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## **The Same-Location Cost Is Unrelated to Attentional Settings: An Object-Updating Account**

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# The Same-Location Cost Is Unrelated to Attentional Settings: An Object-Updating Account

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What mechanisms allow us to ignore salient yet irrelevant visual information has been a matter of intense debate. According to the contingent-capture hypothesis, such information is filtered out, whereas according to the salience-based account, it captures attention automatically. Several recent studies have reported a same-location cost that appears to fit neither of these accounts. These studies showed that responses may actually be slower when the target appears at the location just occupied by an irrelevant singleton distractor. Here, we investigated the mechanisms underlying this same-location cost. Our findings show that the same-location cost is unrelated to automatic attentional capture or strategic setting of attentional priorities, and therefore invalidate the feature-based inhibition and fast attentional disengagement accounts of this effect. In addition, we show that the cost is wiped out when the cue and target are not perceived as parts of the same object. We interpret these findings as indicating that the same-location cost has been previously misinterpreted by both bottom-up and top-down theories of attentional capture. We propose that it is better understood as a consequence of object updating, namely, as the cost of updating the information stored about an object when this object changes across time.

*Keywords:* selective attention, attentional capture, object files, feature-based inhibition, fast disengagement

When we search for a specific target, for example, our car in a large parking lot, our attention can be directed to cars that resemble ours by color or form. Such allocation of attention is said to be controlled by top-down factors, such as intentions and task requirements. On the other hand, highly distinctive cars (a moving car among stationary cars, or a red car among white cars, for example) might capture our attention regardless of our goals. Such attentional capture is considered to be stimulus driven and controlled by bottom-up factors.

How top-down and bottom-up mechanisms interact to set attentional priorities has been much debated. According to the salience-based model (Schreij, Theeuwes, & Olivers, 2010; Theeuwes, 1992, 1994, 2010), the most salient object within a spatially defined window of attention is always granted attentional priority mandatorily and irrespective of the observer's goals. Only after the most salient stimulus has been processed is attention redirected according to task demands. At the other end of the spectrum, Folk and colleagues' (e.g., Folk & Anderson, 2010; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992) contingent-capture account postulates that only stimuli that share the target-defining feature can capture attention, and that salient information in a

visual scene can be ignored when it does not match the attentional set of the observer.

Variants of the spatial cuing paradigm have been most often used to test these accounts against each other. In a typical experiment (Anderson & Folk, 2012; Folk & Remington, 1998), participants are required to search for a target defined by its known color (e.g., red) and report its shape. Shortly before the search display is presented, a salient uninformative cue appears in one of the possible target locations. This cue might be a color singleton in the same color as the target (e.g., a red object among uniformly gray objects, henceforth, relevant-color cue) or in a different color (e.g., a green object among uniformly gray objects, henceforth, irrelevant-color cue). If the cue captures attention, then reaction times (RTs) on trials in which the target happens to appear at the cue location should be faster than trials in which it appeared elsewhere.

The salience-based and contingent-capture models make opposite predictions with regard to the irrelevant-color cue. Whereas according to the former, it should capture attention (e.g., Theeuwes, Atchley, & Kramer, 2000), according to the latter (e.g., Folk & Remington, 1998), it should have no spatial effect. These predictions should hold both when the target is a color singleton (e.g., when the target is the unique red object among uniformly gray objects, henceforth, known singleton search) and when it is not a singleton (e.g., when it is a red object among objects of various colors, henceforth, feature search). Surprisingly however, a number of feature-search studies reported a pattern of results that can be accommodated by neither of these models.

For instance, Lamy, Leber, and Egeth (2004) found that a singleton cue that does not match the target color not only fails to capture attention but also elicits slower RTs when it appears at the same location as the target than elsewhere (see also Lamy & Egeth,

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2003). Later studies reported similar same-location costs (Anderson & Folk, 2012; Becker, Folk, & Remington, 2013, Exp. 3; Belopolsky, Schreij, & Theeuwes, 2010; Eimer, Kiss, Press, & Sauter, 2009, Exp. 2; Folk & Remington, 2008; Schönhammer & Kerzel, 2013; Schreij et al., 2010), but so far, accounts for these effects have been elusive. Lamy et al. (2004) suggested that attending to the location of a to-be-ignored feature is delayed. Consistent with this idea, Eimer et al. (2009) reported that the event-related potential component associated with attentional selection, N2pc (e.g., Eimer, 1996, Eimer et al., 2009) occurs later for targets at cued versus uncued locations, suggesting that perceptually salient but task-irrelevant visual events trigger location-specific inhibition mechanisms that can delay subsequent target selection. However, whether such inhibition is indeed tied to the known feature of the irrelevant salient object, as postulated by the feature-based inhibition hypothesis, was not tested in either study.

Theeuwes and his colleagues (Belopolsky et al., 2010; Schreij et al., 2010; Theeuwes, 2010, Theeuwes et al., 2000) suggested a different account, according to which the same-location cost reflects fast disengagement following capture by a cue that does not match the top-down set. These authors suggest that attention is always captured by the most salient object in the visual field, but is quickly disengaged from its location when the participants realize that the cue color is not the color they were looking for. By this account, the same-location cost reflects inhibition of the non-matching cue after it has captured attention. Support has come from two types of findings. Theeuwes et al. (2000) showed that when an irrelevant cue appeared at various time intervals prior to the target, the presence of this cue interfered with performance at short intervals (50 ms), suggesting that it captured attention, and such interference disappeared at later intervals (>150 ms), suggesting that attention was later disengaged from the cue location (but see Chen & Mordkoff, 2007, and Lamy, 2005, 2010, for criticisms of this interpretation). Theeuwes et al. (2000) also examined the time course of the effect of the compatibility between the response features at the cued and target locations. Paralleling the interference findings, they found performance benefits on compatible relative to incompatible trials at early cue-to-target intervals. Interestingly, however, this effect was reversed at 150- to 200-ms cue-to-target intervals, which was taken as evidence that the cue was inhibited. As the design did not include same-location trials, these results provide only indirect evidence for a same-location cost.

More direct evidence comes from a study by Belopolsky et al. (2010, Exp. 3, and see also Exp. 4). Each target display contained either a color target or an onset target, and participants had to respond to one type of target (go trials) and refrain from responding to the other type (no-go trials). Which target type was associated with a “go” response was specified at the beginning of each trial. Each target display was preceded by either an onset or a color-singleton cue. The finding that is relevant to the present purposes is that when the cue had the property associated with a no-go response (e.g., when the cue was an onset singleton and the target was a color singleton), RTs were slower when the target appeared at the cued location than when it appeared elsewhere. The authors concluded, yet did not demonstrate, that such spatially selective suppression at the location of a cue that did not match the attentional set could take place only after attention had been at that location, in line with the fast-disengagement hypothesis. However,

as suggested by Anderson and Folk (2012), Belopolsky et al.’s (2010) findings may reflect inhibitory processes at the motor-response level, rather than at the selection level, because the feature characterizing the irrelevant cue was associated with a no-go response.

The objective of the present study was to clarify the mechanisms that give rise to the same-location cost reported when the target appears at the location of an irrelevant-color cue (Anderson & Folk, 2012; Becker et al., 2013, Exp. 3; Belopolsky et al., 2010; Eimer et al., 2009; Folk & Remington, 2008; Lamy & Egeth, 2003; Lamy et al., 2004; Schönhammer & Kerzel, 2013). Because in all these studies, the feature of the irrelevant cue was kept constant throughout the experiment, all the reported results are theoretically consistent with a feature-based inhibition account, according to which selection of the location at which a known-to-be-irrelevant feature has just appeared is delayed. Therefore, we tested this account first. The feature-based inhibition account predicts that inhibition should be stronger when it accrues to one known feature than to many possible features (see Theeuwes & Burger, 1998, for a similar rationale).

Same-location costs were typically robust in experiments in which the irrelevant feature was associated with a no-go response (e.g., Anderson & Folk, 2012; Belopolsky et al., 2010; Folk & Remington, 2008). In contrast, when the irrelevant feature was not associated with a no-go response, same-location costs were either inconsistent (e.g., Becker et al., 2013, Exp. 3 vs. Exp. 2; Eimer et al., 2009, Exp. 1 vs. Exp. 2; Schönhammer & Kerzel, 2013) or absent (e.g., Folk & Remington, 1998) in some studies, but reliable in others (Lamy & Egeth, 2003; Lamy et al., 2004). Based on our review of the literature and on pilot experiments from our lab, we observed that same-location costs tended to be more robust when (a) the target appeared among heterogeneous distractors (i.e., in feature search) than when it was a known singleton, and (b) when the cue remained visible until target display onset than when it disappeared during the interstimulus interval (ISI). As our objective was to investigate the processes underlying the same-location cost, we sought to maximize the probability that it should emerge here by including these characteristics in our design.

