

## Attentional Capture by Irrelevant Color Singletons

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Four experiments investigated attentional capture by a color singleton in visual search for a nonsingleton target. B. S. Gibson and E. M. Kelsey (1998) found that a color singleton in a precuing array facilitated target discrimination at that location if the same color also signaled the target array onset. The authors found similar cuing effects regardless of whether the singleton color matched the target array and regardless of whether subjects could anticipate the singleton or target-array color. In Experiment 4, a color singleton captured attention when it appeared in the precuing array but not when it appeared in the target array. The results indicate that attentional control settings for displaywide attributes are imprecise: Although subjects may anticipate a specific color, they cannot avoid attentional capture by other irrelevant colors. In addition, the effect of irrelevant singletons depends on whether a target is simultaneously present in the array.

In visual search tasks, observers must search for a predefined target among multiple nontargets and respond according to some attribute, such as presence-absence or identity. It is well established that a target that is defined by a simple featural difference from the nontargets can be detected or identified rapidly, with relatively little effect of the number of nontargets (Neisser, 1963; Treisman & Gelade, 1980). For example, looking for an *O* among *Ks*, *Xs*, and *Ls* is faster than looking for an *O* among *Cs*, *Qs*, and *Gs*. Under some conditions, a nontarget that is made especially salient by a featural difference from other nontargets—an *irrelevant singleton*—may also affect visual search time. For example, Theeuwes (1992) found that search for a particular shape was slowed if one nontarget was colored differently from the rest of the array items. Such effects are often described as an *attentional capture* by singleton stimuli (for reviews, see Yantis, 1996, 1998).

According to some theories, attentional capture occurs automatically; that is, it is driven by stimulus properties irrespective of the observer's goals or intentions (e.g., Theeuwes, 1991, 1992, 1994). In the guided search model proposed by Wolfe (1994; Cave & Wolfe, 1990), the order in which display items are searched is determined by the sum of display-driven salience and target-driven salience. Display-driven salience of a display item increases with featural dissimilarity from other display items, whereas target-driven salience of a display item increases with similarity to the critical target features. Assuming that featural similarity to the target is otherwise held constant, the increased salience of a

singleton nontarget will increase the probability that it is evaluated before the target, thereby delaying response to the target. Conversely, if the target is itself a featural singleton, responding to it will be facilitated by the combined effects of display-driven and target-driven salience.

Some researchers have challenged the assertion that attentional capture is ever purely stimulus driven, because it can depend on the search strategy adopted by the observer. In many experiments that have demonstrated attentional capture, the target stimulus was a featural singleton (e.g., Theeuwes, 1991, 1992, 1994). Bacon and Egeth (1994) argued that attentional capture by an irrelevant singleton depends on whether the observer adopts a *singleton detection mode*—that is, if the observer knows that a target will be uniquely different from nontargets on some perceptual attribute, he or she may adopt a strategy of looking for a perceptually salient stimulus that “pops out” of the array. Under these conditions, an irrelevant singleton may capture attention. However, if the observer does not adopt such a strategy, an irrelevant singleton may have little effect. (In terms of Wolfe's [1994] guided search model, attention to display-driven salience may be optional.)

Folk, Remington, and Johnston (1992) suggested that effects of irrelevant singletons are contingent on “attentional control settings” that are adopted by the observer. The boundaries of these control settings are often based on one of two broad functional stimulus classes: (a) dynamic discontinuities, such as onset, offset, and motion, and (b) static discontinuities, such as color, shape, and orientation. The distracting effects of irrelevant singletons are normally shown only within a stimulus class. For example, if the target in a task is a shape singleton, then an attentional control setting is developed for static discontinuities, thereby leading to attentional capture by another singleton in this class (e.g., an odd color) but not by a singleton based on a dynamic discontinuity (e.g., motion). From this point of view, attentional capture is not automatic in the sense of being purely stimulus driven, because it depends on attentional control settings. However, given a particular control setting, attentional capture is arguably automatic in that processing of irrelevant attributes in the relevant class may be involuntary (Folk et al., 1992; Folk, Remington, & Wright, 1994).

