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Does a salient distractor capture attention early in processing?

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Kim and Cave (1999) used spatial probes in order to measure the effects of bottom-up and top-down factors on the allocation of spatial attention over time. Subjects searched for a target with a unique shape, with a uniquely colored distractor present on each trial. The singleton distractor captured attention early in processing, whereas attention homed in on the target's location later on. Kim and Cave (1999) concluded that top-down factors cannot prevent the presence of a salient distractor from delaying target selection. The present study tested the idea that such results were obtained only because subjects adopted the strategy of searching for the most salient item. Kim and Cave's (1999) finding was replicated in Experiment 1. In Experiment 2, instead of a feature search, subjects performed a conjunction search—that is, a task that could not be performed using a salience-based strategy. Probe response times were longest at the salient distractor's location at both the short and the long stimulus onset asynchronies. These results suggest that, early in processing, top-down factors can exert their influence and prevent the capture of attention by a salient distractor.

Most theories of attention distinguish between two successive stages in the processing of information. The preattentive stage operates without capacity limitations and performs preliminary analyses across the visual field, whereas the attentive stage requires the allocation of limited attentional resources and allows a more detailed analysis of selected parts of the visual field. Two types of factors are thought to be able to control attentional priority at the preattentive stage. 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 will be selected for further visual processing. Stimulus-driven, or bottom-up, control refers to the capacity of certain stimulus properties to attract attention. In what follows, local uniqueness on some dimension (e.g., color, shape, or orientation) will be used as the operational definition of bottom-up factors or stimulus salience.[1] The term *salience* will be used only in reference to local stimulus-driven contrast.

Much research has investigated the influence of top-down and bottom-up factors in guiding attention at the preattentive stage, but no clear picture has emerged as yet. Some authors assume that both types of factors affect the allocation of attentional priority (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Treisman & Sato, 1990; Turatto & Galfano, 2001; Wolfe, 1994). In contrast, Theeuwes claims that only bottom-up factors can guide attention—that is, that top-down selectivity is not possible at the preattentive stage, attention being captured automatically and involuntarily by the most salient element, irrespective of tasks demands (e.g., Theeuwes, 1991a, 1992; Theeuwes, Atchley, & Kramer, 2000). Finally, Folk and colleagues proposed that the ability of a unique element to capture attention is contingent on the establishment of a top-down control setting for its unique property (e.g., Folk & Remington, 1998; Folk, Remington, & Johnston, 1992). Consistent with this idea, other authors have suggested that attention may be guided solely on the basis of top-down factors at the preattentive stage, with bottom-up salience determining performance only when subjects adopt the strategy of searching for a discontinuity (e.g., Bacon & Egeth, 1994; Lamy & Tsal, 1999; Yantis & Egeth, 1999). Thus, it remains unclear how bottom-up and top-down processes combine to determine attentional priority.

Recently, new insights into the roles of bottom-up and top-down factors have been sought by investigating their time courses (e.g., Kim & Cave, 1995, 1999; Theeuwes, 1995; Theeuwes et al., 2000). On the basis of the finding that successful search for a target letter in a visual display depends on the allocation of attention to the target's spatial position (Hoffman & Nelson, 1981; Hoffman, Nelson, & Houck, 1983), Kim and Cave (1995) designed a procedure that allows measuring how the allocation of

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spatial attention develops over time. Subjects had to search for a predefined target among distractors. On some of the trials, a probe appeared after a variable stimulus onset asynchrony (SOA), randomly at any of the locations previously occupied by the target display elements. Subjects had to respond to the probe onset as fast as possible and then report whether or not the target had been present in the target display. Response time to the probe was taken to reflect the amount of spatial attention that was allocated to the probed location during visual search.

In feature search, Kim and Cave (1995) found faster responses to the probe at the location of the target, relative to distractor locations, very early on (30-msec SOA). Since the target had a unique feature, the activation at the location of the target could result from bottom-up factors, top-down factors, or both. However, in conjunction search, in which the impact of bottom-up factors on target detection is minimal, they found faster responses to probes at the locations containing at least one of the target features, relative to locations containing no target feature, from early stages of visual processing (60-msec SOA). This finding strongly suggests that top-down factors affect attentional priority at the preattentive stage.

In a later study, Kim and Cave (1999) used the same procedure to investigate the interaction between bottom-up and top-down processes in visual search. Subjects searched for an element with a unique shape (the target) among distractors that had the same color as the target, except for one uniquely colored singleton distractor. Thus, on target-present trials, there were both a color singleton and a shape singleton, whereas on target-absent trials, there was only a color singleton. On half of the trials, a probe appeared with one of two different delays after the offset of the target display, randomly at any of the locations previously occupied by the display elements. Again, subjects had to respond to the probe onset as fast as possible and then report whether or not the target had been present in the target display.

