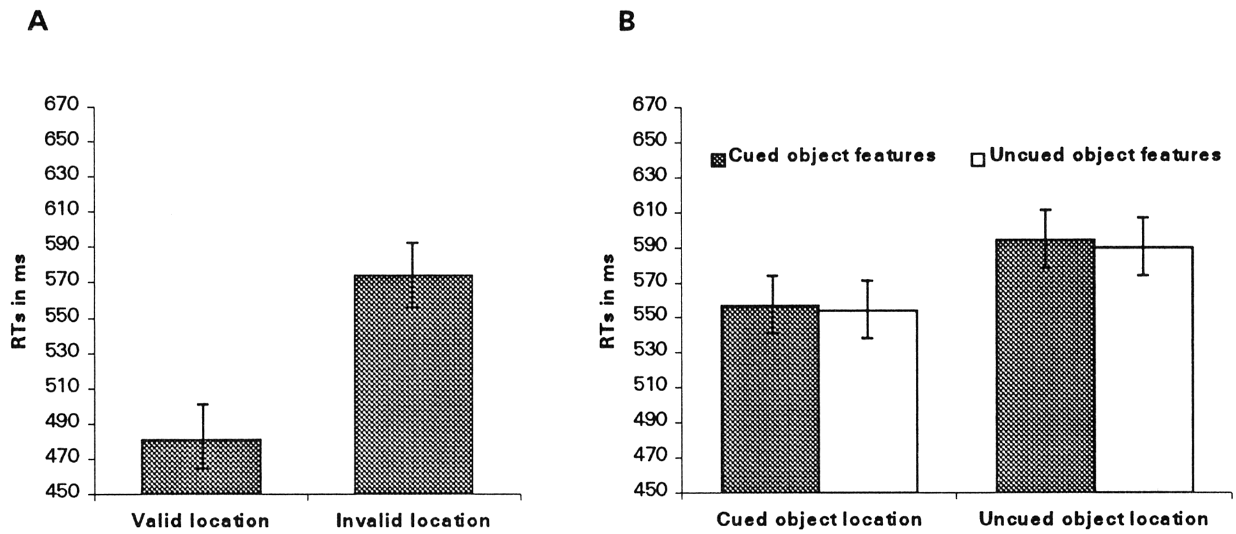

Figure 3. Experiment 1: A shows mean reaction times (RTs) to detect a target in the valid cue versus invalid cue conditions. B shows mean RTs on invalid cue trials, within the cued versus uncued object location, and within the cued versus uncued set of features. Intervals of confidence were calculated following Loftus and Masson (1994).

displays, swapping locations on some of the trials). None of the participants opted for Interpretation B. Thus, taken together, the results of Experiment 1 and report data suggest that when object file continuity is disrupted, attention selects object locations and does not select object features.

Experiment 2

The purpose of Experiment 2 was to investigate the representation within which attention operates when object file continuity is maintained. We examined whether attention follows objects as they move (object file effect) and/or whether attentional resources remain associated with the group of locations in which attention was initially engaged (object location effect). This issue has not been investigated in the literature to date. Indeed, earlier studies showing that attending to an item entails that its location is activated used static displays (e.g., Cave & Pashler, 1995; Tsal & Lavie, 1993). Studies that did include moving displays investigated only the inhibitory component of attention and did not yield clearcut findings (e.g., Tipper et al., 1990; Tipper et al., 1994). This experiment was identical to Experiment 1 except for the fact that the colored shapes remained visible during the ISI, and that in the swap condition, they moved smoothly to their new positions instead of exchanging locations abruptly.[2]

Method

Participants. Participants were 12 Tel Aviv University undergraduates, who were paid 5 dollars to participate in the experiment. All reported having normal or corrected-to-normal vision.