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Recently, Gibson and Kelsey (1998) showed that color singletons can capture attention in the absence of a singleton-detection mode, if color is relevant to detecting the presence of the whole target array. Observers in their experiments viewed a sequence of displays similar to that shown in Figure 1. After viewing a fixation display, they saw one of two types of distractor display, randomly intermixed: In onset-singleton display, one of the four boxes surrounding fixation was increased in luminance (gray to white); in color-singleton displays, one of the boxes was changed in color (gray to red) while the other three were only increased in luminance. After another brief fixation array in which the boxes all returned to gray, a target array of four letters appeared. The observer's task was to decide whether the array contained an *H* or a *U*, ignoring the other three letters. The locations of the distractor-display singleton and the target-array target were both randomized, so that the singleton location was not at all predictive of the target location.

In the first experiment reported by Gibson and Kelsey (1998), all four target-array letters were the same color as the distractor-array color singleton, that is, red. Here, reaction time (RT) to identify the target was faster if it appeared in the same relative location as the distractor-array singleton, either color or onset, than if it appeared in one of the other three locations. Thus, the singletons appeared to have attracted attention to their location, favoring the processing of a target in the same location. A second experiment differed from the first only in that the target-array letters were white instead of red. In contrast to the first experiment, only onset singletons produced a cuing effect; RT to a target in a color-singleton location was no faster than to a target in an uncued location.

Because the target was not defined by a simple feature difference from the nontargets it is unlikely that observers had adopted a singleton-detection mode. Yet, a nominally irrelevant color singleton appeared to capture attention in their first experiment. (Alternatively, if observers were attempting to detect a unique target feature, they should have been equally likely to do so in both experiments.) On the other hand, because attentional capture presumably depended on observers' foreknowledge of the target-array color, it could not be strictly stimulus driven.

Gibson and Kelsey (1998) interpreted these results as indicating that observers can adopt an attentional control setting for display-wide visual features that signal the presence of the whole target array, not just features that define the target item. A distractor-array stimulus that also happens to include these displaywide

features will attract attention to that location in much the same fashion as occurs when observers adopt an attentional set for target-specific features. That onset singletons produced a cuing effect in both experiments presumably reflects the unchanged usefulness of onset information in detecting the target array.

The present experiments were designed to address some persisting ambiguities in the results reported by Gibson and Kelsey (1998). To begin, it may be noted that observers' foreknowledge of a red versus a white target array, between experiments, was confounded with the presence or absence of a physical color match between the color singleton and the target array. Thus, it is possible that the advantage to the color-singleton location in the first experiment was due not to attentional capture by the distractor-array singleton but to the detection of a color match between the distractor and target array at that location. In other words, attentional capture may have occurred during the target array rather than during the distractor array. To test whether a color singleton can attract attention to a location independently of a color match, we varied whether the singleton was in fact in the same color as the target array.

Second, Gibson and Kelsey's (1998) analysis suggested that subjects prepare for a specific color if the target-array color is known. If subjects can prepare for a specific color, then a different-color singleton should not capture attention (even though it might do so if the target-array color is not known). However, Folk et al. (1992, 1994) have suggested that attentional control settings may be imprecise; if the subject adopts a general attentional setting for color detection, then any color singleton might capture attention. To test whether subjects can prepare for a specific color to the exclusion of irrelevant colors, we varied across experiments whether the specific target-array color was known beforehand.

