

Effects of Task Relevance and Stimulus-Driven Saliency in Feature-Search Mode

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Attentional allocation in feature-search mode (W. F. Bacon & H. E. Egeth, 1994) is thought to be solely determined by top-down factors, with no role for stimulus-driven saliency. The authors reassessed this conclusion using variants of the spatial cuing and rapid serial visual presentation paradigms developed by C. L. Folk and colleagues (C. L. Folk, R. W. Remington, & J. C. Johnston, 1992; C. L. Folk, A. B. Leber, & H. E. Egeth, 2002). They found that (a) a nonsingleton distractor that possesses the target feature produces attentional capture, (b) such capture is modulated by bottom-up saliency, and (c) resistance to capture by irrelevant singletons is mediated by inhibitory processes. These results extend the role of top-down factors in search for a nonsingleton target while arguing against the notion that effects of bottom-up saliency and top-down factors on attentional priority are strictly encapsulated within distinct search modes.

Visual selective attention can be allocated to objects in the visual field in either a goal-directed or a stimulus-driven manner. Attention is said to be goal directed, or controlled by top-down factors, when observers are able to direct their attention according to their goals and intentions. Attention is said to be stimulus driven, or controlled by bottom-up factors, when it is summoned by display attributes independently of the observers' goals and intentions.

Most current models of attention assume that selection is the result of the joint influence of goal-directed and stimulus-driven factors. For instance, the guided search model (Cave & Wolfe, 1990) and Treisman and Sato's (1990) revised feature integration theory posit that an item's overall level of attentional priority is the sum of its bottom-up activation level and its top-down activation level. Bottom-up activation is a measure of how different an item is from its neighbors. Top-down activation (Cave & Wolfe, 1990), or inhibition (Treisman & Sato, 1990), depends on the degree of match between an item and the set of target properties specified by task demands.

However, recent research on the role of saliency and task relevance in search performance has yielded findings that are inconsistent with the view that bottom-up and top-down factors combine additively to determine attentional priority. Specifically, this research suggests that depending on the attentional set adopted by the observer, only bottom-up factors or only top-down factors determine which items in the visual field receive attention.

Early studies by Theeuwes (e.g., Theeuwes, 1991, 1992, 1994) showed that when observers are engaged in parallel search for a particular singleton (e.g., a unique diamond among circles), an irrelevant singleton that is more salient than the target singleton (e.g., a red element among green ones) interferes with search, even though observers know they have to ignore the irrelevant singleton. On the basis of such findings, Theeuwes initially concluded that no top-down guidance is possible at the preattentive stage, because the most salient item in the display captures attention independently of the observers' goals.

Bacon and Egeth (1994) provided a major qualification to this position. They showed that capture by irrelevant singletons occurs only when the task can be performed using *singleton-detection mode*, in which observers search for a discontinuity. In contrast, when singleton-detection mode is inappropriate to carry out the task and subjects have to use *feature-search mode*,¹ that is, search for a known-to-be-relevant feature, attentional capture by a salient distractor does not occur (see Pashler, 1988, for the original version of this distinction).

Consistent with this proposal, other studies showed that featural singletons do not capture attention when subjects search for a nonsingleton target possessing known features (e.g., Folk & Remington, 1998; Jonides & Yantis, 1988; Lamy & Tsal, 1999; Lamy, Tsal, & Egeth, 2003; Yantis & Egeth, 1999). Recent findings from our laboratory (Lamy & Egeth, 2003) suggested that such resistance to capture may be mediated by inhibitory processes. When a subject searched for a target shape among heterogeneously shaped distractors (feature-search mode), a color singleton presented at a 50-ms to 300-ms stimulus onset asynchrony (SOA) before the target display not only failed to capture attention but in fact elicited

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¹ In this article the phrase *feature-search mode* is used in an atheoretical descriptive sense, to refer to only searches in which the target is not defined as being a singleton: that is, in which looking for the most salient object in the display cannot lead the observer to the target.

slower reaction times (RTs) at its location (Experiments 5 and 6), suggesting that its location may have been inhibited.

A common aspect of the experiments in which irrelevant singletons did not capture attention is that the to-be-ignored singleton did not share the target-defining feature. For instance, if subjects searched for a specific shape, the irrelevant singleton might have a unique color. Or, if subjects looked for a red item, the irrelevant singleton might be a unique green item. Folk and colleagues (e.g., Folk, Leber, & Egeth, 2002; Folk & Remington, 1998) showed that if, in contrast, the irrelevant singleton distractor did share the target-defining feature it elicited a shift of attention to its location. To illustrate, in Experiment 1 of Folk and Remington's (1998) spatial cuing study, subjects searched for a red target in a display that also contained one green item and two gray items. Because the target was not the only uniquely colored element, subjects could not find the target simply by searching for a discrepancy. The task thus promoted the use of feature-search mode. A red singleton in the distractor display immediately preceding the target display produced spatial capture, whereas a green singleton did not. That is, a singleton distractor having the target feature summoned attention to its location, whereas an equally salient singleton distractor without the target feature did not. The foregoing overview suggests that in a search for a nonsingleton target (i.e., when subjects use feature-search mode), an irrelevant singleton does not capture attention unless it shares the target feature. In other words, whether an irrelevant singleton captures attention seems to depend on how closely it matches the target feature and not on how salient it is. Accordingly, it appears that the allocation of attentional priority in feature-search mode is solely determined by top-down factors, with no role for bottom-up factors.

However, reaching such a conclusion on the basis of the current state of the literature may be premature. Indeed, it is important to realize that in studies in which a distractor matching the attentional set was found to capture attention, the degree of match between the distractor and target features was manipulated but the level of bottom-up salience² of the distractor was not. Namely, the distractor was always a singleton (e.g., Folk et al., 2002; Folk & Remington, 1998; Remington, Folk, & McLean, 2001). Thus, it remains possible that bottom-up salience is a necessary condition for top-down effects to be observed in feature search mode. Indeed, no study to date has investigated whether a distractor that is not a singleton but possesses the target feature captures attention. If we were to find that an irrelevant object possessing the target-defining feature captures attention only when it is perceptually salient, this finding would reveal a much more central role for bottom-up factors in feature-search mode than had previously been envisaged.

Moreover, even if bottom-up salience is not a necessary condition for observing top-down effects, it may nonetheless modulate these effects. That is, salience may enhance capture by a distractor that possesses the target feature. Again, because the level of bottom-up salience of a distractor possessing the target feature has not been manipulated so far, the literature in its present state does not address this point.

Our purpose in the present study was to reevaluate the relative roles of goal-directed factors and stimulus-driven salience in feature-search mode. We investigated whether a distractor that possesses a defining feature of the target but is not a singleton captures attention, and we found that it did. Further, we found that

such capture is somewhat weaker than when the distractor is a singleton.