On target-present trials, the authors found that the probe tended to be detected most quickly at the salient distractor's location at the short SOA (but this was true only on a minority of trials, when the salient distractor was not adjacent to the target) and at the target's location at the long SOA. On target-absent trials, the salient distractor's location was no more activated than the other distractors' locations, even at the short SOA. The results of an additional experiment showed that after extended practice, the salient distractor no longer captured attention at the short SOA, but the target was not selected at this early stage either.

According to Kim and Cave (1999), these results suggest that at the preattentive stage, an irrelevant salient element attracts attention automatically (see also Theeuwes, 1995, and Theeuwes et al., 2000, for related results). Moreover, they indicate that the presence of this salient element prevents subjects from allocating their attention to the location of the target early in visual processing. Indeed, whereas responses to the probe were faster at the location of the target at the shortest SOA tested (30 msec) in a study in which no salient distractor was present (Kim & Cave, 1995), the location of the target became more activated than the other locations only at a 150-msec SOA when a salient distractor was present (Kim & Cave, 1999). The authors concluded that although top-down selectivity was not completely impossible at the preattentive stage, as revealed (1) by the absence of the early selection of the singleton distractor in the target-absent condition and (2) by the fact that practice prevented attentional capture by the singleton distractor, the presence of the color singleton "seemed to delay selection of the target even after extended practice" (p. 1021).

Bacon and Egeth (1994) proposed that capture by irrelevant singletons occurs only when the task is performed using a *singleton detection mode,* in which observers search for a discontinuity. In contrast, when the singleton detection mode is inappropriate to carry out the task and subjects have to use a *feature search mode*—that is, search for a known-to-be-relevant feature—involuntary capture by a salient distractor does not occur (see Pashler, 1988, for the original version of this distinction). In relation to this work, Kim and Cave (1999) noted that their data are also consistent with the possibility that the subjects used the singleton detection mode—that is, they may have searched for the singleton with the highest bottom-up salience, regardless of feature dimension. The authors did not favor this alternative account. They argued that it would require the additional assumption that a singleton distractor draws attention less effectively when it is located near another singleton (the singleton target), since the singleton distractor failed to capture attention early in processing when adjacent to the singleton target. However, if the singleton detection strategy is more parsimoniously renamed the salience-based search strategy, with subjects simply looking for the element with the highest local bottom-up activation, the fact that a singleton is less activated when it is located near another singleton requires no additional assumption. It stems straightforwardly from the fact that bottom-up calculations are local.

The salience-based search mode account offers a reasonable explanation for most of Kim and Cave's (1999) data.[2] In their study, the salient distractor was always unique on the color dimension, and the target was always unique on the shape dimension. More bottom-up activation is likely to have accrued to the salient distractor than to the target, because color discrimination is often easier than form discrimination (e.g., Theeuwes, 1991a) and no particular step was taken to ensure that discrimination difficulty was matched for the two dimensions. If the subjects adopted a salience-based search mode instead of feature search mode, the salient distractor was selected first, the target being selected only after the salient distractor was rejected. This could explain the time course of attentional allocation found by Kim and Cave

(1999)—namely, the fact that the distractor singleton's location was more activated than the target's location at the short SOA, not at the long SOA.

To summarize, since the target always possessed a unique feature in Kim and Cave's (1999) study, subjects had the opportunity to use a salience-based search strategy. It should be noted that such a strategy would be quite inefficient, since the salient distractor was always more salient than the target. However, earlier studies have shown that even when the singleton detection mode provides a less direct route to the target than does the feature search mode, it appears to be preferred nonetheless (Bacon & Egeth, 1994). Further research is clearly needed in order to determine the mechanisms underlying the hypothesized bias in favor of the singleton detection mode. If the subjects did use the singleton detection mode in Kim and Cave's (1999) study, their results would simply reflect the fact that when subjects adopt a salience-based strategy—that is, when they search for the item with the highest level of local bottom-up activation—singletons are selected by order of salience until the target is found. As such, they would provide no evidence for the idea that bottom-up factors affect search early on by delaying the deployment of attention to task-relevant objects, irrespective of task demands.

The objective of the present study was to test this alternative account of Kim and Cave's (1999) finding. The first experiment was a replication of Kim and Cave's (1999) Experiment 1. In the second experiment, adopting the procedure of Lamy and Tsal (1999), the incentive to resort to the singleton search mode was eliminated by requiring the subjects to search for a conjunction target, rather than for a target possessing a unique feature. Thus, the strategy of looking for a singleton could never direct the observer's attention toward the target. Accordingly, if top-down guidance can override bottom-up capture early on, no processing advantage should be found at the location of the salient distractor at the shorter SOA. In contrast, if the presence of a salient distractor delays the deployment of attention irrespective of task demands, effects of top-down guidance should be observed only at the longer SOA.

EXPERIMENT 1

Method

Subjects. The subjects were 10 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. Displays were generated by an IBM-compatible PC attached to a VGA color monitor, using 600 × 480 graphics mode. Responses were collected via the computer keyboard.

