

## Research Article

# SURPRISE! AN UNEXPECTED COLOR SINGLETON DOES NOT CAPTURE ATTENTION IN VISUAL SEARCH

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**Abstract**—*The existence of a pure form of stimulus-driven attentional control has been aligned exclusively with the existence of attentional capture. Unfortunately, there has been little evidence provided in support of attentional capture. The present study investigated whether the repeated failure to observe attentional capture might be due to the way in which attentional capture has been measured. A new visual search procedure was used to investigate whether attention would be captured by an initial and unexpected encounter with a color singleton. Despite this important change in procedure, the color singleton still did not capture attention. Further evidence showed that visual search for the color singleton could be highly efficient, but only after its relevance became established, and that the failure to observe capture in the present experiment was not due to other potentially detrimental effects of surprise. The present results suggest that new conceptions of stimulus-driven attentional control are required.*

Visual selective attention is currently thought to be controlled by two distinct mechanisms. On the one hand, attentional control is said to be *goal-directed* when visual selective attention is oriented to objects and events in the external world that are consistent with the current behavioral goals of the observer. On the other hand, attentional control is said to be *stimulus-driven* when visual selective attention is “captured” by objects and events in the external world that are independent of the current behavioral goals of the observer. Together, these two attentional control mechanisms are thought to ensure that the selection of visual information will occur in an efficient and adaptive manner (see Yantis, 1993a, 1996, for reviews).

However, despite the importance of the stimulus-driven attentional control mechanism for contemporary models of visual attention (Cave & Wolfe, 1990; Koch & Ullman, 1985; Wolfe, 1994, 1996), there has been relatively little evidence offered in support of the notion that salient visual events can capture attention in a purely stimulus-driven fashion, independent of current behavioral goals. For instance, several studies have failed to find evidence that color, brightness, or motion singletons can elicit attentional capture in a visual search task (Folk & Annett, 1994; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Todd & Kramer, 1994; cf. Theeuwes, 1992). Some studies have reported that abrupt-onset (or new-object) singletons do appear to capture attention in a purely stimulus-driven fashion (Jonides & Yantis, 1988; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984), but other researchers have argued that these results may reflect a sensory bias that favors the abrupt-onset element (Gibson, 1996a, 1996b; cf. Yantis & Jonides, 1996). These and other important studies (Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Gibson & Kelsey, in press) have led to the conclusion that all forms of

attentional control are ultimately dependent on goal-directed processes.

Rather than dismiss the notion that attention can be captured in a purely stimulus-driven fashion, we decided to examine whether previous failures to observe stimulus-driven attentional capture might have been due to the way in which attentional capture was measured. Previous studies of stimulus-driven attentional capture have assumed that attention-capturing events generally cannot be ignored over time, even when those events are known to be irrelevant (see, e.g., Jonides, 1981; cf. Yantis & Jonides, 1990). For this reason, in these studies, an irrelevant event occurred repeatedly, and the attentional response to this irrelevant event was averaged over hundreds of trials (Folk & Annett, 1994; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Todd & Kramer, 1994; Yantis & Jonides, 1984). Attentional capture would be inferred if the irrelevant event could not be ignored over the duration of the experiment.

In the present study, we used a visual search task to investigate whether visual selective attention could be captured in a purely stimulus-driven fashion by an initial (and unexpected) encounter with a color singleton (i.e., a red target surrounded by several white distractors). Measuring the initial encounter with an unexpected singleton may be critical because stimulus-driven attentional capture might rapidly habituate to the repeated occurrence of a salient visual event, unless that event is deemed relevant to the current behavioral goals of the observer (in which case, attentional allocation would no longer be controlled in a purely stimulus-driven fashion). We chose a color singleton (as opposed to a brightness, onset, or motion singleton) for our initial investigation because the present study required that observers' attentional set be carefully controlled, and the variables that influence attentional set for color are relatively well understood (see, e.g., Folk et al., 1992; Gibson & Kelsey, in press).