In our first experiment, each display contained four circles, each of which enclosed a “T” letter rotated to either the left or right. Two critical events occurred during each trial. First, during the “cue” display, all circles thickened and one of them became a color singleton for a brief time interval (e.g., the cue display contained one green circle among gray ones). Then, during the “target” display, each T took on a different color (e.g., red, yellow, green, and blue). The cue color was always different from the target color in this experiment. Observers were required to search for the T defined by its specific color (e.g., red). The T orientation at each location remained constant throughout each trial. On different-location trials, the orientation of the T at the cued location could be either compatible or incompatible with that of the T at the target location. In the blocked-color condition, the cue color remained fixed throughout each block of trial, whereas in the mixed-color condition, it varied randomly within blocks of trials.

Feature-based inhibition applied to several features, if at all possible, should be weaker than when applied to a single feature. Thus, if feature-based inhibition underlies the same-location cost, then this cost should be eliminated, or at least substantially reduced, in the mixed-color relative to the blocked-color condition.

In addition, we should observe no effect of the compatibility between the letters appearing at the cued and target locations in the blocked-color condition, because feature inhibition is preemptive: It prevents the cue from capturing attention.

In contrast, the fast-disengagement hypothesis predicts a cue-target compatibility effect, resulting from processing the cue before attention was disengaged from it. With regard to the cue color variability manipulation, it is noteworthy that Theeuwes et al. (2000) reported attentional capture (indexed by a positive response compatibility effect) and cue inhibition (indexed by a reverse compatibility effect) to be similar when the cue color was fixed (Experiments 2 and 3) and when it varied (Experiment 4). Thus, assuming that the same mechanism indeed underlies this effect and the same-location cost (Belopolsky et al., 2010), the fast-disengagement account predicts the same-location cost as well as the compatibility effect to be observed also when cue color is variable. Finally, because the design did not include no-go trials, motor inhibition could play no role in the present experiment.

## Experiment 1

### Method

**Participants.** Eleven Tel Aviv University undergraduate students (aged 21 to 28 years) participated in the experiment for course credit. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

**Apparatus.** The experiment was performed on a PC desktop computer. Stimuli were presented on a CRT monitor (1024 × 768, 85Hz refresh rate). Viewing distance was set at about 60 cm. The experiment room was dimly lit.

**Stimuli.** Each trial consisted of a ready display, a cue display, a target display, and a response display (see Figure 1). All stimuli were presented on a black background. The ready display consisted of a gray  $0.6 \times 0.6^\circ$  plus sign (+), surrounded by 4 gray  $0.1^\circ$ -thick outline circles, subtending  $0.9^\circ$  in radius, and positioned

$2.8^\circ$  above, below, to the left, and to the right of the fixation sign. Centered inside each circle was a T letter (8 mm × 8 mm) rotated by  $90^\circ$  and pointing either to the right or to the left. The cue display was similar to the ready display, except that the circles were thickened to  $1.7^\circ$ . In the cue-absent condition, all four circles remained gray. In the cue-present condition, one of the circles was drawn using one of five possible nontarget colors: blue, green, yellow, magenta, or cyan for the red-target group, and red, green, yellow, magenta, or cyan for the blue-target group. The target display was identical to the ready display, except that the rotated Ts were colored red, green, yellow, and blue. Colors were randomly assigned to locations. The response display was similar to the ready display, except that the rotated Ts no longer appeared.

Colors coordinates were gray (CIE .281, .291, 25.1 cd/m<sup>2</sup>), red (CIE .585, .335, 25.3 cd/m<sup>2</sup>), green (CIE .312, .537, 42.5 cd/m<sup>2</sup>), yellow (CIE .432, .464, 70.2cd/m<sup>2</sup>), blue (CIE .180, .183, 21.6 cd/m<sup>2</sup>), cyan (CIE .303, .210, 28.3 cd/m<sup>2</sup>), or magenta (CIE .229, .330, 57.7 cd/m<sup>2</sup>).

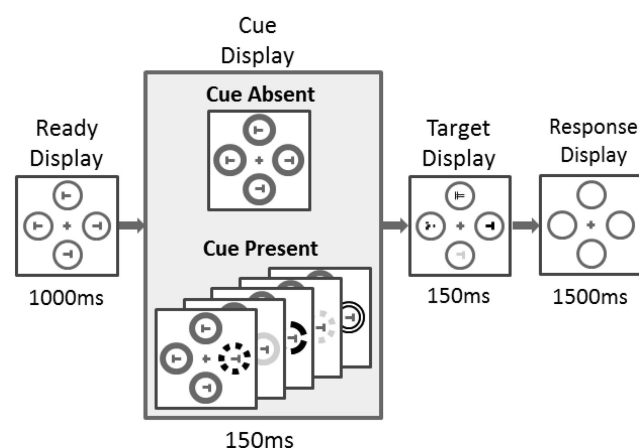
**Procedure.** The participants were instructed to determine the orientation of the target T, defined by its specific color (either red or blue, counterbalanced between subjects), and to respond by pressing designated keys on the computer keyboard as quickly as possible, while maintaining high accuracy. Each trial began with a fixation display that was replaced after 1,000 ms with a 150-ms cue display. The target display immediately followed for 150 ms, after which the response display was presented for 1,350 ms or until response. There was no intertrial interval. Eye movements were not monitored, but subjects were explicitly requested to set their eyes on the fixation cross throughout each trial.

**Design.** The experimental trials were divided into 10 blocks of 90 trials each. The cue was absent on 20% of the trials. In the mixed-color condition, the cue color was randomly selected from the five possible colors on each trial, whereas in the blocked-color condition, the cue color was fixed within each block of trials. Thus, the cue was equally likely to take on any of the possible nontarget colors in each condition, but on any given trial, this color was known in the blocked-color condition and unknown in the mixed-color condition. Condition order was fully counterbalanced between subjects, and color order in the blocked-color condition was set using a Latin square design. On cue-present trials, cue and target locations were set randomly and were uncorrelated. The experimental phase was preceded by a 30-trial practice block. Practice trials were identical to the mixed-color condition experimental trials.

### Results

Data from two participants were removed from analysis because their response accuracy was lower than the group mean by more than two standard deviations (52% and 74% vs.  $M = 91.7\%$ ,  $SD = 5.7\%$ ).<sup>1</sup> All RT analyses were conducted on correct trials (90% of all trials). In this and the following experiments, RTs faster than 150 ms or exceeding the mean of their cell by more than 2.5 standard deviations (2.4% of all correct trials in Experiment 1) were also removed from analysis.

Mean RTs and accuracy are presented in Figure 2 (see Table 1 for more detailed information). In order to examine the effect of



**Figure 1.** Sequence of events in Experiment 1. When the cue was present, its color either varied randomly (mixed-color condition) or remained constant in each block (blocked-color condition). The colors used were red (solid black), green (solid light gray), yellow (dotted black), blue (double-line black), magenta (dotted light gray), and cyan (dashed black). The target was defined by its known color.

<sup>1</sup> In this and the following experiments, the pattern of results did not differ when the data from excluded outlier participants were included.

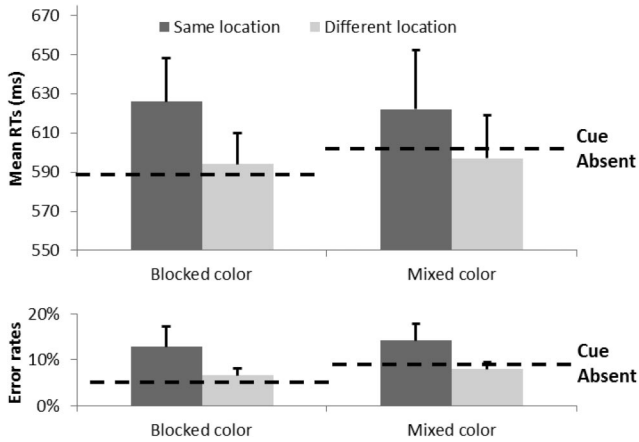


Figure 2. Mean RTs and error rates by cue location (same as target vs. different from target) in Experiment 1 in the blocked- and in the mixed-color cue conditions.

the cue color variability manipulation, a repeated-measures ANOVA was conducted on cue-present trials only, with cue location (same vs. different) and cue color variability condition (mixed vs. blocked) as within-subject factors. Preliminary analyses showed no significant effect of target color,  $F(1, 7) = 2.39$ ,  $p = .16$ ,  $\eta_p^2 = 0.25$ , and no interaction involving this variable, all  $ps > 0.24$ . Therefore, target color was not included as a factor in the following analyses.

