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Stimulus-Driven Attentional Capture Is Contingent on Attentional Set for Displaywide Visual Features

Bradley S. Gibson and Erin M. Kelsey
University of Notre Dame

This research showed that the current criterion for stimulus-driven attentional capture is not sufficient to rule out goal-directed processes that are critical for producing attentional capture. This was shown by demonstrating a contingency between displaywide visual features (i.e., features that signal the appearance of the task-relevant target display as a whole) and the features that capture attention. In Experiment 1, the target display was signaled by both color and onset; in Experiment 2, the target display was signaled only by onset. As expected, Experiment 1 showed that task-irrelevant color and onset distractors both captured attention, whereas Experiment 2 showed that only onset distractors captured attention. These contingencies suggest that the strongest evidence currently available for stimulus-driven attentional capture may be caused by goal-directed processes.

Psychologists have long been interested in the question of how visual attention is controlled (James, 1890/1950). Much of this research has focused on how subjective factors such as expectation and intention influence where visual attention is oriented in the visual field. Over the past decade, however, another form of attentional control has gained prominence in the literature. Unlike "goal-directed" attentional control, this alternative "stimulus-driven" form of attentional control is thought to be driven solely by visual features that are extrinsic to the observer. Stimulus-driven attentional control is important because it suggests that visual attention may sometimes be unintentionally (or involuntarily) captured by particular objects or events in the world, a phenomenon that has come to be called *stimulus-driven attentional capture* (Yantis, 1993a, 1996).

However, although stimulus-driven attentional capture has been defined as a form of attentional orienting that is independent of the goals and intentions of the observer, there has been only modest empirical evidence provided in support of such a mechanism (see Yantis, 1996, for a review). Moreover, at least some evidence that has previously been provided in support of stimulus-driven attentional capture has now been shown to reflect significant contributions from goal-directed attentional control processes. For instance, one important source of evidence for stimulus-driven attentional capture involved studies in which an irrelevant abrupt-onset distractor (or "cue") was presented shortly before a to-be-detected abrupt-onset target (Posner, 1980; Posner & Cohen, 1984). Because the abrupt-onset distractors did not predict where the target would appear, it was assumed that observers would not intentionally attend to the irrelevant distractors. Despite the fact that the distractors did not predict when the target would appear, these studies typically showed that response time (RT) to detect the target was faster when the target and distractor appeared at the same location than when they appeared at different locations, suggesting that attention was unintentionally captured by the irrelevant abrupt-onset distractors. However, a critical role for goal-directed attentional control processes arises in these studies when it is realized that the visual features that defined the distractors also defined the target. As such, the abrupt-onset distractors may have controlled where attention was oriented in these studies because observers were intentionally set to detect abrupt-onset targets.

The hypothesis that stimulus-driven attentional capture is contingent on an attentional set for target-defining features was recently tested in experiments conducted by Folk, Remington, and Johnston (1992). In their experiments, two types of targets were crossed with two types of distractors. For one group of observers, the target was uniquely defined by an abrupt-onset singleton (i.e., the appearance of a single white character); for the other group, the target was uniquely defined by a color singleton (i.e., the appearance of a single red character among three white characters). In each target condition, both onset singleton and color singleton distractors preceded the target display, and the distractors were not predictive of the target location. The results were consistent with the contingent capture hypothesis: When observers were set for onset singleton targets, onset distractors captured attention, but color distractors did not; in contrast, when observers were set for color singleton targets, color distractors captured attention, but onset distractors did not (cf. Theeuwes, 1994). These findings are important because they suggest that visual selective attention is oriented toward uninformative distractors only when those distractors are defined by features that match the defining features of the target. Moreover, because target-defining features repre-

Bradley S. Gibson and Erin M. Kelsey, Department of Psychology, University of Notre Dame.

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Correspondence concerning this article should be addressed to Bradley S. Gibson, Department of Psychology, University of Notre Dame, Notre Dame, Indiana 46556. Electronic mail may be sent to bradley.gibson.16@nd.edu.

sented the primary goal state of the observer in these experiments, attentional orienting to such distractors likely does not reflect pure stimulus-driven attentional capture. For this reason, it has been suggested that the occurrence of pure stimulus-driven attentional capture must be confined to those situations in which the attribute that elicits it is independent of the defining attribute of the target (Yantis, 1993b; cf. Folk, Remington, & Johnston, 1993).[1]

