Attentional misguidance in visual search

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Previous research has shown that a task-irrelevant sudden onset of an object will capture an observer's visual attention or draw it to that object (e.g., Yantis & Jonides, 1984). However, further research has demonstrated the apparent inability of an object with a task-irrelevant but unique color or luminance to capture attention (Jonides & Yantis, 1988). In the experiments reported here, we explore the question of whether task-irrelevant properties other than sudden onset may capture attention. Our results suggest that uniquely colored or luminous objects, as well as salient though irrelevant boundaries, do not appear to capture attention. However, these irrelevant features do appear to serve as landmarks for a top-down search strategy which becomes increasingly likely with larger display set sizes. These findings are described in terms of stimulus-driven and goal-directed aspects of attentional control.

The exogenous or unintentional capture of an observer's attention by environmental properties has been the subject of several recent investigations (e.g., Folk, 1990; Jonides, 1981; Jonides & Yantis, 1988; Muller & Rabbitt, 1989; Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1984, 1990). These studies have sought to examine the conditions under which a task-irrelevant aspect of a visual stimulus captures an observer's attention, independently of his or her intentions, and thus affects performance of that task. The hypothesis that our attention may be captured by external events before we recognize their intrinsic meaning illustrates an important aspect of how we perceive the world.

Yantis and Jonides (1984) hypothesized that within a multiple-object display an abruptly presented object would capture attention to a greater extent than would objects with less abrupt presentations. To test this hypothesis, Yantis and Jonides adapted the methodology of Todd and Van Gelder (1979) to create no-onset objects; these objects (letters) appeared by erasing elements of individual masks superimposed on them. Note that the individual onset styles of the letters within a display were independent of the target's presence or absence, and, if present, of its location—the target letter was as likely to be the sudden-onset object as it was to be any one of the remaining no-onset objects. It was demonstrated in a visual-search task that detection of a target letter was faster when this target was, by chance, a sudden-onset object than when it was a no-onset object. In a subse-

quent study, Jonides and Yantis (1988) sought to examine whether any salient difference between individual objects within a display may capture attention. Following the methodology of Yantis and Jonides (1984), they examined the attentional capture of a sudden-onset object among no-onset objects, of a bright object among dim objects, and of a red (green) object among green (red) objects. As before, these dimensions of the stimulus array—onset, brightness, and hue—were irrelevant to the task at hand, namely, a visual search for a target letter. Performance over display sizes of 2 and 4 objects (Experiment 1) and of 3, 5, and 7 objects (Experiment 2) was examined. Their results indicated, again, that a sudden-onset object captured attention. However, a unique luminance or hue failed to do so: There was no significant decrease in reaction time (RT) to detect the target letter when it was either a unique brightness or a unique hue. Mean RT increased as the number of objects within the display increased for both the irrelevantly unique and nonunique target conditions, suggesting a serial self-terminating search process unaffected by the presence of a uniquely luminous or colored letter.

Recently, however, Folk, Remington, and Johnston (1992) have proposed that an observer's attentional disposition or set is an important variable in determining the capture of focal attention. Specifically, they hypothesized that an irrelevant event or object will capture attention only if that object shares a property used for the detection and perception of the current task's relevant target object. This proposal differs from that of Yantis and Jonides (1984), in that capture does not depend on a particular stimulus dimension (e.g., sudden onset), but instead is driven by attentional set. As predicted, Folk et al. (1992) found that a task-irrelevant cue captured attention only when it shared the same defining property as the upcoming target. This occurred for both color and onset cues. Folk et al. concluded that "although exogenous shifts are modulated by endogenous factors, they are still driven by external stimuli; the attention shift is

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involuntary given the external stimuli and preestablished control settings" (p. 1043). These findings differ from those of Jonides and Yantis (1988), who failed to find evidence of attentional capture by a unique color or luminance. Yantis (1993b), while noting the value of Folk et al.'s (1992) work, does not agree that they have shown attentional capture. Yantis defines stimulus-driven attentional capture to "occur only when the attribute that elicits it is independent of the defining and reported attributes of the target" (p. 679); in the work of Folk et al., the irrelevant cue captured attention only when it shared the defining attribute of the relevant target object. Folk, Remington, and Johnston (1993) have replied that their subjects were unable to ignore the irrelevant cue and that this is indeed a form of attentional capture.

Yantis (1993b) also noted that the color-cue and color-target objects of Folk et al. (1992) were color "singletons." A singleton is an object that is unique within a field of homogeneous objects within a particular dimension. A red circle among blue circles and squares is a color singleton; a red circle among red and blue squares is a form singleton. Jonides and Yantis (1988) required subjects to perform visual search for a target letter among a display of heterogeneous letters; thus, their subjects were not engaged in singleton search.¹ They found a failure of a unique color or luminance to capture attention. Yantis (1993b) suggested that the special qualities of singleton search and capture—an area previously investigated by Pashler (1988)—provided a possible explanation for Folk et al.'s results.

Pashler (1988) required subjects to search for the location of a uniquely shaped object within a field of 90 objects and to indicate whether it was in the left or the right half of the display. The objects were the characters "O" and "/" . Thus, a subject had to detect the sole "O" among 89 "/" characters, or vice versa—a form-singleton search. On half of the trials, two elements were randomly colored either red or green, with the remaining elements the opposite color; on the remaining trials, the elements were all one color (Experiment 6). Orthogonal to this manipulation, on half of the trials, the specific form of the unique element was identified before each trial. When the specific form of a trial's unique element was not identified, the addition of two uniquely colored objects (quasi-singletons) severely disrupted performance. This effect decreased when the target was identified prior to each trial. These results show that singleton search may be disrupted by a salient singleton within an irrelevant dimension (singleton capture). Pashler suggested that singleton detectors exist for the separate dimensions, though their individual outputs are pooled before becoming available for further processing. Others have also shown singleton capture to occur during singleton search (Pashler 1988, Experiment 7; Theeuwes 1991, 1992).

Yantis and Jonides (Jonides & Yantis, 1988; Yantis & Jonides, 1984) also differ from Folk et al. (1992) and Pashler (1988) in how they measured attentional cap-

ture. For Yantis and Jonides, attentional capture was shown by demonstrating the rapid perception, on average, of the sudden-onset object regardless of the number of distractor objects present within the visual array. The procedures of Folk et al. and Pashler, however, did not include manipulation of display size; instead, attentional capture was shown by an increased interference due to the presence of a capturing object (see also Remington et al., 1992; Yantis & Jonides, 1990).

While Yantis (1993b) and Folk et al. (1992, 1993) debate the necessity of an observer's attentional set in the capture of attention and discuss the role of singleton search and capture in the demonstration of attentional capture by a unique color, we hypothesize that attentional capture may also occur independently of both of these constraints. We propose that an object, salient and unique within a task-irrelevant dimension (other than onset), may capture attention without the observer being engaged in singleton search.