Stimuli, procedure, and design. The stimuli, procedure, and design were the same as in Experiment 1, except for the following changes. The colored shapes remained visible during the ISI in both the swap and no-swap conditions. In the swap condition, they moved smoothly from one location to the other instead of changing locations abruptly. To create apparent motion, the two colored shapes were flashed in six frames during the ISI. The first frame appeared immediately following cue offset. Each frame remained on the screen for 23 ms. It took the computer an average of 2 ms per frame to erase and redraw the shapes, that is, a total of 12 ms. Thus, the ISI lasted 150 ms ($6 \times 23 + 12$), as in the previous experiments. In each frame, the colored shapes appeared at a distance of 0.25° (leftwards, rightwards, upwards, or downwards, for the right, left, lower, and upper shape, respectively) from the location they had occupied in the previous frame, except for Frame 6, in which the displacement was of only 0.1° relative to Frame 5. As the two objects passed each other, they were never completely superimposed. Instead, they partly overlapped immediately before and after they crossed the middle of the screen. Each object was portrayed in front of the other equally often and in randomized order.

Results

Error trials were removed from analysis (1.6% of all trials) as were trials with RTs faster than 150 ms (0.4% of all trials) or exceeding the mean RT on correct trials by more than three standard deviations for each participant (1.8% of all trials). The mean hit rate on target-present trials was 99.5% and the mean false-alarm rate on catch trials was 6.0%.

As shown in Figure 4A, the effect of cuing was again significant: 462 ms on valid cue trials vs. 513 ms on invalid-cue trials, $t(11) = -10.63, p < .0001$. Participants' mean RTs on invalid-cue trials were analyzed in a two-way, within-subject ANOVA with

[2] An additional interpretation was possible for the moving displays (we thank Gordon Logan for this suggestion). Participants may have perceived the objects to move toward each other, collide, exchange properties, and bounce back to their original positions (Interpretation A) instead of simply exchanging positions by moving directly to each other's location (Interpretation B). Using the same procedure as in Experiment 1, we asked 10 participants to report what they saw in the displays. In the free report part, all the participants reported seeing two objects that either remained static or exchanged locations by moving directly to each other's location (Interpretation A). In the forced-choice part, none of the participants chose Interpretation B, and all of them judged it to be implausible.

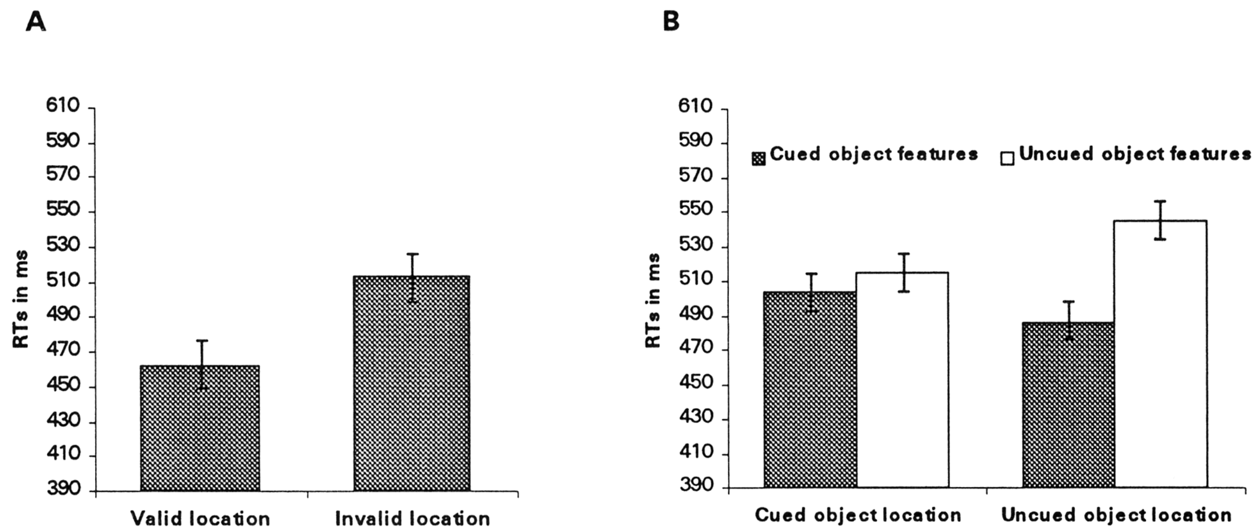

Figure 4. Experiment 2: A shows mean reaction times (RTs) to detect a target in the valid cue versus invalid cue conditions. B shows mean RTs on invalid cue trials, within the cued versus uncued object location and within the cued versus uncued set of features.

cued versus uncued object location and cued versus uncued object features as factors (see Figure 4B). RTs were significantly faster on trials in which the target appeared in the cued rather than uncued set of features: 496 ms vs. 531 ms, respectively, $F(1, 11) = 17.69, p < .002$. There was no effect of object location: 510 ms on cued object-location trials versus 517 ms on uncued object-location trials; $F(1, 11) = 0.38, p > .5$. The interaction between the two factors did not reach significance, $F(1, 11) = 2.08, p > .1$.