For instance, consider the study by Jonides (1981). In Jonides's experiment, target displays containing eight different letters were preceded by the brief appearance of an irrelevant onset singleton distractor, and observers determined which of two predefined letters (*L* or *R*) appeared in the display. Note that Jonides's study differed from the Folk et al. (1992) onset target condition in that the target was not uniquely defined by onset (because all eight letters appeared abruptly as in the Folk et al. color target condition); rather, the target was uniquely defined by identity in this experiment. Hence, this study is consistent with the criterion for stimulus-driven attentional capture because the onset distractors were unrelated to the defining attribute of the target. Nevertheless, the results showed that RTs were faster when the target and distractor appeared at the same location than when they appeared at different locations. Such effects have been taken to provide strong evidence for stimulus-driven attentional capture by abrupt visual onsets (Yantis, 1996).[2]

Of course, although Jonides's (1981) study may rule out the operation of certain goal-directed attentional control processes, there may be other, less obvious, goal-directed attentional control processes operating in his study that have not been properly controlled. One intriguing possibility is the idea that observers may routinely monitor the experimental display for visual features that signal the appearance of the task-relevant target display as a whole (Folk et al., 1992). Indeed, the observer's primary goal of locating the target may be founded on the detection of these displaywide visual features because they signal the appearance of the display that contains the target. If this hypothesis is correct, then observers may adopt an attentional set for displaywide visual features, as they do for target-specific visual features (Folk et al., 1992), which may in turn control which visual features capture attention. Such evidence would be important because it would further constrain the conditions under which stimulus-driven attentional control can be inferred and in so doing would rule out the strongest available evidence for stimulus-driven attentional capture.

Accordingly, our experiments were designed to show a contingency between the visual features that signal the appearance of the task-relevant target display as a whole and the visual features that capture attention (in the form of irrelevant distractors). In the following experiments, either color and abrupt onset together (Experiment 1) or abrupt onset alone (Experiment 2) were used to signal the appearance of the task-relevant target display as a whole. Furthermore, preceding color and onset singleton distractors were used to manipulate attentional orienting. If the occurrence of stimulus-driven attentional capture is contingent on the features that signal the appearance of the task-relevant target display, then both color and onset singleton distractors should capture attention in Experiment 1, but only onset singleton distractors should capture attention in Experiment 2. As such, the displaywide contingent capture hypothesis was tested solely within the color dimension in this research.[3] Nevertheless, such evidence will have implications for the claim that abrupt onset captures attention in a purely

[1] Bacon and Egeth (1994; see also Yantis, 1993a, 1993b) have argued for an additional constraint on the occurrence of pure stimulus-driven attentional capture. According to Bacon and Egeth, in addition to being independent of the defining attribute of the target, an irrelevant featural singleton can be said to capture attention in a stimulus-driven fashion only when the target is not itself defined as a featural singleton. This is because when the target is so defined, observers may adopt a "singleton search strategy" in which the highest attentional priority is assigned to highly salient singletons (relevant or irrelevant) appearing in the display sequence. In support of this hypothesis, Bacon and Egeth showed that irrelevant singletons influenced attentional orienting only when observers were intentionally searching for featural singletons and the irrelevant singleton was highly salient. As such, these findings further eliminate evidence that has previously been interpreted to reflect stimulus-driven attentional capture (see e.g., Joseph & Optican, 1996; Pashler, 1988; Theeuwes, 1991, 1992, 1994).

[2] Yantis and his colleagues (Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984) have also reported numerous visual search experiments that have been interpreted to show that an irrelevant onset singleton displayed among one or more "no-onset" elements can capture attention in a stimulus-driven fashion under conditions in which other types of irrelevant singletons (e.g., color, brightness, and motion) do not capture attention. Note that the irrelevant featural singletons shown in these studies are consistent with the established criteria for stimulus-driven attentional capture because the target was uniquely defined only by its identity. Hence, the visual feature that defined the irrelevant singleton was dissociated from the defining attribute of the target. However, other recent evidence reported by Gibson (1996a, 1996b) suggests that the occurrence of stimulus-driven attentional capture by abrupt visual onsets in this visual search paradigm may reflect the way in which the no-onset elements were created. In particular, Gibson has argued that the no-onset elements were forward masked by preceding figure-eight placeholders, thus producing a sensory bias (as opposed to an attentional bias) for the onset element (cf. Yantis & Jonides, 1996). Moreover, when this sensory bias was eliminated (or at least greatly reduced), abrupt-onset singletons no longer captured attention. Consequently, the evidence reported by Yantis and his colleagues can no longer be considered strong evidence for stimulus-driven attentional capture.