A third issue explored in these experiments was the role of foreknowledge of the singleton color. Theeuwes and Burger (1998) concluded that observers can avoid distraction by color singletons only if the distractor and target colors are both known in advance. In their experiments, observers had to decide whether an *E* or an *R* was present among an array of other letters. On singleton trials, a single letter in a different color (also *E* or *R*) appeared in the array; subjects were instructed to ignore the singleton. Across experiments, Theeuwes and Burger varied whether the target array and singleton colors were predictable. They found an effect of distractor compatibility (same or opposite letter as the target) if either the target array or singleton color was unpredictable, but not if both were known in advance. Theeuwes and Burger concluded

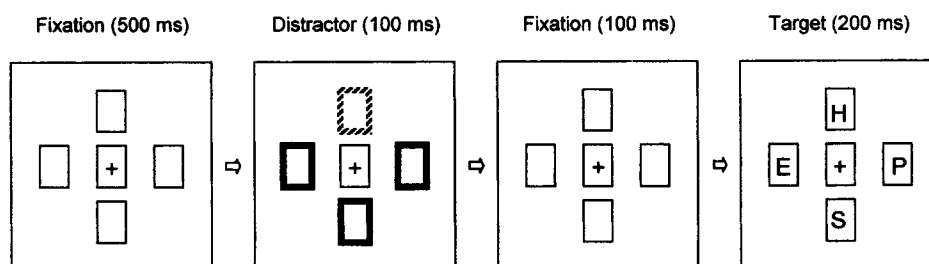


Figure 1. The display sequence for Experiments 1, 2, and 3. All stimuli appeared on a black background, and all items in the fixation display were dark gray. The thick black lines appeared as white in the distractor display; the partially shaded lines appeared as red or green. The letters in the target display were red or green.

that observers could avoid attentional capture only if they could both adopt an attentional set for a specific color and suppress processing of a specific distractor color.

In Gibson and Kelsey's (1998) experiments the target-array color was held constant and so was completely predictable. Color-singleton color was also held constant; however, because color-singleton trials were intermixed with trials with only onset singletons (i.e., no color singleton), it is unclear whether subjects could have anticipated the color-singleton color. Furthermore, although attentional capture might be avoidable in general if the distractor and target-array colors are both known in advance, this might not be possible if they are the same color; that is, it would be detrimental to performance to suppress responding to the distractor color if it is the same as the target-array color. To examine whether foreknowledge of distractor color provides any benefit to avoiding attentional capture, we also varied the predictability of that color across experiments.

The present experiments were closely modeled on those of Gibson and Kelsey (1998) but with distractor singletons and target arrays that varied in color, red or green. No onset-singleton distractor arrays were included. In Experiment 1, both singleton and target-array colors were randomized over trials. In Experiment 2, singleton color was randomized, but target-array color was blocked and therefore predictable. In Experiment 3, each possible singleton and target-array color combination was separately blocked, and so both singleton and target-array color were predictable. Finally, because the results of Experiment 3 appeared to contradict those of Theeuwes and Burger (1998), in Experiment 4 we compared the effect of predictable color singletons in an advance array with their effect when they were present in the target array.

### Experiments 1–3

#### Method

**Subjects.** University at Albany undergraduates participated for partial fulfillment of course requirements in introductory psychology courses. All reported normal or corrected-to-normal vision. In Experiments 1, 2, and 3 we tested 30, 40, and 28 naive subjects, respectively. Each subject was tested individually in a session lasting approximately 40 min.

**Apparatus.** We used PC-compatible microcomputers running Micro-Experimental Laboratory (MEL; Schneider, 1995) to present stimulus displays and collect performance data. Subjects used the "Z" and "/" keys on the computer keyboard to register their responses. Each subject was tested individually in a quiet, moderately lit room, seated approximately 50 cm from the computer monitor.