Experiment 1

The paradigm we used in this experiment was a variant of Folk, Remington, and Johnston's (1992) spatial cuing paradigm, which we described earlier. Subjects had to make a forced-choice response on the basis of shape with respect to a target possessing a known color (red for one group of subjects and green for another group). For illustrative purposes, consider the case in which the target was red. It always appeared among five distractors of various colors. Thus, the target was never a unique singleton, and subjects had to use their knowledge of the task-relevant color to find the target. That is, they had to use feature-search mode. The critical manipulation concerned the distractor display³ that preceded the target display by a variable SOA. There were three conditions of distractor display. In the target-color singleton condition, the distractor display contained a color singleton of the same color as the target (e.g., a red item among gray items). In the nontarget-color singleton condition, the distractor display contained a color singleton, the color of which was different from the target color (e.g., if the target was red, the nontarget-color singleton was a green item among gray items) and also different from the colors of the distractors that appeared in the target display. Finally, in the target-color heterogeneous condition, the distractor display contained an element that possessed the target color and appeared among items of various colors. The critical distractor (i.e., the red element in the target-color singleton and heterogeneous conditions, and the green singleton in the nontarget-color singleton condition) was as likely to appear at the location that would later be occupied by the target as it was to appear at any other location. Thus, the location of the critical distractor did not predict the target location. We measured spatial capture of attention as the difference in performance between trials in which the critical distractor appeared at the same location as the target (same-location trials) and trials in which it appeared at a different location (different-location trials).⁴

On the basis of the literature cited earlier, we expected spatial capture by the target-color singleton (e.g., Folk & Remington, 1998; Folk et al., 1992; Remington et al., 2001) and no spatial capture by the nontarget-color singleton (e.g., Folk & Remington, 1998; Jonides & Yantis, 1988; Lamy & Egeth, 2003; Lamy & Tsai, 1999; Lamy et al., 2003; Yantis & Egeth, 1999). Although this was

² In the present article, an object's *bottom-up salience* refers to the amount of bottom-up activation that accrues to this object; that is, the level of local contrast at its location. Accordingly, a red object in an array of gray objects (color singleton) has higher bottom-up salience relative to the same red object among heterogeneously colored objects.

³ We prefer to use the term *distractor display* to designate the display containing the critical distractor rather than the term *cuing display* used by Folk et al. (1992), because the latter may convey the erroneous idea that the so-called cuing display is informative.

⁴ Remington, Folk, and McLean (2001) suggested an alternative account for the difference between same- and different-location trials in Folk et al.'s (1992) spatial cuing procedure. However, they provided evidence in support of the claim that these effects indeed reflect shifts of attention to the distractor's location.

not the focus of the present study, we also sought to determine whether we could replicate the finding of slower RTs at the location of the irrelevant color singleton. This is of interest because, in the present experiment, the distractor was defined in the same dimension as the target (color), whereas previously we found this when the distractor was defined in a different dimension (color singleton and target defined by its shape; Lamy & Egeth, 2003).

Of main interest, however, was subjects' performance in the target-color heterogeneous condition. We hypothesized the following: If stimulus-driven salience plays no role in feature-search mode then one should expect the distractor in the target-color heterogeneous condition to capture attention to its location to the same extent as in the target-color singleton condition. Significant but weaker capture effects in the target-color heterogeneous condition than in the target-color singleton condition would indicate some role for bottom-up factors in feature-search mode. Note that such a role for bottom-up salience would be contingent on top-down factors, however, because a singleton that does not possess the target feature has been shown repeatedly (e.g., Bacon & Egeth, 1994; Lamy & Tsal, 1999; Lamy et al., 2003; Yantis & Egeth, 1999) to be successfully ignored in feature-search mode. Thus, one would still conclude that, in line with the current consensus, top-down factors contribute the dominant share in the allocation of attentional priority in feature-search mode. In contrast, finding no capture by the target-color distractor when it is not a singleton (heterogeneous condition) would overturn the current view on the status of top-down factors in feature-search mode, because it would indicate that top-down effects are contingent on stimulus-driven salience.

Method

Subjects. Subjects were 31⁵ Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus. Displays were generated by an IBM PC-compatible computer attached to a VGA color monitor, using 640 × 480 graphics mode. Responses were collected via the computer keyboard.

Stimuli. Figure 1 illustrates the sequence of displays. The fixation display was a white 0.8° × 0.8° plus sign, in the center of a black background. The *ready* display consisted of the fixation display with the addition of six gray peripheral boxes, each of which was surrounded by a set of four small, gray-filled dots. The boxes were equally spaced around the circumference of an imaginary circle centered at fixation, with two boxes positioned along the vertical midline, two boxes equally distant from the horizontal midline on the left, and the remaining two boxes equally distant from the horizontal midline on the right. Each box was a gray 1.53°-sided outline square, drawn with a 1-pixel stroke, and its center was distant from fixation by 4.7°. Each set of dots subtended 0.3° in diameter and was arranged in a diamond configuration around a box. The dots were placed such that each was centered approximately 0.3° from its respective side of the box. The distractor display was identical to the ready display except that all six sets of dots changed colors, as described below. The interstimulus display was identical to the ready display. In the *target* display, all six squares changed colors whereas the sets of dots remained gray, and a white sign, either a multiplication sign (0.8° × 0.8° of visual angle) or an equals sign (0.57° × 0.8° of visual angle), appeared in each box. The sign centers and the box centers overlapped. Each target display contained three signs of each type, the locations of which were randomly assigned.

There were two target-color conditions (red and green) and three distractor conditions (target-color singleton, nontarget-color singleton, and

target-color heterogeneous). In the distractor display corresponding to the target-color singleton condition, all sets of dots turned to light gray⁶ except for one set that turned to red in the red-target condition and to green in the green-target condition. In the nontarget-color singleton distractor condition, all sets of dots turned to light gray except for one set that turned to green in the red-target condition and to red in the green-target condition. In the target-color heterogeneous condition, each set of dots turned into a different color: blue, purple, yellow, brown, turquoise, and red in the red-target condition or blue, purple, yellow, brown, pink, and green in the green-target condition. In the target display, each box turned into a different color (we used the same colors as those in the target-color heterogeneous distractor condition). We matched all colors in the distractor and target displays for luminance using a light meter (Photo Research Inc. Lite Mate/Spot Mate System 500 [Chatsworth, CA]).

Procedure. Each trial began with the presentation of the fixation display. After 500 ms, it was replaced by the ready display, which remained on the screen for 1,000 ms. The distractor display then appeared for 50 ms and was replaced by the interstimulus display for a variable duration, which was randomly selected for each trial to be one of four possible values: 10 ms, 50 ms, 100 ms, or 200 ms. Thus, the SOA between the distractor stimulus onset and the target onset was 60 ms, 100 ms, 150 ms, or 250 ms. The target display remained visible for 50 ms and was replaced by a blank screen until the subject responded. A 500-ms intertrial interval elapsed before the next trial began.

Subjects were randomly assigned to the red-target or to the green-target group. They were instructed to indicate which sign had appeared within the target-colored box in the target display while they attempted to ignore the distractor display. They were required to press 1 on the numerical keypad with their right index finger if it had been a multiplication sign and press 2 on the numerical keypad with their right middle finger if it had been an equals sign. They were asked to respond as fast as possible but to keep the number of errors at a minimal level. Error trials were followed by a 500-ms feedback beep. Eye movements were not monitored, but subjects were explicitly requested to maintain fixation throughout each trial.

Design. Target color was the only between-subjects variable. There were three within-subject variables: distractor display (target-color singleton, nontarget-color singleton, and target-color heterogeneous), distractor-target location (same vs. different), and SOA (60 ms, 100 ms, 150 ms, and 250 ms). The target-colored box was equally likely to appear in any of the six possible locations, as was the critical distractor in the distractor display. Thus, the critical distractor was no more likely to appear in the same location as the target-color square than in any other location (one sixth of all trials). The target sign was equally likely to be a multiplication sign or an equals sign. Distractor display conditions were run in separate blocks, and block order was counterbalanced between subjects. SOA conditions were randomly mixed within blocks. Each of the three experimental blocks included 240 trials and was preceded by a short practice block of 20 trials. Subjects were allowed a rest period after each block.

Results

We observed attentional capture of similar magnitude in the target-color singleton and in the heterogeneous target-color distractor conditions. In contrast, the nontarget-color singleton produced inhibition.

⁵ We present combined data from one experiment (17 subjects) and its exact replication (14 subjects).

⁶ We had the color of these sets of dots turn from gray to light gray so that the location of the critical distractor would not be the only location at which a color change occurred. Otherwise, one could claim that the color change, rather than the static color discontinuity, produced capture in the singleton distractor conditions.