[3] The hypothesis that attentional capture by abrupt onset is contingent on displaywide visual features was not explicitly tested here because abrupt onset may represent more than just the occurrence of a luminance increment. For instance, the sudden appearance of a visual stimulus may be represented as a more general type of change independent of whether there is a luminance increment (Yantis & Hillstrom, 1994; Yantis & Jonides, 1996; cf. Gibson, 1996a, 1996b). Such considerations suggest that the strongest test of attentional capture by abrupt onset is one in which the appearance of the target display is not signaled by any kind of change. However, it is difficult to conceive of a paradigm in which the appearance of the target display does not require some kind of stimulus change. Consequently, the specific issue of whether attentional capture by abrupt onset is contingent on displaywide visual features is not resolved in this article.

stimulus-driven fashion (Jonides, 1981; Yantis, 1996) because such evidence is sufficient to redefine the conditions under which pure stimulus-driven attentional capture can properly be inferred.

Experiment 1

Unlike many previous attentional capture experiments (Folk & Annett, 1994; Folk et al., 1992; Folk, Remington, & Wright, 1994; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Joseph & Optican, 1996; Pashler, 1988; Theeuwes, 1991, 1992; Todd & Kramer, 1994), the target displays shown in Experiment 1 never contained a visual singleton (although visual singletons did appear in the form of irrelevant distractors). Rather, either four or eight red letters always appeared in the target display such that the appearance of the target display as a whole was signaled by both color and onset in Experiment 1 (see Figure 1). As in Jonides's (1981) study, targets were defined solely by their identity in this experiment. In particular, observers were required to decide which of two possible targets (*H* or *U*) was present on each trial. In this way, the defining attribute of the target (i.e., identity) was dissociated from the visual features that may potentially contribute to the formation of attentional set in this experiment, thereby satisfying previous criteria for involuntary attentional capture (Bacon & Egeth, 1994; Yantis, 1993b).

The potential impact of attentional set was measured by presenting irrelevant singleton distractors shortly before the task-relevant target display. The distractors used in this study were similar to the distractors used in the Folk et al. (1992) study. On each trial, the locations of the letters were marked by individual boxes. On half the trials, the target display was preceded by an onset distractor that involved the brightening of a single box. On the remaining trials, the target display was preceded by a color distractor. These distractors involved the brightening of all boxes; however, in addition, one of the boxes also turned red. To ensure that the single bright box (onset distractor) or the single red box (color distractor) did not provide any information about the location of the upcoming target, the two locations were uncorrelated (see Folk et al., 1992, Experiment 3; see also Jonides, 1981; Jonides & Yantis, 1988).

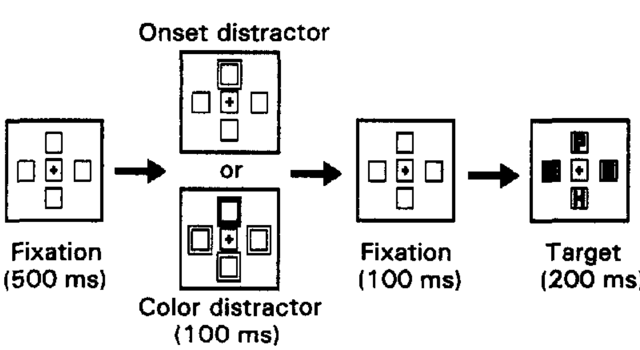

Figure 1. The general display sequence shown in Experiment 1. All stimuli appeared on a black background. The thick, hollow lines shown in the two distractor displays appeared white, and the thick, solid lines appeared red. All letters appeared red in the target display in Experiment 1.

In Experiment 1, stimulus-driven attentional capture will be indicated by RTs that are faster when the distractor appears at the same location as the target than when the distractor appears at a different location than the target. If an attentional set can be induced by the visual features that signal the appearance of the task-relevant target display, then (in the most general instance) observers should be set to detect both onset and color in this experiment. Consequently, if attentional capture is contingent on this form of attentional set, then observers should not be able to ignore either type of distractor in this experiment. Thus, an effect of distractor location should be obtained in both distractor type conditions.

Method

Participants. Sixteen undergraduates from the University of Notre Dame participated in this experiment for course credit. All students reported normal or corrected-to-normal vision.