**Stimuli.** Three types of display were presented on each trial. A fixation display consisted of five light gray (MEL color 7), unfilled boxes, as shown in Figure 1. Each box was 12 pixels wide  $\times$  18 pixels tall and had a border 1 pixel thick. One box was positioned in the center of the display screen and contained a light gray plus (+) sign (standard MEL 12-point font). The remaining four boxes were positioned in a cross-type display, such that the distance from each edge of the center box to the nearest edge of each adjacent box was 20 pixels. The distractor display was similar, except that the edges of the four perimeter boxes were 2 pixels thick instead of 1 pixel thick. One of the boxes was either red (MEL color 12) or green (MEL color 10), whereas the remaining three boxes were white (MEL color 15). The target display was similar to the fixation display, except that capital letters (standard MEL 12-point font) occurred in each of the perimeter boxes. Three of the letters were always *E*, *P*, and *S*; the fourth was either *H* or *U*. Within a single target display the letters were either all red or all green.

**Procedure.** The sequence of displays on each trial is depicted in Figure 1. The fixation display was presented for 500 ms. Next, the distractor display was shown for 100 ms and then replaced by the fixation display for another 100 ms. The target display was next presented for 200 ms. Finally, a white asterisk (standard MEL 12-point font) appeared in the center of the screen until a response was made.

Locations of the distractor-array singleton and the four target-array letters were independently randomized on each trial, as was the target identity (*H* or *U*). As a result, the target appeared in the same location as the singleton (cued location) on 25% of trials and in a different location (uncued location) on 75% of trials.

Subjects were instructed to keep their eyes fixated on the plus sign in the center box throughout the sequence of displays. They were informed that the colored box in the distractor display was irrelevant to the task and was uninformative as to the location of the target letter. For the target display, participants were instructed to press one key on the keyboard if they saw an *H* and another key if they saw a *U*. The assignment of "Z" and "/" keys for these responses was counterbalanced over subjects. The instructions emphasized the importance of both speed and accuracy.

In Experiment 1, singleton color (red or green) and target-display color (red or green) were independently randomized on each trial. After a practice block of 15 trials, subjects received 768 experimental trials. They were given a self-timed break after every 48 trials.

In Experiment 2, target-display color was blocked by first half and second half rather than randomized. The order of target-array colors was counterbalanced over subjects. At the beginning of each half, subjects were informed of the target-array color. They then completed 15 practice trials and 384 experimental trials for that half. As in Experiment 1, a break was provided after every 48 trials.

In Experiment 3, the possible combinations of target-display color and singleton color were blocked by quarters: (a) red singleton and red target display, (b) red singleton and green target display, (c) green singleton and red target display, and (d) green singleton and green target display. A Latin square design controlling both position and transitions was used to counterbalance order over subjects. For each quarter, subjects were informed of both the singleton and target colors. They then completed 15 practice trials and 192 experimental trials for that quarter. Again, a break was provided after every 48 trials.

#### Results

In each experiment, the factorial combination of target location (cued or uncued) and singleton–target-display color match (congruent or incongruent) resulted in four experimental conditions: (a) incongruent color, uncued location; (b) incongruent color, cued location; (c) congruent color, uncued location; and (d) congruent color, cued location. Two subjects in Experiment 1, 5 in Experiment 2, and none in Experiment 3 were eliminated for exceeding a 25% error rate in one or more conditions. For each remaining subject, we calculated geometric means of correct RTs and arithmetic means of error proportions for each condition.<sup>1</sup> We submitted the resulting means to  $2 \times 2$  repeated measures analyses of variance (ANOVAs). In Table 1 are displayed the arithmetic means over subjects. Because error rates did not yield any signif-

<sup>1</sup> We used geometric means of RTs, rather than arithmetic means, because they are less sensitive to long-latency outliers. The geometric mean is the antilog of the arithmetic mean of  $\log(\text{RT})$ . Logarithmic transformation reduces the positive skew typically found in RT distributions (see, e.g., Winer, Brown, & Michels, 1991, pp. 357–358). See Ratcliff (1993) for an extended analysis of various methods for dealing with RT outliers.