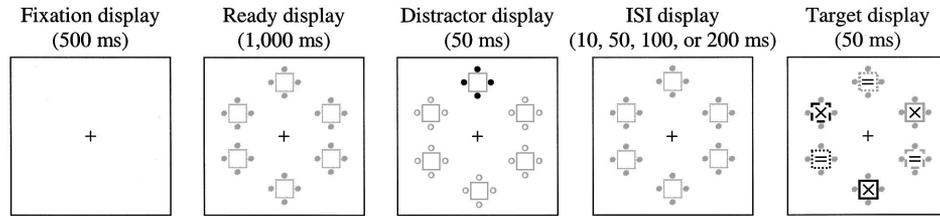


Figure 1. Sequence of events in Experiment 1. The example corresponds to the different-location target-color singleton condition. Black solid dots and black open squares were red or green (in the red- and green-target conditions, respectively). Each of the squares in the target display had a different color, depicted here by various line types (dotted, dashed, etc.). Gray solid dots were gray and gray open dots were white. All stimuli were presented against a black background. The fixation display (+) was white. ISI = interstimulus interval.

In all RT analyses, error trials (5.4% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of distractor display, SOA, and distractor-target location. An RT that exceeded the mean of its cell by more than 3.5 standard deviations was trimmed. This removed fewer than 0.5% of all observations. Preliminary analyses revealed no main effect of the order of distractor-display conditions and no interaction involving this factor. Therefore, the data were collapsed across orders of distractor display. Preliminary analyses also revealed no effect involving target color except for a significant interaction in the separate analysis conducted on the nontarget-color singleton condition. Thus, we examine color effects for the latter analysis only, and data are collapsed across target colors in the other analyses.

We conducted an analysis of variance (ANOVA) with distractor-target location (same vs. different), distractor-to-target SOA (60 ms, 100 ms, 150 ms, and 250 ms), and distractor display (target-color singleton, nontarget-color singleton, and target-color heterogeneous) as within-subject factors. Mean RTs and accuracy data are presented in Table 1.

Reaction times. Same-location trials were faster than different-location trials, $F(1, 30) = 44.59, p < .0001$. The main effect of SOA was also significant, $F(3, 90) = 18.62, p < .0001$. The interaction between same versus different location and distractor display was significant, $F(2, 60) = 59.31, p < .0001$. The location effect (different-location RT minus same-location RT) for each distractor-display condition is presented as a function of distractor-to-target SOA in Figure 2. Planned comparisons revealed that

same-location trials were faster than different-location trials in the target-color singleton and heterogeneous conditions by 55 ms, $F(1, 30) = 65.66, p < .0001$, and by 52 ms, $F(1, 30) = 72.03, p < .0001$, respectively, with no significant difference between the two effects ($F < 1$). In contrast, same-location trials were slower than different-location trials in the nontarget-singleton condition, $F(1, 30) = 10.15, p < .004$. This effect interacted with target color, $F(1, 29) = 5.22, p < .03$. Paired comparisons showed that same-location trials were significantly slower than different-location trials by 27 ms when the target was red and the salient distractor was green, $F(1, 15) = 11.83, p < .004$, and by only 7 ms when the target was green and the distractor red ($F < 1$). Neither attentional capture in the target-color conditions nor inhibition in the nontarget-color condition was modulated by SOA.

Accuracy. Performance was more accurate on same-location trials than on different-location trials, $F(1, 30) = 10.17, p < .004$. The interaction between distractor display and same location versus different location was significant, $F(2, 60) = 4.47, p < .02$. Planned comparisons revealed a significant location effect, that is, more accurate responses on same- than on different-location trials, in the target-color singleton condition, $F(1, 30) = 9.92, p < .004$, and in the heterogeneous condition, $F(1, 30) = 6.62, p < .02$, with no difference between the two effects, $F(1, 30) = 1.51, p > .20$. There was no location effect in the nontarget-color singleton condition ($F < 1$), although accuracy scores in this condition indicate that to the extent that there was such an effect, it was the reverse of the effect found in the other two conditions (see Table 1).

Table 1
Mean Reaction Times (RTs) in Milliseconds and Mean Percentage of Correct Responses (%) as a Function of Condition and SOA in Experiment 1

| SOA | Target-color singleton | | | | Target-color heterogeneous | | | | Nontarget-color singleton | | | |
|--------|------------------------|----|------------|----|----------------------------|----|------------|----|---------------------------|----|------------|----|
| | Same loc. | | Diff. loc. | | Same loc. | | Diff. loc. | | Same loc. | | Diff. loc. | |
| | RTs | % | RTs | % | RTs | % | RTs | % | RTs | % | RTs | % |
| 60 ms | 567 | 98 | 631 | 95 | 586 | 97 | 629 | 95 | 622 | 94 | 613 | 96 |
| 100 ms | 556 | 97 | 599 | 94 | 562 | 95 | 607 | 95 | 610 | 94 | 593 | 95 |
| 150 ms | 542 | 97 | 600 | 94 | 547 | 96 | 603 | 95 | 624 | 96 | 591 | 96 |
| 250 ms | 563 | 97 | 618 | 93 | 559 | 99 | 621 | 95 | 598 | 95 | 587 | 95 |

Note. SOA = distractor-to-target stimulus onset asynchrony; loc. = location; Diff. = Different.

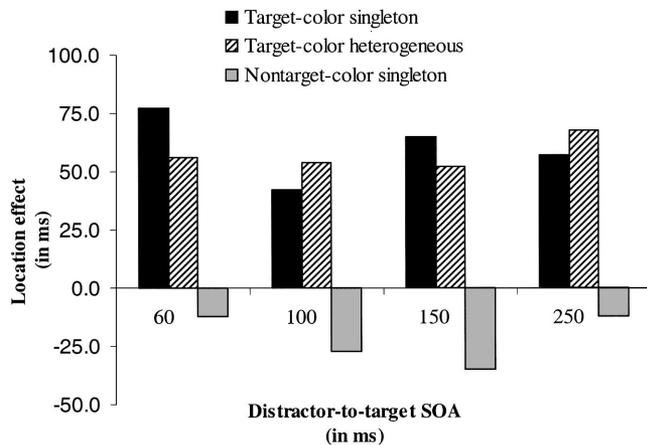


Figure 2. Mean location effect (mean reaction times in the different-location condition minus mean reaction times in the same-location condition) in the target-color singleton, target-color heterogeneous, and nontarget-color singleton conditions, as a function of distractor-to-target stimulus onset asynchrony (SOA) in Experiment 1.

Discussion

The data show that a target-color distractor that is not a singleton (heterogeneous condition) produces strong attentional capture at all SOAs. This finding suggests that stimulus-driven salience is not a necessary condition for top-down effects in feature-search mode to be observed. The role of top-down factors in feature-search mode was also apparent in the pattern of results observed in the nontarget-color singleton condition. In line with Lamy and Egeth's (2003, Experiments 5 and 6) findings, subjects were found to be slower when the target appeared at the location of that singleton as opposed to other locations, which suggests that subjects' ability to ignore an irrelevant singleton in feature-search mode may be mediated by inhibitory processes. There was no evidence for a role of bottom-up factors in the present experiment, because capture was equally strong whether or not the target-color distractor was a singleton.

However, the fact that the different distractor-display conditions were presented in separate blocks may limit the generalizability of the present findings. Specifically, the use of a blocked design may have allowed subjects to use a different strategy in each block. The objective of Experiment 2 was to test this possibility. Experiment 2 was identical to Experiment 1 except that the distractor-display conditions were randomly mixed across trials rather than blocked. We made the following hypotheses: If strategic factors indeed played a significant role in Experiment 1, more attentional capture should be seen in the target-color singleton condition relative to the heterogeneous condition than was observed in Experiment 1. Indeed, subjects may be more prone to adopt a set for ignoring singletons when the same singleton distractor is present on each trial within a block than when different singletons appear unpredictably. As a consequence, the present results may overestimate the weight of top-down factors relative to bottom-up factors in the target- and nontarget-color singleton conditions. Moreover, we hypothesized that the spatial inhibition effect we obtained in the nontarget-color singleton condition might diminish or even disappear⁷ if, for instance, inhibitory processes are triggered only when

the probability of a known salient distracting feature is high. Such a possibility cannot be ruled out on the basis of Lamy and Egeth's (2003) findings because in that study the distractor, when it was present (on 50% of the trials), was always the same singleton. To delineate the boundary conditions of resistance to attentional capture mediated by inhibition, it would be useful to determine whether it occurs also when subjects cannot prepare to ignore a known singleton across a whole block of trials.