Stimuli and apparatus. There were three types of displays shown on each trial. The first type of display was called the "fixation display." The fixation display contained a central fixation cross (0.8° × 0.8°) and either four or eight peripheral boxes (2.3° × 1.8°) that appeared at equally spaced locations around the circumference of an imaginary circle. When four boxes appeared, they appeared at 0°, 90°, 180°, and 270°; when eight boxes appeared, they appeared at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The boxes appeared 5.1° from the central fixation cross (as measured from the center of each box). All stimuli appeared on a black background; the fixation cross always appeared white (IBM Color 15), and the boxes always appeared dark gray (IBM Color 8) unless the distractor display was shown. There were two types of distractor displays shown in this experiment: onset distractors and color distractors. The onset distractors involved changing the outline contour of a single box from a thin (0.06°) gray contour to a thick (0.22°) white contour. The color distractors involved changing the outline contour of all boxes: The outline contours of all but one box were changed from a thin gray contour to a thick white contour (as in the onset distractor condition), and the remaining outline contour was changed from a thin gray contour to a thick red contour (IBM Color 12). The third type of display was called the "target display." The target display contained either four or eight red letters; each letter appeared inside a single box. The letters subtended 1.3° × 0.8° of visual angle. One letter was always the target (H or U), and the other three distractor letters were always E, P, and S. When the display size was four, each of the three distractors appeared once; when the display size was eight, each of the three distractors appeared at least twice. The stimuli were presented on a ZEOS color monitor equipped with a standard video graphics array video card. RTs were recorded by a ZEOS 486 microcomputer.

Procedure. The sequence of displays shown on each trial is depicted in Figure 1. A fixation display appeared first for 500 ms. On half the trials, four peripheral boxes appeared around fixation; on the other half, eight peripheral boxes appeared around fixation. Participants were instructed to maintain fixation on the central "+" throughout each trial. A distractor display was then shown for 100 ms. On half the trials, the distractor display contained an onset distractor; on the other half, the distractor display contained a color distractor. Because we were interested in knowing whether observers could simultaneously adopt an attentional set for both color and onset, we randomly mixed these distractors throughout the experiment. The distractor could appear at the same location as the upcoming target letter, or the distractor could appear at a different location. Both color and onset distractors appeared at the same location as the target only by chance (i.e., on 25% of the trials when display size was four and on 12.5% of the trials when display size was eight). Observers were informed of this chance association and were instructed to ignore the task-irrelevant distractors. After the distractor display, the fixation display returned for an additional 100 ms and then the target display appeared for 200 ms. The target display always contained the same number of letters as the peripheral boxes. Observers were instructed to indicate which of two possible targets was present on each trial. The two possible target letters were H and U. The target letter was always present and was equally likely to be the H or U on each trial. Observers responded by pressing the right shift key on a computer keyboard when the target was H and the left shift key when the target was U. Observers were instructed to respond as quickly and accurately as possible.

Each experimental session consisted of an initial set of 32 practice trials followed by six blocks of 64 experimental trials. Within each block of experimental trials, there were 32 onset distractor trials and 32 color distractor trials. Within each distractor type condition, there were 16 trials in each of the two display size conditions. When the display size was four, there were 4 same-location trials and 12 different-location trials; when the display size was eight, there were 2 same-location trials and 14 different-location trials. The order of trials within each block was randomly determined by the computer. Participants were allowed to take a self-timed break after each block of 64 trials.

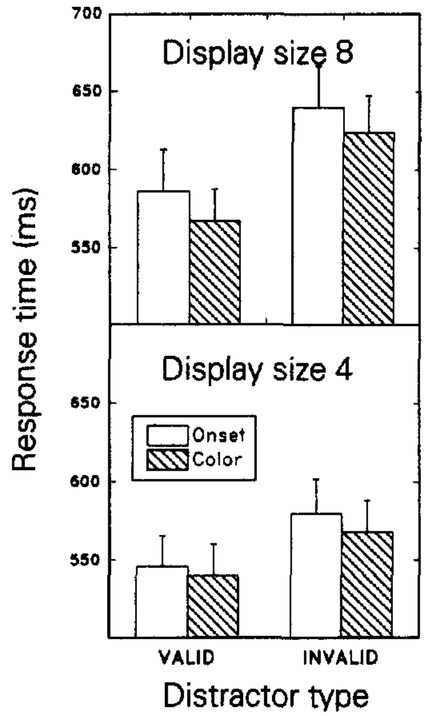

Figure 2. Mean correct response times plotted as a function of display size, distractor type, and distractor location in Experiment 1. Standard error bars are shown.