Several models of visual attention predict just such an effect (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Kahneman, 1973; Kahneman & Henik, 1981; Koch & Ullman, 1985; Ullman, 1984). Ullman's model suggests that an initial representation of the visual environment is created among separate topographical maps of several simple dimensions corresponding to Treisman's feature maps (e.g., Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1990). Within each feature map, local lateral inhibition increases interobject differences, with more active objects inhibiting less active objects, and objects that differ significantly from their neighbors being emphasized. A master *saliency map* then combines the differences from within and across feature maps to find the spatial location of the most conspicuous object in the visual array. The feature-map properties of this location are then provided as input to additional processes which compute location-specific conjunctions. In sum, selective attention is captured by the most conspicuous location.

Duncan and Humphreys (1989; Duncan, 1989) offered a similar model. They described performance of a visual-search task as being based on target-to-distractor and distractor-to-distractor similarities. They predicted that search performance will degrade (a) with increasing target-distractor similarity, and (b) with increasing heterogeneity among the distractor objects. While (a) hinders, in part, the application of an internal "template" used to identify the target object, (b) prevents the "linking" or grouping of distractor objects and their subsequent rejection en masse. Duncan and Humphreys also contemplated the effects of a single nontarget that differs from its neighbors on an irrelevant dimension. They hypothesized that this unique nontarget would not strongly link to the other distractor objects, thus avoiding the group suppression among those objects and becoming relatively salient. This object's irrelevant salience may then induce its selection, regardless of the task at hand.

These models, as well as one's own intuition, predict that an irrelevantly unique object may, at times, capture attention. Indeed, introspection would lead one to believe that a uniquely colored object, such as a red poppy in a green field or the unique luminance of a bright planet among a night sky of dim stars, may capture our attention independently of our intentions. The models outlined above suggest that one important criterion for the capture of attention by a nontarget object is the degree to which it differs from the other objects in the display, including the effects that any local lateral inhibition or grouping with its neighboring objects might have. The influences of these effects are expected to be progressive rather than absolute, and dependent on the salience of the irrelevant distractor.

COLOR AND LUMINANCE

In Experiments 1 and 2, we sought to examine the apparent failure of a unique color and luminance to capture visual attention, as shown by Jonides and Yantis (1988). We hypothesized that variation along a task-irrelevant dimension other than onset, specifically along the dimensions of color (Experiment 1) and luminance (Experiment 2), would capture attention to the degree that this variation was subjectively salient or noticeable.

Jonides and Yantis (1988; see also Yantis & Jonides, 1984) have previously reported that during debriefings their subjects rarely reported the occurrence of sudden-onset stimuli. However, their subjects did often report noticing color and luminance differences (Jonides & Yantis, 1988). On the basis of these data, it would appear that color and luminance differences are actually more salient (noticeable) than are sudden onsets. However, given the special status ascribed to onsets in capturing attention (Jonides & Yantis, 1988), as well as their ability to engage the transient channel in the visual pathways (Livingstone & Hubel, 1988; Zeki & Shipp, 1988), it is conceivable that salience plays a lesser role in attentional capture for sudden onsets than it does for other stimulus features.

Therefore, in the present study we attempted to vary the salience of a uniquely colored item by increasing the number of objects present in the display from the relatively few distractors used in previous studies (e.g., Jonides & Yantis, 1988, used six distractors). Following the methodology of Jonides and Yantis (1988; Yantis & Jonides, 1984), we examined the effect of a task-irrelevant color variation, but over an extended range of display sizes, from 4 to 25 objects. If salience is an important factor in mediating attentional capture for non-onset stimulus features we would expect to obtain a relative decrease in RTs for uniquely colored target letters in large display sizes. We report an independent assessment of the salience of the uniquely colored objects, in different display sizes, in the discussion section of the present experiment.

We also modified the presentation style of the trials' displays. Whereas Jonides and Yantis's (1988) matrix of letters appeared at one static location relative to the subject's initial fixation point, in Experiment 1 of the present study the matrix of letters appeared randomly about that point. This was done in an attempt to disrupt any intentional, patterned scan of the display (e.g., left to right, top to bottom) that a subject may adopt.

EXPERIMENT 1

Method

Subjects. Sixty University of Illinois students (33 male, 27 female) completed one 50-min session in partial fulfillment of a course requirement. The subjects ranged in age from 18 to 28 years, with a mean age of 19.7. All had normal or corrected-to-normal visual acuity (20/40 or better, as measured by the Snellen eye chart) and normal color vision, as tested by the Ishihara color-blindness test (1989). In the subsequent experiments reported here, the subjects were similarly examined.

Stimulus and Apparatus. An example of one of the four display conditions is shown in Figure 1. A display consisted of 4, 9, 16, or 25 letters, arranged in a square matrix, with the location of each letter slightly misaligned by a random distance to avoid the appearance of rigid rows and columns. These matrices were located equally often at all possible locations within an imaginary, monitor-wide 10×10 matrix in a random sequence so that the object density and the average distance from the initial fixation point were equivalent across the display sizes (as in Treisman, 1991). Subjects viewed the display from a distance of 1.4 m. At this distance, an individual letter was 0.38° high and 0.37° wide. Between letters, the center-to-center difference ranged, both vertically and horizontally, from 0.61 to 0.88° , and edge-to-edge from 0.24 to 0.50° . The stimuli were presented using high-resolution VGA graphics.

All displays contained one uniquely colored letter (randomly either red or green), with the remaining letters in the opposite hue, on a black background. On half of the trials, the defined target letter was present (once). Each trial's target letter was randomly selected from the pool of 26 English letters, as were the nontarget letters (the latter with replacement). The target letter, if present, and the uniquely colored letter were placed, independently, equally often across all locations within each matrix type (2×2 , 3×3 ,

Figure 1. An example of a 16-object display (Experiment 1). The solid letters were presented in red (green) and the hollow letters in green (red), in a font style like the one shown here; actual display size was approximately 25% larger.

4×4, and 5×5) in a random sequence. Thus, when the target was present, it was the uniquely colored letter on average once out of every 4, 9, 16, and 25 trials of the respective display sizes.

Procedure. Each trial began with the presentation of a target letter for that trial, placed at the center of the screen and colored white. The subject depressed the space bar to initiate the trial. The white target letter was then replaced by a small fixation cross for 100 msec, followed by the stimulus matrix. The stimulus matrix remained present until the subject's target-present or target-absent response occurred. The subjects responded by depressing either the "f" or the "j" key of a conventional computer keyboard (the mapping of response key to target presence/absence was counter-balanced across subjects). An incorrect response was followed by a brief (20-msec), low-pitched (400-Hz) tone.

Each subject completed 1,050 (unblocked) trials of approximately equal numbers of stimuli of each display size (243, 256, 245, and 252 displays with, respectively, 4, 9, 16, and 25 objects, plus an additional 54 practice trials, whose stimuli were randomly selected from the pool of possible stimulus conditions, and which began each session). The subjects received a graphical historical summary of their average RT and accuracy every 50 trials. They were instructed to respond as fast as possible while maintaining accuracy above 90%. They were told that the target letter would be present on half of the trials and that the colors of the stimulus letters were irrelevant.