## EXPERIMENT 1

### Method

#### Subjects

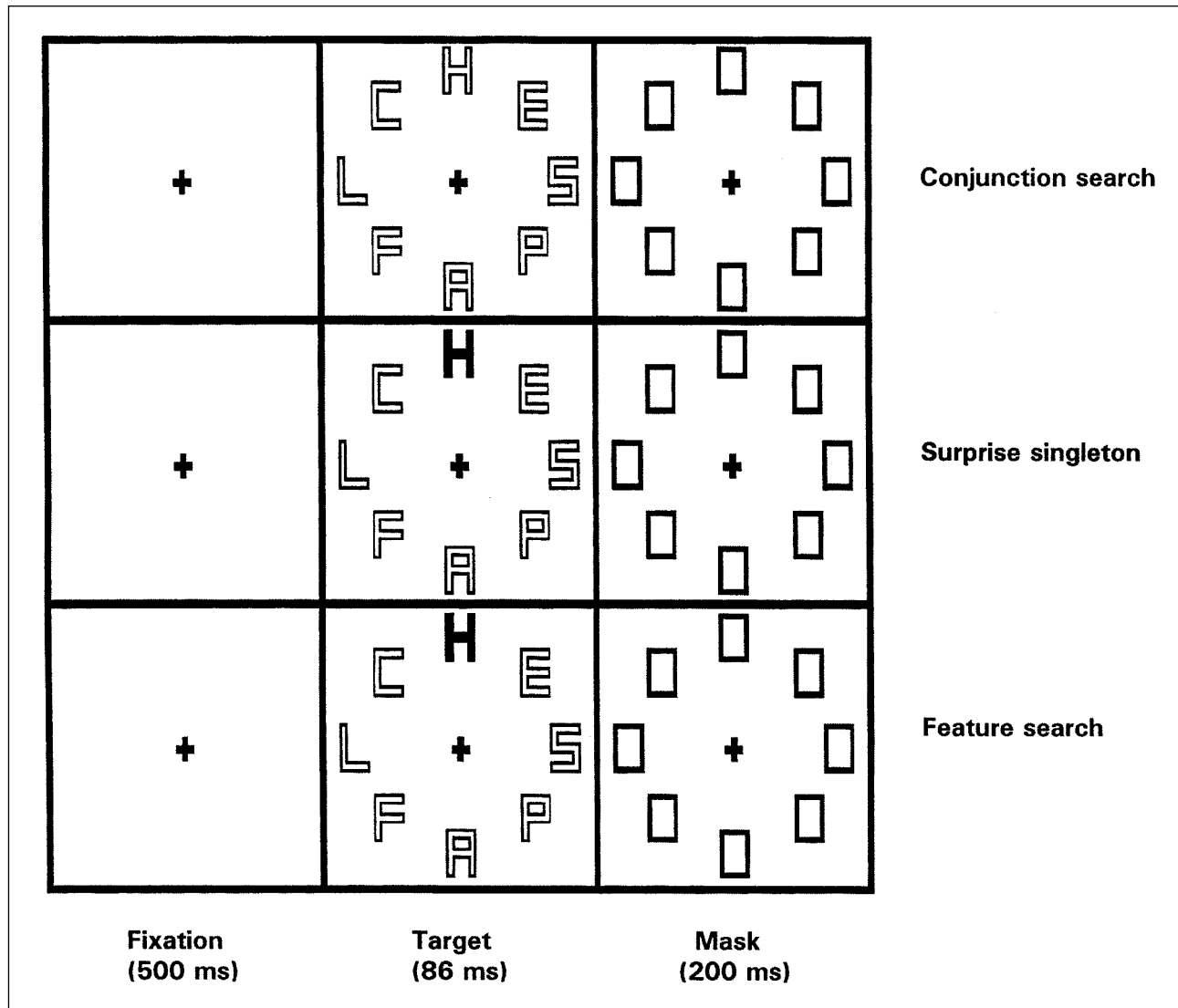
The subjects were 40 students from the University of Notre Dame who participated for course credit.

#### Design and procedure

The first experiment was divided into three segments, which are depicted in Figure 1. The experiment flowed continuously from one segment to another, and observers were never informed that the target would appear as a red singleton at any point in the experiment.