We also conducted a post hoc analysis in order to compare performance on no-swap and swap trials. Indeed, the course of events differed markedly on each type of trial, as on no-swap trials the colored figures remained static, whereas on swap trials they moved. This analysis showed no difference in RTs between static and moving trials (473 ms vs. 472 ms, respectively).

We ran additional statistical analyses in order to compare the pattern of results obtained in Experiments 1 and 2. We first conducted an ANOVA on correct RTs, with validity as a within-subject factor and experiment as a between-subjects factor. There was no main effect of experiment, $F(1, 26) = 2.43, p > .1$. The effect of cuing was highly significant, $F(1, 26) = 129.3, p < .0001$. It interacted with experiment $F(1, 26) = 9.12, p < .006$, with the cuing effect being larger in Experiment 1 than in Experiment 2.

We then conducted an ANOVA on correct RTs for invalid-cue trials with object location and object features as within-subject factors and experiment as a between-subjects factor. The effects of object location and object features were both significant, $F(1, 26) = 8.74; p < .007$, and $F(1, 26) = 13.64; p < .001$, respectively. More important, both factors interacted with experiment, $F(1, 26) = 6.39, p < .02$, and $F(1, 26) = 16.64, p < .0004$, respectively, with the object-location effect being larger in Experiment 1 and the object-features effect being larger in Experiment 2. No other effect reached significance.

Discussion

In this experiment, object file continuity was maintained, whereas in the previous experiment, it was disrupted. This change caused a total reversal in the pattern of results. Whereas in Experiment 1, the effect of object location was significant and the effect of object features was not, in Experiment 2 the effect of object features was significant and the effect of object location was not.

Note that in this experiment, object features and object files were confounded. Thus, in principle, the significant object features effect obtained may indicate either that the representation within which selection operates codes object features such as color and form or that attention selects object files and follows them as they move. We claim that only the latter interpretation of the results is correct.

First, remember that no object features effects were found in Experiment 1. Thus, in order to assume their presence in Experiment 2, one would have to accept the conclusion that object features effects are found only with moving objects. Because there is no principled contingency between object features and movement, such a conjecture seems unwarranted.

Second, earlier research has shown that only spatiotemporal continuity determines the perception of objects' apparent motion and continuity, color and form having little or no effect (e.g., Kolers & Pomerantz, 1971). In other words, participants need not attend to a moving object's color and form in order to maintain this object's perceptual continuity, and we may even assume that their percept would not change dramatically if continuity of color and form was not maintained during movement. We tested this hypothesis with the present stimuli. We designed a set of trials in which the course of events was exactly the same as in Experiment 2, except that in the swap condition, the objects smoothly exchanged their color and form while moving, so that the green rectangle became a red hourglass and vice versa. That is, the green rectangle and red hourglass occupied the same locations in the cuing and target displays not only in the no-swap condition but also in the swap condition, in spite of the movement. The color change was obtained by decrementing the red coordinate and incrementing the green coordinate in the green rectangle's red–green–blue (RGB) coordinates on each of the six successive frames that made up the moving sequence, and vice versa for the red hourglass. The form change was obtained by narrowing or widening the middle part of the rectangle or hourglass, respectively, by an equal number of pixels on each of the six frames that made up the moving sequence. With this procedure, object files and object features were disconfounded (object features and object locations being confounded). We reasoned that if indeed, color and form have little effect on perception of objects' apparent motion and continuity, then participants should perceive two objects exchanging locations (Interpretation A) rather than two objects colliding and bouncing back to their original locations (Interpretation B). Indeed, with these displays, continuity of movement determined object file continuity according to Interpretation A, whereas continuity of color and form determined object file continuity according to Interpretation B. We ran 13 new participants on 10 randomly sampled trials using the new displays and then asked them to report what they saw. In the free report part, 10 participants reported seeing two objects exchanging locations. When, in the forced-choice part, they were asked whether the two objects exchanged locations while also exchanging color and form, or bounced into each other and resumed their original locations, all 10 participants reported that they noticed only the movement of the objects (exchanging locations) and were not aware of the change in color and form. Three participants reported Interpretation B in the free report part and maintained their choice in the forced choice part. These results support the hypothesis that the significant effect of object features found in Experiment 2 should be interpreted as an object file effect.

