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Attentional Capture in Singleton-Detection and Feature-Search Modes

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Six experiments were conducted to determine the circumstances under which an irrelevant singleton captures attention. Subjects searched for a target while ignoring a salient distractor that appeared at different stimulus onset asynchronies (SOAs) prior to each search display. Spatial congruency and interference effects were measured. The strategies available to find the target were controlled (only singleton-detection mode, only feature-search mode, or both search strategies available). An irrelevant abrupt onset captured attention in search for a color target, across SOAs, whatever strategies were available. In contrast, in search for a shape target, an irrelevant color singleton captured attention in the singleton-detection condition but delayed response at its location in the feature-search condition, across SOAs. When both strategies were available, capture was short lived (50- to 100-ms SOAs). The theoretical implications of these findings in relation to current views on attentional capture are discussed.

Visual attention refers to the mechanisms involved in the establishment of processing priority. Two ways in which selection from visual displays may be controlled have been distinguished. Goal-directed or top-down control of attention refers to the ability of the observer's goals or intentions to determine which areas, attributes, or objects are selected for further visual processing. Stimulus-driven or bottom-up control refers to the capacity of certain stimulus properties to attract attention. How these factors interact to determine processing priority is currently one of the most debated issues in the study of visual attention.

Theeuwes's Salience-Based Account

In the early 1990s, Theeuwes proposed that preattentive processing is driven exclusively by bottom-up factors such as salience (e.g., Theeuwes, 1991, 1992), with a role for top-down factors only later in processing (Theeuwes, Atchley, & Kramer, 2000; see also Kim & Cave, 1999). For example, Theeuwes (1992) presented subjects with displays consisting of colored circles or diamonds arranged on the circumference of an imaginary circle. Line segments varying in orientation appeared inside each item. Subjects were required to determine the orientation of the line segment within a target item. The target item was defined as the unique green diamond among green circles. Time to find the target shape singleton increased when an irrelevant color singleton (a red circle) was also present (see Pashler, 1988, Experiment 6 for an accuracy version of this task). When the color singleton was less salient than the shape singleton, the color singleton no longer interfered with the search for the shape singleton, whereas in a reversed version of the task (shape distractor and color target), the shape singleton interfered with the search for the color singleton. Theeuwes concluded that attention is captured by the most salient element in the display.

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Singleton-Detection Mode Versus Feature-Search Mode

Bacon and Egeth (1994) suggested that salience determines attentional priority only when subjects adopt the strategy of searching for a discontinuity (*singleton-detection mode*). In contrast, when subjects adopt the strategy of searching for a known-to-be-relevant feature (*feature-search mode*), bottom-up capture by a salient distractor can be overridden (see Pashler, 1988, p. 317, for the original version of this distinction). They proposed that in tasks where the target is a singleton and has a known feature, both search strategies are available. As a consequence, irrelevant singletons may or may not cause distraction depending on the search strategy used. In support of this claim, they showed that when singleton-detection mode is discouraged and subjects are forced to resort to feature-search mode, the presence of a salient distractor no longer interferes with search.

Other studies showed that whereas featural singletons, in line with Bacon and Egeth's (1994) proposal, do not capture attention when the target cannot be found by monitoring displays for a locally discrepant item (e.g., Lamy & Tsal, 1999; Yantis & Egeth, 1999, Experiments 1–7 and 9; but see Johnson, Hutchison, & Neill, 2001, for discrepant findings), abrupt onsets capture attention automatically, irrespective of task demands (e.g., Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Mounts, 2000; Yantis & Jonides, 1984; but see Theeuwes, 1991, and Yantis & Jonides, 1990, for conditions in which abrupt onsets do not capture attention). For instance, in Jonides and Yantis's study (1988), subjects had to search for a target letter, which was as likely as any of the nontarget letters also present in the display to be abruptly onset. Performance was found to be fast and independent of display size when the target rather than a nontarget was the abrupt onset, suggesting that although irrelevant, the abrupt onset captured attention (Experiment 1). Such capture did not occur when the salient element was a color or a luminance singleton (Experiments 2 and 3, respectively; but see Todd & Kramer, 1994).

Contingent Involuntary Orienting: Static Versus Dynamic Discontinuities

Folk, Remington, and Johnston (1992) claimed that even when subjects search for a singleton, an irrelevant singleton will capture attention only if it matches the attentional control setting adopted by the observer to perform the task. In support for their *contingent involuntary orienting* hypothesis, Folk et al. found that a singleton distractor that appears before a singleton target draws attention to its location only if it is defined by the same type of discontinuity as the target. Thus, for instance, performance was faster on trials in which an irrelevant red color singleton appeared at the same location as a subsequent target than at a different location, only when the target was also a red color singleton but not when it was an abrupt onset (see Remington, Folk, & McLean, 2001, for similar results).

In additional experiments, Folk and colleagues attempted to further define the level of specificity at which attentional settings may be established. For instance, Folk, Remington, and Wright (1994) showed that apparent motion distractors elicited involuntary shifts of attention only when subjects were required to monitor for moving targets or abrupt onset targets. When the task was to monitor for a discontinuity in color, these same distractors did not capture attention to their location. On the basis of such findings, Folk and colleagues proposed that attentional control settings may be established only for broad categories of discontinuities, namely, for either static or dynamic discontinuities.

However, Theeuwes (1994) presented data that are inconsistent with this conclusion. In one condition, subjects searched displays for a color singleton, and an irrelevant onset singleton was also present on half of the trials. In another condition, the target was the onset singleton and the distractor was the color singleton. Irrespective of attentional set, the presence of a singleton distractor did produce a cost, but only when it was more salient than the target.

To summarize, different current viewpoints concerning the level of specificity at which attentional settings can be established are at considerable variance. Accordingly, different authors make different predictions as to when involuntary capture of attention by an irrelevant salient item should occur. At one end of the continuum, Theeuwes's (e.g., 1992) salience-based account stipulates that no top-down selectivity whatsoever is possible at the preattentive stage, and any element that is more salient than the target will thus capture attention. The proposal by Bacon and Egeth (1994) that subjects may adopt one of two possible search strategies and may search either for a discontinuity (singleton-detection mode) or for a specific feature (feature-search mode) allows for limited top-down control. So, whereas the most salient item will capture attention if subjects search for a unique item, the same salient item will be successfully ignored if subjects search for a known nonsingleton.[1] Yantis and colleagues adopt a similar viewpoint (e.g., Yantis & Egeth, 1999) but impose further restrictions on top-down control by claiming that abrupt onsets capture attention automatically irrespective of attentional set (Hillstrom & Yantis, 1994; Jonides & Yantis, 1988). Finally, at the other end of the continuum, Folk and colleagues (e.g., Folk et al., 1992, 1994; Remington et al., 2001) propose that attentional control settings can be established in search for a singleton target (e.g., set for static vs. dynamic discontinuities). Accordingly, they predict that a singleton on a static dimension (e.g., color) will not capture attention in a search for a dynamic discontinuity (e.g., onset or motion singleton) and vice versa.

The studies supporting these various views differed in potentially consequential aspects. In Folk et al.'s studies (e.g., Folk et al., 1992; Folk & Remington, 1998), the distractor display typically preceded the target display by 150 ms (Experiments 1–3). In contrast, in Theeuwes's (1991, 1992, 1994) and Yantis and colleagues' (e.g., Yantis & Egeth, 1999; Yantis & Jonides, 1984) experiments (e.g., Theeuwes, 1991, 1992), the irrelevant salient distractor typically appeared simultaneously with the target. Theeuwes et al. (2000) argued that in Folk et al.'s experiments, the irrelevant distractor may have captured attention, but subjects were able to overcome the attentional capture by the time the search display was presented. In support of this claim, they showed that the presence of an irrelevant color singleton disrupted search for a shape singleton target at distractor-to-target stimulus onset asynchronies (SOAs) of 0–100 ms but that this interference disappeared at later SOAs (see Kim & Cave, 1999; Lamy, Tsal, & Egeth, in press, Experiment 1, for similar results).

Note that within this framework, an additional assumption is required in order to accommodate the asymmetry that is Folk et al.'s most crucial finding. Namely, one must assume that subjects should be able to deallocate their attention from, say, an irrelevant color singleton within 150 ms when subjects search for a discontinuity in another domain, but not when the same and equally irrelevant singleton matches the current attentional control setting. Thus, Theeuwes et al. (2000) further proposed that deallocation of attention from the singleton distractor may be relatively fast when the distractor and target do not share the same defining properties but relatively slow when they do. Folk and colleagues presented data suggesting that distractor-to-target SOAs do not modulate capture by an irrelevant singleton. However, they systematically manipulated SOAs only for conditions in which the irrelevant singleton matched the current attentional settings (Folk et al., 1992, Experiment 4; Remington et al., 2001). These findings are in fact consistent with Theeuwes's proposal that deallocation of attention from singletons matching the current set may be slow. For the critical condition in which the singleton distractor does not match attentional settings, attempts to measure the time course of capture were not systematic (e.g., Folk & Remington, 1999). Thus, it remains possible that involuntary capture by an irrelevant singleton indeed occurs even when this singleton does not match the attentional set adopted by subjects but that it can be overridden with long enough distractor-to-target SOAs.

Moreover, Theeuwes typically manipulated the presence of the irrelevant singleton (e.g., Theeuwes, 1991, 1992; see also Bacon & Egeth, 1994) or the compatibility of the response elicited by this singleton with the response elicited by the target (e.g., Theeuwes, 1996; Theeuwes et al., 2000), using Eriksen's response compatibility paradigm (Eriksen & Hoffman, 1973). Accordingly, capture was measured as a performance cost on distractor-present trials

[1] For the sake of convenience, instead of referring only to an object with a nonunique property, the term *nonsingleton target* will refer to a target the stimulus-driven salience of which is not significantly higher than that of the distractors. Thus, for instance, a target with a unique shape among heterogeneously shaped distractors fits this definition.

relative to distractor-absent trials (interference effect) or as a cost on incompatible-response trials relative to compatible-response trials. In contrast, Folk and colleagues (e.g., Folk & Remington, 1998; Folk et al., 1992) typically measured capture using a spatial congruency paradigm. As was described earlier, a distractor display containing an irrelevant singleton is followed by a display containing a target singleton. Spatial capture is measured as the difference in response latencies on trials in which the irrelevant singleton and target appear at the same versus at different locations (e.g., Folk & Remington, 1998; Folk et al., 1992, 1994; see also Kim & Cave, 1999). Faster performance on same-location trials suggests that attention is summoned to the irrelevant singleton's location and has to be shifted to the target's location on different-location trials, which incurs a cost. Equal performance in these conditions suggests that no processing priority has been assigned to the irrelevant singleton's location relative to other locations in the display, thus indicating that this singleton did not capture attention.