**Reaction times.** Overall, RTs were equally fast in the blocked-color and in the mixed-color conditions, 2 ms,  $F < 1$ ,  $\eta_p^2 < 0.001$ . Reaction times were significantly slower when the target appeared at the same than at a different location relative to the cue, 29 ms,  $F(1, 8) = 14.7$ ,  $p < .01$ ,  $\eta_p^2 = 0.65$ . This same-location cost was not modulated by cue-color condition: It was similar on blocked-color and on mixed-color cue trials, 25 ms versus 32 ms, respectively,  $F < 1$ .

To determine whether the same-location cost resulted from slower responses when the cue happened to appear in the target location, or from faster response when the cue appeared elsewhere, we compared RTs in the same- and different-location conditions versus in the cue-absent condition. We found slower RTs on same-location than on cue-absent trials, 32 ms,  $F(1, 8) = 10.7$ ,  $p < .02$ ,  $\eta_p^2 = 0.58$ , and no significant difference between different-location and cue-absent trials, 3 ms,  $F < 1$ .

**Accuracy.** The accuracy data mirrored the RT data. The main effect of cue color variability was nonsignificant,  $F(1, 8) = 1.23$ ,  $p > .3$ ,  $\eta_p^2 = .13$ . The same-location cost was significant, 5.25%,  $F(1, 8) = 5.27$ ,  $p < .051$ ,  $\eta_p^2 = 0.40$ , and was not modulated by cue color variability,  $F < 1$ . Error rates were higher on same-location than on cue-absent trials by 6.4%,  $F(1, 8) = 8.0$ ,  $p < .05$ ,  $\eta_p^2 = 0.50$ , and different-location trials did not differ from cue-absent trials, 0.1%,  $F < 1$ .

**Compatibility.** We tested the hypothesis that attention was captured by the cue but was rapidly disengaged from it on different-location trials by examining whether the compatibility between the response elicited by the T in the cued location (in the different-location condition) and the response elicited by the T at the target location affected performance. For that purpose, we conducted an ANOVA on different-location trials, with response compatibility (compatible vs. incompatible) and cue color variability (mixed color vs. blocked color) as within-subject factors (see Table 2 for mean RTs and accuracy). The main effect of compatibility was nonsignificant (if anything, it showed a numerical trend toward faster incompatible vs. compatible trials),  $-4$  ms,  $F(1, 8) = 2.7$ ,  $p = .14$ . No effect involving cue color variability was significant (all  $Fs < 1$ ).

## Discussion

We replicated the same-location cost: Performance was impaired when a singleton cue in a nontarget color appeared at the target location relative to when this cue was presented in a different location or was absent. As the motor-inhibition account pertains only to studies in which the color of the irrelevant cue is associated with a no-go response, this account cannot explain the present results. In addition, our findings support neither the feature-based inhibition in its original formulation (e.g., Eimer et al., 2009; Lamy & Egeth, 2003; Lamy et al., 2004) nor the rapid-disengagement hypotheses (Belopolsky et al., 2010; Schreij et al., 2010; Theeuwes, 2010; Theeuwes et al., 2000).

The same-location cost was similar whether the cue could take on just one or several different colors. Assuming that maintaining a feature-based inhibitory set against just one color is more effective than against five different colors, this finding argues against the feature-based inhibition hypothesis. However, inhibition may not be feature specific. Instead, it may be a consequence of adopting a positive task set for one specific target color (e.g., red), and inhibition would thus be applied to the location of any nonred object. In that case, there would be no reason to expect weaker

Table 1  
Mean Reaction Times in Milliseconds and Percentage of Correct Trials (and Standard Deviations) in Experiment 1

	Blocked		Mixed	
	Mean RT (SD)	Accuracy (SD)	Mean RT (SD)	Accuracy (SD)
Cue absent	592 (14.8)	94.9% (1.8%)	597 (26.1)	90.8% (2.7%)
Cue present				
Same location	628 (22.7)	87.1% (4.5%)	622 (30.1)	85.8% (3.6%)
Different location	593 (15.8)	93.4% (1.6%)	597 (21.9)	92.0% (1.6%)

Note. RT = reaction time.



Table 2  
*Mean Reaction Times in Milliseconds and Percentage of Correct Trials (and Standard Deviations) by Cue Compatibility Condition on Cue-Present Trials in Experiment 1*

	Blocked		Mixed	
	Mean RT (SD)	Accuracy (SD)	Mean RT (SD)	Accuracy (SD)
Compatible	592 (14.7)	93.1% (2.0%)	601 (21.7)	92.3% (2.0%)
Incompatible	590 (15.7)	93.5% (1.5%)	594 (20.8)	91.8% (1.5%)

Note. RT = reaction time.

effects when the cue color varies than when it is fixed. Thus, our findings only refute the idea that the same-location cost results from feature-specific inhibition.

The findings of the present experiment also argue against the fast-disengagement hypothesis, as the compatibility between the letters enclosed in the cued and target circles did not affect performance. One could claim that disengagement was too fast to allow processing of the letter at the cued location. However, this argument runs a serious risk of circularity. One the one hand, compatibility effects are used to show that attention was captured (e.g., Theeuwes et al., 2000; Theeuwes & Burger, 1998). On the other hand, failure to observe these effects is attributed to fast disengagement rather than to absence of capture. The burden of proof is on the fast-disengagement account, which is less parsimonious in explaining the absence of compatibility effects than accounts attributing it simply to the cue's failure to capture attention.

Might there be good reason to expect faster disengagement in our study than in similar previous studies in which compatibility effects were observed (e.g., Theeuwes et al., 2000)? Two main observations make this possibility unlikely. First, it should be faster to disengage one's attention from a singleton distractor defined in a different dimension (e.g., from a color singleton in search for a shape target, as was the case in Theeuwes et al.'s study) than in the same dimension (as was the case here). Second, whereas in our experiment, the letter for which compatibility effects were measured was already visible before the color change (i.e., at the beginning of cueing), in Theeuwes et al.'s experiment, this letter became visible only in the target display, that is, after the cue had been offset and the ISI had elapsed—thereby making it less likely to be processed before attentional disengagement. Thus, if anything, disengagement should have been faster in Theeuwes et al.'s study than in ours.

## Experiment 2

The findings of Experiment 1 can be accommodated by none of the current accounts of the same-location cost. A common feature of these accounts is that they all assume that the cost is related to the cue being task irrelevant, that is, to the set adopted by the observers. Alternatively, however, the cost may result from a mismatch between the colors appearing in close temporal succession at the target location, irrespective of the task requirements. The objective of Experiment 2 was to test these alternative accounts against each other.

In Experiment 1, we showed that the same-location cost does not rely on the adoption of a set *against* the irrelevant cue color. In Experiment 2, we questioned the underlying assumption that the cost is contingent on the adoption of a set *in favor* of a specific target feature. Accordingly, we asked whether the same-location cost would be eliminated when observers did not search for a known target feature. There were two search conditions. The feature-search condition was similar to Experiment 1, except that we added a same-color cue condition in which the cue was in the same color as the target. The singleton-search condition differed from the feature-search condition, in that the target color changed unpredictably instead of remaining fixed across trials. Crucially, then, in this condition, the different-color cue was no less relevant to the task than was the same-color cue.

If the same-location cost is related to the mismatch between the cue color and the attentional set for a specific target color, then the predictions go as follows: (a) In the singleton-search condition, all cues should capture attention to the same extent (that is, produce a similar same-location advantage) because no feature information can guide search (e.g., Bravo & Nakayama, 1992); and (b) In the feature-search condition, we should observe a same-location cost when the cue does not match the target color (i.e., replicating the finding of Experiment 1) and attentional capture in the same-color cue condition (in line with Folk et al.'s, 1992, contingent capture hypothesis). However, if the same-location cost is unrelated to the attentional set, but instead depends on the mismatch between the colors successively occupying the attended location, then same-color cues should produce a different pattern of results relative to different-color cues in both search conditions.