To summarize, we note that the results of Experiment 2 indicate that attention selects object files. The results also suggest that attention does not select object locations, as no facilitation was registered when the target appeared at the location grouped with the cued location, in contrast to Experiment 1. However, the notion that attention simply followed the cued object file cannot account for all the findings of Experiment 2. Indeed, a post hoc analysis indicated that in the swap condition, RTs were faster at the valid location within the uncued colored shape than at the invalid location within the cued colored shape: 466 ms vs. 486 ms, $F(1, 11) = 5.60$, $p < .03$. If attention had simply selected the cued colored shape and moved with it, the opposite should have been expected. We propose that attention actually activated the cued object location in addition to the cued object file in Experiment 2 but that the advantage at only the valid location could be measured, and not that at the invalid location grouped with it. We suggested elsewhere (Lamy & Tsal, in press) that attention may propagate from the cued location to the locations grouped with it, rather than selecting perceptual groups as a chunk. In other words, it may take some time for attentional resources to reach the grouped location. In Experiment 2, the cued colored shape started moving immediately after cue offset, so it is possible that when attention reached the grouped location, the latter already occupied a different position in the visual field. This fact may explain why no facilitation was found at the position initially occupied by the grouped location.

Experiment 3

Taken together, the findings of Experiments 1 and 2 suggest that attention does not select object features. However, because participants were instructed to attend to the cued location, space was task relevant, whereas object features were task irrelevant. Indeed, the set of features in which the cue appeared (red hourglass or green rectangle) had no bearing on how participants had to respond. The results obtained may therefore simply reflect the fact that the types of representations activated by attention depend on task demands. In order to test this possibility, we designed a new experiment, in which the cue indicated in which set of features rather than at which location the target was most likely to appear. That is, if for instance the cue had appeared in a green rectangle, then in the target display the target would be most likely to appear in a green rectangle. Except for the change in instruction and target display probabilities, this experiment was identical to Experiment 1. We reasoned that if attention activates object locations only when space is task relevant, then no effect of object location should be found. Moreover, if attention activates object features such as color or form when these properties are task relevant, then performance should be better when the target appears in the cued rather than in the uncued set of features.

The target appeared within the cued set of features on 80% of the trials, 40% in each corner of the shape with the cued features. It appeared within the cued set of features on 20% of the trials, 10% in each corner. Therefore, and in contrast with the conditions prevailing in Experiment 1, the target sometimes appeared in the location diagonal to the cue location, which resulted in eight target conditions. Including invalid locations diagonal to the cue was necessary in order to have the target appear equally often at each possible location relative to the cue, thus creating expectations based only on the color and form of the object in which the cue had appeared and not on the spatial location of the target.[3]

We ran this experiment on 12 participants and obtained no effect of cuing. Performance was similar whether the target appeared within the same set of features as the cue or within the alternative set of features. The absence of a cuing effect may be taken to indicate that attending to an object's color and form does not entail that these features are activated, thus providing an answer to the question at issue in this experiment. However, it may also indicate that participants simply did not attend to the cue, possibly because they did not find it useful to attend to the color and form of the object in which the cue had appeared in order to perform a simple detection task. The likelihood of this possibility is reinforced by the fact that the cue had no effect whatsoever, as there was no facilitation either at the location of the cue or within the cued object location.

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[3] To demonstrate this, suppose we excluded diagonal locations and let us calculate the probability of each possible location to contain the target, given that the target must appear within the cued set of features on 80% of the trials and that the same validity conditions must prevail on swap and no-swap trials. The three possible locations are (a) the cue location, (b) a different location within the same object location, and (c) a different location within the alternative object location. On valid cue no-swap trials, the target is equally likely to appear in a (20%) or b (20%) and on no-swap trials. The target has a probability of 40% to appear in c on swap trials. On invalid cue trials, the target has a probability of 10% to appear in c and on no-swap trials and is equally likely to appear in a (5%) and b (5%) on swap trials. It follows that locations a, b, and c have a probability of 25%, 25%, and 50%, respectively, to contain the target. Thus, in order to circumvent the problem of having different expectations at different locations, we included trials in which the target appeared at the location diagonal to the cue (see Table 2).