The objective of the present study was to determine under what circumstances an irrelevant singleton captures attention. When such capture is found, it remains possible of course that it may be exacerbated when the distractor singleton matches the control setting promoted by the task at hand. This, however, was not the focus of the present study. Thus, in none of the following experiments did the distractor and target share the same defining feature, because there is no controversy about capture obtaining in such circumstances. We examined the time-course of attentional capture by manipulating distractor-to-target SOAs. We used a visual search paradigm with both a spatial congruency manipulation and a no-distractor condition, such that attentional capture could be assessed using Folk et al.'s (1992) spatial congruency effect (same vs. different location trials) and Theeuwes's (e.g., 1992) interference effect (no-distractor vs. different-location trials).

Experiment 1

In the first experiment, we investigated whether a color singleton captures attention in search for a shape singleton. This experiment was based on the same general rationale as Theeuwes et al.'s (2000) Experiment 1, with two notable differences. First, in Theeuwes et al.'s no-distractor condition, distractor displays were simply omitted, such that the target display immediately followed the fixation display. This entails that SOAs were manipulated only in the distractor-present condition, not in the no-distractor condition. Any effect of the time interval between the fixation and target displays was thus confounded with the modulation of capture by distractor-to-target SOAs. For instance, the fact that reaction times (RTs) in the distractor-present condition decreased after 150 ms could have stemmed from a general alerting effect, as subjects had more time to prepare before responding, rather than from top-down control overriding capture after enough time has elapsed. In this case, one would expect RTs to go down as SOAs increase also in the no-distractor condition, but this could not be measured in Theeuwes et al.'s experiment. Here, the SOA manipulation was applied to all three relevant conditions (no-distractor, same-location distractor, and different-location distractor).

Second, in Theeuwes et al.'s (2000) experiment, the distractor and target always appeared at different locations, and interference was measured to assess capture. We added a same-location condition, such that the procedure used in the present experiment was similar to Folk and Remington's (1998) spatial cuing procedure.

Method

Subjects

Subjects were 11 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having 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

The fixation display was a gray 0.8° × 0.8° plus sign (+), in the center of a black background. The "ready" display consisted of six pairs of superimposed dark gray outline diamonds and circles. These were equally spaced around the circumference of an imaginary circle, centered on the fixation sign. In the distractor-absent condition, the distractor display was identical to the ready display, except that all stimuli turned light gray. In the distractor-present condition, one pair of superimposed shapes turned red; the remaining five pairs turned light gray. The red and light-gray colors were matched for luminance (8.1 cd/m^2 and 8.2 cd/m^2, respectively) using a light meter (Photo Research Inc. Litemate/Spotmate System 500).

The interstimulus display was identical to the distractor-absent display. Thus, in the distractor-present condition, the red pair turned light gray. The target display was made up of six light-gray outline shapes: one diamond and five circles. That is, to create the target display, for each pair of superimposed shapes one shape was offset (the diamond at all five distractor locations, with only circles remaining visible, and the circle at the target location, with only the diamond remaining visible).[2] Each shape contained a white sign, either an × or an =. Each target display always contained exactly three × signs and three = signs, randomly assigned to the six possible locations.[3] At a viewing distance of 60 cm, the centers of the shapes were 4.08° from fixation. Diamonds were 2.76° tall and 2.25° wide. Circles had a diameter of 2.04°. When superimposed, diamonds' and circles' centers overlapped. In each display, two elements were positioned along the vertical midline, two items were equally distant from the horizontal midline on the left, and the remaining two were equally distant from the horizontal midline on the right. The × sign subtended 0.75° × 0.75°,

[2] The use of superimposed target and nontarget shapes prior to the target display ensured (a) that search for the target could not begin until target display onset and (b) that the amount of physical change was equivalent at the target and nontarget locations. Thus, the target was not characterized by a unique abrupt onset or offset and differed from nontargets only by its shape.

[3] Because the specific signs within the target and salient distractor could be either identical or different as a result of counterbalancing, our experiment contained a built-in manipulation of compatibility, but a weak one. Indeed, because in each display there was an equal number of × and = signs, the sign at the salient distractor's location competed with other compatible and incompatible signs at different locations. This may explain why we failed to observe any substantial compatibility effects across the experiments reported here and, specifically, why compatibility effects did not parallel spatial congruity effects (although it should be acknowledged that Theeuwes, 1996, did observe a compatibility effect with a similar paradigm). In any event, given our null results, we dispense with further discussion of the compatibility effect in the remainder of this article.

and the $=$ sign subtended 0.31° × 1.02°. All stimuli were drawn with a 1-pixel stroke.

Procedure

Figure 1 (upper row) illustrates the sequence of displays on distractor-present trials. 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. The SOA between the distractor stimulus onset and the target onset was randomly selected for each trial to be one of six possible values: 50, 100, 150, 200, 250, and 300 ms. The target display remained visible until subjects had responded or after 2,000 ms had elapsed. The screen went blank for 500 ms before the next trial began.

Subjects were instructed to indicate what sign had appeared within the unique diamond in the target display, while attempting to ignore the distractor display. They were required to press *1* with their right index finger if it had been an ×, and *2* with their right middle finger if it had been an $=$ sign, using the numerical key pad. They were asked to respond as fast as possible while keeping 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

The design was a 3 × 6 within-subject design, with distractor display (no distractor vs. same-location distractor vs. different-location distractor) and SOA (50, 100, 150, 200, 250, or 300 ms) as factors. The target shape was equally likely to appear in any of the six possible locations, as was the distractor, when present (50% of the trials). Thus, on distractor-present trials, the distractor was no more likely to appear at the same location as the target shape than at any other location (1/6 of distractor-present trials). The target sign was equally likely to be an × or an $=$ sign, as was the sign appearing at the distractor location. Conditions were randomly mixed within blocks. Each subject was run on 20 practice trials followed by 720 experimental trials divided into 6 blocks of 120 trials each. Subjects were allowed a rest period after each block.

Results

Mean RTs on correct trials and accuracy data are presented in Figure 2. In all RT analyses, error trials (2.5% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of distractor display and SOA. RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed fewer than 1% of all observations.

Spatial Congruency Effects

Analyses of variance (ANOVAs) were conducted on RT and accuracy data with SOA and distractor-target location as factors, in both cases excluding the no-distractor condition.

RTs. The main effect of SOA was significant, $F(5, 50) = 2.88$, $p = .03$. Same-location trials were significantly faster than different-location trials (724 ms vs. 749 ms), $F(1, 10) = 9.57$, $p < .02$. The interaction between SOA and distractor-target location was also significant, $F(5, 50) = 3.44$, $p < .01$. Pairwise comparisons revealed that the same-location advantage was significant at short SOAs (50 ms and 100 ms), but was nonsignificant at longer SOAs (150, 200, 250, and 300 ms). More specifically, the advantage at the 50-ms SOA was 55 ms, $F(1, 10) = 14.52$, $p < .04$, and it was 59 ms at the 100-ms SOA, $F(1, 10) = 28.01$, $p < .04$. There was no significant same-location advantage at the 150-ms (−11 ms; $F < 1$), 200-ms (0 ms; $F < 1$), 250-ms (30 ms; $F[1, 10] = 1.87$, $p > .20$), or 300-ms (7 ms; $F < 1$) SOAs.

Accuracy. None of the effects approached significance.

Interference Effects

An additional ANOVA was conducted excluding the same-location condition, with SOA and distractor condition (no distractor vs. different location) as factors.

RTs. The main effect of SOA was significant, $F(5, 50) = 2.42$, $p < .05$. No-distractor trials were significantly faster than

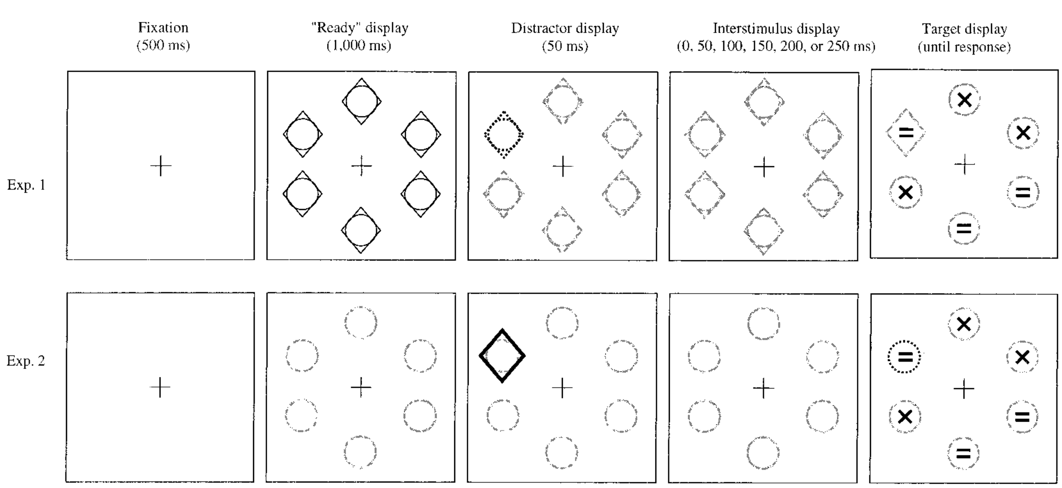

Figure 1. Stimuli and sequence of events in Experiment 1 (upper row) and Experiment 2 (lower row). The examples correspond to the same-location condition. Dotted lines were red, gray lines were light gray, thin black lines were dark gray, and heavy black lines were white. All stimuli were presented against a black background.

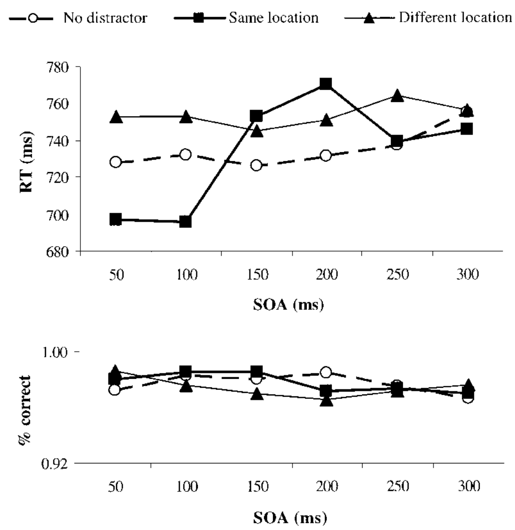

Figure 2. Experiment 1 (in which target was a known shape singleton and distractor was a color singleton): Target identification performance in the no-distractor, same-location, and different-location conditions as a function of distractor-to-target stimulus onset asynchrony (SOA).

different-location trials, $F(1, 10) = 17.64$, $p < .02$. The interaction between SOA and distractor-target location was not significant, $F(5, 50) = 1.43$, $p > .20$. However, paired comparisons indicated that the interference effect was significant at short SOAs, $F(1, 10) = 20.26$, $p < .02$; $F(1, 10) = 7.49$, $p < .03$; and $F(1, 10) = 5.92$, $p < .04$, for 50-, 100-, and 150-ms SOAs, respectively, and became nonsignificant at longer SOAs, $F(1, 10) = 4.14$, $p = .07$; $F(1, 10) = 3.07$, $p > .10$; and $F < 1$ for 200-, 250-, and 300-ms SOAs, respectively.

Accuracy. None of the effects approached significance.