Stimuli. The fixation display was a black 0.1º × 0.1º plus sign (+) in the center of a white background. The primary search display in each trial consisted of four colored shapes, one circle and three squares, equally spaced along the circumference of an imaginary circle, centered at fixation. At a viewing distance of 60 cm, the centers of the shapes were 4.9º from fixation. The target was an outline circle with a diameter of 2.2º, and the distractors were squares, the sides of which subtended 2.2º. Each shape was positioned on the horizontal or the vertical midline. On half of the trials, the target was present, and on the other half, it was absent. On every trial, one of the square distractors had a unique color (color singleton distractor). On half of the trials, the color singleton distractor was red, and the other elements were green; on the other half, this color mapping was reversed. The red and the green colors were matched for luminance using a light meter (Photo Research Lite Mate/Spot Mate System 500). On target-present trials, the target and the color singleton distractor either were adjacent (adjacent condition) or occupied diametrically opposed locations (far condition).

Procedure. Figure 1 illustrates the sequence of displays on probe-present trials (two thirds of the trials, right panel) and on probe-absent trials (one third of the trials, left panel).[3] Each trial began with the presentation of the fixation display. After 400 msec, it was replaced by the primary display, which remained on the screen for 45 msec. On probe-present trials, the probe display followed the primary display after a delay of either 15 or 105 msec. That is, the SOA between the primary stimulus onset and the probe onset was randomly selected, for each trial, to be either 60 or 150 msec. The probe remained visible for 30 msec. It appeared equally often in each of the four possible locations. After the probe offset, the screen went blank for 1,200 msec. On probe-absent trials, following the primary display, a blank screen appeared for 1,200 msec. In both conditions, the 1,200-msec blank screen was followed by a display containing the question, "Was the target present?" which remained on the screen until the subjects responded. The screen went blank for 500 msec before the next trial began.

The subjects were instructed to search for the target in the primary display. They were verbally informed of the target's and the distractors' colors and forms. They were told that shortly after the primary display offset, a probe would appear, on half of the trials, in one of the locations previously occupied by the shapes. The subjects were required to respond to its onset by pressing "A" on the computer keyboard as quickly as possible with their left index fingers.[4] They were told that they should then use their right index fingers to press "1" or "2" on the numerical keypad if a target had or had not appeared, respectively, in the primary display. The experimenter underscored that although, when present, the probe would appear *after* the primary display, in which they had to search for the target, the subjects had to respond *first* to the probe. They were instructed to respond to the target presence only after the message "Was a target present?" had appeared on the screen. They were told that, whereas speed was very important when they reported the onset of the probe, it was irrelevant when they reported the target's presence. The experimenter underscored that the subjects' main task was to respond to the presence of the target shape and that the probe detection task should be allocated lower priority. False alarms and misses when the probe was responded to were followed by a 500-msec feedback beep. A different error beep was sounded if the subjects responded incorrectly to the presence of the target shape. Eye movements were not monitored, but the subjects were explicitly requested to maintain fixation throughout each trial.

Conditions of probe presence, probe location, SOA, target color, and target presence were randomly mixed within blocks. Each subject was run on 25 practice trials, followed by 768 experimental trials that were divided into 18 blocks of 40 trials each. The subjects were allowed a rest period after each block.

Results

All error trials were removed from analysis. The correct response rates were 96% for the probe detection task and 99% for the target detection task. With a procedure similar to Kim and Cave's (1999) to exclude outliers, probe reaction times (RTs) for each subject were sorted into cells according to the conditions of probe presence, target pres-