Experiment 2

Method

Subjects. Subjects were 14 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design. The apparatus, stimuli, and procedure were identical to those in Experiment 1 except that distractor-display conditions (target-color singleton, nontarget-color singleton, and target-color heterogeneous) were mixed instead of blocked. Thus, there were three randomly mixed within-subject variables (distractor display, distractor-target location, and SOA) and one between-subject variable (target color). Each subject completed 20 practice trials followed by 720 experimental trials divided into three blocks of 240 trials each.

Results

Reaction times. The pattern of results was essentially identical to that of Experiment 1. In all RT analyses, error trials (4.3% of all trials) were removed from analysis. The same cutoff procedure used in Experiment 1 was used here and resulted in the removal of fewer than 0.5% of all observations. We conducted the same analyses as we did in Experiment 1. Mean RTs and accuracy data as a function of distractor-display condition and distractor-to-target SOA in the same- and different-location conditions are presented in Table 2. The main effect of location was again significant, with faster RTs in the same- versus different-location condition, $F(1, 13) = 14.23, p < .0001$, and so was the main effect of SOA, $F(3, 39) = 5.08, p < .005$. The interaction between same location versus different location and distractor display was significant, $F(2, 26) = 8.10, p < .003$, and planned comparisons again indicated faster RTs on same-location versus different-location trials in the target-color singleton, 40 ms, $F(1, 13) = 30.67, p < .0001$, and in the target-color heterogeneous condition, 40 ms, $F(1, 13) = 39.73, p < .0001$. In the nontarget-singleton condition, RTs were again slower on same-location than on different-location trials, $F(1, 13) = 7.36, p < .02$, and this effect interacted with color, $F(1, 13) = 5.67, p < .04$. Paired comparisons showed that same-location trials were significantly slower than different-location trials by 50 ms when the target was red and the salient distractor was green, $F(1, 6) = 9.98, p < .02$, and by only 7 ms when the target was green and the distractor red ($F < 1$). Again, none of these effects was modulated by SOA. The difference between same- and different-location trials (or location effect) for each distractor-display condition is presented as a function of distractor-to-target SOA in Figure 3.

Accuracy. The analysis of accuracy data revealed a main effect of only location, with more accurate responses on same-

⁷ We thank an anonymous reviewer for this suggestion.

Table 2
Mean Reaction Times (RTs) in Milliseconds and Mean Percentage of Correct Responses (%) as a Function of Condition and SOA in Experiment 2

| SOA | Target-color singleton | | | | Target-color heterogeneous | | | | Nontarget-color singleton | | | |
|--------|------------------------|----|------------|----|----------------------------|----|------------|----|---------------------------|----|------------|----|
| | Same loc. | | Diff. loc. | | Same loc. | | Diff. loc. | | Same loc. | | Diff. loc. | |
| | RTs | % | RTs | % | RTs | % | RTs | % | RTs | % | RTs | % |
| 60 ms | 605 | 96 | 630 | 96 | 630 | 95 | 656 | 93 | 680 | 94 | 633 | 96 |
| 100 ms | 597 | 97 | 629 | 97 | 578 | 96 | 627 | 95 | 641 | 96 | 623 | 96 |
| 150 ms | 589 | 97 | 648 | 95 | 592 | 98 | 626 | 95 | 652 | 96 | 604 | 96 |
| 250 ms | 607 | 99 | 650 | 95 | 587 | 97 | 646 | 95 | 619 | 97 | 617 | 97 |

Note. SOA = distractor-to-target stimulus onset asynchrony; loc. = location; Diff. = Different.

location trials than on different-location trials, $F(1, 13) = 7.40$, $p < .0001$.

Discussion

The results of Experiment 2, in which distractor-display conditions were mixed rather than blocked, closely replicated all the findings obtained in Experiment 1 (attentional capture of similar magnitude in the singleton and heterogeneous target-color conditions, and inhibition in the nontarget-color singleton condition).

The results reported thus far suggest not only that top-down factors are not contingent upon bottom-up salience but, in fact, that they are the sole determinant of attentional priority in feature-search mode, with no role for bottom-up salience. Note, however, that the latter conclusion may be an artifact of the particular stimuli used in Experiments 1 and 2. Specifically, the distractor display was more similar to the target display in the target-color heterogeneous condition than it was in the target-color singleton condition. In the former condition both displays contained heterogeneously colored items, and the colors used to create them were the same. In contrast, in the target-color singleton condition the target-

color element appeared among gray items in the distractor display but among heterogeneously colored items in the target display. Gibson and Kelsey (1998) showed that subjects are sensitive to the features that signal the appearance of the target display as a whole. Indeed, Gibson and Kelsey observed that a distractor possessing a feature that does not uniquely characterize the target, but rather the whole target display, captures attention. By extension, one may speculate that the more similar the display-wide characteristics signaling the distractor display and the target display are, the more difficult it may be to ignore the distractor display as a whole. That is, a distractor possessing the target color may elicit a faster attentional shift to its location when it appears in a display that has characteristics similar to those of the target display than when the two displays are very different from each other. If this is indeed so, then the faster RTs at the location of the nonsalient distractor possessing the target feature may result also from a set for display-wide characteristics signaling the occurrence of the target (Gibson & Kelsey, 1998), rather than only from a set for the target color. According to this speculation, the results of Experiments 1 and 2 may have overestimated the magnitude of capture in the target-color heterogeneous condition and thereby also underestimated the effects of stimulus-driven salience, that is, the difference in the magnitude of capture in the target-color singleton versus heterogeneous conditions.

Our objective in Experiment 3 was to seek converging evidence for the findings of Experiments 1 and 2 by using a different measure of attentional capture while eliminating the potential confound brought about by the similarity between the distractor and target displays.

Experiment 3

This experiment was based on a paradigm recently developed by Folk et al. (2002) and is similar to the attentional blink paradigm (e.g., Broadbent & Broadbent, 1987; Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). In Folk et al.'s (2002, Experiment 2) study, subjects were required to monitor a centrally presented rapid serial visual presentation (RSVP) stream of 15 colored letters (four different possible colors) for a single red target letter and to report the identity of that letter. Thus, they were induced to use feature-search mode. On each trial, a task-irrelevant peripheral distractor display was presented at a different temporal position relative to the target letter. This distractor display could appear

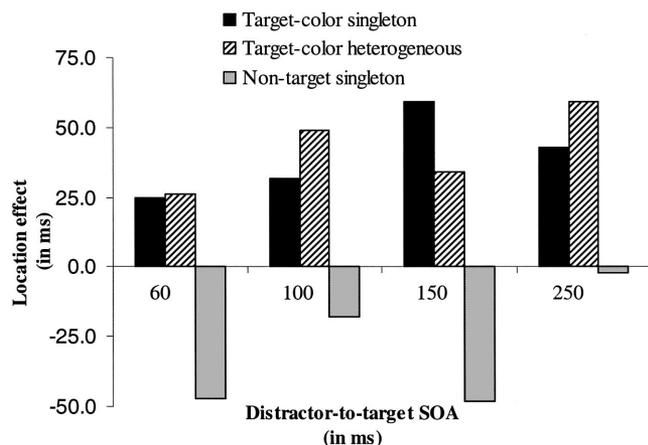


Figure 3. Experiment 2: Mean location effect (mean reaction times in the different-location condition minus mean reaction times in the same-location condition) in the target-color singleton, target-color heterogeneous, and nontarget-color singleton conditions, as a function of distractor-to-target stimulus onset asynchrony (SOA).