Discussion

We replicated the general pattern of results obtained by Theeuwes et al. (2000) using the same SOA manipulation for all distractor conditions. Namely, an irrelevant color singleton interfered with search for a shape singleton when it preceded the target by a short time interval, and this effect disappeared with longer SOAs. However, although early interference effects (i.e., the difference between different-location and no-distractor RTs averaged across 50- and 100-ms SOAs) were comparable in magnitude (around 25 ms in Theeuwes et al.'s Experiment 1 vs. 20 ms in the present experiment), these were more weakly affected by the SOA manipulation here. Interference effects became nonsignificant at longer SOAs, as in Theeuwes et al.'s study, but we did not observe the sharp decrease in different-location RTs reported by these authors. The pattern of recovery from capture was much more marked on the spatial congruency measure. In fact, most of the spatial congruency effect was driven by a benefit on same-location trials rather than a cost on different-location trials, and recovery from capture resulted primarily from RTs becoming longer on same-location trials at SOAs longer than 100 ms. These even displayed a nonsignificant tendency to exceed RTs on no-distractor and different-location trials (at the 150-ms SOA), suggesting that the location of the salient distractor might have become inhibited.

The notion that capture may be overcome by inhibiting the salient distractor's location is consistent with the results obtained in Theeuwes et al.'s (2000) Experiments 2 and 3. The procedure was similar to the one used in their first experiment, described earlier, except that the no-distractor condition was omitted and capture by the color singleton was measured using a response compatibility manipulation. Theeuwes et al. reported faster performance when the letter inside the color singleton was identical to the letter inside the target shape (compatible with the response) than when it was different from it (incompatible with the response) at SOAs of 50 and 100 ms, indicating that the color singleton initially captured attention to its location. With the 200-ms SOA, compatibility effects were reversed, as RTs on trials in which the letter inside the color singleton was incompatible with the response elicited by the letter inside the target were longer than when it was compatible. The compatibility effect was reinstated at the 400-ms SOA, which is outside the SOA range tested in the present experiment. Theeuwes et al. (2000) suggested that "to gain attentional control, subjects may have inhibited the distractor location" (p. 116) and that such inhibition may be short lived. Although it remains unclear why RTs on different-location trials decreased in Theeuwes et al.'s study but remained virtually flat in the present experiment, the same conclusions may be drawn from the results of the two studies. Specifically, evidence for no capture by an irrelevant singleton at a 150-ms SOA may conceal capture at earlier SOAs, and such recovery from capture may perhaps be achieved by inhibitory processes.

The present results suggest that subjects cannot ignore a color singleton when searching for a shape singleton, which indicates that control settings cannot be tuned to a discontinuity in just the shape dimension. This finding is equally consistent with Theeuwes's (e.g., 1992) claim that no selectivity is possible within singleton-detection mode and with Folk et al.'s (1992) claim that "the contingencies for exogenous attention orientation operate at the level of static discontinuities in general" (p. 1040), as the singletons used in the present experiment were both defined as static discontinuities (in color and in shape). The objective of the next experiment was to test Theeuwes's and Folk's proposals against each other by investigating whether attentional control settings can be tuned to a broader level, namely, to the level of static discontinuities. In order to do so, we explored the ability of an irrelevant onset singleton to capture attention when subjects search for a color singleton target, using SOAs ranging from 50 to 300 ms rather than a fixed 150-ms SOA, as in Folk et al.'s (1992) study.

Experiment 2

Method

Subjects

Subjects were 15 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having corrected-to-normal visual acuity and normal color vision.

Apparatus, Stimuli, Procedure, and Design

Figure 1 (lower row) illustrates the sequence of displays. The apparatus, stimuli, procedure, and design were the same as in Experiment 1 except for the following differences. The ready display consisted of light-gray circles instead of dark-gray superimposed diamonds and circles. In the distractor-absent condition, the distractor display was identical to the ready display, whereas in the distractor-present condition, a 3-pixel-thick white outline diamond was superimposed on one of the circles. The interstimulus display was identical to the ready display—that is, the abruptly onset diamond was no longer present. In the target display, one gray circle turned to an equiluminant red. Thus, the target display was made up of five gray outline circles and one red circle. Subjects were required to indicate what sign had appeared within the unique red circle in the target display, while attempting to ignore the distractor display.

Results

The data from 1 subject were excluded from the analysis because this subject made more than 20% errors. Mean RTs on correct trials and accuracy data are presented in Figure 3. In all RT analyses, error trials (3.9% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of distractor display and SOA. RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed less than 1% of all observations.

Spatial Congruency Effects

An ANOVA was conducted excluding the no-distractor condition, with SOA and distractor-target location as factors.

RTs. Only the main effect of distractor-target location was significant, with same-location trials yielding shorter RTs than different-location trials (515 ms vs. 544 ms), $F(1, 13) = 18.31$, $p = .0009$. Neither the main effect of SOA nor the interaction between the two factors approached significance (all Fs < 1).

Accuracy. The interaction between distractor-target location and SOA approached significance, $F(5, 65) = 2.28$, $p < .06$. Whereas at all SOAs, accuracy was higher on same-location than on different-location trials, the reverse was true at 150-ms SOA (0.96 vs. 0.93), but this effect failed to reach significance, $F(1, 13) = 1.84$, $p > .10$.

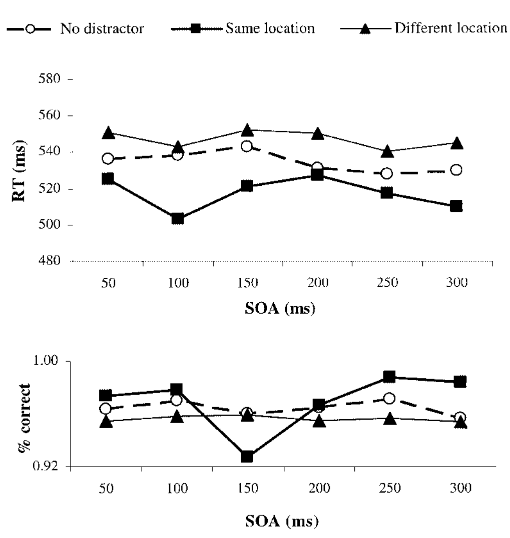

Figure 3. Experiment 2 (in which target was a known color singleton and distractor was an abrupt onset): Target identification performance in the no-distractor, same-location, and different-location conditions as a function of distractor-to-target stimulus onset asynchrony (SOA).

Interference Effects

An ANOVA was conducted excluding the same-location condition, with SOA and distractor condition (no distractor vs. different location) as factors.

RTs. RTs were shorter on no-distractor trials than on different-location distractor trials (530 ms vs. 544 ms), $F(1, 13) = 9.85$, $p < .08$, and the main effect of SOA approached significance, $F(5, 65) = 2.21$, $p < .07$. There was no interaction between the two factors ($F < 1$).

Accuracy. None of the main effects or interactions approached significance.

Discussion

The results of this experiment are straightforward. An irrelevant onset singleton—that is, a dynamic discontinuity—produced spatial capture in a task where subjects had to search for a color singleton—that is, for a static discontinuity. Somewhat surprisingly, on both the spatial congruency and interference measures, capture was stable across SOAs (although we did note a sharp but nonsignificant drop in accuracy in the same-location condition at the 150-ms SOA). We expected these effects to decrease with longer SOAs, which would have been consistent with Folk et al.'s (1992) finding of no capture under similar conditions using a 150-ms SOA. If anything, as the singleton distractor matched more closely the attentional set promoted by the task in Experiment 1 than in Experiment 2, we expected attentional deallocation from the irrelevant singleton to be faster in Experiment 2, in line with Theeuwes et al.'s (2000) speculation. Note that, in contrast with Folk et al.'s typical procedure, the target and distractors in the target display were equiluminant in the present study, which rules out the possibility that subjects might have searched for a difference in luminance.

R. W. Remington (personal communication, August 30, 2002) observed that with larger (six items) but not smaller (four items) display sizes, a distractor that does not match current attentional settings may sometimes produce spatial congruency effects that derive exclusively from the locations immediately adjacent to the target location. Although the explanation for this effect is unclear, it is reasonable to claim that such spatially restricted effects would be diagnostic of weak spatial capture. However, additional analyses of the data showed that this effect does not account for the capture observed in the present experiment. The spatial congruency effect was significant for all distances: 29 ms, $F(1, 13) = 18.25$, $p < .03$; 30 ms, $F(1, 13) = 14.79$, $p < .02$; and 24 ms, $F(1, 13) = 14.05$, $p < .03$, for salient distractors separated from the target by 0, 1, and 2 intervening items, respectively. It did not interact with SOA (all Fs < 1).

Experiment 3

Taken together, the results of Experiments 1 and 2 suggest that perfect top-down selectivity is not possible in singleton search. Attention control settings at the dimension level or at the broader level of static versus dynamic discontinuities cannot prevent capture by an irrelevant singleton, although under certain circumstances, capture can be overridden if enough time is allowed for top-down control to be exerted.

It is important to point out that, as Bacon and Egeth (1994) noted, there is always an inherent ambiguity as to which strategy subjects use when the target is a singleton *and* is defined by a known feature. Indeed, in such cases, subjects may use either singleton-detection mode or feature-search mode to find the target. It is possible that in experiments supporting the contingent involuntary orienting hypothesis, in which the target feature was always known, the conditions were such that subjects used feature-search mode rather than singleton-detection mode—for instance, because displays were sparse and singletons may therefore have been less salient. Previous studies have shown that irrelevant singletons can be ignored when subjects search for a specific feature. Thus, the use of feature-search mode could account for Folk et al.'s (1992) results. Consistent with this possibility, note that Folk and Remington (1998, Experiment 1) found capture by an irrelevant singleton only when that singleton exactly matched the target-defining feature, whether subjects were engaged in a task promoting the use of feature-search mode (i.e., in which the target was not a singleton) or the target was a singleton with a known feature.

Of course, inferring that singleton-detection mode has been used whenever an irrelevant singleton is found to capture attention while inferring that feature-search mode has been used instead whenever an irrelevant singleton does not capture attention is clearly circular reasoning. To avoid this problem, it is essential to unconfound the use of the two modes by ensuring that subjects can use one or the other, but not both.

The objective of this experiment was to investigate the possibility that an abrupt onset may capture attention when subjects adopt singleton-detection mode but not when they adopt feature-search mode, while clearly disambiguating the two modes. Note that whereas previous studies showed that irrelevant featural singletons can be ignored when subjects search for a specific feature (e.g., Bacon & Egeth, 1994; Yantis & Egeth, 1999, Experiments 1–7 and 9), no study to date has shown that using the feature-search mode also allows one to ignore an onset singleton. In studies supporting the idea that abrupt onsets are special in their ability to summon attention to their locations (e.g., Jonides & Yantis, 1988), subjects typically searched for a target letter among distracting letters. Thus, attention could not be guided by knowledge of a simple feature defining the target. Involuntary capture by irrelevant onsets in such experiments may thus have resulted from insufficient top-down guidance.