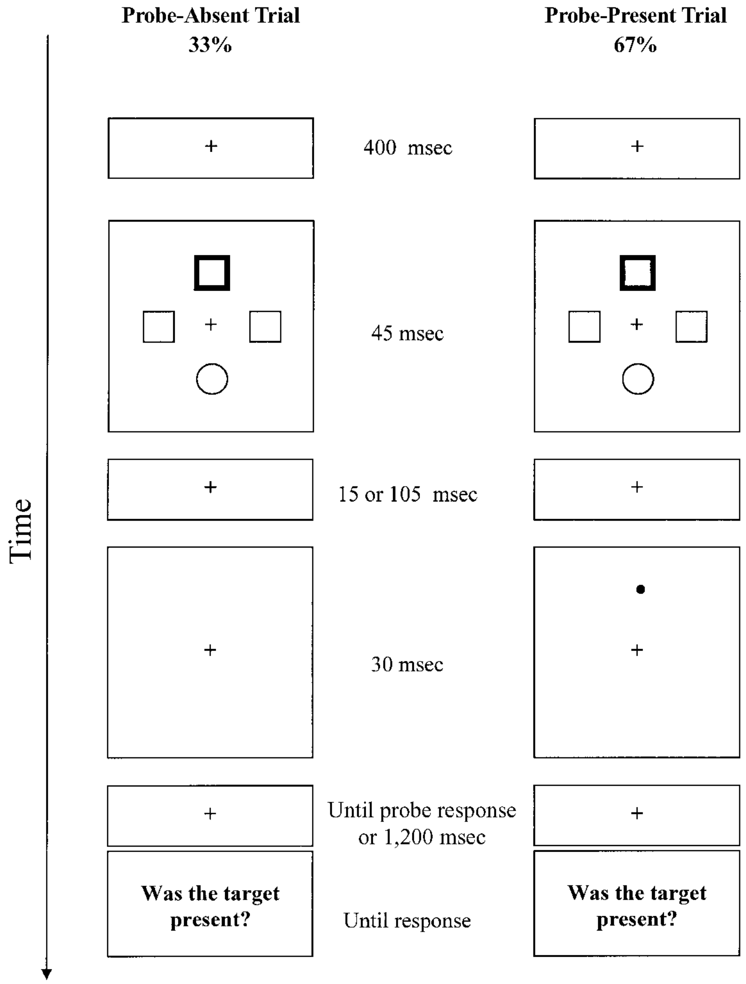

Figure 1. Sample sequence of displays in the target-present condition, for no-probe versus probe trials. The target was a circle. Thin and thick lines represent different colors, either red or green.

ence, distance, and SOA. RTs exceeding the mean of that cell by more than 3.5 standard deviations were trimmed. This removed fewer than 0.5% of all observations.

The mean RTs from correct probe-present trials were subjected to an analysis of variance (ANOVA). Since preliminary inspection of the data revealed no effect involving target color (all *F*s < 1), this factor was not included in the analysis of the data. Separate analyses were conducted for target-present and target-absent trials.

The first ANOVA was conducted on target-present trials. It included three levels of probe location (target, same-color distractor, or color singleton distractor), two levels of SOA (60 or 150 msec), and two levels of distance between the target and the color singleton distractor (adjacent vs. far). Mean RT data are presented in Figure 2. No main effect approached significance (all *F*s < 1). The interaction between probe location and SOA was significant [$F(1,9) = 5.03, p < .02$]. Paired comparisons showed that at the 60-msec SOA, mean RTs were shorter when the probe appeared at the location of the color singleton distractor than at the location of the target [379 vs. 393 msec; $F(1,9) = 5.59, p < .02$]. There was no significant difference in mean probe RTs between the locations of the target and the same-color distractors (393 vs. 392 msec; $F < 1$). At the 150-msec SOA, RTs were shorter at the location of the target than at the locations of either the color singleton distractor [363 vs. 397 msec; $F(1,9) = 8.06, p < .02$] or the same-color distractors [363 vs. 388 msec; $F(1,9) = 10.74, p < .01$]. The difference in probe RTs between the two types of distractors (salient vs. same color) was nonsignificant ($F < 1$).

Although all the interactions involving distance were nonsignificant (all *F*s < 1), planned contrasts were calculated separately for the adjacent and the far conditions, in order to facilitate the comparison with Kim and Cave's (1999) results. At the short SOA, in the far condition, probe RTs at the location of the salient distractor were shorter than those at the location of the target [$F(1,9) =$

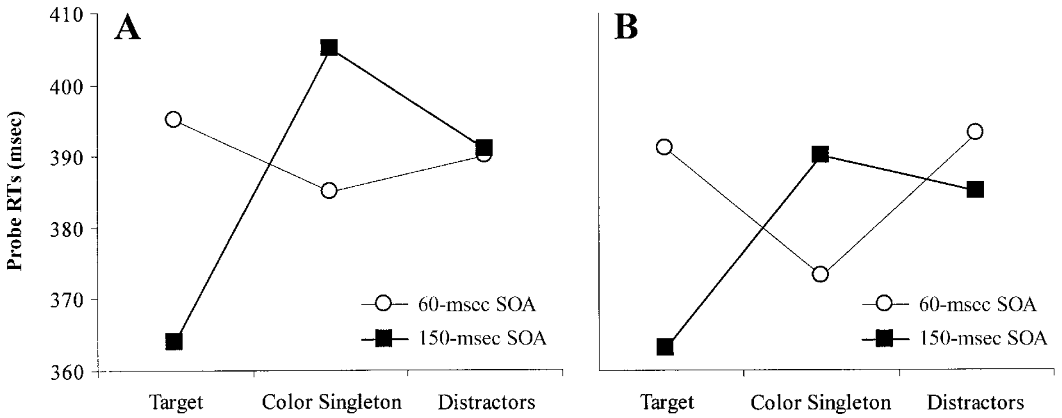

Figure 2. Mean response times (RTs, in milliseconds) to probes by probe location and by stimulus onset asynchrony (SOA) in the target-present condition in Experiment 1. The left panel shows data from the adjacent condition, whereas the right panel shows data from the far condition.

5.20, $p < .05$]. In the adjacent condition, this effect approached significance [$F(1,9) = 4.69$, $p < .08$]. At the long SOA, probe RTs were shorter at the location of the target than at the locations of the salient distractor and the same-color distractors in both the adjacent condition [$F(1,9) = 6.52$, $p < .04$, and $F(1,9) = 5.19$, $p < .05$, respectively] and the far condition [$F(1,9) = 7.83$, $p < .03$, and $F(1,9) = 5.25$, $p < .05$, respectively].