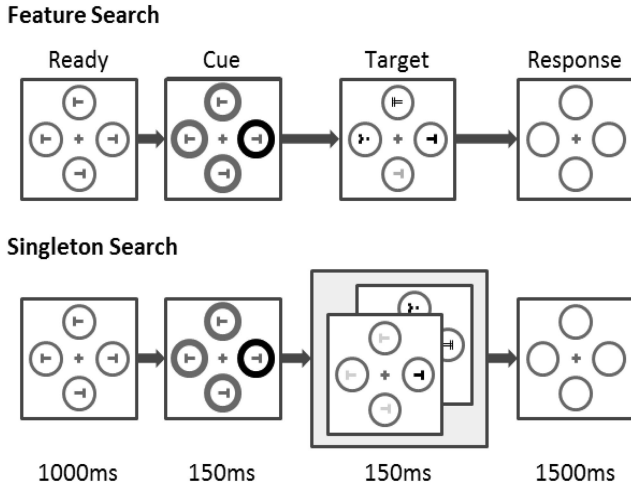
## Method

**Participants.** Twenty-four Tel Aviv University undergraduate students (aged 21 to 27 years) participated in the experiment for course credit. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

**Apparatus, stimuli, and procedure.** The experiment was run on a HP DV5-1110ej laptop computer. Stimuli were presented on the computer built-in 15.6-in. LCD high-resolution (1280 × 800) wide screen (60Hz refresh rate). Viewing distance was set at about 60 cm. The experiment room was dimly lit.

The stimuli and procedure were similar to those of Experiment 1, except for the following changes. In order to use the same target colors in both sessions, the singleton-search target display included either a single red T among green nontargets, or a single blue T among yellow nontargets (See Figure 3). Thus, although nontarget colors were heterogeneous in the feature-search condition, they were homogenous in the singleton-target condition. In order to keep the contrast between target and nontarget colors similar in the singleton- and feature-search conditions, we took the following step: For each of the two possible target colors, the color of the homogenous nontargets in the singleton-search condition was the Euclidean average in CIE color space of the nontarget colors in the feature-search condition. A same-color cue condition, in which the cue color was the same as the target color, was added to the different-color cue and cue-absent conditions.

**Design.** The design was similar to that of the mixed-color condition of Experiment 1 (see Figure 3), except for the following changes. In the feature-search condition, the target color (either red



**Figure 3.** Sequence of events in Experiment 2. This example depicts the same-color cue condition added to the cue-absent and different-color cue conditions described in Experiment 1. The target color was known and fixed in the feature-search task. It was unknown and varied randomly in the singleton-search task. Different shades of gray and the dotted lines represent different colors (see Method section for details).

or blue) was fixed and counterbalanced across subjects. In the singleton-search condition, it varied randomly across trials, and participants were instructed to search for the singleton target. In both search conditions, the cue was absent on 20% of the trials and, when present, was equally likely to be in the same or in a different color relative to the target.

A 30-trial-long practice block was followed by two blocks of experimental trials, of 360 trials each. The participants were allowed a break between the blocks. Thirteen subjects performed the feature-search condition and 11 subjects performed the singleton-search condition.

## Results

Data from one participant in the feature-search session and two participants in the singleton-search session were removed from

analysis because their response accuracy was lower than the group mean by more than two standard deviations (78% vs.  $M = 93.6%$ ,  $SD = 3.4%$ ; and 54% and 65% vs.  $M = 92.1%$ ,  $SD = 3.4%$ , respectively; see Footnote 1). Outlier-RT trials (1.3% of all correct trials) were removed from all RT analyses.

Mean RTs and accuracy are presented in Figure 4 (see Table 3 for more detailed information). A repeated-measures ANOVA was conducted on cue-present trials, with search type (feature vs. singleton) as a between-subjects factor, and cue location (same vs. different) and cue color (same vs. different) as within-subject factors.

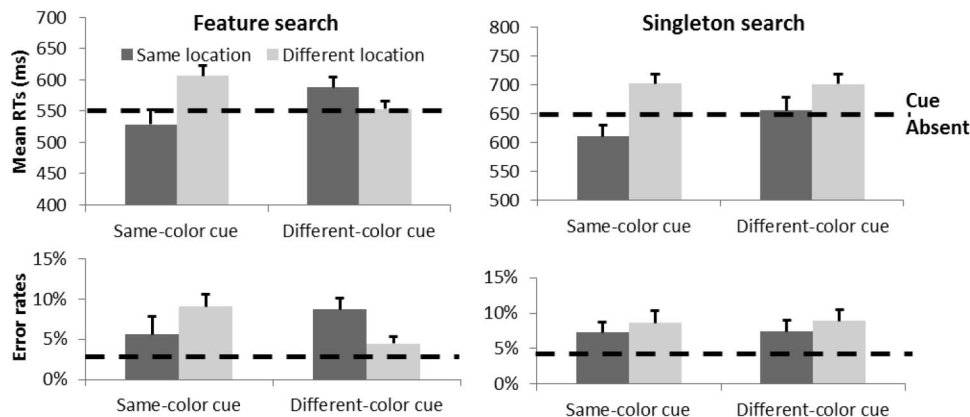
**Reaction times.** All main effects were significant,  $F(1, 20) = 18.72$ ,  $p < .001$ ,  $\eta_p^2 = 0.48$ ,  $F(1, 20) = 19.0$ ,  $p < .001$ ,  $\eta_p^2 = 0.49$ , and  $F(1, 20) = 6.6$ ,  $p < .02$ ,  $\eta_p^2 = 0.25$ , for search condition, cue location and cue color, respectively. The interaction between cue location and cue color was significant,  $F(1, 20) = 52.64$ ,  $p < .0001$ ,  $\eta_p^2 = 0.72$ , and was modulated by a significant three-way interaction with search type,  $F(1, 20) = 9.32$ ,  $p < .01$ ,  $\eta_p^2 = 0.32$ . In order to clarify this interaction, separate follow-up ANOVAs were conducted on the feature-search and singleton-search conditions.

**Accuracy.** The accuracy data mirrored the RT data. The interaction between cue color and cue location approached significance,  $F(1, 20) = 3.42$ ,  $p < .08$ ,  $\eta_p^2 = 0.15$ , as did the three-way interaction of cue color, cue location, and search type,  $F(1, 20) = 3.85$ ,  $p < .07$ ,  $\eta_p^2 = 0.16$ . All other effects were nonsignificant,  $F < 1$ .

### Feature Search

**Reaction times.** The interaction between cue color and cue location was highly significant,  $F(1, 11) = 34.94$ ,  $p < .001$ ,  $\eta_p^2 = 0.76$ . Paired comparisons revealed a same-location cost for different-color cues, as in Experiment 1, 35 ms,  $F(1, 11) = 11.30$ ,  $p < .01$ ,  $\eta_p^2 = 0.51$ , and a same-location benefit for same-color cues, 86 ms,  $F(1, 11) = 11.85$ ,  $p < .01$ ,  $\eta_p^2 = 0.52$  (see Figure 4). No other effect approached significance, all  $ps > 0.15$ .

Additional analyses showed that the same-color cue captured attention, whereas the different-color cue did not. In the different-color cue condition, responses were slower on same-location than on cue-absent trials by 38 ms,  $F(1, 11) = 19.37$ ,  $p < .002$ ,  $\eta_p^2 =$



**Figure 4.** Mean RTs (in milliseconds) and percentage of errors in the feature-search and singleton-search conditions by conditions of cue color and cue location. The hatched lines represent performance on no-cue trials.

Table 3  
*Mean Reaction Times in Milliseconds and Percentage of Correct Trials (and Standard Deviations) by Cue Condition in the Feature-Search and Singleton-Search Conditions in Experiment 2*

	Feature-search		Singleton-search	
	Mean RT (SD)	Accuracy (SD)	Mean RT (SD)	Accuracy (SD)
Cue absent	550 (12.2)	96.4% (6.2%)	648 (12.4)	95.3% (1.3%)
Same-color cue				
Same location	529 (23.6)	94.4% (2.2%)	609 (14.6)	92.7% (1.4%)
Different location	606 (15.6)	90.9% (1.5%)	701 (11.6)	91.4% (1.8%)
Different-color cue				
Same location	588 (16.3)	91.3% (1.5%)	657 (16.7)	92.6% (1.6%)
Different location	553 (12.2)	95.5% (0.8%)	702 (12.6)	91.1% (1.6%)

Note. RT = reaction time.

0.64, but did not differ between different-location and cue-absent trials (3 ms,  $F(1, 11) = 1.39$ ,  $p > .26$ ,  $\eta_p^2 = 0.11$ ). In addition, there was no compatibility effect on different-location trials,  $-1$  ms,  $F < 1$ . By contrast, in the same-color cue condition, different-location trials were slower than cue-absent trials by 56 ms,  $F(1, 11) = 73.68$ ,  $p < .001$ ,  $\eta_p^2 = 0.87$ , and tended to be faster on same-location than on cue-absent trials by 21 ms, although this effect failed to reach significance,  $F(1, 11) = 1.22$ ,  $p = .29$ ,  $\eta_p^2 = 0.10$ . In addition, compatibility effects on different-location trials were significant, 19 ms,  $F(1, 11) = 5.63$ ,  $p < .05$ ,  $\eta_p^2 = 0.34$ .