In the present experiment, we compared a condition in which subjects could use only singleton-detection mode with a condition in which they could use only feature-search mode. In the singleton-detection condition, the specific color of the color singleton target was randomly varied across trials.[4] Thus, subjects had to look for a color discontinuity and could not use feature-search mode. In the feature-search condition, the target appeared among heterogeneously colored distractors. Thus, subjects had to look for a specific color and could not use singleton-detection mode. As in the previous experiments, distractor-to-target SOA was varied in the range of 50 to 300 ms.[5]

Method

Subjects

Subjects were 16 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having corrected-to-normal visual acuity and normal color vision.

Apparatus, Stimuli, Procedure, and Design

The apparatus, stimuli, procedure, and design were the same as in Experiment 2 except for the following differences. Subjects were run on two blocked conditions. In the singleton-detection condition, subjects had to search for the uniquely colored circle among gray circles. The color of the target circle was randomly varied and was equally likely to be red, green, blue, or purple. In the feature-search condition, the target display consisted of one red, one green, one blue, one purple, and two gray circles. Each subject had to search for the circle with a prespecified color that remained constant throughout the feature-search block and was counterbalanced between subjects. The red, green, blue, purple, and gray colors were matched for luminance (8.1 cd/m^2, 8.2 cd/m^2, 7.9 cd/m^2, 8.0 cd/m^2, and 8.2 cd/m^2, respectively) using a light meter (Photo Research Inc. Litemate/Spotmate System 500). The design included three within-subject factors, SOA (50, 100, 150, 200, 250, or 300), distractor-target location (same vs. different), and search mode (singleton-detection vs. feature-search). Search mode order was included as a between-subjects factor, with half of the subjects running on the singleton-detection condition first and the remaining half running on the feature-search condition first. Each search mode condition began with 30 practice trials, followed by three blocks of 100 trials each. Thus, the experiment included 60 practice trials and 600 experimental trials.

Results

Mean RTs on correct trials and accuracy data are presented in Figure 4. In all RT analyses, error trials (4.3% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of search mode (singleton-detection vs. feature-search), SOA, and distractor-target location (same vs. different). RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed less than 1% of all observations. Preliminary analyses revealed no main effect of condition order or target color and no interaction involving any of these factors. To increase the statistical power of the analyses, the data were collapsed across these variables.

RTs

Trials in which the target appeared at the same location as the distractor were significantly faster than trials in which they ap-

[4] Although the term *singleton-detection mode* may imply that subjects look for any singleton, there is no such claim here, as subjects could actually restrict their search to color discontinuities. We simply contrast a situation in which the subjects must search for a discontinuity with a situation in which they must search for a specific feature.

[5] For the experiments in which search mode was manipulated (Experiments 3–5), the no-distractor condition was omitted to maintain statistical power without dramatically increasing the number of trials (and hence practice). We assumed that this omission would not significantly reduce the informative value of these experiments, on the basis of the fact that interference effects generally paralleled spatial congruency effects in Experiments 1 and 2.

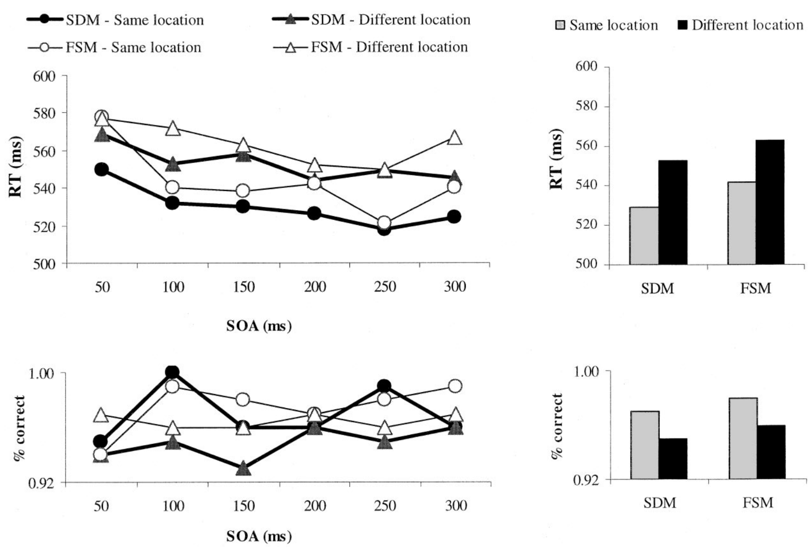

Figure 4. Experiment 3 (in which stimuli were similar to those of Experiment 2): Target identification performance in the same-location versus different-location conditions, in the singleton-detection mode (SDM; target = unknown color singleton; distractor = abrupt onset) and feature-search mode (FSM; target = color nonsingleton; distractor = abrupt onset). Left panels: performance as a function of distractor-to-target stimulus onset asynchrony (SOA); right panels: summary across SOAs.

peared at different locations (536 ms vs. 558 ms), $F(1, 15) = 10.85$, $p < .05$. There was a general tendency for RTs to decrease as SOAs became longer, $F(5, 75) = 10.16$, $p < .01$. RTs were shorter in the singleton-detection condition than in the feature-search condition (549 ms vs. 560 ms), $F(1, 15) = 5.66$, $p < .04$. No interaction approached significance. In particular, the distractor-target location (same vs. different) effect did not interact with SOA, in either the singleton-detection or the feature-search conditions (all Fs < 1). Moreover, the location effect did not interact with search mode, with a similar location effect in the two search mode conditions, 24 ms versus 21 ms, in the singleton-detection and feature-search conditions, respectively ($F < 1$).

Again, further analyses were conducted to examine whether the observed spatial congruency effects might be restricted to locations adjacent to the target. In the singleton-detection condition, the location effect was significant at all distances: 24 ms, $F(1, 15) = 15.42$, $p < .02$; 23 ms, $F(1, 15) = 11.45$, $p < .05$; and 22 ms, $F(1, 15) = 6.75$, $p < .03$, for distractors separated from the target by 0, 1, and 2 intervening items, respectively. In the feature-search condition, the location effect was significant when the target was adjacent to the salient distractor's location, 23 ms, $F(1, 15) = 4.41$, $p = .05$, and when it was separated from it by one intervening item, 22 ms, $F(1, 15) = 7.96$, $p < .02$, but not by two intervening items, 14 ms, $F(1, 15) = 1.19$, $p > .30$. There was no interaction with SOA in any mode for any distance.

Accuracy

None of the main effects or interactions approached significance.

Discussion

An irrelevant onset captured attention both when subjects searched for an unspecified color singleton (singleton-detection condition) and when they searched for a nonsingleton target defined by its color (feature-search condition). Moreover, the irrelevant onset captured attention to the same extent whether subjects adopted singleton-detection mode or feature-search mode, and at all distractor-to-target SOAs, including the 150-ms SOA used by Folk et al. (1992). Thus, the potential use of feature-search mode in Folk et al.'s study cannot account for their finding of no capture by an onset singleton in search for a color singleton target. Finally, this effect was not confined to locations adjacent to the target and was significant at all distances, except for the larger distance in the feature-search mode condition.

It may be significant that our displays differed substantially from Folk et al.'s (1992). Most notably, the irrelevant onset in their study (four small white dots) may have been less salient than the thick outline diamond used here. It is possible that the ability to disengage attention from the location of an onset object may depend on this object's salience. That is, whereas a dim onset may capture attention for a short period of time, it may take longer to disengage one's attention from a brighter onset. This in turn could explain why Folk et al. (1992) observed no attentional capture by an onset in search for a color target, with a 150-ms SOA. Moreover, the display-wide characteristics of our displays may have induced an attentional set for onsets (e.g., Gibson & Kelsey, 1998). Indeed, the target display was characterized by strong luminance transients at all locations, as the signs inside each shape were abruptly onset. Although the same conditions prevailed in Folk et al.'s experiments, it is possible that display-wide characteristics may become more salient as display size—and thus the number of onset elements—increases. We conducted an additional experiment in order to reduce these potentially consequential differences. The procedure was identical to that of Experiment 3, but the stimuli were designed to be identical to those of Folk et al., except for color differences resulting from the search mode manipulation.

Experiment 4

Method

Subjects

Subjects were 16 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected visual acuity and normal color vision.

Apparatus, Stimuli, Procedure, and Design

The apparatus, procedure, and design were identical to those of Experiment 3. The only difference concerned the stimuli used, which were designed to be similar to Folk et al.'s (1992). The fixation display was a gray 0.8° × 0.8° plus sign (+), in the center of a black background. The ready display consisted of the fixation display, on which were superimposed four peripheral boxes (1.15° × 1.15°) placed 4.7° above, below, to the left, and to the right of fixation. All boxes were gray outline squares. The distractor display was identical to the onset-cue display used by Folk et al. It consisted of the ready display with the addition of a set of four small gray circles (0.36° in diameter), in a diamond configuration, surrounding one of the peripheral boxes. The circles were placed such that each was centered approximately 0.3° peripheral to its respective side of the box. The interstimulus display was identical to the ready display. The target display consisted of the ready display with the addition of two × and two = signs randomly assigned to the boxes. The sign and box centers overlapped. Each sign subtended 0.57° of visual angle. Because of the search mode manipulation used in the present experiment, stimulus colors were different from those used by Folk et al. (1992). In the singleton-detection condition, three signs were gray and the remaining sign was colored. It could be green, blue, red, or purple. Thus, each target display contained one color singleton, which was the target. The specific color of the target varied from trial to trial in a random fashion and was equally likely to be green, blue, red, or purple. In the feature search condition, each sign had a different color (green, blue, red, or purple). Each subject had to search for the sign with a prespecified color that remained constant throughout the feature-search block and was counterbalanced between subjects. The red, green, blue, purple, and gray colors were the same as in Experiment 3.

Results

Mean RTs on correct trials and accuracy data are presented in Figure 5. In all RT analyses, error trials (4.2% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of search mode (singleton detection vs. feature search), SOA, and distractor-target location (same vs. different). RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed less than 0.5% of all observations. Preliminary analyses revealed no main effect of condition order or target color and no interaction involving any of these factors. To increase the statistical power of the analyses, the data were collapsed across these variables.

RTs

Trials in which the target appeared at the same location as the distractor were significantly faster than trials in which they appeared at different locations (527 ms vs. 548 ms), $F(1, 15) = 23.61$, $p < .02$. There was also a main effect of SOA, with a general tendency for RTs to decrease as SOAs became longer, $F(1, 15) = 6.82$, $p < .01$. There was no main effect of search mode ($F < 1$). No interaction approached significance. In particular, the distractor-target location (same vs. different) effect did not interact with SOA, $F(1, 15) = 1.15$, $p > .30$, in either the singleton-detection condition ($F < 1$) or the feature-search condition, $F(1, 15) = 1.38$, $p > .20$. Moreover, the location effect was similar in the two search mode conditions, 22 ms versus 20 ms, in the singleton-detection and feature-search conditions, respectively ($F < 1$).