Table 1  
Mean Reaction Times (RTs; in Milliseconds) and Error Rates  
(Proportions) as a Function of Color Congruency  
and Location Validity

Condition	Experiment 1		Experiment 2		Experiment 3	
	RT	Error	RT	Error	RT	Error
Congruent color, invalid location	550	.06	551	.07	587	.06
Congruent color, valid location	541	.06	542	.07	582	.06
Cuing effect	9 ms		9 ms		5 ms	
Incongruent color, invalid location	556	.06	553	.08	603	.06
Incongruent color, valid location	543	.06	534	.08	589	.05
Cuing effect	12 ms		19 ms		14 ms	

inant effects in the three experiments, only the RT analyses are discussed here.

The results of the three experiments are remarkably similar. Responses were faster to targets at cued locations than at uncued locations: In Experiment 1,  $F(1, 27) = 16.33$ ,  $MSE = 198.49$ ,  $p < .001$ ; in Experiment 2,  $F(1, 34) = 28.11$ ,  $MSE = 251.55$ ,  $p < .001$ ; and in Experiment 3,  $F(1, 27) = 4.09$ ,  $MSE = 598.10$ ,  $p = .053$ . As shown in Table 1, the magnitude of the location-cuing effect was consistently greater for the incongruent colors than for the congruent colors, although the Location  $\times$  Color interaction was statistically significant only in Experiment 2,  $F(1, 34) = 5.94$ ,  $MSE = 147.03$ ,  $p < .02$ , and approached significance in Experiment 3,  $F(1, 27) = 3.28$ ,  $MSE = 176.12$ ,  $p = .081$ . There were no significant main effects of color congruency.

To further assess whether foreknowledge of singleton or target-display color affected the pattern of results, we entered the data from all three experiments into a mixed-model ANOVA with experiment as a between-subjects variable. As in the individual analyses, the main effect of location was significant, reflecting an 11.4-ms advantage for cued locations,  $F(1, 88) = 34.49$ ,  $MSE = 341.60$ ,  $p < .001$ . The Location  $\times$  Color interaction also achieved significance,  $F(1, 88) = 8.82$ ,  $MSE = 143.04$ ,  $p < .01$ , reflecting a larger cuing effect for opposite-color displays (15 ms) than for same-color displays (8 ms). Both of these cuing effects, however, were significant:  $t(90) = 6.36$  and  $t(90) = 3.64$ , respectively, both  $ps < .001$ , two-tailed.

The only other effect to approach significance was a marginal Color  $\times$  Experiment interaction,  $F(2, 88) = 2.55$ ,  $MSE = 605.35$ ,  $p = .084$ , reflecting a negligible overall difference between congruent and incongruent color trials in Experiment 1 (546 ms vs. 549 ms) and Experiment 2 (546 ms vs. 543 ms) but a somewhat larger difference in Experiment 3 (584 ms vs. 596 ms).

## Discussion

These results replicate Gibson and Kelsey's (1998) main finding, that an irrelevant color singleton can capture attention even though subjects are not in a singleton-detection mode. However, the results also indicate that the effect does not depend on subjects' precise knowledge of the target-array color. In Experiment 1,

subjects did not know whether the target display would be red or green, yet a color singleton still attracted attention to that location. (Other research has indicated that subjects cannot simultaneously prepare for two different colors—see, e.g., Wolfe et al., 1990.) In Experiments 2 and 3, the target-display color was known in advance. If subjects were able to adopt an attentional set restricted to one color, one would expect that attentional capture would be more likely by a singleton in the anticipated color than in the alternative color. This did not happen; in fact, opposite-color singletons produced a larger cuing effect than same-color singletons did.

That opposite-color and same-color singletons both produced significant cuing effects also argues against the hypothesis that the cuing effects reported by Gibson and Kelsey (1998) were due to detection of a color match during processing of the target array. As such, these results support Gibson and Kelsey's assumptions that the singleton attracts attention to its location prior to the target array and that processing of a target at that location is facilitated by the prior positioning of attention there. On the other hand, the greater cuing effect by an opposite-color singleton seems to contradict recent findings by Folk and Remington (1998) of a greater cuing effect by same-color singletons in a somewhat similar procedure. This discrepancy is addressed in the General Discussion.