We conducted a new experiment (Experiment 3), in which we modified the initial task so as to make it necessary for participants to attend to the cue. Again, participants were instructed to attend to the set of features within which the cue would appear, because the target would be most likely to appear within the same set of features. Thus, color and form were task relevant, whereas space was not. The displays consisted of the same red hourglass and green rectangle as in Experiment 1, but on part of the trials, a blue rectangle replaced one of the two shapes. Participants were required to respond to target presence or absence only if the cue had appeared in the green rectangle or in the red hourglass, and to refrain from responding if it had appeared in the blue rectangle. Thus, with this modification of the original task, failing to attend to the cue should increase error rates and provide a direct measure for whether or not the cue was attended.

Method

Participants. Participants were 11 Tel Aviv University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected-to-normal vision.

Stimuli, procedure, and design. This experiment was similar to Experiment 1 except for the following changes. The displays consisted of the same red hourglass and green rectangle as in the previous experiments, but on part of the trials, a blue rectangle of the same size replaced one of the two shapes (CIE chromaticity coordinates and luminance values: $x = .192$, $y = .223$, lum = 9.8 cd/m^2). Thus, there were three possible displays in this experiment: a green rectangle and a red hourglass (60% of the trials); a green rectangle and a blue rectangle (20% of the trials); and a red hourglass and a blue rectangle (20% of the trials). In the cuing display, the cue appeared equally often and in random order in each possible location. Thus, it appeared in the blue rectangle on 20% of the trials. In the target display, the target appeared in the cued set of features on 80% of the trials, 40% in each possible corner within the cued shape. It appeared in the uncued set of features on 20% of the trials, 10% in each possible corner within the uncued shape. Therefore, and for the reasons stated earlier, the target sometimes appeared in the location diagonal to the cue location. The distribution of target-present trials across the eight resulting target conditions is described in Table 2.

Participants were instructed to respond to target presence or absence only if the cue had appeared in the green rectangle or in the red hourglass, and to refrain from responding if it had appeared in the blue rectangle. They were also told that in most of the trials, the target would appear within the cued set of features. The experimenter underscored that participants should pay attention to the features of the shape in which the cue appeared because (a) it informed them whether to respond to the target, and (b) it indicated in which colored shape the target would most probably appear, which would help them respond faster to the presence of the target.

Although the sequence of events was the same as in Experiment 1, we also asked 10 new participants to report what they saw in the displays of this experiment. We used exactly the same procedure as in Experiment 1, except that participants viewed a random sample of 10 trials for each display type (red and green shapes, red and blue shapes, and green and blue shapes). Order of display type presentation was counterbalanced across participants.

Table 2
Distribution of Target-Present Trials by Condition in Experiment 3

	Valid object features		Invalid object features		
Object location	No-swap	Swap	No-swap	Swap	All
Cued	20%	20%	5%	5%	50%
Uncued	20%	20%	5%	5%	50%
All	40%	40%	10%	10%	

Results

Error trials were removed from analysis (6.5% of all trials) as were trials with RTs faster than 150 ms (0% of all trials) or exceeding the mean RT on correct trials by more than three standard deviations for each participant (1.7% of all trials). Two types of errors were analyzed. One type concerned participants' accuracy in deciding whether to respond, based on the colored shape in which the cue appeared. Participants made this type of error on 13.6% of the trials. One participant was excluded because he made errors on 37% of the trials. There were 11.7% false alarm trials (on which participants responded when the cue appeared in the blue rectangle), and 11.5% of miss trials (on which participants failed to respond when the cue had not appeared in the blue rectangle). Such an error level indicates that participants did attend to the cue. The second type of error concerned participants' accuracy in judging whether a target had appeared in the target display, on relevant trials (i.e., trials in which the cue had not appeared in the blue rectangle). Participants made this type of error on 4.7% of the trials. One participant was excluded because she made more than 20% false alarms (thus, overall, the data from 2 participants, were removed from analysis). Hit rate on target-present trials was 97.6% and false alarm rate on catch trials was 12.5%.