Results and Discussion

The mean correct RTs in each of the distractor type and distractor location conditions are depicted in Figure 2 as a function of display size. The corresponding error rates are shown in Table 1. In the two experiments reported here, RTs greater than 4,000 ms or less than 200 ms were excluded from the analysis. In Experiment 1, 0.03% of the trials were excluded from analysis, and in Experiment 2, 0.20% of the trials were excluded from analysis. In addition, correct RTs greater than 3 *SD*s from the overall mean for each participant were trimmed to that value. In Experiment 1, 1.76% of the trials were trimmed, and in Experiment 2, 1.55% of the trials were trimmed.

A three-way repeated measures analysis of variance (ANOVA) was performed on the mean correct RTs and percentage errors, with display size (four vs. eight), distractor type (onset vs. color), and distractor location (same vs. different) as within-subjects variables. As expected, the target was located faster in a display of four letters than in a display of eight letters, $F(1, 15) = 55.56$, $MSE = 1{,}223.61$, $p < .0001$, for the main effect of display size. This display size effect was also manifested in the error rates, which generally increased as display size increased, although this difference did not attain conventional levels of significance, $F(1, 15) = 3.39$, $MSE = 16.41$, $p < .09$. There was also a marginally significant trend toward faster RTs in the color distractor condition relative to the onset distractor condition, $F(1, 15) = 3.74$, $MSE = 1{,}524.45$, $p < .08$. This main effect of distractor type suggested that the prior appearance of a red distractor might have facilitated processing of the red target display relative to the prior appearance of an onset distractor. Note, however, that this RT effect should be interpreted cautiously because error rates were also slightly higher overall in the color distractor condition than in the onset distractor condition, $F(1, 15) = 3.68$, $MSE = 14.91$, $p < .08$, indicating a possible speed–accuracy trade-off.

Most important, the results were consistent with the displaywide contingent capture hypothesis: The main effect of distractor location was significant, $F(1, 15) = 44.41$, $MSE = 1{,}355.53$, $p < .0001$, indicating that RTs were faster in the same-location condition ($M = 560$ ms) than in the different-location condition ($M = 603$ ms). In addition, error rates were also significantly lower in the same-location

Table 1
Percentage Error Rate as a Function of Display Size, Distractor Type, and Distractor Location in Experiment 1

Distractor location	Distractor type: Onset	Color
Display Size 4		
Same	2.34	4.18
Different	3.49	3.99
Display Size 8		
Same	3.11	4.68
Different	5.08	6.41

condition ($M = 3.58\%$) than in the different-location condition (4.74%), $F(1, 15) = 12.05$, $MSE = 3.59$, $p < .005$. Moreover, the magnitude of the distractor location RT effect (different-location RT − same-location RT) was nearly identical across the two distractor type conditions. In the Display Size 4 condition, the effect of distractor location was 34 ms in the onset distractor condition and 28 ms in the color distractor condition. In the Display Size 8 condition, the effect of distractor location was 54 ms in the onset distractor condition and 57 ms in the color distractor condition. As such, neither the Distractor Type × Distractor Location interaction nor the Display Size × Distractor Type × Distractor Location interaction approached significance (both Fs < 1). Similar results were found when error rates were compared (both Fs < 1). These findings suggest that observers adopted a complex attentional set involving both onset and color.

Finally, there was a significant Display Size × Distractor Location interaction, $F(1, 15) = 12.30$, $MSE = 402.33$, $p < .005$. This interaction indicated that the 30-ms distractor location RT effect observed in the Display Size 4 condition was significantly smaller than the 56-ms distractor location effect observed in the Display Size 8 condition, although both distractor location effects were found to be significant in separate ANOVAs: $F(1, 15) = 41.29$, $MSE = 370.86$, $p < .0001$, and, $F(1, 15) = 35.93$, $MSE = 1{,}387.00$, $p < .0001$, respectively. The corresponding analysis performed on error rates did not achieve significance, $F(1, 15) = 2.06$, $MSE = 7.22$, $p > .15$.[4]

In summary, the results obtained in Experiment 1 were consistent with the displaywide contingent capture hypothesis: Both onset singleton distractors and color singleton distractors were shown to capture attention in this experiment, presumably because an attentional set for onset and color was induced by the defining attributes of the target display as a whole. However, before this conclusion can be stated with confidence, the distractor location effect observed in the color distractor condition must be shown to be contingent on the color of the target display.