The second ANOVA was conducted on target-absent trials. It included two levels of probe location (same-color distractor and color singleton distractor) and two levels of SOA (60 or 150 msec). This analysis revealed no effect of SOA ($F < 1$). The effect of probe location did not reach significance [$F(1,9) = 3.27$, $p > .1$]. The interaction between the two factors was also nonsignificant ($F < 1$).

Discussion

In this experiment, Kim and Cave's (1999, Experiment 1) main findings were replicated. Probe RTs showed that a color singleton drew attention to its location at the short SOA (60 msec), whereas at the long SOA (150 msec), attention was allocated to the location of the target. In fact, the results of the present experiment provided stronger evidence for this idea than did Kim and Cave's (1999) results.

First, note that in Kim and Cave's (1999) study, evidence for early capture of attention by bottom-up factors was revealed only by the fact that at the short SOA, RTs were shorter when the probe appeared at the salient distractor's location than when they appeared at the same-color distractor location, but RTs were not significantly different at the location of the salient distractor and at the location of the target. Kim and Cave (1999) could, therefore, conclude only that the presence of the salient distractor "prevented the subjects from allocating their attention to the target early in visual processing" (p. 1015). In contrast, in the present experiment, overall probe RTs were significantly shorter at the location of the salient distractor than at the location of the target. This effect was significant in the far condition and only approached significance in the adjacent condition ($p < .08$), paralleling Kim and Cave's (1999) finding of weaker effects in that condition. Thus, in the present experiment, the color singleton distractor not only prevented capture by the target, but actually captured attention to its location.

Second, as is illustrated in Figure 2, we found a similar pattern of results whether or not the target and the color singleton distractor were adjacent. In both distance conditions, the probe was detected fastest at the location of the salient distractor at the short SOA and at the location of the target at the long SOA. In contrast, Kim and Cave (1999) found no trend indicating that the salient distractor captured attention at the short SOA in the adjacent condition; moreover, at the long SOA, they did not report significantly shorter RTs at the location of the target than at the location of the salient distractor in the far condition.

EXPERIMENT 2

The results of Experiment 1 replicated Kim and Cave's (1999) finding that when subjects are required to detect the presence of a shape singleton, a uniquely colored distractor captures attention early in processing and attention homes in on the location of the target only later in processing. We propose that rather than showing a differential time course for top-down and bottom-up processes, these results may reveal only that when subjects can adopt a salience-based search strategy, singletons are selected in order of salience until the target is found. The objective of Experiment 2 was to test the hypothesis.

We used the same procedure as that in Experiment 1, except that the subjects were required to perform a conjunction search task instead of looking for a singleton shape. In order to enhance the singleton distractor's bottom-up salience, the colors of the target and the conjunction distractors were chosen to be similar to each other and highly distinguishable from the singleton distractor's color. Moreover, the singleton distractor was salient on both the color and the form dimensions. Display size was increased to six elements, because a conjunction search with four elements would entail that each of the two conjunction distractors would be a singleton on either the form or the color dimension. Fixation-to-shape distance was the same as that in Experiment 1. Thus, display density was increased, which should also contribute to enhance local bottom-up activation (e.g., Todd & Kramer, 1994).

If, as Kim and Cave (1999) suggested, bottom-up factors dominate early in processing and a salient distractor captures attention automatically until attention is redirected to the relevant locations in a top-down fashion later on, the same pattern of results should be obtained in the present experiment as in Kim and Cave's (1999) study and Experiment 1 of the present study. Alternatively, if as we suggest, top-down guidance may override bottom-up factors early on, shorter RTs at the salient distractor's location should be found neither at the short nor at the long SOA, when subjects are required to search for a nonsalient conjunction target and cannot, therefore, rely on a salience-based search strategy.

Method

Subjects. The subjects were 12 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, fixation display, and probe display were the same as those in Experiment 1. The primary search display is illustrated in Figure 3. It consisted of six colored shapes, equally spaced along the circumference of an imaginary circle, centered at fixation. Two shapes were aligned with the vertical axis; two other shapes were equally distant from the horizontal axis on the left side, as were the remaining two shapes on the right side. Distance from shape center to fixation was the same as that in Experiment 1 (4.9°). There were two possible sets of stimuli: the red target and the green target sets of stimuli. Half of the subjects were run with one set, and the other half were run with the other set. In the red target set, the target was a red circle, the conjunction distractors were pink circles and red squares, and the salient distractor was a green triangle. In the green target set, the target was a green circle, conjunction distractors were greenish blue circles and green squares, and the salient distractor was a red triangle. The red and green colors were the same as those in Experiment 1. The greenish blue and pink colors were matched for luminance with the red and green colors.