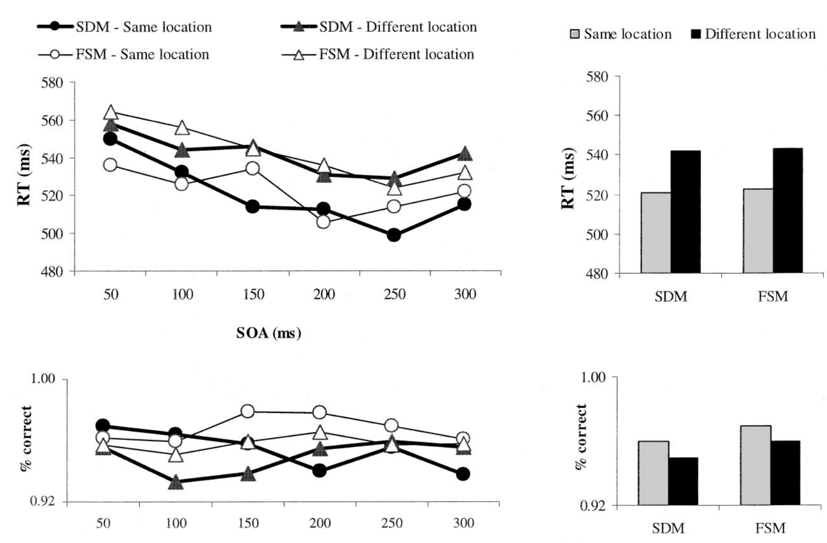

Figure 5. Experiment 4 (in which stimuli were similar to those of Folk et al., 1992): Target identification performance in the same-location versus different-location conditions, in the singleton-detection mode (SDM; target = unknown color singleton; distractor = abrupt onset) and feature-search mode (FSM; target = color nonsingleton; distractor = abrupt onset). Left panels: performance as a function of distractor-to-target stimulus onset asynchrony (SOA); right panels: summary across SOAs.

Accuracy

The main effect of location approached significance, with higher accuracy in the same-location than in the different-location condition (0.96 vs. 0.95), $F(1, 15) = 4.06$, $p < .07$. No other effect approached significance.

Discussion

The results of the present experiment closely replicated those of Experiment 3, thus making it unlikely that stimuli differences may account for the discrepancy between our results and those of Folk et al.'s (1992). Although we did not attempt an exact replication of their experiment, according to the contingent capture hypothesis no spatial congruency effect should have been observed in the conditions prevailing here. It is important to note, however, that the present results do not speak to Folk et al.'s central claim, which is that attentional control settings may modulate attentional capture. They only refute a strong version of the contingent capture hypothesis, according to which attentional capture by abrupt onsets is strictly contingent on these settings.

The present results confirm the conclusion of Experiments 2 and 3 that an irrelevant dynamic discontinuity may capture attention when subjects search for a static discontinuity (singleton-detection condition). They also extend previous findings suggesting that abrupt onsets (or certain categories of dynamic events; see Franconeri & Simons, in press) are unique in their ability to capture attention. Indeed, we showed that this happens also with strong top-down guidance, namely, in search for a known nonsingleton color (feature-search condition) clearly discriminable from the other colors present in the display, rather than only in difficult search for a specific letter (e.g., Jonides & Yantis, 1988).

Experiment 5

It may be somewhat surprising that in Experiments 3 and 4, no difference was found in the magnitude and time-course of capture by an irrelevant onset whether subjects were forced to adopt singleton-detection or feature-search mode. One would have expected larger and longer lasting spatial congruency effects in the former condition, as subjects were searching for a discontinuity. This finding may have implications for the status of onsets in the hierarchy of attentional control settings. Attentional capture by abrupt onsets may be impervious to top-down control settings, in the sense that whatever the attentional set adopted by the observer, irrelevant onsets capture attention in the same manner. According to this hypothesis, the distinction between singleton-detection and feature-search modes may in fact be a distinction between set for a static discontinuity versus set for a specific feature, with neither set being able to override capture by irrelevant onsets.

Another possibility is that, as was initially proposed by Theeuwes (e.g., 1991, 1992), there is no top-down selectivity at the preattentive stage, and the most salient element in a display captures attention whatever the observer's attentional set. Indeed, the results of Experiments 3 and 4 showed no effect of the distinction between singleton-detection and feature-search modes. We may attribute this finding to the special status of abrupt onsets, or we may question the distinction itself. Although it has been widely embraced in the literature, actual empirical support for it comes only from Bacon and Egeth's (1994) study. They showed that when the target was a shape singleton and had a known feature, the presence of an irrelevant color singleton impaired performance (their Experiment 1). In contrast, this disruption disappeared when up to three identical target shapes were presented on each trial (their Experiment 2) or up to two different unique shapes in addition to the unique target shape (their Experiment 3). They concluded that subjects used singleton-detection mode in their Experiment 1 and feature-search mode in their Experiments 2 and 3, where the use of singleton-detection mode was discouraged.

Although the distinction between singleton-detection and feature-search modes provides a reasonable account for Bacon and Egeth's (1994) results, one should keep in mind that this account is contingent on several assumptions that have not been tested. Subjects are held to have used singleton-detection mode in their Experiment 1, where both strategies were available, although feature-search mode was more attractive from a probabilistic viewpoint. Indeed, feature-search mode would guide attention directly to the target on 100% of the trials, whereas singleton-detection mode would direct attention to the wrong singleton on 50% of the trials. Thus, in order to accept Bacon and Egeth's conclusions, one must assume that (a) singleton-detection mode must be a less cognitively demanding mode of processing than is feature-search mode, such that it remains the preferred search strategy even when it is detrimental on 50% of the trials (Bacon & Egeth's Experiment 1), and (b) it ceases to be the preferred strategy when it is detrimental on 5/6 of the trials (their Experiments 2 and 3). We are currently exploring this issue.

The objective of Experiment 5 was to verify whether the distinction between singleton-detection and feature-search modes is valid when subjects look for a static discontinuity. We examined to what extent—if at all—the tendency of an irrelevant color singleton to capture attention differs when subjects are forced to use singleton-detection mode (search for a discrepant shape) versus feature-search mode (search for a specific shape). On the basis of Bacon and Egeth's (1994) findings, we expected spatial capture to be observed only in the singleton-detection condition, not in the feature-search condition.

Method

Subjects

Subjects were 18 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected visual acuity and normal color vision.

Apparatus, Stimuli, Procedure, and Design

The apparatus, stimuli, and procedure were the same as in Experiment 1 except for the following differences. Similar to Experiment 3, there were two blocked conditions, a singleton-detection condition and a feature-search condition. Figure 6 illustrates the sequence of events in the singleton-detection condition (upper row) and in the feature-search condition (lower row). In the singleton-detection condition, the target display contained one target shape and five circles. The target shape singleton could be a diamond, a square, or a triangle, with equal probability. Its specific form varied from trial to trial in a random fashion. In the feature-search condition, the target display always contained one diamond, one square, one triangle, and three circles. The target was a diamond, a square, or a triangle, and its specific form was counterbalanced between subjects. That is, 6 subjects searched for the diamond throughout the feature-search

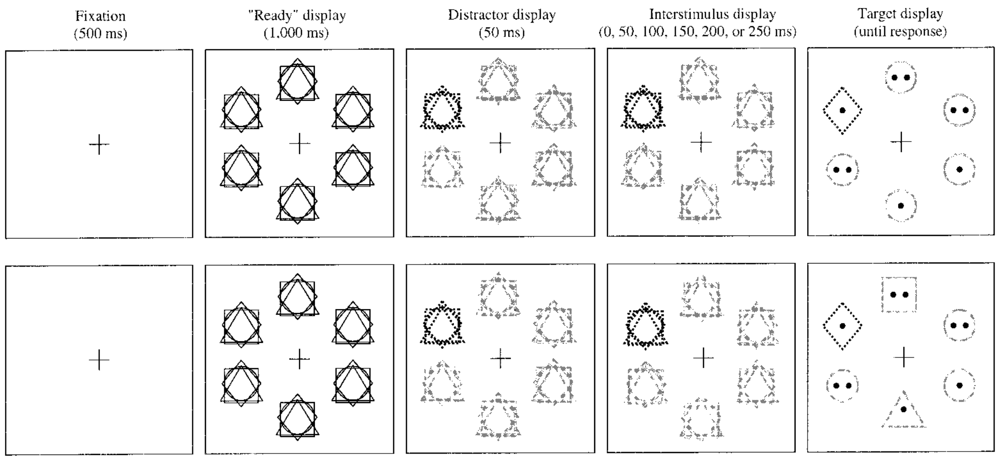

Figure 6. Experiment 5: Stimuli and sequence of events in the singleton-detection condition (upper row) and feature-search condition (lower row). The examples correspond to the same-location condition. Dotted lines were red, gray lines were light gray, thin black lines were dark gray, and black dots were white. All stimuli were presented against a black background.

block, 6 other subjects searched for the square, and the remaining 6 subjects searched for the triangle.

In the ready display, the superimposed shapes at each of the six possible locations were a diamond, a square, a triangle, and a circle, instead of just a diamond and a circle. All four shapes were centered on one another. The circle and diamond were identical to those used in Experiment 1. The triangle was equilateral, each of its sides subtending 2.55° of visual angle. Each of the square's sides subtended 2.04°.

In the distractor display, the four superimposed shapes at the distractor's location turned red. Then, instead of returning to gray, the red distractor remained red until the end of the trial.[6] That is, (a) the interstimulus display (between the distractor and target displays) was identical to the distractor display, and (b) in the target display, in the same-location condition, three of the superimposed red shapes, including the circle, were offset, with the target being the remaining red shape. In the different-location condition, the red square, triangle, and diamond were offset, and the remaining red circle was one of the nontargets. There was no distractor-absent condition.

In the target display, each shape contained either one or two white dots instead of either an × or an = sign.[7] Subjects were required to press *1* if the target shape contained one dot and *2* if it contained two dots. Each dot was a white filled circle with a diameter of 0.3°. In the three shapes in which only one dot appeared, it was centered on the shape center. In the remaining three shapes, the dots were on the right and left of the shape center, and their centers were distant from it by 0.3°. The design was the same as in Experiments 3 and 4.

Results

Mean RTs on correct trials and accuracy data are presented in Figure 7. In all RT analyses, error trials (4.2% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of search mode (singleton-detection vs. feature-search), SOA, and distractor-target location (same vs. different). RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed less than 1% of all observations. Preliminary analyses showed no effect of SOA and no interaction involving this factor (all Fs < 1). In the following analysis, the data were thus collapsed across SOAs. Moreover, counterbalance checks revealed an unexpected but significant interaction involving condition order. Thus, this factor was entered in the analysis.