Experiment 2

The distractor effects observed in Experiment 1 are thought to depend on a complex attentional set that was induced by attributes (i.e., onset and color) that signaled the appearance of the task-relevant target display. Unfortunately, the contingent nature of this effect was compromised in Experiment 1 because both distractors matched at least one component of the attentional set. Experiment 2 was conducted to provide stronger evidence for this contingency. The sequence of displays used in Experiment 2 was identical to that used in Experiment 1, except that white letters appeared in the target display (as opposed to red letters). White letters were shown under the assumption that the appearance of white would not induce an attentional set for color in this experiment as the appearance of red did in the previous experiment (see Wolfe, 1994, for a more complete discussion of this issue). Thus, the appearance of the target display was assumed to be signaled only by onset (not color) in this experiment. Consequently, if attentional set is controlled by these visual features, then only onset distractors should capture attention in this experiment.

Method

Participants. Sixteen undergraduates from the University of Notre Dame participated in this experiment for course credit. All students reported normal or corrected-to-normal vision.

Stimuli and apparatus. The stimuli were identical to those used in Experiment 1, except that the letters were always white (IBM Color 15) in the target display.

Procedure. The procedure was identical to that used in Experiment 1.

Results and Discussion

The mean correct RTs in each of the distractor type and distractor location conditions is shown in Figure 3 as a function of display size. The corresponding error rates are shown in Table 2. With respect to RTs, observers located the target faster when the target display contained four letters than when it contained eight letters, $F(1, 15) = 23.15$, $MSE = 2{,}604.56$, $p < .0005$, for the main effect of display size. There was also a significant main effect of distractor location in this experiment, $F(1, 15) = 28.20$, $MSE = 840.75$, $p < .0001$, indicating that RTs were faster in the same-location condition ($M = 551$ ms) than in the different-location condition ($M = 578$ ms).

However, unlike Experiment 1, this distractor location RT effect depended on distractor type: There was a significant Distractor Type × Distractor Location interaction, $F(1, 15) = 10.43$, $MSE = 1{,}181.95$, $p < .01$, as well as a significant Display Size × Distractor Type × Distractor Location interaction, $F(1, 15) = 9.02$, $MSE = 717.61$, $p < .01$. In the onset distractor condition, the distractor location effect increased from 22 to 71 ms as display size increased from four to eight letters. Subsequent ANOVAs indicated that both distractor location effects were significant: $F(1, 15) = 17.52$, $MSE = 227.38$, $p < .001$, for the Display Size 4 condition; $F(1, 15) = 32.00$, $MSE = 1{,}273.59$, $p < .0001$,

[4]Another signature of attentional capture is a relatively flat slope of the display size function in the same-location distractor condition and a more substantial slope of the display size function in the different-location distractor condition. Slopes were not emphasized in this analysis because they are typically calculated under conditions in which the target display is available until the response is made. Recall that in this article, the target display was terminated after 200 ms. This may have artificially terminated visual search in some conditions, thereby leading to misleading slope estimates. Nevertheless, for the sake of completeness, in the color distractor condition the slope was estimated to be 6.92 ms/item in the same-location distractor condition and 14.23 ms/item in the different-location distractor condition. In the onset distractor condition, the slope was estimated to be 9.91 ms/item in the same-location distractor condition and 15.03 ms/item in the different-location distractor condition. These slope estimates are consistent with previous attentional capture experiments (Yantis & Jonides, 1984).

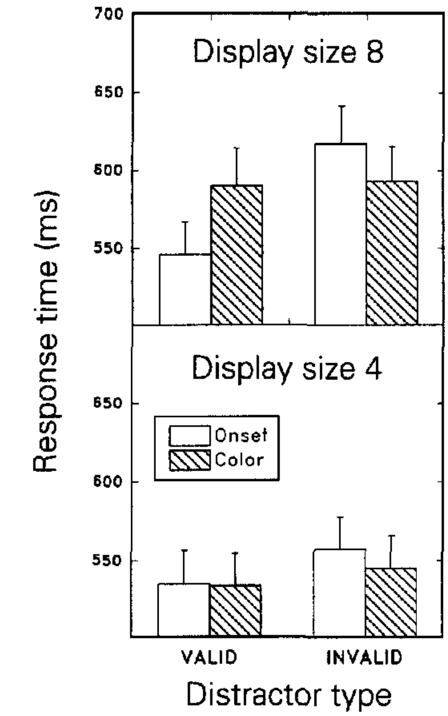

Figure 3. Mean correct response times plotted as a function of display size, distractor type, and distractor location in Experiment 2. Standard error bars are shown.

for the Display Size 8 condition. In contrast, in the color distractor condition, the distractor location effect decreased from 11 to 3 ms as display size increased from four to eight letters. Moreover, subsequent ANOVAs indicated that neither of these distractor location effects reached significance: $F(1, 15) = 3.41$, $MSE = 310.60$, $p > .05$, for the Display Size 4 condition; $F(1, 15) < 1$, for the Display Size 8 condition. Finally, an identical three-way ANOVA performed on error rates revealed no significant effects (all $ps > .15$).[5] Thus, the results obtained in Experiment 2 establish the contingency between the visual features that signal the appearance of the task-relevant target display and the visual features that produce stimulus-driven attentional capture.