simultaneously with the target letter (Lag 0), follow it by one frame (Lag -1) or precede it by 1 or 2 frames (Lags 1 or 2, respectively). Unlike the standard attentional blink task in which both critical items are task-relevant, in Folk et al.'s (2002) study subjects had to ignore one critical item (the distractor) while attending to the other (the target). There were four different distractor conditions, which were randomly mixed. In the no-distractor condition, the central stream was presented alone in the display throughout the trial. Displays in the other three distractor conditions contained four pound signs (i.e., #) presented peripherally at one point in time, in addition to the central stream of letters. That is, in these conditions, 1 of the 15 frames making up the letter stream contained four peripheral distractors in addition to the letter at fixation. In the all-gray (henceforth, *homogeneous*) distractor condition, all four pound signs were gray. In the target-color singleton distractor condition, one pound sign was red and the remaining pound signs were gray. Finally, in the nontarget-color singleton distractor condition, one pound sign was green and the remaining pound signs were gray. Folk et al. (2002) reasoned that when peripheral distractors capture attention, one should observe a decrement in the processing of the central target, which would result in an effect that is perhaps akin to the attentional blink. They found that relative to the homogeneous distractor condition, subjects' accuracy in identifying the target letter was significantly impaired in the target-color singleton condition but not in the nontarget-color singleton condition. This finding suggests that in feature-search mode a singleton with the target-defining color captures attention, whereas a singleton with a different color does not capture attention.

The present experiment was modeled on Folk et al.'s (2002, Experiment 2) study with several important changes.

1. In addition to Folk et al.'s four original distractor conditions, we added a target-color heterogeneous distractor condition, in which the distractor display consisted of one target-colored pound sign, with the remaining pound signs in different colors.
2. We also added a heterogeneous control condition. This condition was identical to the target-color heterogeneous condition except that the target-color pound sign was replaced with a pound sign in a different color, that is, the peripheral distractor display did not include the target color.
3. The peripheral distractor displays contained eight pound signs instead of just four, because increasing display density should enhance singleton conspicuity.
4. In the singleton and homogeneous conditions, the color of the background elements (i.e., in the two singleton conditions, all the elements other than the singleton) changed from trial to trial to each of the distractor colors present in the heterogeneous condition. For example, on one trial a red pound sign might be presented along with seven blue pound signs, and on the next trial a red pound sign might be presented along with seven purple pound signs.
5. The peripheral distractor display appeared simultaneously with the target display (Lag 0) or preceded it by 1, 2, or 5 frames (Lag 1, Lag 2, and Lag 5, respectively).

With the present procedure, the distractor display (eight peripheral pound signs) and the target display (a single central letter) were highly discriminable in all conditions. Thus, if, as in Experiments 1 and 2, capture was observed in the target-color heterogeneous condition, it could not be attributed to the similarity between the distractor and target displays in this experiment.

It is important to keep in mind that with the present procedure, unlike the spatial capture effect measured in Experiments 1 and 2, performance disruption cannot be attributed with certainty to one specific element in the distractor display, namely to the pound sign matching the set, because some disruption may also be caused by other aspects unique to the display. Thus, for instance, the finding that subjects' accuracy is lower in the target-color heterogeneous condition than in the no-distractor condition cannot be taken to indicate that the target-color distractor in the heterogeneous condition captured attention, because the onset of any peripheral display is likely to be more disruptive than no onset at all. For similar reasons, the homogeneous condition may not serve as an adequate baseline for measuring capture by the nonsalient target-color distractor, because a heterogeneous display may be more salient than a homogeneous display regardless of whether it contains the target feature and thus may yield lower accuracy scores for reasons that are irrelevant to the issue investigated in this study. For one to isolate the effect of the target-color distractor, a control condition is required that differs from the target-color heterogeneous condition only in the fact that it does not include the target-color distractor. We therefore added the heterogeneous control condition, as mentioned in the second point above, which brought the number of distractor conditions to six. Following the same rationale, the homogeneous condition served as the baseline for measuring the effect of the singleton in the target-color and the nontarget-color singleton conditions.

Method

Subjects. Subjects were 24 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus and stimuli. The apparatus was the same as in Experiments 1 and 2. Figure 4 illustrates the sequence of displays. Stimuli making up the RSVP stream were letters selected from the English alphabet (excluding *I*, *O*, *W*, and *Z*). Again, there were two target-color conditions. Nontarget letters in the RSVP stream were gray, blue, purple, or green in the red-target condition and gray, blue, purple, or red in the green-target condition. When present, the peripheral distractor array appeared on frame 5, 6, or 7 of the RSVP stream. It consisted of eight, uniformly spaced pound signs and at a distance of 5.2° from fixation. There were 10 possible colors for the pound signs, 2 possible target colors (red and green), and 8 nontarget colors. All letters and pound signs were 1.0° tall × 1.0° wide with a stroke of 0.3°. There were six distractor conditions. In the no-distractor condition, the RSVP stream was presented alone with no peripheral distractor at any stage of the trial. In the homogeneous condition, all pound signs were drawn in 1 color, which was randomly selected for each trial from the set of 8 possible nontarget colors. In the heterogeneous condition, each of the eight pound signs had a different nontarget color. Color-to-location mapping was randomized on each trial of this type. The

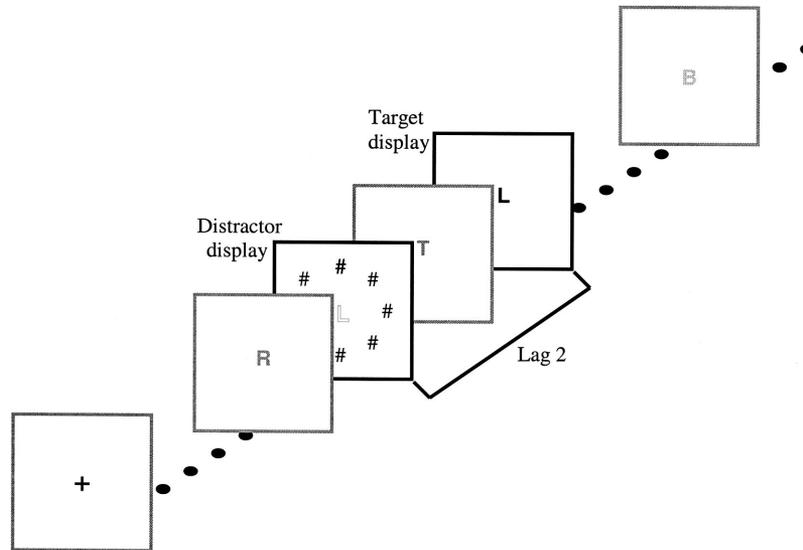


Figure 4. Sequence of events in Experiment 3. The example corresponds to the nontarget-color singleton condition for Lag 2. The target letter (bold black letter) was red or green (in the red- and green-target groups, respectively). Other letters were drawn in one of the three nontarget colors. In the distractor display, the bold black pound sign (#) was red or green (in the red- and green-target groups, respectively). The other pound signs were all drawn in the same color, which was one of the eight possible distractor colors. Each frame in the rapid serial visual presentation was presented for 50 ms and the frame-to-frame interval was 50 ms. All stimuli were presented against a black background. The fixation display (+) was white.

target-color singleton condition was identical to the homogeneous condition except that one of the pound signs was drawn in the target color. The nontarget-color singleton condition was identical to the target-color singleton except that the unique color was that of the alternative target (red in the green-target group and green in the red-target group). The target-color heterogeneous condition was identical to the heterogeneous condition except that one of the pound signs was drawn in the target color. All stimuli were presented on a black background.