Experimental design. The experiment was a within-subject, two-way factorial design. The factors were display size (4, 9, 16, or 25 total letters) and target condition (absent, present and uniquely colored, or present but not uniquely colored).

Data analysis. Trials with RTs faster than 100 msec or greater than that subject's 98.5 percentile were deleted prior to the calculation of that subject's means. Data were excluded for six subjects whose errors exceeded 15% within one or more of the four display-size conditions (resulting in $N = 54$). Mean RT was computed for correct trials only.

Results

The mean correct RTs and percent-error values are shown in Table 1. The RT and accuracy data were initially submitted to two-way weighted repeated measures analyses of variance (ANOVAs) of display size × target absence or presence (collapsed over target present unique and nonunique).² Mean RT was significantly affected (all $ps < .01$) by display size [$F(3,159) = 279.74$] and by target presence [$F(1,53) = 220.32$], as well as by their interaction [$F(3,159) = 171.59$]. These results are not surprising, given the longer and increasing RTs of the target-absent trials across the four display sizes. Likewise, accuracy was significantly affected (all $ps < .01$) by display size [$F(3,159) = 99.24$], by target pres-

ence [$F(1,53) = 296.20$], and by their interaction [$F(3,159) = 21.40$]: Accuracy remained high for target-absent trials, though it dropped for target-present trials in the two larger display-size conditions.

The data for target-present trials were then analyzed over display size × target condition (unique target, nonunique target). Mean RT was significantly affected (all $ps < .01$) by display size [$F(3,159) = 166.32$] and by target condition [$F(1,53) = 11.67$], as well as by their interaction [$F(3,158) = 5.45$]. This interaction indicates that there is a difference between the slopes of the two target conditions. The difference in RT between the two target conditions within each display size is shown in Table 1. Planned comparisons between the two target conditions within each display size show that an irrelevantly unique target was detected faster under the two larger display-size conditions [$F(1,53) = 5.57, p < .05$ (16-letter display), and $F(1,53) = 6.67, p < .05$ (25-letter display)].

Accuracy was affected by display size [$F(3,159) = 36.15, p < .01$] and by an interaction of display size and target condition [$F(3,158) = 7.75, p < .01$]. Planned comparisons between the two target conditions within each display size show this interaction to have arisen from a lower-than-expected accuracy in the condition of a display size of 9 letters with a uniquely colored target [$F(1,53) = 21.98, p < .01$]. While error rates were somewhat higher for the unique-target conditions across the range of display sizes, this does not represent a speed-accuracy tradeoff for the unique- and nonunique-target trials. The pattern of errors—higher error rates for the target-present than for the target-absent trials—suggest that any response bias that was present was toward the target-absent response. Therefore, the faster RTs for the unique- than for the nonunique-target trials cannot be attributed to a more liberal response criterion for the unique-target trials.

Discussion

Although the RTs obtained in the unique-target condition do not conform to the zero-slope criterion of attentional capture, the results do indicate that response times for unique and nonunique targets diverged with increasing display size. These results were obtained from subjects who were not engaged in singleton search, nor

Table 1
Experiment 1. Average Reaction Times (RT, in Milliseconds), Differences Between Unique- and Nonunique-Target Conditions, and Percent Errors (PE) by Display Size

Target Condition	Display Size								Slope	R ²
	4		9		16		25			
	RT	PE	RT	PE	RT	PE	RT	PE		
Absent	833	3.0	1,107	2.6	1,539	3.4	1,956	6.2	54.0	.996
Present, unique	753	6.4	877	16.7	1,003	19.7	1,184	19.6	20.2	.997
Present, nonunique	746	5.7	893	7.9	1,076	13.3	1,297	16.8	26.1	.998
Unique–nonunique difference	+7	0.7	–16	8.8	–73	6.4	–113	2.8		

was there any *a priori* reason to believe that subjects would voluntarily attend to the colored object. Thus, while our results do not suggest stimulus-driven capture by an irrelevant, uniquely colored object, they do suggest an increased probability of rapid processing of these unique items with larger display sizes. Hereafter, we will refer to this effect as *attentional misguidance* to distinguish it from the phenomenon of attentional capture. The potential mechanisms that might underlie the attentional-misguidance effect will be discussed in the general discussion of the color and luminance studies (Experiments 1 and 2).

Earlier, we had suggested that the faster RTs for unique than for nonunique targets with increasing display size might be the result of increases in the salience of the unique color with larger numbers of objects in the display. However, thus far, we have offered no independent evidence that the salience of the uniquely colored items increases with increases in display size. In an effort to examine this issue, we had 26 new subjects perform a visual-search task much like that performed in Experiment 1.³ However, in the present case, a uniquely colored nontarget letter appeared only on the last of 20 trials. Thus, for the first 19 trials, the subjects searched for a predefined target letter in a monochrome red or green display. Thirteen of the subjects searched through displays of 9 letters, and the other 13 searched through displays of 25 letters. After the last trial of the 20-trial sequence, the subjects were first asked to recall all of the letters that they could from the last display and were then also asked whether they noticed anything different about this last display.

Twelve of the subjects who had viewed the large displays and four of the subjects who had viewed the small displays recalled the uniquely colored item first. This difference was highly significant ($\chi^2 = 10.4, p < .01$). All 13 of the subjects who viewed the large displays and 9 of those who viewed the small displays reported that a uniquely colored letter had appeared on the last trial of the 20-trial series ($\chi^2 = 4.72, p < .05$). These results support our hypothesis that the salience of the uniquely colored item increases with display set size. Furthermore, these results, in conjunction with the findings obtained in Experiment 1, suggest that the influence of an irrelevant but uniquely colored object on search performance is a function of the relative salience of this object: As display size increased, the uniquely colored letter became more salient, leading to reduced RTs.

Folk (1990) also questioned Jonides and Yantis's (1988) conclusion that a uniquely colored object would not capture attention. Folk hypothesized that Jonides and Yantis's displays, whose interobject distances were greater than 5° visual angle, may have allowed no effective local lateral inhibition, and thus no increase in an object's relative salience (Koch & Ullman, 1985; Ullman, 1984). To test this hypothesis, Folk created displays similar to that shown in Figure 2, containing either 2 or 4 letters, with or without the smaller background

Figure 2. An example of a display used to reevaluate Folk's (1990) hypothesis concerning the necessity for local lateral inhibition to incur attentional capture by an irrelevant color. The placement of the four letters within the 25 interior locations of the matrix varied across trials; the dots were the same color as the majority of letters within any one display.

dots. These dots were intended to enable inhibition to occur. When present, the dots were the same color as one of the two letters, or as three of the four letters. However, Folk did not find improved detection of an irrelevantly unique target with or without the presence of the background dots in either display-size condition. These findings differ from the present results.