A preliminary analysis showed that blue rectangle trials in which participants had to respond (i.e., in which the cue had appeared in the other shape) were significantly slower than trials in which there was no blue rectangle in the display, $t(11) = 7.97$; $p < .0001$. Because the blue shape was associated with a no-go response, its presence may have caused participants to hesitate before responding. Thus, in the following analyses, trials in which a blue rectangle appeared were excluded. Trials in which the target appeared in the location diagonal to the cued location were also excluded from the analyses so that cue-to-target distance was equal in conditions in which the target did not appear at the same location as the cue.

Participants' mean RTs on trials in which the target appeared at an uncued location were analyzed in a two-way ANOVA with cue validity (or object features) and object location as factors (see Figure 5B). RTs were significantly faster on valid cue trials, that is, when the target appeared in the cued rather than in the uncued set of features, 558 ms vs. 586 ms, respectively, $F(1, 8) = 11.34$, $p < .01$. RTs were also significantly faster when the target appeared in the cued object location than in the uncued object location, 562 ms versus 581 ms, respectively; $F(1, 8) = 5.12$, $p = .05$. The interaction between the two factors was not significant $F(1, 8) = 0.003$, $p > .9$. A t test revealed no difference between cued location and uncued location trials, 556 ms versus 563 ms, respectively; $t(8) = -0.70$, $p > .5$, see Figure 5A.

Report data were consistent with the data collected for the display of Experiment 1. Again, no participant came up with a novel interpretation in the free report part of this experiment. In the forced choice part, 8 participants opted for Interpretation C (i.e., they reported seeing new objects in the target display), 2 participants opted for Interpretation A (i.e., they reported seeing the same

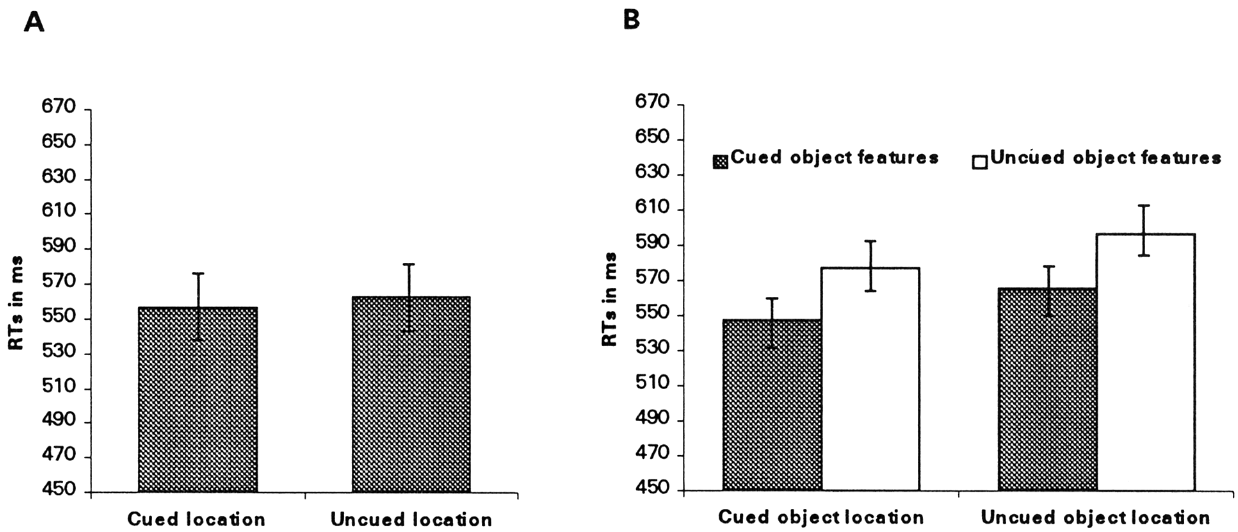

Figure 5. Experiment 3: A shows mean reaction times (RTs) to detect a target at the cued versus uncued location. B shows mean RTs on uncued-location trials, within the cued versus uncued object location and within the valid versus invalid set of features.

objects in the cuing and target displays, swapping locations on some of the trials). None of the participants opted for Interpretation B.