Table 2
Percentage Error Rate as a Function of Display Size, Distractor Type, and Distractor Location in Experiment 2

Distractor location	Distractor type: Onset	Color
Display Size 4		
Same	3.13	3.66
Different	4.01	2.71
Display Size 8		
Same	4.68	3.64
Different	3.96	3.80

The notion that attentional capture is contingent on the visual features that signal the appearance of the task-relevant target display also was supported by a comparison of the two distractor type conditions across Experiments 1 and 2. As expected, the distractor location RT effect was approximately equal in the onset distractor condition across Experiments 1 and 2, as reflected by a significant main effect of distractor location, $F(1, 30) = 52.72$, $MSE = 1{,}262.74$, $p < .0001$. Neither the main effect of experiment ($F < 1$) nor any of the interactions involving experiment and distractor location approached significance: $F(1, 30) < 1$, for the Experiment × Distractor Location interaction; $F(1, 30) = 2.38$, $MSE = 685.94$, $p > .10$, for the Experiment × Display Size × Distractor Location interaction. This finding is important because it suggests that the simultaneous maintenance of two attentional sets (as in Experiment 1) does not significantly reduce the magnitude of the observed distractor effect compared with when only one attentional set is maintained (as in Experiment 2). In addition, there was a significant Display Size × Distractor Location interaction, $F(1, 30) = 14.11$, $MSE = 685.94$, $p < .001$, indicating that the magnitude of the distractor location effect increased with display size. An identical ANOVA performed on error rates revealed no significant effects (all $ps > .05$).

In contrast, the distractor location RT effect in the color distractor condition was significantly larger in Experiment 1 than it was in Experiment 2, as reflected by a significant Experiment × Distractor Location interaction, $F(1, 30) = 8.23$, $MSE = 1{,}175.28$, $p < .005$. Moreover, there was also a significant Experiment × Display Size × Distractor Location interaction, $F(1, 30) = 6.28$, $MSE = 437.20$, $p < .02$. The nature of this three-way interaction was further investigated in two ANOVAs that isolated the effect of distractor location within each display size condition across the two experiments. In the Display Size 4 condition, there was a significant main effect of distractor location, $F(1, 30) = 15.53$, $MSE = 396.82$, $p < .0005$. Although the distractor location effect was larger in Experiment 1 (28 ms) than in Experiment 2 (11 ms), the predicted Experiment × Distractor Location interaction did not attain significance, $F(1, 30) = 2.66$, $MSE = 396.82$, $p > .10$. However, a more powerful test of this interaction was available in the Display Size 8 condition, in which the potential impact of the distractors on attentional orienting was greater. In this case, there was a significant main effect of distractor location, $F(1, 30) = 12.12$, $MSE = 1{,}215.66$, $p < .002$; more important, there was also a significant Experiment × Distractor Location interaction, $F(1, 30) = 9.35$, $MSE = 1{,}215.66$, $p < .005$, indicating that the 57-ms distractor location effect observed in Experiment 1 was significantly larger than the 3-ms

[5] As in Experiment 1, the slope of the display size function was estimated for each distractor type and distractor location condition in Experiment 2. In the onset distractor condition, the slope was estimated to be 2.66 ms/item in the same-location distractor condition and 14.92 ms/item in the different-location distractor condition. In the color distractor condition, the slope was estimated to be 13.89 ms/item in the same-location distractor condition and 11.94 ms/item in the different-location distractor condition.

distractor location effect observed in Experiment 2. Finally, there was no evidence of a speed–accuracy trade-off (all $ps > .20$).