This discrepancy may be due to differences between the stimuli used by Folk (1990) and those employed in the present experiment. In the latter, the matrix of letters appeared randomly about the initial fixation point, and the location of the target letter within the matrix also varied. In Folk's experiment, the locations of the letters were static. This may have prompted the subjects to read or scan these locations in a set, stable pattern from trial to trial, suppressing any attentional misguidance by the uniquely colored letter. To test this hypothesis, a follow-up experiment was conducted, using stimuli similar to Folk's (Figure 2), though locating this matrix, and the letters within it, randomly across trials.⁴ Mean RT to detect the target letter was significantly faster when it was uniquely colored than when it was not [$F(1,16) = 10.57, p < .01$]. It appears that when subjects cannot adopt a tightly defined scanning strategy, a unique color will misguide attention.

EXPERIMENT 2

In Experiment 2, we examined whether an irrelevantly unique bright object among many dim objects, or the re-

verse, may also misguide attention because of its relative salience. As in the first experiment, this would be demonstrated by a relative decrease in RTs for irrelevantly unique target letters in large displays. Unlike Experiment 1 however, in Experiment 2, the physical characteristics of the two letter types (bright and dim) could reasonably be expected to influence perception of the target letter, regardless of that letter's uniqueness within a display.

Method

Subjects. Thirty University of Illinois students, 6 male, 24 female, 16 to 27 years old (mean age 20.1) completed two 50-min sessions, earning \$4.00 per hour.

Stimulus and Apparatus. All of the displayed letters now appeared as one of two shades of gray, either "bright" (44.5 cd/m²) or "dim" (8.7 cd/m²), replacing the red and green coloring of the first experiment. These gray values approximate those used by Jonides and Yantis (1988), of 42.3 cd/m² and 7.1 cd/m², respectively. Each trial's initial, prestimulus target letter was also presented colored gray (26.8 cd/m²). All displays contained one uniquely luminous letter (randomly either bright or dim), with the remaining letters in the opposite shade. Otherwise, the stimuli and apparatus were identical to those used in Experiment 1.

Procedure. Each subject completed two sessions, for a total of 2,100 trials. In all other respects, the procedure was identical to that of Experiment 1.

Experimental design. The experiment was a within-subject, three-way factorial design. The factors were display size (4, 9, 16, or 25 total letters), target condition (absent, present and uniquely luminous, or present but not uniquely luminous), and luminance of the irrelevantly unique letter (bright or dim).

Results

The mean correct RTs and percentage-error values are shown in Table 2. Again, trials with RTs faster than 100 msec or greater than that subject's 98.5 percentile were deleted prior to the calculation of that subject's means.

The mean RT and accuracy data were initially submitted to two-way weighted repeated measures ANOVAs of display size $\times$ target presence. Reaction time was sig-

nificantly affected (all $ps < .01$) by display size [$F(3,87) = 226.76$] and by target presence [$F(1,29) = 145.54$], and by their interaction [$F(3,87) = 106.33$]. Again, these results are not surprising, given the longer and increasing RTs of the target-absent trials across the four display sizes. Likewise, accuracy was significantly affected (all $ps < .01$) by display size [$F(3,87) = 72.13$], by target presence [$F(1,29) = 167.89$], and by their interaction [$F(3,87) = 52.19$]: Accuracy remained high for target-absent trials, though it dropped for target-present trials in the two larger display-size conditions.

The RT and accuracy data for the target-present trials were then analyzed, this time by three-way weighted repeated measures ANOVAs of display size $\times$ target condition (unique target, nonunique target) $\times$ unique luminance (bright unique/nonunique, dim unique/nonunique). Mean RT was significantly affected ($p < .01$ unless noted) by display size [$F(3,87) = 143.12$], by target condition [$F(1,29) = 7.29, p < .05$], and by unique luminance [$F(1,29) = 28.38$]; by their two-way interactions [display size $\times$ target condition: $F(3,87) = 2.79, p < .05$; display size $\times$ unique luminance: $F(3,87) = 5.74$; and target condition $\times$ unique luminance: $F(1,29) = 29.17$]; and, most notably, by their three-way interaction [$F(3,87) = 7.09$]. Accuracy was significantly affected by display size alone [$F(3,87) = 27.28$].

The three-way interaction of display size, target condition, and unique luminance indicates that the luminance (bright or dim) of the irrelevantly unique object differentially affected its ability to influence attentional allocation. Separate analyses of the bright unique/nonunique and dim unique/nonunique conditions were therefore performed. The data were submitted, separately by unique luminance, to two-way weighted repeated measures ANOVAs of display size $\times$ target condition (unique, nonunique).

Bright unique. A comparison of performance between the bright-unique versus bright-nonunique target-

Table 2
Experiment 2. Average Reaction Times (RT, in Milliseconds), Differences Between Unique- and Nonunique-Target Conditions by Unique Luminance, and Percent Errors (PE) by Display Size

Target Condition	Display Size								Slope	R^2
	4		9		16		25			
	RT	PE	RT	PE	RT	PE	RT	PE		
Bright										
Absent	784	1.8	1,017	1.9	1,400	2.2	1,837	3.0	50.6	.999
Present, unique	669	3.1	749	8.8	893	12.6	1,022	12.2	17.1	.994
Present, nonunique	688	4.0	819	7.2	1,005	11.6	1,206	16.1	24.8	.998
Unique–nonunique difference	–19	0.9	–70	1.6	–112	1.0	–184	–3.9		
Dim										
Absent	787	1.8	1,002	1.5	1,422	2.1	1,868	3.1	52.4	.997
Present, unique	717	5.4	872	10.5	1,080	16.4	1,225	19.6	24.3	.976
Present, nonunique	712	4.3	839	6.9	1,017	11.2	1,208	14.6	23.7	.998
Unique–nonunique difference	+5	1.1	+33	3.6	+63	5.2	+17	5.0		

letter conditions showed RT to be significantly affected (all $ps < .01$) by display size [$F(3,87) = 82.81$], by target condition [$F(1,29) = 21.21$], and by their interaction [$F(3,80) = 8.22$]. As in Experiment 1, this interaction indicates that there is a difference between the slopes of the two target conditions. Accuracy was affected by display size [$F(3,87) = 15.38, p < .01$] and target condition [$F(1,29) = 5.83, p < .05$]: Accuracy decreased with display size and increased when the target was, by chance, the irrelevantly bright unique object.

Planned comparisons between the two target conditions show that within each display size, a uniquely bright target letter was detected faster than a nonunique bright target letter in all four display-size conditions [$F(1,29) = 5.44, (p < .05), 6.28 (p < .05), 11.28 (p < .01),$ and $12.79 (p < .01)$ for display sizes 4, 9, 16, and 25, respectively]. Accuracy between the two target conditions was significantly different only in the largest display-size condition [$F(1,29) = 5.68, p < .05$].