RTs

An ANOVA was conducted on correct RTs with condition order as a between-subjects factor and distractor-target location and search mode as within-subject factors. Trials in which the target appeared at the same location as the distractor were significantly faster than trials in which they appeared at different locations (767 ms vs. 791 ms), $F(1, 16) = 5.67$, $p = .03$. No other main effect approached significance (all Fs < 1). The triple interaction between distractor-target location, condition order, and search mode was significant, $F(1, 16) = 7.56$, $p < .02$. Paired comparisons showed that for the singleton-detection block, the location effect was significant whether this block was presented to subjects first (749 ms vs. 807 ms), $F(1, 8) = 9.60$, $p < .02$, or second (721 ms vs. 771 ms), $F(1, 8) = 6.36$, $p < .04$. In the feature-search block, same-location trials were significantly slower than different-location trials when this block was presented first (836 ms vs. 785 ms), $F(1, 8) = 6.16$, $p < .04$, whereas a same-location advantage was found when the feature-search block followed the singleton-detection block (762 ms vs. 801 ms), $F(1, 8) = 2.90$, $p = .13$. Although the latter effect failed to reach significance, it should be noted that out of the 9 subjects who received the feature-search

[6] This change in procedure relative to the preceding experiment was necessary to allow for the comparison of the present experiment and the next one with previous studies that examined the effects of a salient distractor in search for a nonunique target (e.g., Bacon & Egeth, 1994; Jonides & Yantis, 1988) and in which the salient distractor and target appeared simultaneously.

[7] This change was introduced because in a pilot version of this experiment, subjects had difficulties performing the task, with RTs over 1,300 ms on average. The subjective impression was that the shape discrimination required in deciding whether an × or an = sign appeared in the target shape and the task of detecting the target shape interfered with each other.

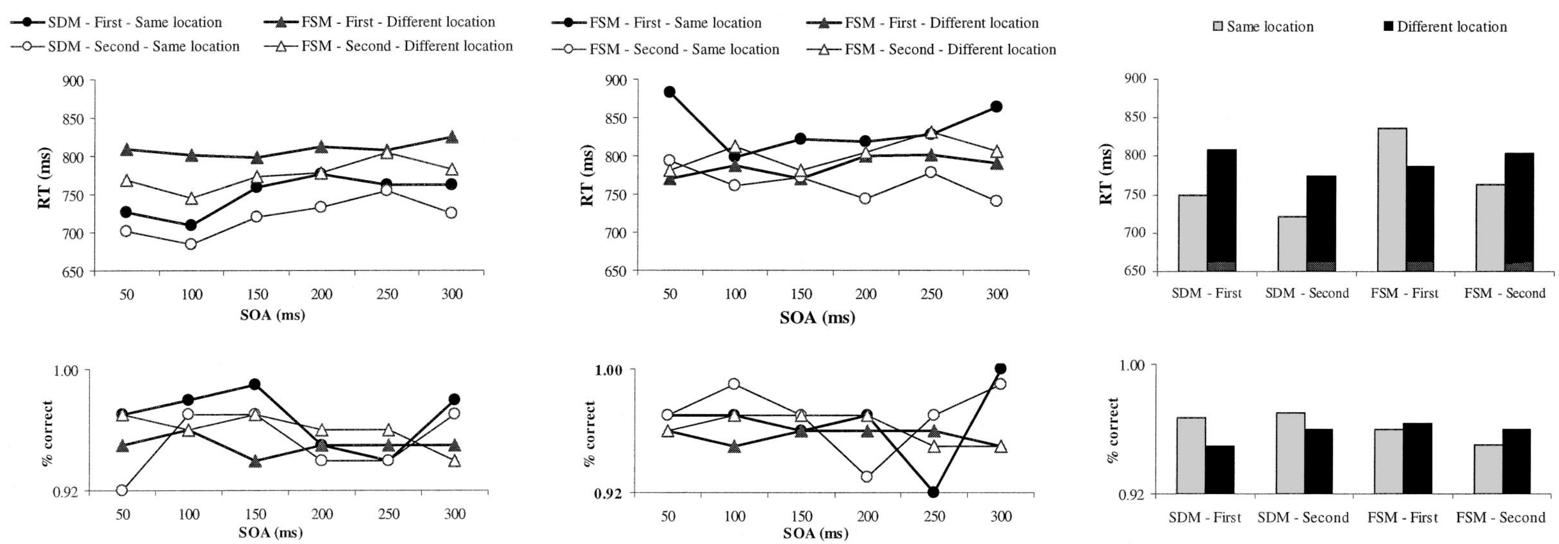

Figure 7. Experiment 5 (in which the target was defined by its shape and distractor was a color singleton): Target identification performance in the same-location versus different-location conditions. Left panels: performance as a function of distractor-to-target stimulus onset asynchrony (SOA) in the singleton-detection mode (SDM) when it was presented as the first (SDM-first) versus the second (SDM-second) block. Middle panels: performance as a function of SOA in the feature-search mode (FSM) when it was presented as the first (FSM-first) versus the second (FSM-second) block. Right panels: summary across SOAs.

block second, 7 showed a large same-location advantage (744 ms vs. 805 ms), $F(1, 6) = 8.66$, $p < .03$, whereas 2 showed a large same-location cost (835 ms vs. 774 ms). For comparison, note that all subjects showed a large same-location cost when the feature-search block was presented first (835 ms vs. 770 ms), except for one subject, who showed a large same-location advantage (846 ms vs. 924 ms). The same-location advantage was of comparable magnitude in the singleton-detection mode second and feature-search mode second conditions (54 ms vs. 40 ms, respectively), $F(1, 8) = 1.59$, $p > .20$.

Accuracy

No effect approached significance.

Discussion

The results showed a different pattern in the singleton-detection and in the feature-search conditions, thus supporting Bacon and Egeth's (1994) proposal that these modes should be distinguished. When subjects had to search for a unique shape, the form of which varied across trials—that is, when they had to use singleton-detection mode—same-location trials were faster than different-location trials, suggesting that the irrelevant color singleton captured attention. This finding is consistent with the results of Experiment 1 as well as with earlier reports (e.g., Theeuwes, 1991, 1992; Theeuwes & Burger, 1998, Experiment 2). Note, however, that capture was stable across SOAs in the present experiment, whereas in Experiment 1 it was found to disappear with distractor-to-target SOAs of 150 ms and above. It is unlikely that differences in the displays used (namely, the fact that the target might be a square, a triangle, or a diamond instead of always a diamond) account for this discrepancy, as no effect of target shape was found in the present experiment ($F < 1$). The two experiments also differed in distractor display exposure time. Whereas the distractor array was removed after 50 ms in Experiment 1, the salient distractor remained present until the offset of the target array in Experiment 5, and this may have made it more difficult for subjects to deallocate their attention from the salient distractor's location. Note, however, that Theeuwes et al. (2000) reported recovery from capture that followed a time course similar to that observed in the present Experiment 1, despite the fact that the color singleton remained visible until response. Thus, distractor exposure duration does not appear to be the critical factor. One final possibility is that recovery from capture may be difficult or even impossible when produced by a distractor that matches current control settings. That is, the process underlying recovery from capture might be triggered by a mismatch between the target-defining feature and the distractor's salient feature. In Experiment 5, the target was defined by its having a unique feature, such that the irrelevant distractor possessed the target-defining feature (it was a singleton), and recovery from capture was therefore not observed. In Experiment 1, subjects could use both singleton-detection and feature-search modes to find the target. One may speculate that when the two modes are available, they compete to control behavior at the preattentive stage, with singleton-detection mode prevailing early on and feature-search mode dominating thereafter. We are currently exploring this possibility.

An additional but unexpected finding in Experiment 5 concerns the pattern of performance in the feature-search condition. When subjects had to search for a nonsingleton target with a specific form, same-location trials were actually slower than different-location trials. However, this happened only when subjects had not previously been searching for a singleton. When subjects searched for a specific shape after a block of searching for a discrepant shape, the irrelevant singleton captured attention and did so to the same extent as it did in the singleton-detection condition. Thus, it appears that in order to prevent capture by an irrelevant singleton, subjects actively inhibit its location but are usually unable to use such a strategy if they have recently been looking for a task-relevant singleton. Note that when the singleton-detection block was presented first, subjects had to ignore the same irrelevant color singleton as in the following block—that is, the feature-search condition. Such practice did not make them more proficient in ignoring the color singleton. Instead, practice in searching for a shape discontinuity prevented them from ignoring the previously to-be-ignored discontinuity in color. This result strongly suggests that there is little or no selectivity within singleton-detection mode, as looking for a *shape* singleton in the first block made a *color* singleton more likely to capture attention in the second block.

The finding that subjects inhibit the location of an irrelevant singleton when they use feature-search mode is inconsistent with other authors' findings. For instance, Jonides and Yantis (1988) found that subjects are equally fast to find a target letter when this letter happens to be a color singleton as when one of the distracting letters is a color singleton. In other words, they found no difference between the same- and different-location conditions. However, the distractor and target appeared simultaneously in their study, whereas here, they were separated by 50 ms at the shortest SOA. Thus, the present findings can be reconciled with Jonides and Yantis's findings if it takes some time (within 50 ms) for inhibition to accrue to the irrelevant distractor's location. This possibility is explored in Experiment 6.

It may be significant that condition order was confounded with practice in Experiment 5, such that an alternative interpretation for the observed condition order effects may be that unusual effects obtained in the feature-search condition early in practice, namely, long RTs on same-location trials, may disappear when subjects become more practiced with the task. To test this account, practice effects in the feature-search-first condition were analyzed. An ANOVA with target-distractor location (same vs. different), SOA, and block (first, second, or third block of 100 trials) was conducted on data from the feature-search-first condition. The main effect of block approached significance, $F(2, 16) = 3.27$, $p < .07$, but did not interact with the target-distractor location (same vs. different) effect, $F(2, 16) = 1.31$, $p > .20$. Obviously, it remains true that subjects were more practiced with the task upon entering the feature-search-second condition than they were even in the last third of the feature-search-first condition. Thus, it is in principle possible—although unlikely—that practice may affect behavior in feature-search mode with practice longer than 300 trials. A corollary objective of Experiment 6 was to examine this possibility.

Experiment 6

Experiment 6 was an attempt to bridge the gap between Jonides and Yantis's (1988) study, in which the location of an irrelevant featural singleton was found to be neither prioritized nor inhibited, and the feature-search condition of the present Experiment 5, in which we observed longer RTs when the target appeared at the same location as the irrelevant featural singleton. Accordingly, Experiment 6 was similar to the feature-search condition in Experiment 5. There were two blocked conditions: the simultaneous condition, in which the target and salient distractor appeared simultaneously, and the successive condition, in which the distractor display preceded the target display by a variable SOA.[8] We expected to replicate (a) the slower performance obtained in Experiment 5 on same-location trials in the successive condition and (b) the absence of a target-distractor location (same vs. different) effect reported by Jonides and Yantis in the simultaneous condition. A no-distractor condition was included to verify that we could replicate Bacon and Egeth's finding that an irrelevant salient distractor produces no interference in feature-search mode.

Moreover, the successive condition was a replication of the feature-search-first condition in Experiment 5 but contained close to twice as many trials (588 vs. 300 trials, respectively). Thus, if the results of Experiment 5 reflect the fact that same-location trials become faster than different-location trials in feature-search mode only late in practice, this should become apparent in the present experiment.