**Accuracy.** The accuracy data paralleled the RT data. The interaction between cue color and cue location was significant  $F(1, 11) = 5.62$ ,  $p < .05$ ,  $\eta_p^2 = 0.34$ , with a significant same-location cost in the different-color cue condition, 4.2%,  $F(1, 11) = 21.6$ ,  $p < .001$ ,  $\eta_p^2 = 0.66$ , and a numerical trend toward a same-location benefit in the same-color condition, 3.5%,  $F(1, 11) = 1.61$ ,  $p > .23$ ,  $\eta_p^2 = 0.13$ . No other effect approached significance, all  $F$ s  $< 1$ .

In the different-color cue condition, accuracy was lower on same-location than on cue-absent trials, 5.0%,  $F(1, 11) = 18.30$ ,  $p < .005$ ,  $\eta_p^2 = 0.62$ , and did not differ between different-location and cue-absent trials, 0.9%,  $F(1, 11) = 2.46$ ,  $p = .15$ ,  $\eta_p^2 = 0.18$ . By contrast, in the same-color cue condition, accuracy was lower on different-location than on cue-absent trials, 5.5%,  $F(1, 11) = 21.57$ ,  $p < .001$ ,  $\eta_p^2 = 0.66$ , and did not differ significantly on same-location versus cue-absent trials, 2.0%,  $F < 1$ ,  $\eta_p^2 = 0.05$ . There was no significant effect involving cue-target T orientation compatibility (all  $p$ s  $> 0.30$ ).

### Singleton Search

**Reaction times.** The main effects of cue location and cue color were significant,  $F(1, 9) = 23.5$ ,  $p < .001$ ,  $\eta_p^2 = 0.72$ , and  $F(1, 9) = 25.8$ ,  $p < .001$ ,  $\eta_p^2 = 0.74$ , respectively, and interacted with each other,  $F(1, 9) = 45.5$ ,  $p < .0001$ ,  $\eta_p^2 = 0.83$ . Paired comparisons revealed that same-location trials were faster than different-location trials in both cue color conditions, but this same-location benefit was larger in the same-color than in the different-color cue condition, 92 ms versus 45 ms,  $F(1, 9) = 44.7$ ,  $p < .001$ ,  $\eta_p^2 = 0.83$ , versus  $F(1, 9) = 8.84$ ,  $p < .02$ ,  $\eta_p^2 = 0.50$ , respectively. The compatibility effect on different-location trials was signifi-

cant, 16 ms,  $F(1, 9) = 6.66$ ,  $p < .05$ ,  $\eta_p^2 = 0.43$  and was not modulated by cue color,  $F < 1$ ,  $\eta_p^2 = 0.09$ .

**Accuracy.** There were no significant effects for the accuracy data in this experiment, all  $p$ s  $> 0.1$ .

### Discussion

All cues captured attention in singleton search. In feature search, different-color cues were associated with a same-location cost, thus replicating the finding from Experiment 1, whereas same-color cues captured attention, in line with the contingent-capture hypothesis. Of main interest, however, was the finding that in singleton search, the same-location benefit was smaller by 46 ms when the cue color happened to be different from the target's color than when it shared the same color. Remember that in this search condition, same- and different-color cue trials had the same status with regard to their match with the attentional set, because the target color varied from trial to trial.

Neither the feature-unspecific inhibition account described in the discussion of Experiment 1 nor the fast-disengagement account can easily accommodate this finding. As all cue colors equally belonged to the attentional set, there is no reason to expect more inhibition of or slower disengagement from cues with a color that happened to be different from the color of the subsequent target.

We suggest that the location effects observed in this experiment reflect two independent mechanisms. One mechanism is related to the attentional set promoted by the task (e.g., Folk et al., 1992): In singleton search, all singletons capture attention to the same extent, and in feature search, only same-color cues capture attention, whereas different-color cues have no effect. Another mechanism, yet to be defined and unrelated to attentional settings, is responsible for the same-location cost when the cue and target colors differ, and operates in the same way in the two search conditions. Two aspects of the data support the latter claim. First, note that although differences between same-location and cue-absent trials may result from both attentional capture and the same-location cost, differences between different-location and cue-absent trials are only associated with attentional capture. Accordingly, we found that the difference in the magnitude of spatial capture between same- and different-color cue conditions in singleton search resulted only from differences between same-location and



cue-absent trials (39 ms vs.  $-9$  ms,  $F[1, 9] = 39.10$ ,  $p < .0001$ ,  $\eta_p^2 = 0.81$ , respectively), with no difference on different-location trials relative to cue-absent trials (54 ms vs. 53 ms,  $F < 1$ ,  $\eta_p^2 < 0.01$ ). Thus, the difference between same- and different-color cue conditions in singleton search was unrelated to attentional capture. Second, the hypothesized same-location cost was of the same magnitude in the singleton and feature-search conditions, 46 ms versus 35 ms, respectively,  $t(20) = 0.92$ ,  $p = .37$ ,  $\eta^2 = 0.11$ .

### Experiment 3

Having established in Experiments 1 and 2 that the same-location cost is unrelated to task-dependent attentional requirements, the objective of Experiment 3 was to explore the mechanisms that might underlie this effect. We tested two candidate accounts.

One possibility is that the cue might impair target processing by serving as a forward mask. Because the cue and target contours did not overlap, such an effect would be akin to paracontrast masking (Ogmen, Breitmeyer, & Melvin, 2003). Paracontrast masking is critically dependent on the time interval that separates the mask and target and is maximal at a 150-ms interval. We thus manipulated the stimulus onset asynchrony between the cue and target, such that it ranged between 150 ms and 350 ms. We reasoned that if the same-location cost survives the longer interval, this would allow us to reject the masking hypothesis.

The other possibility that we tested relies on the observation that the circles and enclosed Ts remained in view throughout each trial and were likely to be perceived as four distinct bound objects. Thus, on same-location trials, the cue and target events were likely to be perceived as successive changes occurring in the same object: One part (the circle) underwent a color change during the cueing display, whereas the other part (the T) underwent a color change during the target display.

Kahneman and Treisman (1984; see also Kahneman, Treisman, & Gibbs, 1992, and Treisman, 1993) proposed the notion of object file in order to explain how objects maintain their perceptual continuity across changes (for instance, when they move). An object file is “a temporary episodic representation, within which successive states of an object are linked and integrated” (Kahneman et al., 1992, p. 175). It retains only very basic information about the object, such as its primary features (Kahneman et al., 1992; Wolfe & Bennett, 1997) and higher-level information relevant to the task at hand (Gordon & Irwin, 1996). The same-location cost observed in Experiments 1 and 2 may reflect the cost of updating the color information associated with the target object: Such updating would be necessary only when the cue circle and target T take on different colors.

In order to test this account, we designed a new condition (henceforth, “discontinuous-objects” condition), in which we “unbound” the circle and enclosed T by presenting them sequentially (see Figure 5). Thus, the cueing display included a color singleton, for instance, an empty red circle among three empty gray circles, which disappeared during the ISI. It was followed by the target display, which contained four heterogeneously colored Ts. We reasoned that if the same-location cost is indeed object based and reflects an object-updating cost, then it should disappear when the cue and target are no longer perceived as being bound into the same object. This experiment thus included the discontinuous-

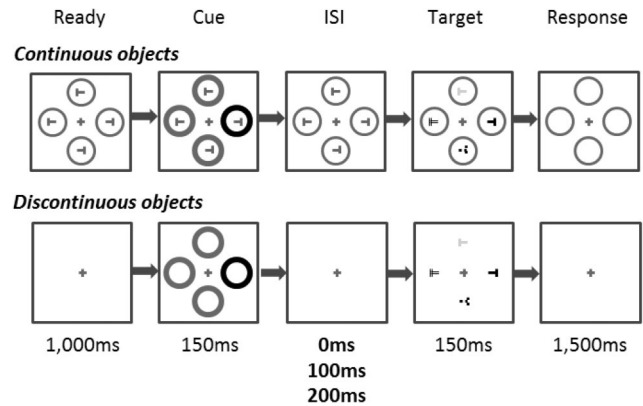


Figure 5. Sequence of events in the continuous-objects and discontinuous-objects conditions Experiment 3.

objects condition just described and, for comparison, a continuous-objects condition, similar to the feature-search condition of Experiment 2. In both conditions of object type, the target display appeared at various ISIs (0 ms, 100 ms, or 200 ms) from the cue display, which included a same-color cue, a different-color cue, or no cue at all.