Dim unique. A comparison of performance between the dim-unique versus dim-nonunique target-letter conditions showed both RT and accuracy to be significantly affected by display size alone [respectively, $F(3,87) = 99.88, p < .01$ and $F(3,87) = 14.0, p < .01$]. Planned comparisons between the two target conditions showed that in the 9-object display-size condition, a uniquely dim target letter was detected more slowly than was a nonunique dim target letter [$F(1,29) = 7.40, p < .05$].

Discussion

The results obtained in this study indicate that the specific luminance of the irrelevantly unique letter influenced subjects' performance. When the unique letter was one bright object among several dim objects, increasing display sizes led to an increasing performance benefit for this unique-target condition over the bright nonunique-target condition. This was not the case when the unique letter was one dim object among several bright objects. In sum, a bright unique object misguided attention, while a dim unique object did not.

Why did a uniquely dim object fail to misguide attention? As discussed above, Ullman's (1984; Koch & Ullman, 1985) and Duncan and Humphreys' (1989) models predict that a unique object may be perceived as the most salient or noticeable object within a display and thus subsequently attract attention. Within Ullman's model, however, an object's salience depends in part on the level of activity generated by that object: Surrounding bright (active) objects will inhibit a dim (less active) object, rendering the dim object less salient and therefore less likely to attract attention. Treisman and Gormican (1988) have documented a similar phenomenon of search asymmetry: Targets that were defined by greater values of a quantitative dimension (e.g., contrast) among distractors of lesser values were detected more easily than in the opposite condition. We hypothesize that, for the display parameters used, any salience due to the

uniqueness of the dim object was negated by the greater salience of the brighter, distractor objects, thus leading to the failure of the uniquely dim object to misguide attention.

GENERAL DISCUSSION

Color and Luminance

The results of Experiments 1 and 2 temper the claim that unique but task-irrelevant objects, defined by color or luminance, do not influence the allocation of visual attention. In Experiment 1, a target letter was detected faster when it was an irrelevantly unique color than when it was not. In Experiment 2, a target letter was detected faster when it was an irrelevantly unique, bright letter than when it was a nonunique, though still bright, letter. These results were obtained under conditions in which the subjects were not engaged in singleton search, nor was there any *a priori* reason to believe that the subjects would voluntarily attend to these unique but task-irrelevant features.

As described earlier, several models of visual attention predict that an irrelevantly unique, salient object may, at times, attract attention (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Koch & Ullman, 1985). The results presented here show that, with larger display sizes, an increasingly salient, irrelevantly colored or brightened object will indeed influence attention. However, the slopes of the unique-target conditions across display size are greater than the minimal slopes found by the capture of attention by a sudden onset (Jonides & Yantis, 1988; Yantis & Jonides, 1984). In fact, in most of the studies that have examined the attention-capturing ability of sudden onsets, search slopes have not been significantly different from zero. Such a pattern of data would indicate that the unique, sudden-onset object was processed first, regardless of the number of distractor objects present in the display.

The magnitude of the search slopes obtained in Experiments 1 and 2 clearly indicate that unique but irrelevant objects defined by color or luminance are not always the first objects to be processed from the display. On the other hand, our results indicate that the processing-speed advantage for the unique over the nonunique target trials increases with the number of distractors, presumably as a function of the relative salience of the unique object. Thus, it is conceivable that the proportion of trials on which attention is captured (i.e., trials on which the unique item is processed first) may increase with the salience of the uniquely colored or bright objects. Alternatively, it is possible that the processing advantage that accrues for the unique-target trials with increasing display size is not an all-or-none phenomenon, as would be suggested by the capture hypothesis, but instead reflects a graded attention allocation process that depends on the salience of the unique target object.

These two hypotheses can be contrasted by examining changes in the pattern of the within-subject, within-condition RT variance across the different display set sizes. An increase in the number of trials on which attention was initially directed to the unique target item (i.e., attentional-capture hypothesis) with increasing display size would be consistent with an increase in the RT variance for the unique-target trials relative to the nonunique-target trials for larger display sizes (Sperling & Doshier, 1986). On the other hand, a failure to find changes in the relative RT variances in the unique- and nonunique-target conditions would be consistent with a graded attention allocation process. In an effort to address this issue, we submitted the logarithmically transformed within-subject variances to two-way ANOVAs, with display size and target condition as factors. A significant main effect was obtained for display size for both the colored and the bright objects [$F(1,53) = 11.2$ and $F(1,29) = 23.6$, respectively], indicating that variances increased with display size. However, neither the target condition nor the target condition $\times$ display size effects were significant for either Experiment 1 or 2. Thus, these results are consistent with the graded attention allocation hypothesis.⁵

An important question concerns the manner in which such a graded attention allocation process might function. Our working hypothesis is as follows: Consistent with the proposal by Koch and Ullman (1985; see also Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman & Souther, 1985; Ullman, 1984), we assume that the rate at which the representations of different objects are activated within their feature maps is dependent upon the relative salience of these features, and that the salience is determined, in part, by the number and density of nonunique objects. We further assume that the time at which a person detects a unique object is a stochastic process that depends upon the time at which the activation level of the object exceeds a particular threshold or criterion. Finally, we assume that once the unique object is detected, subjects can voluntarily attend to this object, given that the search has not yet been successfully completed. Within this context it is conceivable that the unique object serves as a landmark from which to begin or continue the search.

The findings obtained in Experiments 1 and 2 are quite compatible with this proposal. Given that detection thresholds are exceeded more quickly with large than with small displays, the influence of the unique targets on performance would be expected to increase with increasing display size. The differential time course of unique-object detection for different display sizes would also be expected to interact with the serial-search processes evident in our studies. Thus, since longer searches occur in the same situations that result in faster unique-object detection—that is, with larger display set sizes—the likelihood of the unique object being detected and subsequently attended before search completion increases with the number of objects in the display.

In sum, the results of Experiments 1 and 2 suggest that an irrelevant but uniquely colored or luminous object may influence visual attention. In contrast to the capture of attention by a sudden onset, which is argued to be a stimulus-driven process (Yantis, 1993a, 1993b; but see Folk et al., 1993), misguidance of attention by these dimensions is dependent on the number and properties of the distractor objects, as well as on the voluntary allocation of attention to the unique object.

BOUNDARIES

In the two experiments presented above, we have seen that an object, irrelevantly unique in either color or luminance, may influence attention. In the following two experiments, we examine whether another property within the visual array, namely, the boundary or edge between two areas of distinct texture, may also influence attention.

One of the earliest stages of visual processing has long been assumed to be that of the parsing of the visual array into separate areas or objects (Beck, 1982; Kahneman, 1973; Neisser, 1967). These objects are created hierarchically, so that an object may be considered to be both part of some greater object as well as a collection of lesser, individual objects (Marr & Nishihara, 1978; Palmer, 1977), and this segmentation or grouping of the visual array is influenced by the spatial proximity and similarity of these individual objects (e.g., Beck, Prazdny, & Rosenfeld, 1983; Wertheimer, 1923). How might this segmentation affect the allocation of visual attention?