General Discussion

An understanding of the factors that contribute to an observer's state of attentional readiness or attentional set is critical to current theory development in visual attention. One theoretical issue that is critically dependent on this understanding concerns the question of whether visual attention can ever be captured in a purely stimulus-driven fashion (Jonides & Yantis, 1988; Yantis, 1993b, 1996; Yantis & Jonides, 1984) or whether all forms of attentional orienting, including stimulus-driven attentional capture, are dependent on attentional set (Folk et al., 1992, 1993, 1994). One way this issue has been addressed is by establishing various contingencies between featural aspects of the target display and featural aspects of the cue display. For instance, Folk et al. (1992) showed that attentional capture can be contingent on the defining features of the target (also called "target-specific visual features" in this article). According to Folk et al., such capture cannot be considered purely stimulus-driven because observers are intentionally set to detect target-defining features. As a result, it has been suggested that stimulus-driven attentional capture can be properly inferred only when the attribute that elicits it is independent of the defining features of the target (Yantis, 1993b; cf. Folk et al., 1993).

Our research has extended this issue by investigating whether attentional capture can also be contingent on visual features that signal the appearance of the target display as a whole. In accordance with this hypothesis, we found that attentional capture is contingent on these displaywide visual features, at least within the color dimension. In particular, both onset singleton distractors and color singleton distractors captured attention when the appearance of the target display was signaled by both onset and color. However, only onset singleton distractors captured attention when the appearance of the target display was signaled only by abrupt onset.

The observed contingency between displaywide visual features and attentional capture therefore suggests that visual features need not uniquely define the target, as in the Folk et al. (1992, 1994) studies, to influence attentional orienting. Consequently, our research has further narrowed the conditions under which stimulus-driven attentional capture can be properly said to occur. In particular, our findings suggest that stimulus-driven attentional capture can no longer be defined simply as attentional orienting to an attribute that is independent of the defining features of the target (Yantis, 1993b; see also Bacon & Egeth, 1994). Rather, our research indicates that stimulus-driven attentional capture must now be defined as attentional orienting to an attribute that is also independent of the defining features of the target display as a whole. Failure to meet these two criteria may result in instances of attentional capture that appear to be stimulus driven but in actuality are goal directed.

In fact, a survey of the relevant literature (see Yantis, 1993a, 1993b, 1996) suggests that none of the existing evidence meets these two criteria for stimulus-driven attentional capture. Recall that the strongest evidence currently available for stimulus-driven attentional capture was provided by Jonides (1981). However, although Jonides showed that an uninformative onset distractor can capture attention when the experimentally defined target letter was defined solely by its identity, the possibility remains that this capture occurred because observers were set for the onset of the target display as a whole. Hence, the existence of pure stimulus-driven attentional capture by abrupt visual onset (or any other visual feature) remains to be established.

Another important issue raised by our research concerns the possibility of functional differences between attentional sets that are induced by target-specific visual features (Folk et al., 1992) and attentional sets that are induced by displaywide visual features (see our Experiments 1 and 2). For instance, Folk et al. (1992) failed to observe capture by onset distractors when the target was defined as a red singleton. Recall that in this color target condition, a single red target character always appeared among three white distractor characters. As such, the appearance of the four-element target display as a whole was signaled by onset, whereas the specific location of the target was signaled by color. The Folk et al. results therefore suggest that the attentional consequences associated with displaywide visual features (i.e., onset) may be diminished when target-specific visual features (i.e., color) are available (cf. Yantis, 1993b). Further studies will be required to understand the nature of this interaction.

Finally, although the contingency that was observed between displaywide visual features and attentional capture in our research suggests a mediating role for attentional set, further studies will be required to determine the precise manner in which displaywide visual features influence attentional set. Following Folk et al. (1992), it has been assumed that observers are set to detect displaywide visual features because these features define the set of task-relevant stimuli. In this view, the target display as a whole may be detected as a target in its own right, in addition to the identity-defined local target. However, it also is possible that the observed contingency occurred simply because these features were consistently associated with the identity-defined local target, although not in any informative way. At any rate, our results may not demand the conclusion that observers are typically set to detect two types of targets (one global and one local) when multielement displays such as those used in this research are shown.

In summary, on the basis of our research (see also Folk et al., 1992, 1994), we conclude that all known instances of attentional capture are contingent on attentional set and thus ultimately on goal-directed attentional control processes (see also Gibson, 1996a, 1996b). Hence, the existence of a pure form of stimulus-driven attentional capture remains to be established. Moreover, existing research suggests that attentional capture is contingent on behavioral goals that are specifically related to target detection processes. This conclusion is important, not only because it clarifies the nature of attentional control but also because it reveals an important functional dependency between anatomically distinct attention networks for target detection and attentional orienting in the brain (Posner & Petersen, 1990).

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