### Method

**Participants.** Twenty-six Tel Aviv University undergraduate students (aged 19 to 33 years) participated in the experiment. All participants reported having normal or corrected-to-normal visual acuity and normal color vision.

**Apparatus, stimuli, procedure, and design.** The apparatus, stimuli, procedure, and design were similar to those of Experiment 2, except for the following changes. The continuous-objects condition was similar to the feature-search task condition of Experiment 2 (see Figure 5), except for the fact that an ISI display, identical to the ready display, was introduced between the cue and target displays.

The ISI display was presented for 0 ms, 100 ms, or 200 ms. The discontinuous-objects condition was similar to the continuous-objects condition, but the circles were omitted from all displays in the trial sequence, except for the cue display (see Figure 5). Thirteen participants performed the continuous-objects condition, and 13 performed the discontinuous-objects condition.

### Results

Mean accuracy was 95.4% in the continuous-objects condition and 97.6% in the discontinuous-objects condition. The data from three participants were removed from analysis because their response accuracy was lower than the group mean by more than two standard deviations (78%, 82%, and 84% vs.  $M = 95.4%$ ,  $SD = 4.6%$ ; see Footnote 1). Outlier-RT trials (1.8% of trials) were removed from all RT analyses.

Mean RTs and accuracy are presented in Figure 6 (see Table 4 for more detailed information). Same-color and different-color cue conditions were analyzed in separate repeated-measures ANOVAs, with object type (continuous vs. discontinuous objects) as a

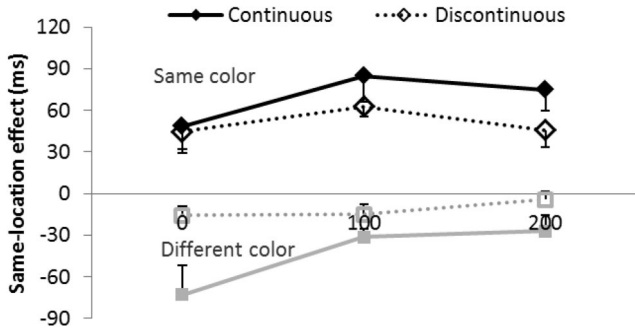


Figure 6. Location effect (mean RT for different-location minus same-location cue) by interstimulus interval, when cue and target presentation was continuous (full lines, Experiment 3) and discontinuous (dotted lines, Experiment 4). The same-color cue condition is drawn in black, and the different-color cue is drawn in gray.

between-subjects factor and cue location (same vs. different) and ISI (0 ms, 100 ms, or 200 ms) as within-subject factors.

**Different-color cues.**

**Reaction times.** The main effect of cue location was significant, 28 ms,  $F(1, 20) = 93.6, p < .0001, \eta_p^2 = 0.82$ , replicating the same-location cost demonstrated earlier, and so was the main effect of ISI,  $F(2, 40) = 30.9, p < .0001, \eta_p^2 = 0.81$ , with faster RTs as the ISI became longer. Despite a clear numerical trend toward faster RTs in the continuous relative to the discontinuous objects condition, the main effect of object type was nonsignificant,  $F(1, 20) = 2.73, p = .11, \eta_p^2 = 0.12$ .

Importantly, cue location interacted with object type,  $F(1, 20) = 31.5, p < .0001, \eta_p^2 = 0.61$ , demonstrating a larger same-location cost for continuous objects, 44 ms, than for discontinuous objects, 12 ms. The interaction between cue location and ISI approached significance,  $F(2, 40) = 3.16, p < .08, \eta_p^2 = 0.13$ , reflecting that the same-location cost tended to become smaller as the ISI became

longer. The interaction between ISI and object type was also significant,  $F(2, 40) = 7.47, p < .005, \eta_p^2 = 0.27$ , but is not theoretically relevant to the issues at hand. The three-way interaction between cue location, object type, and ISI was not significant,  $F < 1, \eta_p^2 = 0.04$ .

Planned comparisons using Benjamini and Hochberg’s (1995) procedure to correct for false discovery rate (FDR) of ISI effects for each combination of object type and ISI showed that in the continuous-objects condition, the same-location cost was significant for all ISIs, 73 ms,  $F(1, 9) = 12.3, p < .01, \eta_p^2 = 0.58$ , and 31 ms,  $F(1, 9) = 27.8, p < .001, \eta_p^2 = 0.76$ , and 27 ms,  $F(1, 9) = 5.2, p < .05, \eta_p^2 = 0.37$ , for the 0-, 100-, and 200-ms ISIs, respectively. In the discontinuous-objects condition, the same-location cost only approached significance under the FDR correction for the 0-ms stimulus-onset asynchrony (SOA), 16 ms,  $F(1, 11) = 5.5, p < .04, \eta_p^2 = 0.33$ , and was not significant for the 100-ms and 200-ms ISIs, 15 ms,  $F(1, 11) = 4.5, p < .06, \eta_p^2 = 0.29$ , and 4 ms,  $F < 1, \eta_p^2 = 0.05$ , respectively.

**Accuracy.** Analysis of accuracy data removed any concern of speed-accuracy trade-off. Only the main effect of cue location approached significance,  $F(1, 20) = 4.30, p < .06, \eta_p^2 = 0.18$ , with a trend toward more errors on same-location versus different-location trials, all other  $ps > 0.16$ .

**Same-color cues.**

**Reaction times.** The main effects of cue location and ISI were significant,  $F(1, 20) = 45.9, p < .0001, \eta_p^2 = 0.70$ , and  $F(2, 40) = 43.1, p < .001, \eta_p^2 = 0.68$ , respectively. The interaction between these factors was significant,  $F(2, 40) = 5.6, p < .01, \eta_p^2 = 0.22$ , indicating that the same-location benefit roughly followed an inverted “U” pattern, yet the same-location benefit was significant at all ISIs, 47 ms,  $F(1, 11) = 12.9, p < .005$ ; 74 ms,  $F(1, 11) = 70.1, p < .001$ ; and 60 ms,  $F(1, 11) = 14.9, p < .005$ , for 0-, 100-, and 200-ms ISIs, respectively. No other effect approached significance, all  $ps > 0.27$ . In particular, the same-location benefit was not modulated by object type.

Table 4

Mean Reaction Times in Milliseconds and Percentage of Correct Trials (and Standard Deviations) by Cue Condition as a Function of the Interval Between the Cue and Target (ISI in Milliseconds) When the Cue and Target Belonged to the Same Object (Continuous Objects Condition) or to Different Objects (Discontinuous Objects Condition) in Experiment 3

	Mean RT (SD)			Accuracy (SD)		
	0 ms	100 ms	200 ms	0 ms	100 ms	200 ms
Continuous objects						
Cue absent	594 (22.7)	568 (19.5)	570 (18.8)	96.4% (1.7%)	97.9% (1.1%)	96.8% (1.6%)
Same-color cue						
Same location	595 (19.5)	538 (18.8)	545 (21.3)	92.8% (2.5%)	97.6% (1.9%)	98.0% (0.7%)
Different location	643 (26.7)	623 (25.3)	620 (27.3)	93.5% (2.2%)	93.8% (1.8%)	95.7% (1.3%)
Different-color cue						
Same location	665 (33.7)	603 (20.4)	594 (18.4)	92.2% (2.6%)	92.9% (3.9%)	94.3% (2.7%)
Different location	593 (20.7)	572 (20.3)	567 (20.4)	95.4% (1.8%)	96.6% (1.5%)	96.5% (1.0%)
Discontinuous objects						
Cue absent	559 (12.4)	560 (12.9)	536 (15.3)	98.8% (0.7%)	97.6% (0.9%)	97.1% (1.1%)
Same-color cue						
Same location	554 (17.7)	518 (15.7)	522 (18.0)	98.1% (0.7%)	99.0% (0.5%)	99.0% (0.5%)
Different location	599 (12.1)	580 (13.5)	568 (12.8)	97.5% (0.9%)	96.6% (0.6%)	97.0% (0.5%)
Different-color cue						
Same location	578 (13.3)	569 (14.9)	550 (11.4)	96.9% (1.4%)	98.1% (0.8%)	96.4% (1.1%)
Different location	562 (12.5)	554 (12.5)	546 (13.5)	98.2% (0.5%)	97.2% (0.7%)	97.7% (0.7%)

Note. ISI = interstimulus interval; RT = reaction time.