The first segment of the experiment was a standard conjunction search task in which a display of eight white letters was shown for 86 ms and then energy-masked for 200 ms by bright white rectangles. This search task was expected to be relatively demanding because the display letters were all composed of different configurations of horizontal

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**Fig. 1.** The stimulus displays used in Experiment 1. Trials 1 through 192 were included in the conjunction search condition, Trial 193 was included in the surprise singleton condition, and Trials 194 through 385 were included in the feature search condition. Note that the target was either *H* or *U*, and it appeared equally often in each of the eight locations. In this illustration, the unfilled letters depict characters that were white in the actual display, and the filled letters depict characters that were red.

and vertical line segments, and thus the target letter could not be distinguished from the distractors on the basis of any simple featural discontinuity (Wolfe, Cave, & Franzel, 1989). Observers determined which of two possible target letters (*H* or *U*) was present among the distractors, and they were instructed to respond as accurately as possible without worrying about the speed of their response. Accuracy was stressed over speed in the present experiment because unexpected events can affect decision-level processes, which in turn can inflate response times (see, e.g., Meyer, Niepel, Rudolph, & Schutzwahl, 1991). For this reason, accuracy served as a better index of visual selective attention in the present experiment. There were 192 experimental trials presented in this first segment, and the experimental trials were preceded by 24 practice trials. The experimental conjunction search trials were presented in blocks of 8 trials; within each block, the target letter appeared randomly

in each of the eight display locations once. In addition, the two target letters appeared equally often within each block of 8 trials. The same random order was used for all observers.

The second segment of the experiment was designed to measure stimulus-driven attentional capture, should it occur. This segment consisted of a single trial in which the target appeared unexpectedly as a red singleton (cf. Rock, Linnett, & Grant, 1992; see also Moore & Egeth, 1997). Across observers, the two targets appeared in each of the eight display locations equally often. It is generally thought that when a stimulus captures attention, it is the first (or nearly the first) item to be selected in the display (see, e.g., Johnston & Schwarting, 1997; Yantis & Jonides, 1984). Hence, if the red singleton could capture attention in a purely stimulus-driven fashion, then accuracy to detect the target on this single surprise trial should have been significantly

greater than accuracy to detect the target on the previous conjunction search task (during which the target should have been selected first on any given trial only by chance).

It is worth pointing out that although the design of the present experiment differed significantly from the design of previous attentional capture experiments (e.g., Folk & Annett, 1994; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Todd & Kramer, 1994; Yantis & Jonides, 1984), it nevertheless met the current criteria for establishing stimulus-driven attentional capture (Gibson & Kelsey, in press). In particular, during the first segment of the experiment, observers should have been set to detect only the identity of the two target stimuli (Yantis, 1993b) and the onset of the display as a whole (Gibson & Kelsey, in press); thus, observers should not have been intentionally looking for color when the red singleton appeared unexpectedly.

In the third segment of the experiment, in addition to being defined by identity, the two targets were consistently defined by color for the remaining 192 trials of the experiment. As in the first segment, the target appeared randomly in each of the eight display locations before appearing again in the same locations. This segment of the experiment was identical to a standard feature search task in which observers intentionally search for a relevant featural singleton (see, e.g., Treisman, 1988; Treisman & Gelade, 1980). Accuracy was expected to be much higher during this segment of the experiment than during the conjunction search task, as the target was now associated with a feature that could be detected preattentively. The feature search task was included in the present study because performance on this segment of the experiment could serve as a baseline from which to assess whether attentional capture occurred on the surprise trial. If the appearance of the unexpected color singleton did capture attention, then performance on the surprise trial should have been similar to an estimate of performance on the feature search task because in both cases, attention should have been allocated to the color singleton first.

In addition, high-accuracy performance on the third (feature search) segment of the experiment could serve as a manipulation check in the event that attentional capture was not observed on the surprise trial because it would show that the color singleton could be used to benefit visual search. In this case, performance on the single surprise trial should have been similar to an estimate of performance on the conjunction search task, but significantly lower than an estimate of performance on the feature search task (see Results and Discussion for details). Such an accuracy difference could be attributed to the development of an intention to look for the (now relevant) color singleton during the feature search segment of the experiment, and would echo Yantis's (1996) warning that the highly efficient visual search performance that is often observed when a featural singleton is known to be relevant need not imply that the singleton will capture attention when it is known to be irrelevant (see also Jonides & Yantis, 1988), or when its relevance is unknown (as in the second, surprise, segment of the present experiment).