In Experiment 3, subjects could fully anticipate both the singleton and target-array colors. Still, a significant location cuing effect was found. As such, the results appear to contradict the results of Theeuwes and Burger (1998). As described in the beginning of this article, Theeuwes and Burger found cuing effects when either the singleton or target-array color was unpredictable, but not when both were known beforehand. However, a potentially important methodological difference exists between the two studies: In our experiments (and those of Gibson & Kelsey, 1998), the color singleton appeared in a distractor array presented before the target array (i.e., a stimulus onset asynchrony [SOA] of 200 ms). In contrast, in Theeuwes and Burger's experiments the singleton appeared in the target array itself (SOA = 0). In Experiment 4 we used a modified version of Experiments 1–3 to examine whether effects of the color singleton depend on when it is presented.

## Experiment 4

### Method

**Subjects.** Thirty-one University at Albany undergraduates participated for partial fulfillment of course credit. All had normal or corrected-to-normal vision. None had participated in any of the previous three experiments.

**Apparatus and stimuli.** The apparatus used in Experiment 4 was identical to that used in the previous experiments. The stimuli were identical to those used in the previous experiments, except for additional target arrays in which one of the perimeter boxes was red or green and the others were white.

**Procedure.** As in Experiment 3, each combination of singleton color and target-array color was blocked and thus completely predictable. All other aspects of the procedure were the same as in Experiment 3, except that on half of the trials in each block, randomly selected, the target array appeared immediately after the 500-ms fixation array. (In other words, there was no distractor array.) On such trials, one of the perimeter boxes was randomly green or red, duplicating the appearance of a distractor array except for the presence of the target and nontarget letters. The instructions to subjects were slightly modified to indicate that an irrelevant colored box could occur either prior to the target array or simultaneously.

## Results

Data from 6 subjects were removed because of excessive error rates. We submitted geometric means of correct response latencies and arithmetic means of error rates for the remaining 25 subjects separately to repeated measures ANOVAs with within-subject variables of color, location, and distractor–target SOA. The arithmetic means for conditions, over subjects are displayed in Table 2.

Both RT and error analyses yielded significant main effects of location,  $F(1, 24) = 22.27$ ,  $MSE = 564.61$ ,  $p < .001$ , and  $F(1, 24) = 14.34$ ,  $MSE = .0006$ ,  $p < .005$ , respectively. Both effects reflect an overall advantage for cued locations over uncued locations (582 ms vs. 598 ms, and error rates of .046 vs. .059).

In addition, RT yielded a significant interaction between location and SOA,  $F(1, 24) = 14.54$ ,  $MSE = 740.55$ ,  $p < .005$ , reflecting a larger cuing effect in the SOA = 200 condition (31 ms) than in the SOA = 0 condition (1 ms). In other words, a cuing effect on RT occurred when the color singleton preceded the target array, but not when it was simultaneous with it.

## Discussion

As in Experiment 3, color singletons preceding the target array captured attention even when they differed in color from the target array. One may note that the magnitude of the cuing effect is much larger than in the previous experiments. This is not surprising, given the change here in procedure. In the previous experiments, the onset of the target array was temporally predictable from the display sequence. As a result, use of an attentional set for display color may have been attenuated. In contrast, in the present experiment, the onset of the target array was relatively unpredictable and therefore may have encouraged the use of display color as a cue to whether the target array was present. The enhanced cuing effect here further supports the assumption that the effect depends on an attentional set rather than stimulus-driven attentional capture.

Despite the enhanced attentional capture by singletons preceding the target array, the same singletons present in the target array had no effect on RT (although they had a small effect on error rates). It is perhaps not surprising that a congruent-color singleton present in the target array would have little effect. A red square, for example, would not be exceptionally salient in an array of red letters. Indeed, although such a stimulus is a “singleton” relative to the other squares, it is not a singleton relative to the whole array.