Discussion

In Experiment 1, performance was faster when the target appeared within the same group of locations (or object location) as the cue, and performance was not different whether the target appeared in the cued or in the uncued set of features. These results suggest that selection occurs within a spatial representation in which objects are represented as grouped arrays of locations (Vecera, 1994), with no coding of other properties such as color or form. However, space was task relevant, whereas color and form were not. In Experiment 3, we tested the hypothesis that the opposite findings may be found when object features are task relevant and space is not. In that experiment, the target was most likely to appear in the same set of features as the cue rather than at the same location. Moreover, participants had to attend to the features of the object in which the cue had appeared in order to respond correctly, because they were required to refrain from responding to the presence or absence of the target when the cue had appeared within a certain set of features (blue rectangle). The relatively low error rate indicated that the manipulation was successful in directing participants' attention to the cued set of features. This experiment yielded three main findings.

First, it showed that attention activates the cued set of features when these features are task relevant. In Broadbent's (1970, 1971) terminology, stimulus set defines the relevant stimuli by a shared physical characteristic, whereas response set restricts the vocabulary of possible responses. In Experiments 1 and 3, the cued attribute indicated at which location or in which set of features, respectively, the target was most likely to appear and was therefore relevant to the stimulus set. However, in Experiment 3, the cue also instructed the participants as to whether they should respond, so that it was relevant to the response set. Therefore, one may argue that in this experiment, object features were relevant in a way that differed from the relevance space had in the previous experiment. This difference, however, was irrelevant to the effects measured. The object features effect was revealed by faster responses when the target appeared within the cued rather than within the uncued set of features, but both sets of features belonged to the same response category. Thus, the feature effect could not have resulted from the response set. The same rationale holds for the object location effect.

Second, the results of the present experiment showed that attention activates the cued object location even when space is not relevant to the task.

Third, the results revealed no facilitation when the target occupied exactly the same location as the cue. This finding may appear to be surprising in light of previous studies showing that a peripheral cue automatically attracts attention to its location regardless of task requirements (e.g., Jonides, 1981; Yantis & Jonides, 1990). The cue, an abrupt-onset small white square superimposed on a colored outline, should have captured attention and reduced the time necessary to detect a target appearing at the same location. However, it is noteworthy that the cue appeared rather close to fixation (at less than 2° of eccentricity) and was thus much less peripheral than the transients shown to elicit automatic shifts of attention (e.g., Jonides, 1981). Moreover, because participants always had to attend to the combination of color and form in which the cue appeared, the size of the attentional window may have been fit to the size of the colored shape rather than to the size of the cue, with the shape of this attentional window being constrained by Gestalt grouping factors.

General Discussion

Summary of the Findings

The results of the experiments reported in this article yielded three main findings. First, we showed that when object file continuity is disrupted, the cued object location (or grouped array of locations) is mandatorily attended, whether or not space is task relevant. Second, we showed that, in contrast, object features are activated only when they are relevant to the task. Third, we showed that when object file continuity is maintained through continuous movement, attentional activation follows the object to which this cue belongs as it moves to a new position in the visual field while also accruing to the cued location.

Conclusions

As was pointed out in the introduction, there is a strong dichotomy in theorizing about attentional selection between space-based models and object-based models (but see Logan, 1996, for an attempt to integrate space-based and object-based approaches to attention). The results of the series of experiments presented in this article clearly suggest that the real picture does not fit all into one camp, for two different reasons. One reason is that several aspects of the selection representational format are relevant to the controversy between the two families of theories. In this article, we mention three such aspects: whether the representation within which attention operates codes grouping; whether it represents objects in spatial or in space-invariant coordinates; and whether it codes information about objects features other than location. Depending on which of these aspects was measured, we found support for both space-based and object-based theories. For instance, under certain conditions, we found that attention selects from a representation that codes grouping and object properties such as color and form (in keeping with object-based theories) but represents objects in spatiotopic coordinates (in keeping with space-based theories). The other reason is that task requirements determine within which representations attentional selection takes place. For example, we found that attention selects an object's color or form only when such properties are task relevant.

Against the background of previous research, one contribution of this article is that it fills a number of gaps in the literature concerned with the representational substrate of attentional selection.