**Accuracy.** The same-location benefit was significant, 1.7%,  $F(1, 20) = 4.5$ ,  $p < .05$ ,  $\eta_p^2 = 0.18$ , and interacted with ISI,  $F(2, 40) = 4.6$ ,  $p < .02$ ,  $\eta_p^2 = 0.19$ . It followed the same pattern as the effect on RTs, 0%, 3.1%, 2.2% for 0-, 100-, and 200-ms ISIs, respectively, therefore eliminating any concern of a speed-accuracy trade-off. The interaction between ISI and objects type was significant,  $F(2, 40) = 5.26$ ,  $p < .02$ ,  $\eta_p^2 = 0.21$ , but is not theoretically relevant to the issues at hand. No other effect approached significance, all  $F_s < 1$ .

## Discussion

The results of this experiment argue against a masking-related account: The same-location cost associated with the irrelevant-color cue in the continuous-objects condition remained significant when the SOA between the irrelevant cue and target was as long as 350 ms (corresponding to the 200-ms ISI condition)—although it decreased following the shortest SOA. It should be noted, however, that the cost measured with the 0-ms ISI was much larger in this experiment than it was in the previous ones (73 ms in Experiment 3 vs. 29 ms and 35 ms in Experiments 1 and 2, respectively), despite the fact that the conditions were very similar. If the effect was indeed spuriously large in the present experiment, then taken together, our data do not indicate that the same-location cost even decreased within 350 ms from cue onset.

The results are consistent with the object-updating account because whether the cue and target letter seemed to belong to the same object played a crucial role in the same-location cost. On the one hand, this cost was significant for all ISIs in the continuous-objects condition. On the other hand, although it was marginally significant when objects continuity disruption was mild (i.e., at the 0-ms ISI, when the target was onset immediately after cue offset), it gradually disappeared as the disruption became larger (100-ms and 200-ms ISIs).

The results also show that object continuity had no incidence on the same-location benefit observed with same-color cues and indicating contingent capture (Folk et al., 1992). The qualitatively different influence of object continuity on the same-location cost and on contingent attentional capture provides additional support for the notion that the same-location cost is unrelated to capture.

The findings of this experiment are also incompatible with the feature-unspecific inhibition and fast-disengagement accounts. Inhibition should accrue to any object not possessing the target color, irrespective of whether or not it is perceived as belonging to the same object as the target. Likewise, at the time attention is disengaged from the cue, the color of the subsequent target is still unknown, such that there is no reason to expect faster disengagement in the same-color than in the different-color condition.

## General Discussion

We replicated the finding that responding to a color target that appears at the location recently occupied by an irrelevant singleton cue with a different color is delayed relative to when this cue is either absent or has the same color as the target (e.g., Becker et al., 2013, Exp.3; Belopolsky et al., 2010; Eimer et al., 2009; Folk & Anderson, 2010; Folk & Remington, 2008; Lamy et al., 2004; Schönhammer & Kerzel, 2013). This same-location cost has been interpreted within the framework of our ability to resist attentional

capture by task-irrelevant objects. In the present study, we strongly establish the existence of this cost, but demonstrate that it has been misinterpreted and that it is unrelated to the role of attentional settings in the allocation of attentional priority. We show that it is not a form of masking and that it is contingent on the cue and target being perceived as two parts of the same perceptual object.

The main contribution of the present study is thus twofold. On the one hand, we invalidate previous conclusions with regard to the interplay between stimulus- and goal-directed factors that relied on the same-location effect, and thereby shed new light on this debate. On the other hand, we open the way for a novel line of investigation by reporting a phenomenon by which performance at responding to an object is impaired when this object is successively associated with different features on the same dimension relative to when it remains associated with the same feature. We suggest that this performance cost results from an object-updating process, during which the information pertaining to an object is modified as this object changes over time.

## The Same-Location Cost and Attentional Capture

The same-location cost has been put forward as supporting evidence for different models of attentional priority allocation. Theeuwes and his colleagues (e.g., Belopolsky et al., 2010; Schreij et al., 2010; Theeuwes, 2010; Theeuwes et al., 2000) claimed that attention is always captured by the most salient stimulus in the visual field, and that the same-location cost reflects fast attentional deallocation mediated by spatial inhibition that allows for recovery from capture. By contrast, Lamy and her colleagues (e.g., Lamy, 2010; Lamy & Egeth, 2003; Lamy et al., 2004) proposed that attention is not always captured by the most salient stimulus. Instead, they suggested that attentional capture only indexes the net difference between the relative weights of salience-based and goal-directed contributions to attentional priority, and that the same-location cost reflects a goal-directed feature-based inhibition mechanism that may offset salience-based signals at the location of the known salient distractor and produce net inhibitory effects at its location.

Our findings support neither of these accounts. Compatibility between the letters enclosed in the cued and target circles did not affect performance in search for a known color, suggesting that the irrelevant-color cue did not capture attention at any stage during the trial, thereby invalidating Theeuwes's (2010) fast disengagement account (see Chen & Mordkoff, 2007; Lamy, 2005, 2010 for further evidence against this account). In addition, the same-location cost was similar whether the cue could take on just one or several different colors (Experiment 1), thus invalidating Lamy's feature-based inhibition account. Although express disengagement of attention from the irrelevant cue and a feature-unspecific-inhibition mechanism might accommodate the findings of Experiment 1 (as explained in the discussion of that experiment), these accounts cannot parsimoniously explain the finding that the benefit on same-location trials was larger on same- than on different-color cues during singleton search, in which all colors had the same attentional status (Experiment 2), nor the finding that the same-location cost disappeared when the cue and target did not belong to the same object (Experiment 3).

Taken together, the present findings provide strong support for Folk's (e.g., Folk & Remington, 1998) contingent capture hypothesis.

esis, according to which attentional capture by an irrelevant object is entirely determined by this object's match with the observer's attentional set. Indeed, in the present experiments, same-location trials were faster, and different-location trials were slower, than no-cue trials in the same-color cue condition, thus demonstrating that same-color cues captured attention. In contrast, in the different-color cue condition, performance was equally good when the target appeared at a different location than the irrelevant-color cue as when this cue was absent. As we showed that the same-location cost is unrelated to selection, and presumably reflects an object-updating cost that occurs after selection, the fact that different-location and no-cue trials did not differ further demonstrates that the irrelevant-color cue did not capture attention: Such capture was not "masked" by the same-location cost—it simply did not happen.

There are two important qualifications to these conclusions. First, in the present experiments, we examined attentional capture when the critical distractor and target were defined within the same dimension, as was the case in most previous reports of the same-location cost. Lamy and Egeth (2003), however, reported a same-location cost during cross-dimensional capture. The salient cue was a color singleton, whereas the target was defined by its known shape. If, as we speculate, the same-location cost reflects an object-updating cost that arises when an object is successively associated with different features within the same dimension relative to when it remains associated with the same feature, then this account does not naturally apply in this situation. It is therefore possible that feature-based inhibition may be exerted only when the cue and target are defined in different dimensions (see Zehetleitner, Goschy, & Müller, 2012 for findings supporting the notion that experience-dependent suppressive attentional tuning is dimension specific, and Vatterott & Vecera, 2012, for evidence that it can be feature specific). Further research is required to clarify this issue.

Second, although our findings indicate that goal-directed factors can bias attentional priority allocation and prevent attentional capture by salient irrelevant objects, other research has demonstrated that if such objects are made salient enough, attentional control breaks down (e.g., Lamy, 2005; Liao & Yeh, 2011; Yeh & Liao, 2008). In order to demonstrate that physical salience plays no role in the computation of attentional priority, as the strong version of contingent-capture theory (e.g., Folk et al., 1992) stipulates, one must manipulate the salience of the critical distractor—which we did not do. Thus, the present findings indicate that the irrelevant-color singleton used in our study did not capture attention, yet they do not show that physical salience does not affect allocation of attentional priority (for discussion, see Lamy, 2010).

### Comparison With Previous Studies of the Same-Location Cost

The present experiments were designed so as to maximize the probability to observe same-location costs, and as such, they differed from previous studies in several respects. Some of these differences seem to be inconsequential. For instance, we used a null cue-target interval, whereas most other studies used a 100-ms interval, but our findings were replicated when we varied this interval between 0 and 200 ms (Experiment 3). Other differences, however, may be more critical. In particular, most studies used

50-ms cue presentation durations (e.g., Eimer et al., 2009; Folk & Remington, 2008; Schönhammer & Kerzel, 2013), and reported overall small and volatile effects, whereas we used 150-ms durations, and our effects were large and reliable. Notably, Becker et al. (2013) used 100-ms cues and found same-location costs of intermediate magnitude. We are currently investigating the role of cue duration. Specifically, relying on the informal observation that with 150-ms cues, participants typically report seeing the cues whereas with 50-ms cues, they most often fail to notice their presence, we explore the possibility that conscious perception of the cue may be necessary for retrieval of its features during object updating (and thus for same-location costs to be observed).