Procedure. Subjects were instructed to identify a target, defined by its color (red in the red-target group and green in the green-target group) and embedded in a rapid stream of letters at the fixation location. They were asked to report the target's identity by entering the correct letter into a computer keyboard after the completion of the RSVP stream. Also, they were informed about the peripheral distractors and told to ignore them. Accuracy was emphasized (speeded responses were not necessary nor could they be advantageous, because responses were accepted only after the completion of the RSVP stream).

The experiment consisted of 24 practice trials, followed by 576 experimental trials, with breaks after every 72 trials. Trials were initiated by a spacebar press, which prompted a blank-screen presentation for 1,000 ms. A white fixation cross was then presented for 500 ms, followed by a 200-ms interstimulus interval. Next, an RSVP stream consisting of 20 letters began. Each letter was selected randomly without replacement from the 22-letter set and presented for 50 ms, followed by a 50-ms blank interval, yielding a rate of 100 ms/letter. At the completion of the RSVP stream, subjects were prompted to report the target letter. A 250-ms feedback tone was presented for incorrect responses.

Design. Target color (red or green) was the only between-subjects variable. There were two within-subject variables, distractor display (no distractor, homogeneous, heterogeneous, target-color singleton, nontarget-color singleton, target-color heterogeneous) and lag between distractor and target display (0, 1, 2, or 5).

Results

We again observed disruption in the target-color heterogeneous condition, that is, disruption resulting exclusively from top-down factors. However, it occurred earlier when the target-color item was a singleton, suggesting a role for bottom-up factors. Moreover, as in Folk et al.'s (2003) study, the nontarget-color singleton had no effect on performance.

Mean percentage of correct target identifications as a function of distractor condition and distractor-to-target lag are presented in Figure 5. Preliminary analyses revealed no main effect of target color and no interaction involving this factor. Therefore, in the following analyses, we collapsed the data across target-color conditions.

A first ANOVA with distractor-to-target lag (0, 1, 2, 5) and distractor display (no distractor, homogeneous, target-color singleton, and nontarget-color singleton) as factors revealed that Folk et al.'s (2002, Experiment 2) findings were closely replicated in the present experiment. Main effects of distractor-to-target lag, $F(3, 69) = 12.56, p < .0001$, and distractor display, $F(3, 69) = 5.00, p < .005$, were significant. The interaction between the two factors was also significant, $F(9, 207) = 2.78, p < .005$. At all lags other than 0 (where $F < 1$) the target-color singleton distractor produced a significant impairment in identification performance relative to the homogeneous distractor, $F(1, 23) = 17.27, p < .0005$; $F(1, 23) = 15.24, p < .001$; and $F(1, 23) = 4.96, p < .04$, for Lags 1, 2, and 5, respectively. In contrast, the nontarget-color singleton distractor produced no significant performance cost relative to the homogeneous distractor at any lag, $F(1, 23) = 3.14, p > .08$, for Lag 5 ($F_s < 1$, for Lags 0, 1, and 2).

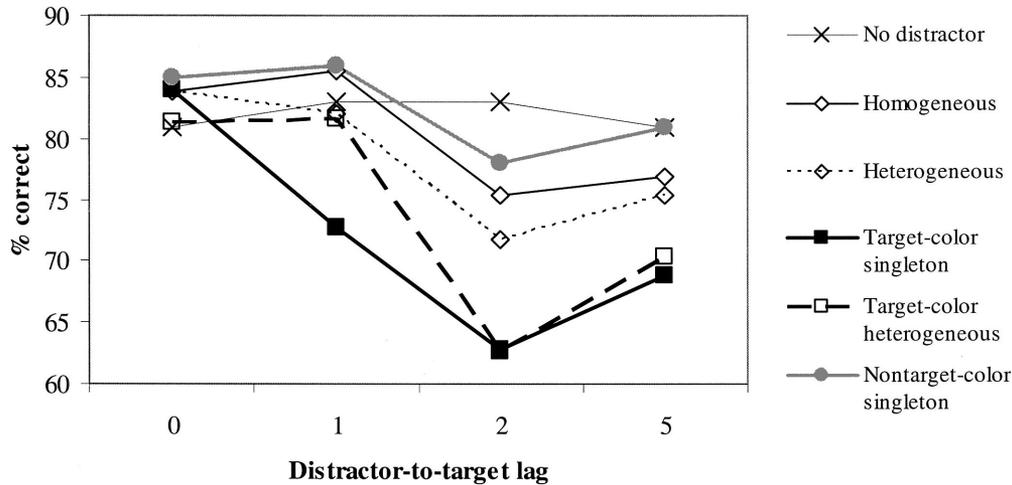


Figure 5. Mean percentage of correct responses in identifying the target letter by distractor condition as a function of distractor-to-target lag in Experiment 3.

We conducted an additional ANOVA to address the specific questions that were investigated in the present study. That is, we used it (a) to assess whether the presence of a target-color item in a heterogeneous peripheral distractor display disrupts performance and (b) to compare this disruption to that caused by the presence of a target-color item in an otherwise homogeneous distractor display (i.e., to assess potential effects of bottom-up salience within the relevant set). We had suggested that the weak bottom-up effects observed in Experiments 1 and 2 might stem from the high similarity between the distractor and target display that prevailed in these experiments, and Experiment 3 was designed in part to overcome this problem.

As noted earlier, it may be inappropriate to compare heterogeneous and homogeneous distractor-display conditions directly. Thus, the effect of the target-color distractor was measured against different baselines in the target-color heterogeneous and singleton conditions, namely against the heterogeneous and homogeneous conditions, respectively. We based the present analysis on the difference in identification accuracy between each critical distractor condition (target-color singleton and target-color heterogeneous) and its control condition (homogeneous and heterogeneous, respectively). The mean differences are presented as a function of distractor-to-target lag in Table 3. The analysis included three factors, distractor-to-target lag (0, 1, 2, and 5), distractor-display heterogeneity (homogeneous vs. heterogeneous), and target-color presence (present vs. absent). Thus, we examined four distractor conditions: (a) target-color singleton (homogeneous, target color present)⁸ and (b) its control condition, that is, homogeneous (homogeneous, target color absent) plus (c) target-color heterogeneous (heterogeneous, target color present) and (d) its control condition, that is, heterogeneous (heterogeneous, target color absent).

There was a main effect of lag, $F(3, 69) = 23.07, p < .0001$. There was also a main effect of target color presence, $F(1, 23) = 22.58, p < .0001$, with poorer performance when the target color was present than when it was absent; this is reflected in the preponderance of minus signs in Table 3. There was no main effect of distractor-display heterogeneity. The interaction Target-Color

Presence \times Lag interaction was significant, $F(3, 69) = 3.53, p < .02$. Planned comparisons revealed that the presence of the target color in the distractor display affected performance at all lags greater than zero, $F(1, 23) = 13.40, p < .002$; $F(1, 23) = 14.72, p < .001$; and $F(1, 23) = 6.32, p < .02$, for Lags 1, 2, and 5, respectively. For Lag 0, no effect was observed in either the target-color heterogeneous or singleton displays relative to their respective baselines (both $F_s < 1$). The interaction between distractor-display heterogeneity and target-color presence was also significant, $F(1, 23) = 4.44, p < .05$, with the presence of the target color producing a larger effect with homogeneous displays than with heterogeneous displays. In other words, the target-color singleton distractor display was more disruptive than the target-color heterogeneous display when the effect in each of these conditions was assessed relative to its baseline.

This effect was qualified by a significant triple interaction, $F(3, 69) = 2.96, p < .04$. Planned comparisons revealed that at Lag 1, there was a drop in performance relative to control in the target-color singleton, $F(1, 23) = 17.27, p < .0004$, but not in the target-color heterogeneous condition ($F < 1$). At all other lags the two conditions relative to their respective baselines did not differ from each other (all $F_s < 1$). Direct comparisons between them (i.e., not relative to their respective baselines) yielded the same results, $F(1, 23) = 9.64, p < .005$ at Lag 1 ($F_s < 1$, at all other SOAs).