Earlier research has focused on whether attention selects perceptual groups or unparsed locations and on whether objects are represented in space-based or in space-invariant coordinates. In this article, we investigated a relatively unaddressed question. We asked whether selecting an object entails activating its features (e.g., its color and form). Our findings are in line with Tsal and Lavie's (1993) results, as we showed that attention activates an object's features when these are task relevant. However, a number of differences between the two studies are worth noting. First, our results could not arise from simple perceptual priming (see our criticism of Tsal & Lavie's study above) but indeed from attentional activation, because both the cued and uncued set of features appeared in both the cuing and target displays. Second, in our study, attention was directed toward the features of the perceptual group in which the cue appeared rather than to the features of the cue itself. Thus, we showed that attention selects from a representation that codes grouped arrays of locations with their features, whereas Tsal and Lavie's study was insensitive to grouping effects and only showed that attention selects both the location and color of the cue itself. Third, whereas Tsal and Lavie used a long-term cue, that is, for each participant, the relevant color remained the same across trials, we used a short-term cue, as on each trial, the cue could appear within a perceptual group with a different set of features. Fourth, and most important, we manipulated the relevance of object features and demonstrated that object features are activated only when they are task relevant.

Moreover, by showing that attention activates the grouped array of locations to which the cue belongs even when space is not relevant to the task, we provided an integration between two separate lines of findings in the literature. On the one hand, some authors showed that selection is mediated by space even when space is task irrelevant but used procedures that were insensitive to grouping effects (e.g., Cave & Pashler, 1995; Tsal & Lavie, 1993). On the other hand, other investigators showed that attention selects grouped arrays of locations (e.g., Kim & Cave, 1996; Kramer & Jacobson, 1991; Vecera, 1994) but used procedures in which attention was always directed by a spatial cue, space being therefore task relevant.

Finally, we investigated whether attentional activation follows a moving object, whereas earlier research with moving objects has focused only on the inhibitory component of selection. We found that attention followed the object within which the cue had appeared to this object's new location while also accruing to the cued location. We concluded that attention selects both the cued object file and the cued object location. Note that earlier evidence for space-based selection did not preclude the possibility that attention may also select object files (or space-invariant representations). Indeed, in studies that showed that selection is mediated by space (e.g., Kim & Cave, 1996; Tsal & Lavie, 1993), the object initially attended was no longer present in the subsequent display, in which attentional effects were measured. A new object typically replaced it. Thus, object file effects could not be measured because object file continuity was disrupted.

Another contribution of this article lies in the advantages of our experimental strategy over the procedures used by researchers in earlier experiments.

In this series of experiments, task relevant and task irrelevant conditions were kept as similar as possible to each other, and the notion of task relevance was tightly defined, that is, it referred to the property used to direct attention. The two conditions differed mainly as to the instructions given to participants and the probability of occurrence for the different types of displays. For instance, when object features were task irrelevant, participants were instructed that the target would most probably appear at the location of the cue. When they were task relevant, participants were instructed that the target would most probably appear in the same set of features as the cue. However, the two conditions involved very similar sequences of displays and required subjects to perform the same detection task. In contrast, in Vecera and Farah's (1994) experiments, the displays and sequence of events in the task-relevant and task-irrelevant conditions differed substantially more than in the present study. Thus, it was unclear, for instance, whether the bias toward one mode of selection resulted from the way attention was directed (abrupt onset cue vs. no cue) or from the task the participants were required to perform (detection vs. discrimination).

Moreover, previous studies exploring the selection medium were such that they could yield only a dichotomic pattern of results. For instance, in Vecera's experiments (Vecera, 1994; Vecera & Farah, 1994; see also Kramer & Jacobson, 1991) an absence of distance effects was interpreted as indicating that selection occurs from a spatially invariant object representation, whereas the presence of such effects was taken to reveal space-based selection. Thus, their procedure could not test the possibility that attention may activate both space-based and object-centered representations. In contrast, we used a procedure in which different effects could be dissociated and measured separately. Rather than being only procedural, this difference has important implications for the conceptualization of how attentional selection operates. Indeed, whereas the traditional space-based versus object-based dichotomy implies that selection always takes place at the same locus, the introduction of task relevance in earlier studies implies that attention may select from a certain representation under certain conditions and from a different representation under other conditions. In contrast, the experimental strategy adopted here and the findings that resulted imply that attention may be better described as a pattern of activation that involves several representations rather than only one, the distribution of attentional activation among these representations changing according to the task at hand.

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