Pashler (1988), while examining singleton capture, also tested the effects of "salient texture boundaries" within his 90-element stimuli (Experiment 7). He hypothesized that an irrelevant color singleton may disrupt search for an unspecified form singleton simply because of its salient boundary against the remaining elements, and not because of its status as a singleton. To test this hypothesis, he compared seven stimulus arrays, all monochromatic, three with nonsingleton texture (horizontal stripes, vertical stripes, and checkerboard), and three with singletons. Pashler concluded that "it is singletons in the irrelevant dimension, rather than just the presence of any compelling textural organization in that dimension, that produces interference in the speeded detection of form singletons." The textures or boundaries used (repetitive stripes and a checkerboard) did not influence the allocation of attention, at least not during singleton search.

Banks and colleagues (Banks, Bodinger, & Illige, 1974; Banks & Prinzmetal, 1976) examined the effects of segregation due to spatial proximity on the discrimination of a target letter (an "F" or a "T") among distractors. Banks and Prinzmetal found improved performance with the addition of distractors, as long as the additional distractors formed a subjective group not including the target letter. They concluded that the objective organization of the visual array induced formation

of these groups, and suggested that these groups were then used as input to additional processes involved in target discrimination. When a group contained both the target and distractors, this group would need to be reparsed, directed by an attentive process, in order to distinguish the individual target letter (as described, for example, by Kahneman, 1973).

While Banks and colleagues' research has shown some specific costs and benefits of unintentional segregation, they considered these effects to be due to the application of attentional resources to groups of objects (Banks et al., 1974; Banks & Prinzmetal, 1976). Treisman (1982) also investigated the effects of grouping objects into spatially separate groups. Treisman's theory of feature integration held that detection of a conjunctively defined target (e.g., a red "X," as a unique conjunction among red "O"s and green "X"s) requires focal attention. Hypothesizing that if objects are preattentively grouped, and that, in the search for a target, attention may be applied to a group as a whole (the groups were arranged so that within any one group, the conjunctively defined target would be unique along one of its two dimensions, essentially becoming a feature search), Treisman predicted and found that search for a conjunctively defined target occurs in parallel within groups and serially from group to group.

We are concerned with examining the misguidance of attention due to segregation in situations in which such segregation would be irrelevant or even detrimental to the task at hand. We hypothesize that just as an irrelevant but salient color may influence attention, so too may a salient boundary. In the present study a boundary may influence attention either because it provides a landmark from which to begin or continue a search or because the contrast between the objects at this boundary is exaggerated and therefore more salient (Ratcliff, 1965).

EXPERIMENT 3

In this experiment we examined the effects of segregation due to the task-irrelevant colors of individual letters on visual search for a target letter. If attention is allocated to the letters near a salient boundary, a target letter located near this boundary would be expected to be detected faster than one located some distance from this boundary. Likewise, this difference should increase with increasing salience of this boundary, a factor influenced again by increasing display size.

Method

Subjects. Twenty-four University of Illinois students, 11 male and 13 female, 17 to 20 years old (mean age 18.3), completed one 50-min session in partial fulfillment of a course requirement.

Stimulus and Apparatus. An example of one of the four display conditions is shown in Figure 3. A display consisted of 8, 16, or 24 letters, arranged around imaginary circles of increasing diameter so that interletter distances were equivalent across the three display sizes. These circles were centered randomly within 3.68° horizontally and 2.58° vertically of fixation with the constraint that the average distance of a potential target letter from the initial fix-

Figure 3. An example of an 8-object stimulus (Experiment 3). The solid letters were presented in red (green) and the hollow letters in green (red), in a font style like the one shown here; actual size was approximately 25% larger.

ation point would be equivalent across the three display sizes (as in Treisman, 1991). Subjects viewed the display from 1.4 m. An individual letter was 0.38° high and 0.37° wide; the center-to-center difference between letters for all display sizes was 0.73°. The diameters of the three imaginary circles were 2.00, 3.85, and 5.74°. The stimuli were presented with high-resolution VGA graphics.

In all displays, one contiguous half of the letters forming the circular array was green (red) and the other red (green), over a black background. The location of the boundary between these two contiguous arcs varied randomly across trials. On half of the trials, the defined target letter was present (once). Each trial's target letter was randomly selected from the pool of 26 English letters, as were the nontarget letters, the latter with replacement. The target letter, if present, was placed equally often across all locations within each display size in a random sequence. Thus, when the target was present, it was on average located at the boundary between the colored arcs once out of every 2, 4, and 6 trials of the respective display sizes.

Procedure. The procedure was the same as that in the previous two experiments, except that in this case each subject completed 1,008 (unblocked) trials—320 of each display size, plus an additional 48 practice trials that began each session.

Experimental design. The experiment was a within-subject, two-way factorial design. The factors were display size (8, 16, or 24 total letters) and target condition (absent, present and located at a boundary, or present but not located at a boundary).

Results

The mean correct RTs and percent-error values are shown in Table 3. Trials with RTs faster than 100 msec

Table 3
Experiment 3. Average Reaction Times (RT, in Milliseconds), Differences Between Boundary and Nonboundary Target Conditions by Display Size, and Percent Errors (PE)

Target Condition	Display Size						Slope	R ²
	8		16		24			
	RT	PE	RT	PE	RT	PE		
Absent	1,179	1.6	1,958	2.1	2,604	3.2	89.1	.997
Present, boundary	943	6.1	1,220	9.4	1,504	11.8	35.0	.999
Present, nonboundary	970	6.2	1,284	10.1	1,619	13.3	40.6	.981
Boundary– nonboundary difference	–27	–0.1	–64	–0.7	–115	–1.5		

or greater than that subject's 98.5 percentile were deleted prior to the calculation of that subject's means.

The RT and accuracy data were initially submitted to two-way weighted repeated measures ANOVAs of display size $\times$ target presence. Both RT and accuracy were significantly affected (all $ps < .01$ unless noted) by display size [respectively, $F(2,46) = 172.31$ and $F(2,46) = 25.88$] and by target presence [$F(1,23) = 135.49$ and $F(1,23) = 140.09$], as well as by their interaction [$F(2,46) = 120.87$ and $F(2,46) = 4.82$, $p < .05$]. There were longer and increasing RTs for target-absent trials and there was a drop in accuracy for target-present trials across the four display sizes.

The data for target-present trials were then analyzed over display size $\times$ target condition (boundary target, nonboundary target). Mean RT was significantly affected (all $ps < .01$) by both display size [$F(2,46) = 133.17$] and target condition [$F(1,23) = 25.96$], as well as by their interaction [$F(2,46) = 6.95$]. Again, this interaction indicates that there is a difference between the slopes of the two target conditions. The difference in RT between the two target conditions within each display size is shown in Table 3. Planned comparisons between the two target conditions within each display size show that a target located at the boundary of the two colored arcs was detected significantly faster under the two larger display-size conditions [$F(1,23) = 6.71$, $p < .05$ (16-letter display) and $F(1,23) = 23.06$, $p < .01$ (24-letter display)]. Accuracy was affected by display size [$F(2,46) = 16.74$, $p < .01$].