Discussion

The results of Experiment 3 yielded three main findings. First, when the distractor display was heterogeneous and contained a target-colored item, central target identification was disrupted at Lags 2 and 5. Thus, the attentional capture effects we observed in Experiments 1 and 2, which resulted exclusively from top-down

⁸ Note that in this condition, the term *homogeneous* applies to the background rather than to the entire distractor display because, of course, a display containing a singleton is not homogeneous.

Table 3
Mean Decrease in Percentage Correct Relative to Baseline in the Target-Color Singleton Condition and Target-Color Heterogeneous Condition as a Function of Distractor-to-Target Lag in Experiment 3

| Lag | Target-color singleton (%) ^a | Target-color heterogeneous (%) ^b |
|-----|---|---|
| 0 | 0.1 | -2.5 |
| 1 | -12.9** | 0.5 |
| 2 | -12.5** | -9.0* |
| 5 | -8.1* | -5.0* |

Note. For Lag 1, the difference between the target-color singleton and the target-color heterogeneous conditions was significant at .001.

^a Mean percentage correct in the target-color singleton condition minus mean percentage correct in the homogeneous condition. ^b Mean percentage correct in the target-color heterogeneous condition minus mean percentage correct in the heterogeneous condition.

* $p < .05$. ** $p < .001$.

factors, were replicated with a procedure that did not suffer from the potential confound of similarity between distractor and target displays.

Second, we obtained the same effect in the target-color singleton condition, but the effect was also significant at Lag 1. This finding suggests that although bottom-up salience is not a necessary condition for top-down effects to be observed, there is some role for bottom-up factors in feature-search mode, because the target-color distractor seemed to elicit shifts of attention that began earlier when this distractor was a singleton than when it appeared in a heterogeneous background. This result contrasts with those of Experiments 1 and 2, in which no effect of salience was observed. A possible explanation for this difference is that, as we suggested in the discussion of Experiment 2, the high similarity between the distractor and target displays in the target-color heterogeneous condition may have masked such bottom-up effects, because the fact that the appearance of the target display was signaled by the same characteristics as the distractor display may have prompted subjects to start searching for the target earlier after the onset of the distractor display. However, given the numerous other differences between the two tasks, such an interpretation can be only tentative.

Finally, consistent with the results obtained in Experiments 1 and 2, we observed no attentional capture when the distractor display contained a nontarget-color singleton, thus replicating the main finding of Folk et al.'s (2002, Experiment 2) study that is the signature of feature-search mode. Note that the inhibition effect in the nontarget-color singleton condition reported in all the previous experiments of the present study could not be observed with the present paradigm, because this inhibition is location specific.

General Discussion

Summary of the Results

The results of the three experiments presented in this study showed that a nonsalient distractor that matches current attentional control settings, that is, a distractor that is not a singleton but possesses the target feature, produces strong attentional capture in

search for a nonsingleton target, with effects lasting up to at least 250–500 ms.

Such effects appear to be enhanced if the target-color distractor is a singleton. Specifically, the results of Experiment 3 suggest that attentional capture occurs earlier with increased bottom-up salience of the target-color distractor. We attributed our failure to observe such bottom-up salience effects in Experiments 1 and 2 to the fact that high similarity between the distractor and target displays may have artificially boosted effects of top-down relative to bottom-up factors, and thus reduced the probability of observing bottom-up salience effects. Further research is required to confirm this claim.

Finally, consistent with earlier findings, in none of the experiments reported in the present study did a singleton distractor outside of the task-relevant set summon attention. In fact, in Experiments 1 and 2, in which spatial effects could be measured directly, subjects were slower to respond to the target when it appeared at the location of a nontarget-singleton distractor relative to other locations. This finding provides further support for the idea that resistance to attentional capture by irrelevant singletons is mediated by top-down inhibition (Lamy & Egeth, 2003).

Attentional Capture Based on Top-Down Factors

To our knowledge the present study is the first report of attentional capture in feature-search mode resulting exclusively from top-down factors. Prior to this study, the role of top-down factors had only been demonstrated by showing that a singleton distractor does not capture attention unless it matches current attentional settings (e.g., Folk et al., 2002; Folk & Remington, 1998). Although these earlier findings provide good support for the claim that bottom-up salience is not a sufficient condition for capture to be observed, they do not allow one to overrule the possibility that bottom-up salience may nonetheless be a necessary condition. We replicated the finding of attentional capture by a distractor that possesses the target feature but is not a singleton in three experiments, using a blocked design and a mixed design, two different types of stimulus displays, two different paradigms (variants of the spatial cuing and attentional blink paradigms), and two different dependent measures (reaction times and accuracy). We thus conclude that effects of top-down factors in feature-search mode are not contingent on stimulus-driven salience.

At first glance, the fact that when subjects search for a red item any red item will pull attention to itself may appear to be rather unsurprising. However, this finding has important implications for our understanding of feature-based attention. First, it suggests that when looking for a target with a known color, one is limited in one's ability to restrict attentional control settings to a certain ordinal position in time (the second event). Note that such a failure was observed despite the fact that (a) the two events were clearly distinct (two successive color changes) and (b) the target was additionally characterized by its known shape characteristics (large outline square in Experiments 1 and 2 or block letter in Experiment 3), which were highly discriminable from those of potential distractors (groups of small dots in Experiments 1 and 2 or pound signs in Experiment 3). Moreover, the results of Experiment 3 impose new restrictions on the idea that when the location of a target is certain, irrelevant stimuli are no longer capable of producing attentional capture (Theeuwes, 1991; Yantis & Jonides,

1990). Specifically, spatial certainty may suffice to eliminate capture by salient objects outside of the current attentional set (e.g., abrupt onsets in Yantis and Jonides's, 1990, and Theeuwes's, 1991, studies) but not from even nonsalient objects that match the target-defining feature. Consistent with this view, Saenz, Buracas, and Boynton (2002) used functional magnetic resonance imaging and showed that attention to a stimulus feature (color or direction of motion) increased the response of visual cortical areas to a spatially distant, ignored stimulus that shared the same feature. Thus, our findings suggest that the effects of feature-based attention are global in time and in space.

The time course of attentional capture has been investigated only in tasks involving search for a singleton target with a known feature (Kim & Cave, 1999; Lamy et al., 2003; Theeuwes, Atchley, & Kramer, 2000). When subjects searched for a known unique shape, effects of capture by an irrelevant color singleton were found to disappear by 150 ms after distractor-display onset. Theeuwes et al. (2000) concluded that by that time, subjects are able to disengage their attention from the irrelevant singleton's location. To accommodate Folk et al.'s (1992) finding that with a 150-ms SOA a task-relevant singleton distractor does capture attention, Theeuwes et al. speculated that attention is automatically summoned to the location of the most salient object in the visual field irrespective of task demands but that disengagement and redirection of attention from the distractor location may take longer when the distractor possesses the target-defining property.

While providing general support for the latter speculation, the present findings further specify the conditions under which recovery from attentional capture takes place. We observed that capture effects in the target-color distractor conditions (singleton and heterogeneous) did not wane at the longer SOAs (up to 500 ms) in any of the experiments presented in this article. This result suggests that whenever attentional capture is observed (e.g., whether it results exclusively from top-down factors or also from stimulus-driven salience), recovery from capture may not be possible or at least may start after an extended time when the distracting item matches the target-defining feature. Further corroboration of this notion comes from recent findings reported by Lamy and Egeth (2003, Experiment 5). Subjects searched for a shape target that was a singleton on every trial but the specific form of which varied from trial to trial. Thus, the target was defined by its uniqueness. An irrelevant color singleton—which therefore matched the target-defining feature of uniqueness—captured attention across SOAs ranging from 50 ms to 300 ms; that is, there was no recovery from capture.