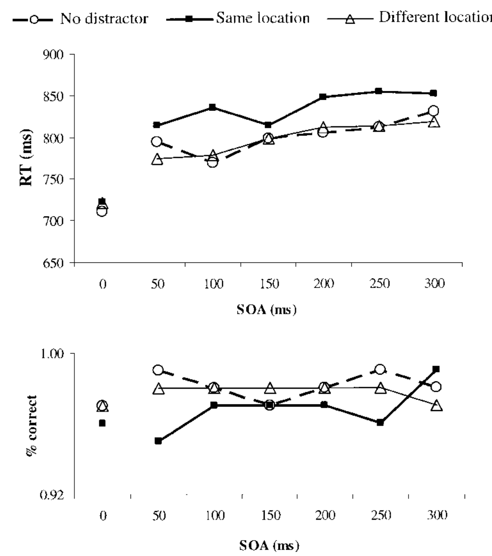

Figure 8. Experiment 6 (in which target was a shape nonsingleton and distractor was a color singleton): Target identification performance in the no-distractor, same-location, and different-location conditions as a function of distractor-to-target stimulus onset asynchrony (SOA). The simultaneous condition is plotted as SOA = 0.

Method

Subjects

Subjects were 18 Johns Hopkins University undergraduates, who participated in the experiment for course credit. All reported having normal or corrected visual acuity and normal color vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were the same as in Experiment 5 except for the following differences. Subjects were run in the feature-search condition throughout the experiment—that is, there was no singleton-detection condition. There were two blocked conditions, the successive and simultaneous conditions. The successive condition was identical to the feature-search condition used in Experiment 5, except that on 50% of the trials, there was no distractor. That is, on distractor-absent trials, all shapes remained gray during the whole trial. The simultaneous condition was identical to the successive condition except that the target display appeared immediately after the fixation display, with no distractor display and no interstimulus display. Thus, in the simultaneous condition the color-singleton distractor no longer appeared before the target shape but instead simultaneously.

Design

There were two within-subject factors, distractor display (no distractor vs. same-location distractor vs. different-location distractor) and distractor-target onset (successive vs. simultaneous). In the successive condition, there were six equiprobable and randomly mixed possible distractor-to-target SOAs (50, 100, 150, 200, 250, and 300). The order of distractor-target onset condition was included as a between-subjects factor, with half of the subjects running on the simultaneous condition first and the remaining half running on the successive condition first. The simultaneous condition began with 30 practice trials followed by one experimental block of 96 trials. The successive condition began with 30 practice trials, followed by six experimental blocks of 96 trials each.

Results

Mean RTs on correct trials and accuracy data are presented in Figure 8. In all RT analyses, error trials (2.4% of all trials) were removed from analysis, and RTs for each subject were sorted into cells according to the conditions of SOA (0 ms for the simultaneous condition, and 50–300 ms for the distractor-first condition) and distractor condition (no distractor, same-location, or different location). RTs exceeding the mean of a cell by more than 3 standard deviations were trimmed. This removed less than 0.5% of all observations. Preliminary analyses showed no main effect of condition order and no interaction between this factor and any of the variables of interest.[9] In the following analyses, the data are thus collapsed across condition order.

Spatial Congruency Effects

An ANOVA was conducted excluding no-distractor trials, with block type (successive vs. simultaneous) and distractor condition (same vs. different location) as factors.

RTs. There was a main effect of block type, with shorter RTs in the simultaneous than in the successive condition (721 ms vs. 804 ms), $F(1, 17) = 17.28$, $p < .07$. The main effect of distractor condition was nonsignificant, $F(1, 17) = 2.49$, $p > .10$, but the interaction between the two factors was significant, $F(1, 17) = 4.69$, $p < .05$. Planned comparisons showed that whereas same-

[8] These conditions were run in separate blocks rather than mixed in the same block, because in a pilot study, we found that when mixed, the two conditions produced task-switching costs, possibly because they produced very different subjective impressions.

[9] There was a significant interaction between condition order and simultaneous versus successive condition, $F(1, 16) = 25.34$, $p < .01$, with the advantage in the simultaneous condition being larger when this condition was presented second rather than first. This effect is entirely attributable to practice. Indeed, whereas the second block was run after 576 trials if it was the simultaneous condition, it was run after only 96 trials if it was the successive condition.

location trials were significantly slower than different-location trials in the successive condition (838 ms vs. 797 ms), $F(1, 17) = 6.57$, $p = .02$, there was no difference between these conditions in the simultaneous condition (724 ms vs. 720 ms), $F < 1$. Further analyses were conducted for the successive condition, to determine whether the cost on same-location trials was modulated by distractor-to-target SOA. There was a main effect of SOA, $F(5, 85) = 3.81$, $p < .04$, with longer RTs as SOAs increased. The main effect of distractor was also significant, $F(1, 17) = 7.00$, $p < .02$. The interaction between the two factors was nonsignificant ($F < 1$).

To examine potential effects of practice on behavior in feature-search mode, as was suggested in the discussion of Experiment 5, an ANOVA with block (1 to 6) and distractor condition (same vs. different) was conducted on the data of the successive condition. The main effect of practice was significant, $F(5, 85) = 7.04$, $p < .01$, with RTs becoming shorter with increased practice. So was the main effect of distractor condition, $F(1, 17) = 6.76$, $p < .02$, with longer RTs on same- relative to different-location trials. However, the interaction between the two factors did not approach significance, $F(5, 85) = 1.50$, $p = .20$.

Accuracy. None of the effects approached significance.

Interference Effects

An additional ANOVA was conducted excluding the same-location condition, with block type (successive vs. simultaneous) and distractor condition (no distractor vs. different location) as factors.

RTs. There was a main effect of block type, with shorter RTs in the simultaneous condition than in the successive condition (716 ms vs. 799 ms), $F(1, 17) = 16.60$, $p < .08$. There was no main effect of distractor condition (788 ms vs. 787 ms; $F < 1$) and no interaction between the two variables, $F(1, 17) = 1.60$, $p > .20$. Again, potential effects of practice on interference were examined. The main effect of practice was significant, $F(5, 85) = 11.32$, $p < .01$, with RTs becoming shorter with increased practice. Neither the main effect of condition nor the interaction with practice was significant (Fs < 1).

Accuracy. None of the effects approached significance.

Discussion

The results confirm that when subjects had to use feature-search mode to find a target defined by its shape, an irrelevant color singleton that appeared simultaneously with the target did not capture attention to its location (e.g., Jonides & Yantis, 1988) and caused no interference (Bacon & Egeth, 1994). Furthermore, when the irrelevant color singleton preceded the target, its location appeared to be inhibited (as indicated by longer RTs on same-location trials relative to different-location and no-distractor trials), across the range of SOAs from 50 to 300 ms, thus replicating the results of Experiment 5, and its presence caused no interference (i.e., no difference between no-distractor and different-location trials) across the same SOA range. Moreover, the observed inhibition did not diminish with practice, even after subjects were run on close to 600 trials. This finding allows us to reject the alternative interpretation for the results of Experiment 5, according to which the long RTs on same-location trials in the feature-search condition may be obtained only early in practice.

It may be noteworthy that evidence for inhibition in this experiment and the previous one came from conditions that yielded particularly long RTs (about 800 ms). The present findings may therefore constitute a special case, reflecting the use of atypical strategies to find the target form, and might not allow for generalization to easier searches. However, the results of a recent study by Lamy, Leber, and Egeth (2002) weaken this possibility. They observed the same pattern of results in an experiment where subjects had to search for a red-color target using feature-search mode and ignore a green-color singleton. Specifically, trials in which the target appeared at the same location as the irrelevant green singleton (same-location trials) were found to be slower than different-location trials, suggesting that inhibitory processes might be involved. Yet RTs were substantially shorter than in the present Experiments 5 and 6 (about 600 ms).

General Discussion

Summary

The goal of the present experiments was to investigate under what circumstances an irrelevant singleton captures attention. Three main variables were manipulated. First, to characterize the time course of attentional capture, distractor-to-target SOA was systematically manipulated over a range of 50 ms to 300 ms in all experiments. Moreover, in separate experiments, distractors and targets were defined either both within static dimensions (color distractor and shape target; Experiments 1, 5, and 6) or in different dimension types (dynamic distractor [abrupt onset] and static target [color]; Experiments 2–4). Finally, the search modes available for searching the target were controlled: In one condition, the specific feature of the singleton target was randomly varied across trials such that the target's only defining property was its possessing a unique feature on the target dimension (Experiments 3–4). Thus, subjects had to look for a discontinuity (singleton-detection mode) and could not use feature-search mode. In a second condition, the target appeared among distractors heterogeneous with regard to the target dimension. Thus, subjects had to look for a specific feature (feature-search mode) and could not use singleton-detection mode (Experiments 3–6). In a third condition, both modes were available, as the target was a singleton with a known feature (Experiments 1 and 2). Attentional capture was assessed using two measures: spatial congruency effects (same vs. different location trials) and interference effects (no-distractor vs. different-location trials).

Evidence for attentional capture was observed under the following conditions: (a) An abrupt onset distractor captured attention in search for a color target regardless of whether subjects could use only singleton-detection mode or only feature-search mode (Experiments 3 and 4) or both modes (Experiment 2). (b) A color-singleton distractor captured attention in search for a shape-singleton target, whether this target's feature was known (i.e., both search strategies were available; Experiment 1) or varied from trial to trial (i.e., only singleton-detection mode was available; Experiment 4). (c) A color-singleton distractor captured attention in search for a shape target under conditions inducing the use of feature-search mode, if subjects had used singleton-detection mode in the previous block (Experiment 5).

No capture by an irrelevant color singleton was observed when subjects were induced to use feature-search mode to locate a target defined by its form (but only when subjects had not used singleton detection mode in the previous block; Experiments 5 and 6). Moreover, subjects tended to overcome capture by a color singleton in search for a shape singleton with a known form at distractor-to-target SOAs of 150 ms and up (Experiment 1). As we show below, several features of the results favor the view that in both instances, such resistance to capture may have been mediated by feature-based inhibition.

The findings yielded by the present series of experiments have four main theoretical implications, which are detailed below. To summarize: (a) The present results support the distinction between singleton-detection and feature-search mode proposed by Bacon and Egeth (1994) while providing important refinements to it. (b) They suggest that resistance to capture is mediated by feature-based inhibition. (c) They support the notion that abrupt onsets have a special status compared with static discontinuities. (d) They are inconsistent with a strong version of contingent attentional capture (e.g., Folk et al., 1992), according to which attentional capture by abrupt onsets is strictly contingent on top-down attentional control settings.

Singleton-Detection Mode Versus Feature-Search Mode

The distinction between singleton-detection mode and feature-search mode proposed by Bacon and Egeth (1994) is articulated around three major hypotheses. First, effects of salience result from a set for searching for discrepant items (singleton-detection mode). Second, when subjects adopt the strategy of searching for a specific feature (feature-search mode), there is not a role for salience. Third, when both modes can be used, subjects use singleton-detection mode. Each of these claims now is evaluated in light of the present findings.