On the other hand, it is rather more surprising that an incongruent-color singleton also did not capture attention when present in the target array. One might expect that a red square, for example, would be quite salient among an array of green letters.

An incongruent-color singleton present in the target array is most similar to the conditions tested by Theeuwes and Burger (1998). The lack of attentional capture here thus replicates the null effect found by Theeuwes and Burger when target-array and singleton colors are completely predictable. Yet it must be an oversimplification to conclude that subjects can suppress attentional capture under these conditions, because the same singleton did capture attention when presented 200 ms ahead of the target array. Possible explanations for the dependency of attentional capture on precuing versus simultaneous presentation are addressed in the General Discussion.

## General Discussion

The major result of these four experiments taken together is that attentional capture by a color singleton did occur, (a) regardless of whether subjects could anticipate its color and the color of the target array and (b) despite the fact that the target stimulus was not itself a featural singleton, and so subjects should not have been in a singleton-detection mode. The simplest interpretation of these results would be that purely stimulus-driven (or, more appropriately, display-driven) attentional capture does occur, independent of subjects’ strategies. However, this interpretation falls short in view of Gibson and Kelsey’s (1998) Experiment 2: Attentional capture by a color singleton did not occur even though the distractor displays were identical to their Experiment 1 and similar to our experiments. The critical difference appears to be that the target display in their Experiment 2 did not differ in color from either the fixation array or most of the distractor array. If attentional capture were truly stimulus driven, we would expect it to occur regardless of the nature of the target array. Stimulus-driven attentional capture would also not account for the enhanced cuing effect resulting from temporal uncertainty in Experiment 4.

We interpret these results instead as broadly consistent with the arguments made by both Folk et al. (1992, 1994) and Gibson and Kelsey (1998). Folk et al. (1992, 1994) argued that when subjects are engaged in a singleton-detection mode, attentional control settings are broadly tuned, that is, attentional capture may occur from singletons among a general class of dimensions, either static or nonstatic, depending on what attribute defines a target stimulus. Gibson and Kelsey argued that attentional control settings can also be determined by expectations regarding the whole target array, not just the target stimulus itself. Given both arguments, it is a simple inference that attentional control settings based on display-wide expectations must also be imprecise. In all of our experiments, the target array was distinguished from the preceding arrays by a gross color change. Subjects may adopt an attentional set for a color change but do not adopt more restrictive control settings that would exclude colors known to be irrelevant to the task.

Folk and Remington (1998), however, reversed their previous stance on the specificity of attentional control settings (Folk et al., 1992, 1994). Many previous experiments have measured attentional capture by a singleton distractor relative to a no-singleton baseline. Folk and Remington argued that the mere presence of a singleton distractor induces a general “filtering cost” that is inde-

Table 2  
*Mean Reaction Times (RTs; in Milliseconds) and Error Rates (Proportions) as a Function of Color Congruency, Location Validity, and Distractor–Target Stimulus Onset Asynchrony (SOA) in Experiment 4*

Condition	200-ms SOA		0-ms SOA	
	RT	Error	RT	Error
Congruent color, invalid location	606	.05	588	.06
Congruent color, valid location	579	.04	584	.05
Cuing effect	27 ms		4 ms	
Incongruent color, invalid location	609	.06	591	.07
Incongruent color, valid location	575	.04	592	.05
Cuing effect	34 ms		-1 ms	

pendent of the time to switch attention from a cued location to the target. Thus, the disruptive effect of a color-singleton distractor when searching for a square, for example, may be due to such a filtering cost rather than attentional orienting to the color singleton's location. Orienting effects per se must be inferred from the difference between validly and invalidly cued locations.