In addition, our design differed from that of studies in which the cue and target were defined on different dimensions (Lamy & Egeth, 2003), or in which nontarget color cues were associated with a no-go response (e.g., Belopolsky et al., 2010; Folk & Anderson, 2010; Folk & Remington, 2008). The same-location cost in these studies may thus reflect mechanisms other than object-file updating that remain to be elucidated in further research.

### Space-Based Versus Object-Based Attentional Capture

The results of Experiment 3 show that attentional capture in the same-color cue condition was of similar magnitude in the continuous- and discontinuous-objects conditions. In other words, attentional capture by an irrelevant cue possessing the target feature was unaffected by whether the attentional capturing event (the cue) and the target belonged to the same or to different perceptual objects. This finding may indicate that such capture is mediated by space-based, rather than by object-based, allocation of attention. Had selection been object based, one would have expected to observe larger capture in the continuous- than in the discontinuous-objects condition: In the continuous-objects condition, attention had to be disengaged both from the cued location and from the cued object in the different-location relative to the same-location condition; in the discontinuous-objects condition, both same-location and different-location trials involved a shift to a new object, and same-location trials therefore benefitted only from a space-based advantage.

Alternatively, however, attention may be directed to grouped arrays of locations (e.g., Lamy & Tsal, 2000, 2001; Vecera, 1994) and thus select the successive locations occupied by an object as this object moves. Accordingly, space and grouped arrays of locations are confounded when objects are static, as was the case in the present study. Further research using moving objects is needed to test these different accounts.

### An Object-Updating Account of the Same-Location Cost

Our findings show that the same-location cost is unrelated to attentional priority settings or attentional capture. The cost was unaffected by whether the irrelevant cue feature was known or unknown (Experiment 1), and by whether the target feature was known or unknown (Experiment 2). In the latter experiment, we showed that spatial effects reflected two independent mechanisms with additive effects on performance (Experiment 2): spatial capture effects and the same-location cost. Finally, in Experiment 3



we showed that the same-location cost was largely contingent on the cue and target belonging to the same perceptual object, whereas this did not affect spatial capture effects. In order to account for these findings, we suggest that the same-location cost reflects the cost of updating the information stored about an object when this object changes across time.

Is the object-updating account consistent with previous reports of the same-location cost? Many of the studies that demonstrated a same-location cost (e.g., Anderson & Folk, 2012; Belopolsky et al., 2010; Folk & Remington, 2008; Lamy et al., 2004; Schönhammer & Kerzel, 2013<sup>2</sup>) used stimuli similar to Folk et al.'s (1992). Our object-updating account can accommodate these findings to the extent that the target character and the four dots that surrounded the box enclosing it were perceived as belonging to the same object—which seems to be a reasonable conjecture. In one study in which different stimuli were used (Eimer et al., 2009), the cue and target clearly did not belong to the same perceptual object. However, the same-location cost in that study was very small (8 ms) and was observed only in one of two similar experiments.

Finally, it is important to note that our study is mute as to whether (a) the same-location cost reported when the irrelevant cue was associated with a no-go response (e.g., Anderson & Folk, 2012; Belopolsky et al., 2010; Folk & Remington, 2008) might reflect inhibitory processes at the motor-response level, and (b) the same-location cost reported when the cue is salient on a dimension other than the target-defining dimension (Lamy & Egeth, 2003) might reflect feature-based inhibition. In other words, it is possible that very different mechanisms give rise to a same-location cost. It will be useful to address this issue in further research.

Our investigation of the same-location cost in this study was initiated within the framework of attentional capture research and the paradigm we used to explore it was therefore borrowed from this literature. Other paradigms were more specifically designed to study the mechanisms by which information pertaining to an object is bound and stored in a temporary episodic representation—often referred to as an object file, (e.g., Kahneman et al., 1992) or an event file (e.g., Hommel, 1998). Of particular relevance are Kahneman et al.'s (1992) object previewing paradigm, Park and Kanwisher's (1994) negative priming paradigm, and Hommel's (1998) partial repetition paradigm. Yet, in the following section, we highlight the advantages of the spatial cueing task used in the present study to investigate the cost associated with *updating* the information pertaining to an object as this object changes.<sup>3</sup>

In Kahneman et al.'s (1992) study, a visual array of boxes, each enclosing a different letter (the preview or prime display), was first presented. Then all letters disappeared while the boxes remained visible. Finally, one letter (the probe or target) appeared in one of the boxes, and the observers' task was to name this letter. Performance was better when a probe letter identical to the target had appeared in the same box than in a different box in the prime display. The authors concluded that focusing attention on a target object selectively reactivates the recent history of that object, a process they called object-file reviewing. They further suggested that, during reviewing,

when a match is found within the same single object file, perception of the new stimulus will be faster than when a new object file must be created, or a radical and physically implausible change made to a previously existing file. (Kahneman et al., 1992, p. 184)

The spatial cueing paradigm used here bears many similarities with the object-previewing paradigm: In both paradigms, the pairing between the box and feature (a color or a letter shape, respectively) in the cue (or prime) display was arbitrary as well as task irrelevant, and attending to the box enclosing the target color (or letter shape) triggered retrieval of the color (or letter shape) previously associated with this box. There was a cost when the cue (or prime) and target features mismatched relative to when they matched.

An important difference, however, is that although the changing feature (letter shape) was also the response feature in the object previewing paradigm, the changing feature (color) in the spatial cueing paradigm used here was not. As a consequence, in the object-previewing paradigm, the mismatch found within the same object-file may hamper performance because of a conflict at the response selection level, rather than due to the presumably time-consuming process of object-file updating. In other words, the spatial cueing paradigm provides a purer measure of object-file updating than does the object-previewing paradigm. A similar observation applies to the negative priming (e.g., Park & Kanwisher, 1994) and partial repetition (e.g., Hommel, 1998; van Dam & Hommel, 2010) paradigms, in which the mismatch also pertained to the response-relevant feature.

One could argue that the response for which the conflict arose in our study is not the motor response but the attentional response associated with the critical object: Because observers were required to search for a red target and a different color had just appeared in the same object, a conflict might have arisen as to whether this object was indeed the target and attending to it may have been delayed. However, the finding that the same-location cost emerged even without an attentional set for a

<sup>2</sup> Schönhammer and Kerzel (2013) reported that same-location costs are strongly modulated by the specific cue-target color combination employed. In this study, there were very few trials per color combination in each experiment, yet because we used the same colors across experiments, we were able to examine this issue (and replicate the color-dependent modulation of the same-location cost) by combining the data from the continuous-objects feature-search conditions of Experiments 1, 2, and 3. We ran an ANOVA with cue color, target color, and cue location as within-subject factors. The three-way interaction was highly significant,  $F(4, 116) = 6.37, p < 0.001$ . Paired comparisons showed that the same-location cost was significant for red targets when the cue was green, yellow, or magenta, all  $ps < 0.02$ , but not when it was either blue or cyan, and for blue targets when the cue was red, green, or magenta, all  $ps < 0.001$ , but not when it was cyan.

<sup>3</sup> The notion that the representation of an object must be updated as the features making up this object undergo changes has also been used to account for many perceptual phenomena, such as object-substitution masking or the negative compatibility effect (see Enns, Lleras, & Moore, 2009, for a review). However, in these studies, object updating resulted in perception of the object's new state overriding perception of its initial state, which occurred within rather specific and limited temporal windows. In contrast, the same-location cost reported here as well as the object reviewing effects reported by Kahneman et al. (1992) persisted for relatively long time intervals between successive changes (e.g., for a 350-ms SOA here in Experiment 3) and actually appears to be contingent on conscious perception of the object's initial state (Lamy, Alon, Shalev, & Carmel, 2014). Further research is therefore needed to determine whether the findings emanating from the two lines of study can be accommodated with a general model of object updating.



given known color (Experiment 2) invalidates this alternative account.

Finally, our results show that although shared location may be necessary for different features to be integrated into the same object file, it is not sufficient. Synchronicity seems to be crucial: When the appearance of the two object parts in which changes occurred at the same location did not overlap in time, no cost was observed. A small effect was obtained when the target was onset at the time of cue offset but disappeared when the cue and target were separated by as little as 100 ms. However, previous research has shown that the temporal integration window is affected by a variety of factors, such as observers' expectations as to the time available for target processing (Akyürek, Toffanin, & Hommel, 2008), but our results only indicate that under some circumstances, the temporal integration window is shorter than 100 ms.

To the extent that our interpretation of the same-location cost as indexing object-file updating is further validated in future research, this cost may thus serve as a marker to elucidate the conditions under which parts of the visual field are integrated into the same object-file or event-file.

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