Inhibitory Processes in Feature-Search Mode

The role of top-down factors in feature-search mode was also revealed by the inhibition observed at the location of the nontarget-color singleton (Experiments 1 and 2). This result provides an important generalization of the findings reported by Lamy and Egeth (2003). For one thing, it shows that the location of an irrelevant color singleton is also inhibited when this distractor is defined in the same dimension as the target (color) rather than only in a different dimension (irrelevant singleton in the color dimension and target defined by its shape; Lamy & Egeth, 2003).

An additional difference between the two studies concerns the duration of distractor exposure. In Lamy and Egeth's (2003) study,

the distractor remained visible throughout the SOA and target display exposure time. This aspect of the procedure raises the possibility that the slower RTs observed when the shape target is also unique on the color dimension may, in fact, result from response-related processes. For instance, subjects in that study may have been reluctant to respond to the target in the same-location condition because, on such trials, the target was presented in an infrequent color. Indeed, in the red-target group, for instance, the target shape was red on 1/12 of the trials (same-location trials) and gray on the remaining 11/12 of the trials (different-location and no-distractor trials). In the present Experiments 1 and 2, the distractor disappeared together with the distractor display; that is, the uniquely colored dots turned back to gray after 50 ms, immediately after distractor-display offset. Thus, there was nothing unusual at the target location on same-location trials in the target display. The present replication of the inhibition effect therefore undermines the claim that this effect may be attributable to response-related, rather than attentional, processes.

It is not yet clear at this point what the nature of such inhibitory effects might be. One possibility is that they may be related to inhibition of return (IOR; Posner & Cohen, 1984). IOR refers to the finding that with exogenous cuing, faster RTs at the cued location relative to an uncued location are followed by slower RTs at that location. Accordingly, in the present study attention may first be grabbed by the salient singleton whether or not it possesses the target feature, but this transient attentional capture may then come under top-down control, such that it is replaced by top-down inhibition at the location of the singleton distractor when its feature does not match the target feature.⁹

Note that whereas IOR typically emerges 200 ms or more after cue onset, inhibition could already be observed at the shortest SOA (60 ms) in the present Experiments 1 and 2 and in Lamy and Egeth's (2003) study (Experiment 6). For comparison, Theeuwes and Godijn (2002) recently observed capture by a color singleton with a 133-ms SOA (Experiment 2) as opposed to inhibition with a 1,300-ms SOA (Experiments 1 and 3). However, recent evidence suggests that the onset of IOR can be modulated by several factors. For instance, Danziger and Kingstone (1999) showed that the appearance of IOR can be accelerated by shifting attention away from the cue sooner. Moreover, Klein (2000) proposed that whereas the typical interpretation for the biphasic pattern characteristic of IOR is that inhibition begins when attention moves away from the cued location, another possibility is that both facilitation and inhibition begin when the cue is presented. Klein further suggested that inhibition remains constant, whereas facilitation decreases over time, such that the net effect of cuing on performance is net facilitation at early SOAs and net inhibition at later SOAs. This proposal was supported in a neuroscientific study by Klein, Munoz, Dorris, and Taylor (2001). It is thus conceivable that facilitation in the present study was completely overridden by inhibitory processes within the shortest SOA (60 ms).

Although we can think of no aspect of our experiment that may have induced such express IOR (for instance, we used a discrimination task, which is actually known to produce delayed IOR; see Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997), further research is needed to resolve this issue. We are currently investigat-

⁹ We thank Jan Theeuwes for this suggestion.

ing an alternative account for the inhibition finding reported in the present study, according to which subjects adopt an inhibitory set for ignoring a known feature (say, green) throughout an entire block or experiment. This hypothesis shares in common with Klein's interpretation of IOR the idea that inhibitory processes do not follow bottom-up processes in time but rather simultaneously affect the allocation of attentional priority in the opposite direction, as soon as the distractor display appears on the screen. However, this hypothesis also differs from Klein's account because it implies that inhibition is not triggered anew on each trial but rather results from a long-term inhibitory set.

An additional possibility is that the inhibitory effects observed here may be related to feature-based visual marking. Visual marking refers to the finding that subjects can actively inhibit old irrelevant information (information that was presented in a preview display preceding the display known to contain the target), thereby prioritizing new information (Watson & Humphreys, 1997). Olivers and Humphreys (2003) showed that such inhibition can be feature-based: They found RTs to an orientation singleton target to be slower when this target had the same color as the objects previously "marked" in the preview display. In the present study RTs were delayed if the target shared the location of the singleton distractor possessing a to-be-ignored color, whereas in Olivers and Humphreys's study, RTs were delayed if the target possessed the same color as the previously marked distractors at a different location; the two inhibitory effects could reflect the same feature-based inhibitory mechanism mediated by location (i.e., the location of any object sharing the ignored feature is inhibited). Note that according to an interpretation in terms of visual marking, Olivers and Humphreys's results are taken to reflect an inhibitory mechanism that is triggered by the preview display on each trial. However, because the preview display was identical on each trial (green left-tilted lines), it is possible that subjects in fact adopted a long-term inhibitory set for ignoring the feature *green*, as we think might be the case in our study.

Implications for the Role of Bottom-Up Salience in Visual Search

A distractor possessing the target color produced earlier capture when it was a singleton than when it appeared among heterogeneously colored items (Experiment 3), which suggests that there is also some role for stimulus-driven salience in feature-search mode. In contrast, a singleton distractor with a nontarget color did not capture attention. Thus, we found stimulus-driven salience to have differential effects depending on what feature was salient (i.e., whether it matched the target-defining feature).

On the face of it, this finding is consistent with Folk and Remington's (1998) suggestion that

establishing the effect of top-down control over spatial attentional capture does not necessarily rule out any role for stimulus-driven salience. For example, once a control setting is in effect, stimulus-driven salience may further prioritize multiple stimuli consistent with this setting. (p. 856)

An account of the present findings based on Folk and Remington's idea would imply that the contribution of bottom-up processes is contingent on top-down settings; that is, that the computation of attentional priority simply does not include the level of

bottom-up salience of objects that do not match current control settings. The following argument, however, undermines this interpretation.

We found that a salient distractor outside the relevant set not only failed to produce spatial capture but in fact elicited significantly slower responses at its location (Experiment 1 and 2; see also Lamy & Egeth, 2003). Reconciling this result with the idea that bottom-up salience of only task-relevant features contributes to the allocation of attentional priority entails some redundancy. Why would subjects have to inhibit the location of task-irrelevant features if they can ignore bottom-up salience of distractors outside of the task-induced set? We prefer a more parsimonious account according to which stimulus-driven salience always plays a role in visual search but its effects may be offset by top-down inhibition. Thus, whether inhibition of a task-irrelevant feature can offset the bottom-up activation that accrues to a singleton possessing this feature should be an empirical matter, depending on parameters such as relative perceptual salience of the to-be-ignored feature. In line with this idea, it is noteworthy that various patterns of results are found in the literature that investigates the ability of irrelevant singletons to elicit shifts of attention in feature-search mode, with reports of no activation (e.g., Folk & Remington, 1998; Jonides & Yantis, 1988), a small net activation (e.g., Yantis & Egeth, 1999, effects of bright and large singletons in Experiments 7 and 8), or net inhibition (the present study and Lamy & Egeth, 2003) at the location of the irrelevant singleton distractor.

Recent data from our lab support this hypothesis. In a variant of Bacon and Egeth's (1994, Experiment 2) feature-search mode task, we found a significant interaction between display density and the effect of the presence of an irrelevant singleton. Specifically, the presence of the irrelevant singleton (a color singleton in search of a target defined by its shape) speeded search with low-density displays (reflecting inhibitory processes) but impeded search with high-density displays (reflecting capture by the distractor). In other words, when the distractor's bottom-up salience was high enough, it offset top-down inhibition to produce net interference (see Theeuwes, 2004, for similar results).

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