In their experiments, Folk and Remington (1998) required subjects to decide whether a target in a specified color (red or green) was "X" or "=". Because nontargets in the array were also "X" or "=", subjects were presumably forced to adopt an attentional set for the specified color. A distractor array was presented prior to the target array, similar to the procedures here and those used by Gibson and Kelsey (1998). In singleton-distractor arrays, dots flanking one of the possible target locations were either the same or opposite color to the specified target color. In the first two experiments, distractor color was blocked, analogous to our Experiment 3; in two subsequent experiments, distractor color was randomized, analogous to our Experiment 2. In Folk and Remington's Experiments 2–4, distractor arrays lacking a singleton distractor were also included. Relative to the no-singleton baseline, opposite-color distractors invariably slowed RT to the target. However, only same-color distractors produced a cuing effect, that is, faster RTs to targets appearing in the singleton distractor location than to targets appearing in another location.

Folk and Remington (1998) concluded that subjects can in fact adopt an attentional control setting for a specific target color, precluding an attentional orienting effect of a different color. This conclusion appears to conflict with our finding of an actually greater cuing effect of an opposite-color singleton. At the very least, our results suggest that attentional control settings for displaywide features are less precise than for specific target features. This gains some plausibility when one considers the different task demands: In Folk and Remington's experiments an attentional set for a specific attribute was necessary to distinguish the target from the nontargets; in contrast, an attribute-specific set could not distinguish between targets and nontargets in our experiments. On the other hand, a set for an overall color change would be sufficient to distinguish the target array from the fixation and distractor arrays in our experiments. In principle, it would have been to subjects' benefit to adopt a more specific set (when target-array color was known) that would exclude attentional capture by opposite-color singletons—particularly because singletons appeared in nontarget locations on 75% of trials. However, a more specific attentional set might be more effortful or perhaps would entail a "filtering cost" that would outweigh any benefits of a more restrictive set.

Theeuwes and Burger (1998) concluded that foreknowledge of both target-array and singleton color allowed subjects to circumvent attentional capture by the singleton. This conclusion conflicts with our finding of a cuing effect in Experiment 3 despite full foreknowledge of the singleton and target-array colors. However, our singletons were presented in a distractor array that preceded the target array by 200 ms, whereas singletons in the experiments by Theeuwes and Burger appeared in the target array. In our Experiment 4 we directly compared the two types of singleton display. The results replicated both those of our Experiment 3 and those of Theeuwes and Burger's Experiment 2 in the corresponding display types: A singleton in a preceding distractor array

yielded a cuing effect, whereas a singleton in the target array did not.

The dependency of attentional capture on the singleton-to-target SOA immediately suggests two possibilities: First, attentional capture under these conditions may be relatively slow. When the singleton precedes the target array by 200 ms, there may have been sufficient time for attentional orienting to the singleton location prior to target processing. However, the same singleton present in the target array might capture attention too slowly to affect localization of the target, identification of the target, or both. Under this interpretation the singleton may actually capture attention, but too late to yield an overt cuing effect. Alternatively, the presence of the target might affect the ability of the singleton to capture attention. An early detection of the target (or even the target array) might cause a more restricted focus of attention, more effectively excluding the color singleton.

The major conclusions from this study can be summarized as follows: First, attentional capture by a color singleton can occur in the absence of a singleton-detection mode. Although our results could be explained by stimulus-driven attentional capture, Gibson and Kelsey's (1998) results are persuasive that the present cuing effects are due to attentional settings for attributes of the whole target display. Second, given that the present cuing effects reflect attentional settings, such settings must here be imprecise, admitting influences by singleton attributes that differ from known target attributes. Therefore, it is premature to conclude that all previously reported effects of such singletons are simply due to "filtering costs" (Folk & Remington, 1998). Third, the effects of an irrelevant singleton can depend on whether it appears in an array preceding the target array or is simultaneous with it. Researchers must therefore exercise caution in generalizing results from one procedure to the other.

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