1. Bacon and Egeth proposed the existence of a singleton-detection mode, that is, a goal-directed strategy for looking for discrepant objects. In contrast, other authors (e.g., Kim & Cave, 1999; Theeuwes et al., 2000) argued that salience affects search in a purely bottom-up fashion and that only after attention is captured at the location of the most salient object may top-down control exerted at the attentive stage allow attention to be shifted elsewhere (Theeuwes et al., 2000, p. 122). The present findings support the existence of a singleton-detection mode. First, the tendency of a color singleton distractor to capture attention was affected by whether the known shape target was a singleton (Experiment 1 vs. feature-search condition in Experiment 5). If salience operated solely in a bottom-up fashion, whether the target is a singleton should have no effect. We must thus assume that knowing that the target was a singleton induced an attentional set for singletons. Second, the tendency to ignore irrelevant singletons in feature-search mode was eliminated if subjects had just previously been forced to use singleton-detection mode (Experiment 5). Note that this tendency was eliminated rather than just modulated, as capture was as strong as in the singleton-detection condition. This finding is incompatible with a purely bottom-up account of salience-based effects. Instead, it strongly suggests that subjects were simply unable to switch out of singleton-detection mode.

2. The notion of feature-search mode implies that subjects may adopt a mode in which attentional priority allocation is based only on the outputs of feature maps, with the output from a hypothetical discrepancy map (e.g., Koch & Ullman, 1985) being ignored and excluded from the process. Consistent with this view, earlier studies showed no effect of a salient distractor when subjects searched for a nonsingleton target (e.g., Bacon & Egeth, 1994; Lamy & Tsal, 1999; Yantis & Egeth, 1999, Experiments 1–7 and 9). The present results suggest that subjects' ability to ignore salient singletons in feature-search mode may be mediated by inhibitory processes that may become effective within 50 ms. This claim is based on the finding that under task conditions inducing the use of feature-search mode, RTs were longer on same-location than on either different-location or no-distractor trials with SOAs exceeding 50 ms, with no difference between these when the target and distractor appeared simultaneously.

3. Under the dual-strategy hypothesis proposed by Bacon and Egeth (1994), there is a built-in bias in favor of singleton-detection mode. Specifically, they assumed that whenever the target is a singleton, subjects use singleton-detection mode. As we noted earlier, the results of Experiment 1 are generally consistent with this claim, as subjects were found to adopt a set for a discrepancy, although ignoring the fact that the target was a singleton would have allowed them to better resist capture by the irrelevant singleton. The present findings also suggest that it may be easy to switch into singleton-detection mode, as in Experiment 5 capture in the singleton-detection condition was not affected by whether subjects had been previously engaged in feature-search mode. In contrast, switching out of singleton-detection mode into feature-search mode was difficult. To account for this difficulty, one may speculate that adopting a set for inhibiting the known-to-be irrelevant feature may incur a processing cost. The hypothesized cost was not apparent in Experiment 6, in which performance was the same on no-distractor and different-location trials. However, because we used a mixed design, subjects were as prepared to ignore the known color singleton on no-distractor trials as on distractor-present trials. Further investigation using a blocked design could clarify this issue.

Feature-Based Inhibition

What mechanisms underlie the finding that same-location trials are slower than different-location trials under conditions inducing the use of feature-search mode? One possibility is that salience per se is inhibited. That is, more inhibition instead of more activation would accrue to salient items, on the basis of computations of local contrast. Two observations argue against this account. First, adopting feature-search mode could not prevent or even modulate capture by an irrelevant onset (Experiments 3 and 4). If inhibition in feature-search mode accrued to locations with high bottom-up activation, we should have expected to find longer RTs on same-location trials relative to different-location trials also with onset distractors, which was clearly not the case. Second, a recent finding by Lamy et al. (2002) suggests that the known feature of the irrelevant singleton rather than salience per se may be inhibited in feature-search mode. They had subjects search for a predesignated target color (say, red) among heterogeneously colored distractors, similar to the feature-search condition used here. The critical manipulation concerned the distractor display, which, as in the present study, preceded the target display with a variable SOA. It contained a green singleton, a red singleton, or a red nonsingleton. Attention was captured to the location of the red distractor in both of the latter conditions but more strongly so when the red distractor was a singleton. In contrast, RTs were longer when the target appeared at the same location as the green distractor rather than at a different location, suggesting that the location of the green singleton was inhibited. If salience per se was inhibited, more inhibition should have accrued to the location of the red singleton (it matched the set for a red target but was salient) relative to the red nonsingleton (it matched the set for the red target and was nonsalient), resulting in less rather than more capture in the red-singleton condition. Taken together, these results favor the notion that salience plays a role also in feature-search mode but that a feature-based inhibition mechanism may offset salience-based activation and sometimes produce net inhibitory effects at the location of the salient distractor in feature-search mode. We are currently testing this idea by examining whether manipulating the strength of bottom-up activation (e.g., by varying stimulus density) and top-down inhibition (e.g., by varying the number of to-be-ignored features) affects spatial congruency effects according to the predictions of the account suggested here.

Theeuwes also proposed that inhibitory processes may underlie subjects' ability to overcome attentional capture by salient distractors, in two different studies. Theeuwes and Burger (1998) had subjects search for a nonsingleton shape with a known form. An irrelevant color singleton was present on each trial. This irrelevant singleton was found to summon attention to its location when its color varied from trial to trial (Experiment 3) but not when its color was fixed (Experiment 4). Theeuwes and Burger concluded that inhibition of the irrelevant feature is required in addition to the activation of the known-to-be-relevant target feature in order to ensure complete top-down control over search (p. 1350). In other words, they suggested that an inhibitory preparatory set for the salient distractor's feature is a necessary condition for resisting capture by this distractor. This conclusion is based on the assumption that such an inhibitory set cannot be held simultaneously for two different features, as it is the very fact that attentional capture effects were reinstated when the salient distractor's feature could take on two values rather than just one that was held as evidence for the involvement of inhibitory processes. Note that Theeuwes and Burger did not measure inhibition but only assumed a feature-based inhibitory mechanism in order to explain the absence of capture. In contrast, in the present study inhibition was directly measured as longer RTs on the same-location than on no-distractor trials.

Theeuwes et al. (2000) also invoked a role for inhibitory processes in order to account for the recovery from capture by an irrelevant color singleton in search for a shape singleton with a known form observed in their Experiments 2 and 3. As was described earlier, they found reverse compatibility effects at the 200-ms SOA, suggesting that the location of the salient distractor had been inhibited. However, this effect was not eliminated when the color of the irrelevant singleton was varied from trial to trial (their Experiment 3) rather than remaining fixed throughout the session (their Experiment 2). If anything, it was statistically significant only in their Experiment 3. To account for this finding, one must assume that the fast deallocation of attention observed in Theeuwes et al.'s study resulted from the inhibition of the location of the salient distractor after attention had been summoned to it, rather than from the preparatory feature-based inhibitory set proposed by Theeuwes and Burger (1998).

Thus, Theeuwes proposed two different inhibitory mechanisms. In search for a nonsingleton target, resistance to capture is achieved using a preparatory feature-based inhibitory set (Theeuwes & Burger, 1998), which is consistent with the findings reported in the present Experiments 5 and 6. In search for a singleton target, fast attentional deallocation mediated by spatial inhibition allows for recovery from capture (Theeuwes et al., 2000). Although this mechanism is in line with the findings of the present Experiment 1, where recovery from capture appeared to be mediated by same-location trials becoming slower at SOAs exceeding 100 ms, the conditions under which such deallocation would be possible are elusive. Why, for instance, would subjects be unable to recover from capture by an irrelevant abrupt onset (Experiments 2–4) or by a color singleton (Experiment 5, singleton-detection condition) if the mechanism supposed to allow for recovery consists of the inhibition of the location to which attention has just been summoned? The alternative mechanism proposed in the discussion to Experiment 5—namely, the competition between singleton-detection and feature-search modes—provides another possible explanation for the absence of recovery in such cases. Abrupt onsets produce long-lasting capture because they have no feature that can be inhibited. No recovery from capture is observed when subjects are induced to use singleton-detection mode because the irrelevant distractor possesses the target's defining feature (it is a singleton), such that the mismatch between the distractor's salient feature and the target's defining feature that is held to trigger feature-based inhibition is absent. However, such a mechanism cannot account for Theeuwes et al.'s finding (2000, Experiment 3) that inhibition of the salient distractor's location is maintained when the latter's salient feature varies unpredictably. This issue remains open for further enquiry.

Folk's Contingent Orienting Hypothesis

Folk et al. proposed that a salient distractor captures attention only if it matches the attentional set adopted by the observer (Folk & Remington, 1998; Folk et al., 1992, 1994; Remington et al., 2001). The data presented here provide only partial support for this claim. In line with Folk et al.'s contingent capture hypothesis, under conditions in which subjects searched for a nonsingleton target (Experiments 5 and 6), we found no evidence that attention was diverted to the location of an irrelevant static discontinuity (color singleton). When subjects searched for a known singleton, singletons defined in a different dimension than the target captured attention. Namely, a color singleton captured attention in search for a shape singleton (Experiment 1 and singleton-detection condition of Experiment 5), and an onset distractor captured attention in search for a color singleton (Experiment 2 and singleton-detection conditions of Experiments 3 and 4). These results are not necessarily inconsistent with the contingent capture hypothesis, if one assumes that depending on stimulus factors yet to be defined, subjects may adopt a general singleton detection mode or a more specific search mode (e.g., search for a shape target), when both attentional settings can be used to find the target.

However, abruptly onset distractors summoned attention to their locations when subjects searched for a nonsingleton color target (feature-search conditions in Experiments 3 and 4)—that is, when there was no basis for a match between the possible target-defining features (and corresponding possible attentional sets) and the distractor. Such a finding cannot be reconciled with the notion that attentional capture is strictly contingent on control settings. The source of the discrepancy between our results and those of Folk et al. is not clear at this point. Although we attempted no direct replication of Folk et al.'s experiments, it is unlikely that stimulus factors could explain the difference between our results, as the stimuli in Experiment 4 were designed to be as similar as possible to theirs. On the basis of the present results, however, one may conclude that strict contingency of capture by abrupt onsets on attentional settings is not a general phenomenon and may prevail only under specific conditions. It is important to keep in mind that although the present study demonstrated that attentional settings may not always be successful in preventing capture, it remains possible and even likely that they may nonetheless modulate the effects of bottom-up salience, which is the main thrust of Folk et al.'s view. We did not address this issue, because we did not manipulate the relevance of the salient distractor.

The Status of Abrupt Onsets

Several authors have proposed that abrupt visual onsets are special in their ability to capture attention (e.g., Jonides, 1981; Yantis & Jonides, 1984). The present findings support this view and extend previous reports by showing that capture by onsets cannot be prevented even when attention is guided by knowledge of a simple target feature. We found that capture by a featural singleton could be prevented when subjects were induced to use feature-search mode or could be overridden after some time when the target was a singleton with a known feature. In contrast, abrupt onsets captured attention to the same extent whatever the search mode adopted by the observers (Experiments 2–4) and across SOAs ranging from 50 ms to 300 ms. As a possible basis for the special status of abrupt onsets, we speculated that feature-based inhibition can be used to prevent capture by featural singletons but not by distractors that summon attention to their location by virtue of being abruptly onset.

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