Discussion

The results support the conclusion that a salient, though task-irrelevant, boundary will guide attention to the letters at this boundary. Detection was quicker for target letters located at this boundary than it was for those that were not, and was as accurate.

EXPERIMENT 4

In the previous experiment, performance was compared between conditions in which the target letter was and was not located at an irrelevant boundary. This comparison, however, may be considered to contain both a benefit (when the target letter was at the boundary) and a cost (since attention was guided to the boundary, away from a nonboundary target letter). To distinguish between these two effects, in Experiment 4 performance in these two conditions was compared with that in a third condition, in which the display's objects were all of one color—a no-boundary condition.

Method

Subjects. Twenty-four University of Illinois students, 11 male and 13 female, 17 to 21 years old (mean age 18.1), completed one 50-min session in partial fulfillment of a course requirement.

Stimulus and Apparatus. The stimuli and apparatus were identical to those used in Experiment 3, with the exceptions that (a) only displays of 24 letters were used, and (b) an additional con-

dition was included, in which all of the letters were of the same color—a monochromatic, no-boundary condition. In this condition, all of the 24 letters were either red or green (randomly varied across trials).

Procedure. The procedure was identical to that of Experiment 3, with the exception that each subject now completed 720 (unblocked) trials, with one-half of these trials testing target detection in the monochromatic, no-boundary condition.

Experimental design. The experiment was a within-subject, one-way factorial design of target condition (absent, present and located at a boundary, present but not located at the boundary, or present within a monochromatic display).

Results

The mean correct RTs and percentage-error values are shown in Table 4. Trials with RTs faster than 100 msec or greater than that subject's 98.5 percentile were deleted prior to the calculation of that subject's means.

The RT and accuracy data were initially submitted to one-way weighted repeated measures ANOVAs of target presence. Both RT and accuracy were greater for the target-absent than for the target-present trials [respectively, $F(1,23) = 239.56$, $p < .01$ and $F(1,23) = 183.04$, $p < .01$].

The data for target-present trials were then analyzed, again by one-way weighted repeated measures ANOVAs of target condition (target present and located at a boundary, target present and not located at the boundary, or target present within a monochromatic display). Both RT and accuracy were significantly affected [$F(2,46) = 12.83$, $p < .01$ and $F(2,46) = 5.51$, $p < .01$, respectively]. Planned pairwise comparisons of RT between the three target conditions showed all to be significantly different [boundary vs. monochromatic: $F(1,23) = 13.97$, $p < .01$; boundary vs. nonboundary: $F(1,23) = 24.97$, $p < .01$; and nonboundary vs. monochromatic: $F(1,23) = 5.38$, $p < .05$]. The boundary condition was 87 msec faster than the monochromatic condition and 118 msec faster than the nonboundary condition; the nonboundary condition was 31 msec slower than the monochromatic condition. Planned pairwise comparisons of accuracy between the conditions showed boundary versus monochromatic [$F(1,23) = 11.02$, $p < .01$] and boundary versus nonboundary [$F(1,23) = 7.63$, $p < .01$] to significantly differ. The boundary condition was 4.3 and 3.4% more accurate than the monochromatic and nonboundary conditions, respectively.

Discussion

These results show that a target letter was detected faster and more accurately when it was located at a color

Table 4
Experiment 4. Average Reaction Times (RT, in Milliseconds) and Percent Errors (PE) of Target-Absent and Target-Present (Boundary, Nonboundary, and No-Boundary Monochromatic) Conditions

Target Condition	RT	PE
Absent	2,540	1.6
Present, boundary	1,455	10.5
Present, nonboundary	1,573	13.9
Present, monochromatic	1,542	14.8

boundary than when it was located within a monochromatic, no-boundary display. In turn, a target letter was detected faster in a monochromatic display than when it was located some distance from a boundary. The former comparison shows a relative benefit, the latter a relative cost, due to the presence of a salient, though task-irrelevant, boundary.

GENERAL DISCUSSION

Boundaries

The results of these two experiments show that attention may be guided by a salient, though task-irrelevant, boundary to objects located near this boundary. In Experiment 3, a target letter was detected faster when it was located near a boundary than when it was not. In Experiment 4, the relative costs and benefits of misguidance of attention by a salient boundary were demonstrated.

Wolfe (1992), in a discussion of the similarities and differences between visual search and texture segregation, suggests that these processes involve both top-down (cognitively driven) and bottom-up (stimulus-driven) components. Wolfe also proposed that this bottom-up component "directs attention to unusual loci including isolated, unique items and borders" (p. 762). Wolfe's suggestion, based on his model of visual search (Cave & Wolfe, 1990; Wolfe, Cave, & Franzel, 1989), and the similar models of Koch and Ullman (1985) and Duncan and Humphreys (1989) all recognize the importance of potential bottom-up, unintentional processes in guiding attention. The results presented here lend credence to Wolfe's proposal.

These results show that with increasing display size there was an increasing benefit when a target letter was located, by chance, near a boundary. However, the slope of the boundary-target condition, while similar to those representing the guidance of attention by a uniquely colored or brightened object (Experiments 1 and 2), is again greater than the shallow slopes found for the capture of attention by a sudden onset (Jonides & Yantis, 1988; Yantis & Jonides, 1984).

This difference may, again, be due in part to the requirement for texture segregation to occur within a context. Beck (1982) has suggested a model of texture segregation where (a) properties of objects (e.g., color, shape) are detected, (b) these properties are compared and differences between objects are noted, and (c) the visual array is segmented on the basis of these differences. Segregation is a function of the size of areas containing groups of similar objects and of the number of these objects. The results presented here agree with Beck's model—that with increasing display size segregation improved, leading to an increasingly salient boundary and thus increased benefits for the boundary-target condition.

The particular organization of a stimulus array will also no doubt affect its segregation and subsequent abil-

ity to guide attention—some organizations will be more effective in guiding visual attention than others. Pashler (1988, Experiment 7) showed a failure of repetitive lines and checkerboard patterns to disrupt search performance. These results may have been obtained because these patterns did not affect visual attention or because Pashler's task was not sensitive to their effects.

CONCLUSION

The present results temper the claim that task-irrelevant attributes other than sudden onsets are unable to influence the allocation of attention within a visual display. Our results show that visual search was affected by the presence of an object with an irrelevant, unique, and salient color or increased luminance and by a salient boundary.