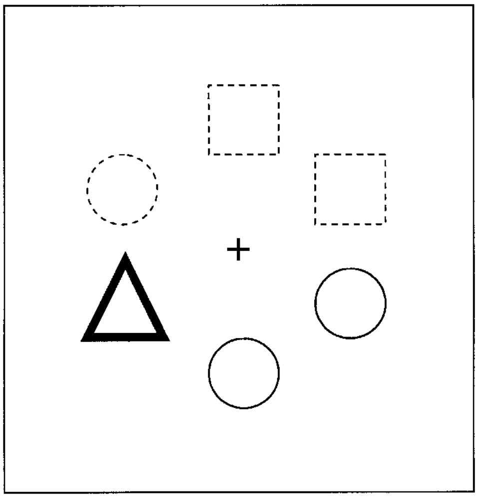

Figure 3. Example of the primary conjunction search display used in Experiment 2. The example corresponds to the target-present condition, with no intervening item between the target and the unique distractor. The target is the thin dashed circle, the conjunction distractors are thin dashed squares and thin solid-line circles, and the salient distractor is the thick black triangle. Thin dashed, thin solid-line, and thick black lines represent red, pink, and green, respectively, in the red target set and green, greenish blue, and red, respectively, in the green target set.

The target was present on half of the trials. On target-absent trials, the display consisted of two or three square conjunction distractors, two or three circle conjunction distractors, and the salient distractor. On target-present trials, there were two conjunction distractors of each type. The probe appeared at the center of one of the six locations previously occupied by the search elements of the primary display.

The procedure was the same as that in Experiment 1, except for the fact that half of the subjects were run with the red target set and the other half with the green target set.

Results

All error trials were removed from analysis. The correct response rate was 96% for the probe detection task and 98% for the target detection task. Probe RTs for each subject were sorted into cells according to the conditions of probe presence, target presence, distance, and SOA. RTs exceeding the mean of that cell by more than 3.5 standard deviations were trimmed. This removed fewer than 0.5% of all observations.

Two separate ANOVAs were conducted on the mean RTs of correct probe-present trials for target-present and target-absent trials. A preliminary inspection of the data revealed no effect involving color set (all *F*s < 1). Thus, this factor was not included in the analysis of the data.

The first ANOVA was conducted on target-present trials. It included three levels of probe location (target, color singleton, and distractor), two levels of SOA (60 or 150 msec), and three levels of distance between the target and the color singleton (zero, one, or two intervening items). Mean RTs are shown in Figure 4. There was a main effect of probe location [$F(2,22) = 15.05$, $p < .0001$]. Planned contrasts revealed that probe detection was slowest when the probe appeared at the location of the salient distractor [$F(1,11) = 29.10$, $p < .0002$]. There was no significant difference between the locations of the target and the conjunction distractors [$F(1,11) = 2.32$, $p > .1$]. The main effects of SOA [$F(1,11) = 1.93$, $p > .1$] and distance [$F(2,22) = 2.48$, $p > .1$] did not reach significance. Neither did the interaction between probe location and SOA [$F(4,44) = 1.80$, $p > .1$]. No interaction involving distance approached significance.

Planned contrasts revealed that at the short SOA, performance was faster at the location of the target than at the location of the salient distractor [$F(1,11) = 5.60$, $p < .04$], but there was no difference between the locations of

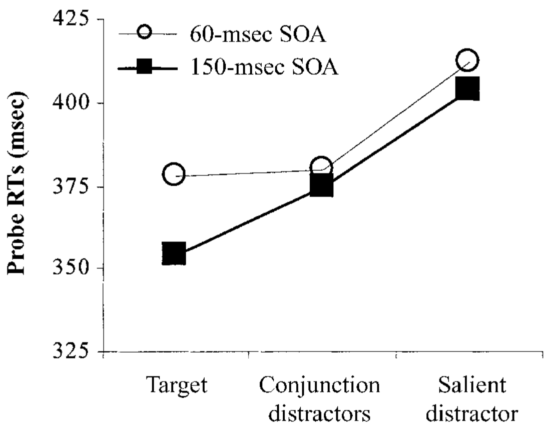

Figure 4. Mean response times (RTs, in milliseconds) to probes by probe location and by stimulus onset asynchrony (SOA) in the target-present condition in Experiment 2.

the target and the conjunction distractors ($F < 1$). At the long SOA, performance at the location of the target was faster than at the locations of the conjunction distractors [$F(1,11) = 6.85$, $p < .03$] and the salient distractor [$F(1,11) = 27.28$, $p < .0003$].

The second ANOVA was conducted on target-absent trials. It included two levels of probe location (conjunction distractor and salient distractor) and two levels of SOA (60 or 150 msec). This analysis revealed a significant effect of probe location [$F(1,11) = 9.14$, $p < .02$]. Planned contrasts revealed that the probe was detected more quickly when it appeared at the location of a conjunction distractor than when it appeared at the location of the singleton distractor. There was no effect of SOA ($F < 1$), and the interaction between the two factors was nonsignificant ($F < 1$).