An important question concerns how to reconcile the present results with the models of attentional capture proposed by Jonides and Yantis (1988; see also Yantis, 1993a, 1993b) and Folk et al. (1992). Yantis and colleagues have proposed that sudden onsets are unique in their ability to capture attention in a stimulus-driven fashion. According to Yantis (1993a, 1993b), only sudden onsets have been shown to capture attention when they are orthogonal to the defining and reporting properties (Duncan, 1985) of search targets (but see Folk et al., 1992, 1993). The ability of sudden onsets to capture attention under these conditions could be due either to the special properties of the transient channels in the visual pathways (Livingstone & Hubel, 1988; Zeki & Shipp, 1988) or to the signaling of the appearance of a new object by its sudden onset (Yantis & Hillstrom, 1994).

Our tasks were similar to Yantis's (Jonides & Yantis, 1988; Yantis & Hillstrom, 1994) paradigm in that the singleton property that defined the unique object was independent of the defining and reporting properties of the target. Our results differ from his findings, however, in that the RTs that we obtained were faster on the unique-color and unique-luminance target trials than they were on the nonunique-target trials. However, unlike Yantis's results with onsets, we obtained relatively steep slopes in the unique-target conditions. Thus, it would be difficult to argue that our misguidance effect provides evidence for stimulus-driven attentional capture in which the unique item is purported to be attended first on each trial.

Folk et al. (1992) have recently proposed that attentional capture is dependent on an observer's attentional disposition or set. If subjects have an attentional set for color, unique but irrelevant colored objects will capture attention, while sudden onsets will not. On the other hand, if subjects have an attentional set for onsets, then task-irrelevant onsets will capture attention, while uniquely colored objects will not. Folk et al. have argued that the attentional set or expectancy primes the attentional system for particular singletons and that, once

primed, the occurrence of the appropriate singleton will capture attention in an involuntary or stimulus-driven fashion. Thus, unlike Yantis's purely bottom-up or stimulus-driven model of attentional capture, Folk et al.'s model includes both goal-directed and stimulus-driven components.

The unique target benefits and costs observed in our studies were obtained under conditions in which the subjects were unlikely to have an attentional set, prior to the experimental trials, for the color, luminance, or location of a unique but task-irrelevant boundary. Nevertheless, these irrelevant attributes did influence attention, albeit not in a purely stimulus-driven fashion (i.e., search slopes were not flat).

We propose that, in a manner similar to that suggested by Folk et al. (1992) for attentional capture, the misguidance phenomenon demonstrated in our studies is the result of the interaction between stimulus-driven and goal-directed components of attentional control. The stimulus-driven component involves the activation of salience or mismatch detectors in feature maps. Consistent with the proposal by Koch and Ullman (1985; see also Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman & Souther, 1985; Ullman, 1984), we assume that the rate at which the representations of different objects are activated within their feature maps is dependent upon the relative salience of these features, and that salience is determined, in part, by the number and density of nonunique objects. Thus, unique but irrelevant objects will reach detection thresholds more quickly with larger display sizes.⁶

One important question concerns why the rate of activation, and hence the time of detection, of the unique but irrelevant features should depend on salience under the present circumstances, whereas the search for a predefined feature is purported to occur in parallel across the display. To begin with, salience does play a role in some models of active search. Wolfe et al. (1989; Cave & Wolfe, 1990) have argued that stimulus salience can be viewed as a manipulation of the signal-to-noise ratio in the feature-detection process. If the salience of a feature exceeds a certain threshold, the feature-detection process will guide the attentional spotlight to the location of the target features. If salience falls short of the threshold, search for the target will occur in a serial fashion in the absence of guidance from the feature-detection process.

In addition to the role espoused for salience in active-search processes, models of visual search incorporate a number of goal-directed aspects of control which conceivably would be absent when a task-irrelevant but unique object is detected in the visual field. For example, Treisman and Sato (1990) have suggested that irrelevant distractor features are inhibited during search for a predefined target. Wolfe et al. (1989) have argued that target features are activated during search. Given that these goal-directed inhibitory and facilitatory processes would not be available to support the detection

of unique but irrelevant objects, a slower detection process for task-irrelevant unique objects, which depends, to a large extent, on the relative salience of the objects in the visual field, seems to be a reasonable proposal.

In the Folk et al. (1992) model the goal-directed component of attentional control is an attentional set for a particular feature. We speculate that in nonsingleton search, as was the case in our studies, people may adopt a fairly general attentional set in which they are predisposed to attend or orient to unique objects as a way of structuring their search, particularly when a large number of objects are present in the visual field. Thus, in a sense, the misguidance phenomenon that we have observed might be said to be contingent upon attentional set. However, the outcome in cases of nonsingleton search that we have labeled attentional misguidance appears to be a graded process rather than the all-or-none phenomenon of attentional capture. Nevertheless, we assert that the benefits and costs observed for the unique but task-irrelevant objects in our studies provide new and important insights into the interaction between stimulus-driven and goal-directed processes of attentional control.

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NOTES

1. The term *singleton* indicates an object that has a unique value within some dimension (e.g., "O" within shape) and is found among objects that both differ from the singleton and are homogeneous among themselves within this dimension (e.g., "X X X X X . . ."). By this definition, an "A" among "B B B B . . ." is a shape singleton; an "A" among "B C D E . . ." is not.

2. An arcsin transformation was applied to the accuracy data before this and all subsequent analyses to increase its normality. Weighted repeated measures ANOVAs were used, since the number of trials (the weighting variable) per display size $\times$ target condition varied widely, owing to the requirement for the target letter to appear as the irrelevantly unique letter only once out of every 4, 9, 16, or 25 trials.

3. The characters were arranged in a 3×3 or 5×5 matrix; each character was 0.38° high and 0.37° wide, and separated by 1.48° , center to center. Presentation of the trials was self-paced. The target letter was present on approximately half of the initial 19 trials, and was always absent on the twentieth. The subjects entered the letters they could recall via the computer keyboard, with these letters echoed to the computer monitor.

4. Nine subjects (mean age 18.8) completed one 50-min session of 900 trials, following 50 practice trials. A display consisted of a 7×7 matrix of small dots, with letters at 4 of the 25 interior locations. Letters were approximately $0.38 \times 0.37^\circ$ in size, dots 0.09° , and center-to-center horizontal and vertical separation 0.75° . Mean RT and accuracy to detect a unique target were 646 msec and 92.8%, respectively; for a nonunique target, they were 678 msec and 91.7%.

5. In an effort to further contrast the all-or-one (i.e., attentional-capture) and graded attention allocation hypotheses with respect to our finding of increasing unique-target processing-speed benefits with larger display set sizes we constructed Vincentized (Ratcliff, 1979; Vincent, 1912) cumulative distribution functions (CDFs) for the RT for each of the display set size conditions, individually for the unique-target and nonunique-target trials, in Experiments 1 and 2. The shape of the CDFs did not change across set sizes or target types for either of the experiments. Such a pattern of results is consistent with the graded attention allocation hypothesis.

6. It is important to note, however, that salience does not appear to be important for sudden onsets, perhaps because the processing of these objects is supported by the transient channels in the visual pathways.