Discussion

This experiment was similar to Experiment 1 except that the subjects were required to search for a nonsalient conjunction target, instead of searching for a uniquely shaped target. Thus, the subjects could no longer use a salience-based strategy to perform the task. The relative bottom-up salience of the singleton distractor was enhanced. First, display density was higher in Experiment 2 than in Experiment 1, thus increasing local difference signals. Moreover, the target possessed no salient feature, since it shared either the form or the color of two conjunction distractors. Local signals at the locations of the target and the conjunction distractors were weakened by the fact that the two types of conjunction distractors were very similar in hue. Finally, the unique distractor was a singleton on both the form and the color dimensions. If attention was automatically captured by a salient element, such display characteristics should have yielded strong bottom-up effects. A control experiment was conducted in order to test our claim that the level of bottom-up activation accruing to the singleton distractor was at least as high in Experiment 2 as it was in Experiment 1.[5]

The results of Experiment 2 showed no evidence for bottom-up capture at either the short or the long SOA. In fact, the unique distractor location was the least activated location at the short SOA. That is, early in processing, any element possessing a target feature—that is, the target or the conjunction distractors—received more attention than did an element with no target feature (i.e., the unique distractor), on both target-present and target-absent trials. Thus, effects of top-down guidance were observed at the 60-msec SOA. It is also noteworthy, however, that at the short SOA, probe RTs were similar at the locations of the target and the conjunction distractors, indicating that search did not converge on the target within 60 msec, but only later, at 150 msec. Taken together, these findings indicate that the search task employed here was neither parallel nor strictly serial. This observation is important because capture by irrelevant salient objects has been shown to be prevented when attention is spatially focused (Theeuwes, 1991b; Yantis & Jonides, 1990), as happens when search is "relentlessly" serial. The evidence for early top-down guidance in the present task invalidates the argument that serial search might account for the failure to observe capture effects.

It is possible to argue that attention may have been allocated to the unique distractor and deallocated from it within 60 msec or allocated to it after 60 msec and deallocated from it before 150 msec. In both instances, attentional capture by the unique distractor could not have been measured.[6] It is unlikely that express allocation and deallocation of attention occurred in the present task. Earlier studies have shown that when a salient distractor captures attention, this effect peaks after 50 msec, and deallocation does not occur with SOAs below 100 msec (Folk, Leber, & Egeth, 2002; Theeuwes, 1995; Theeuwes et al., 2000). This time course was observed with displays that were denser than those in the present Experiment 2 and in which, thus, local differences were enhanced (Theeuwes et al., 2000). If a salient item captures attention automatically early in processing, such capture should not be task dependent, and its time course should depend exclusively on stimulus-driven factors. There is no aspect of the stimulus displays used here that would suggest that speeded bottom-up capture and attentional deallocation should have occurred. The present data also argue against the idea that bottom-up capture occurred between 60 and 150 msec. Indeed, at the 60-msec SOA, RTs at the unique distractor location were found to be longest, indicating that top-down factors were already active at this stage. In order to reconcile this finding with the claim that bottom-up capture occurred after 60 msec, one would have to admit that top-down factors affected attentional distribution earlier than did bottom-up factors.

GENERAL DISCUSSION

By measuring the time course of spatial attention with the probe technique, Kim and Cave (1995) showed that without an irrelevant singleton, target selection occurred at a 30-msec SOA in search for a shape singleton and at a 60-msec SOA in search for a conjunction of color and shape. In a more recent study (Kim & Cave, 1999), these authors claimed that in search for a shape singleton, an irrelevant color singleton captured attention to its location early on (60-msec SOA), with target selection occurring only later (150-msec SOA). They also suggested that although practice did prevent attentional capture by the salient distractor, it could not prevent the presence of a salient distractor from delaying target selection.

We proposed that, rather than showing a built-in primacy of bottom-up processes over top-down processes, these results may reveal only that when subjects can adopt a salience-based search strategy, singletons are selected in order of salience until the target is found. In line with this suggestion, we observed that, at the shorter SOA, probe RTs were shortest at the unique distractor location when the subjects searched for a shape singleton target (Experiment 1) but longest when the subjects searched for a nonsalient conjunction target (Experiment 2). That is, despite the presence of a salient distractor, top-down guidance affected processing as early as in Kim and Cave's (1995) conjunction task with no salient distractor (60-msec SOA).

In the present study, early effects of top-down guidance were reflected by longer RTs at the location of the salient distractor than at the locations of the target or the conjunction distractors, on both target-present and target-absent trials. Theeuwes and Burger (1998) proposed that attentional capture can be prevented when there is maximum opportunity to apply top-down control. In their study, subjects searched for a target letter among nontarget letters and had to ignore a salient color singleton, the shape of which elicited a response that was either compatible or incompatible with the response required by the target. Compatibility effects indicative of capture by the salient distractor were found, except for the condition in which both the target and the salient distractor colors were known. That is, capture could be prevented only when the target features could be activated and the salient distractor's features could be inhibited.[7] Our results are consistent with Theeuwes and Burger's claim, since in the present study, both the target and the salient distractor's features were fixed. However, the temporally more fine-grained measure of attentional allocation provided by the probe technique allowed us to conclude not only that top-down factors can prevent spatial capture (in line with Theeuwes & Burger, 1998, Experiment 2, and Kim & Cave, 1999, Experiment 2), but also that their effects can be observed early in processing.

Whether such control resulted from early activation of objects with target features and/or from early inhibition of objects with nontarget features cannot be determined on the basis of the present results. Note that if inhibitory processes were at play, their effects peaked early, since probe RTs at the location of the salient distractor were equally long at the 60- and at the 150-msec SOAs. Recent findings from our laboratory corroborate this possibility. With a variant of Folk et al.'s (1992) spatial cuing paradigm, subjects had to search for a nonsingleton target with a known color (Lamy, Leber, & Egeth, 2002) or with a known form (Lamy & Egeth, in press). A distractor display containing a known irrelevant color singleton preceded the target display by an SOA ranging from 50 to 300 msec. RTs were significantly longer when the target appeared at the location of the irrelevant singleton than at other locations, and this effect did not interact with SOA.

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NOTES

1. This definition of bottom-up factors does not include other stimulus properties that may affect the attentional prioritization, such as abrupt onsets (e.g., Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1990).

2. Just as in Kim and Cave's (1999) account, however, this account fails to provide a straightforward explanation for the absence of bottom-up capture on target-absent trials. The singleton distractor's location should have been more activated than other locations, at least in the short SOA condition, according to both accounts—that is, whether bottom-up capture was mandatory or whether the subjects used a singleton detection strategy.

3. In Kim and Cave's (1999) experiment, probe-present and probe-absent trials were equiprobable. The rationale for increasing the proportion of probe-present trials is as follows. In Experiment 2, displays contained six items, instead of only four as in Experiment 1. Thus, for an equal total number of trials, the probe occupied either the target or the singleton distractor location on a smaller proportion of the trials in Experiment 2. Since it was important to have enough such trials for each subject, the number of probe-present trials was increased. Another possibility would have been to increase the total number of trials, but this solution was not desirable, because Kim and Cave (1999, Experiment 2) showed that bottom-up capture decreased as practice with the task increased. This higher proportion of probe-present trials was also used in Experiment 1, in order to ensure that Kim and Cave's (1999) results could be replicated under such conditions.

4. There was no left-handed subject. Thus, no alternative response-to-hand mapping was needed.

5. Fifteen subjects were presented with the same displays as those in Experiment 1 in the feature search condition and with the same displays as those in Experiment 2 in the conjunction search condition. They were required to detect either the presence of the same target, as in the original experiments (target search condition), or the presence of the element that was the salient singleton distractor in the original experiments (singleton distractor search condition). These conditions resulted in four blocks. For instance, in the feature search condition, the subjects searched for the unique circle among squares (target search block) or for the unique red shape among green shapes (singleton distractor search block). In the conjunction search condition, the subjects searched for the red circle target (target search block) or for the unique green triangle (singleton distractor search block). Target and distractor colors were counterbalanced in the same way as in the original experiments. In order to create target-absent trials in the singleton distractor search blocks, new displays were added, in which the singleton distractor was absent. As in the original experiments, the displays remained on the screen for 45 msec. An ANOVA with target (target vs. singleton distractor) and display (feature vs. conjunction) was conducted on trials in which both the target and the singleton distractor were present. The subjects were faster to respond to the singleton distractor in the conjunction search than in the feature search condition [$F(1,14) = 6.60, p < .03$]. This result confirms that the singleton distractor used in the conjunction search task was at least as salient (and even more salient) than that used in the feature search task. In addition, we compared salience of the singleton distractors relative to the targets in their respective displays, rather than in absolute terms. The response advantage to the singleton distractor relative to the target was larger in the conjunction search than in the feature search condition [$F(1,14) = 46.17, p < .0001$].

6. We thank Kyle Cave for this suggestion.

7. Lamy and Tsal (1999) showed that the presence of a salient distractor did not slow detection of a conjunction target. They concluded that bottom-up activation exerts no effect in conjunction search. Theeuwes and Burger's (1998) suggestion that the salient distractor's features can be inhibited if they are known undermines the logic underlying this conclusion. Indeed, finding no effect of the salient distractor's presence may reflect only that its features were inhibited strongly enough to offset bottom-up signals at its location, rather than demonstrating that bottom-up factors play no role. In this respect, it should be noted that in Lamy and Tsal's study, the salient distractor's features varied from trial to trial (unique color, unique shape, or unique color and shape). However, if one assumes that subjects can ignore one feature per dimension, but for several dimensions at a time, one may argue that the salient distractor's features could be inhibited in Lamy and Tsal's study. Further research should characterize what inhibitory sets observers can adopt.

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