## Results and Discussion

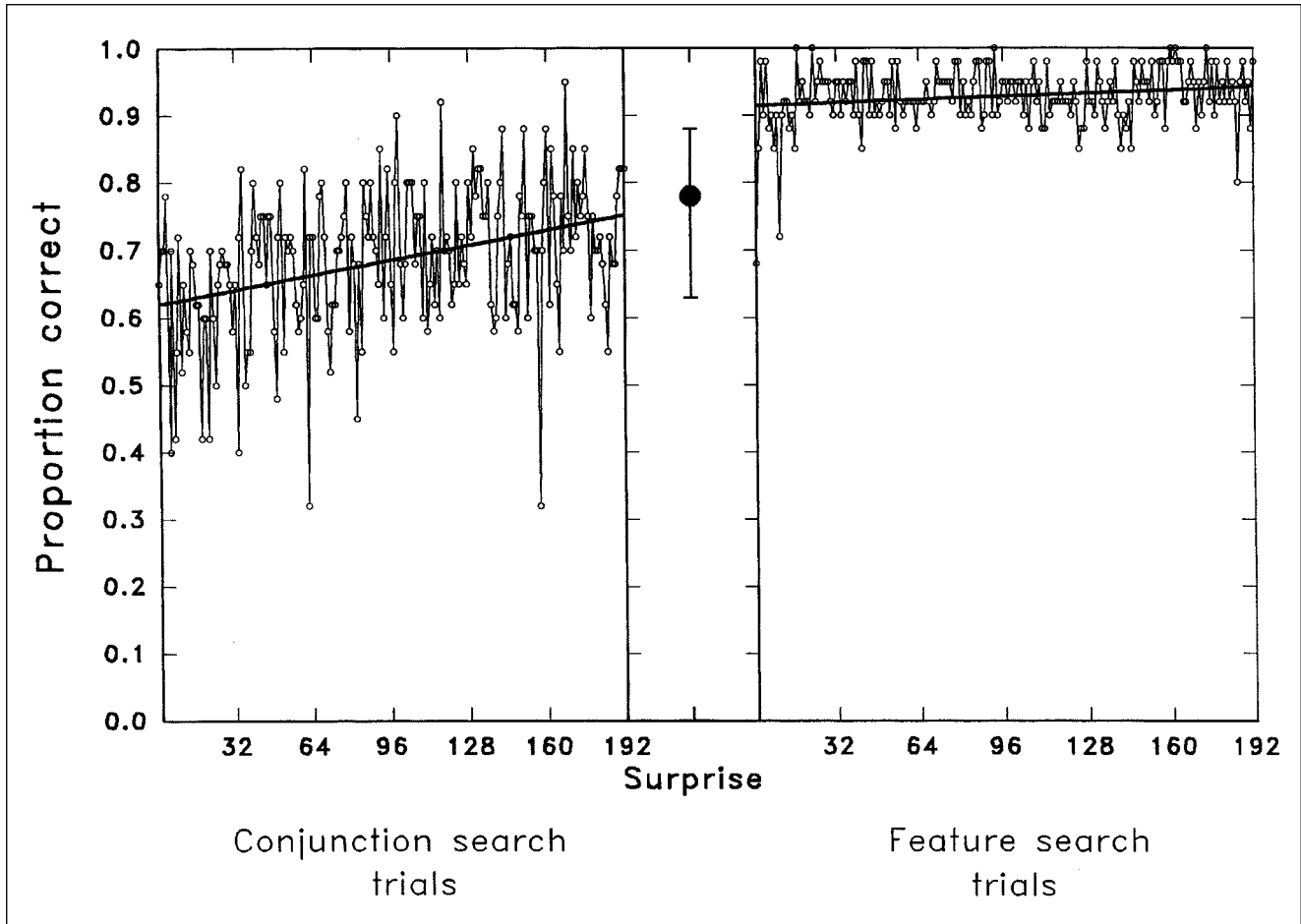
The data appear in Figure 2 as the proportion of observers who responded correctly on each of the 385 trials in this experiment (.50 = chance performance). Summary statistics are listed in Table 1. To ensure that observers could use the red singleton to improve the efficiency of visual search, we first compared overall proportion correct (averaged across both observers and trials) on the conjunction and fea-

ture search tasks. Overall proportion correct was .69 on the conjunction search task and .93 on the feature search task. As expected, observers were significantly more accurate during the feature search task than during the conjunction search task,  $F(1, 39) = 220.01$ ,  $MSE = 53.35$ ,  $p < .0001$ . This finding suggests that observers could use the color singleton to improve the efficiency of visual search, at least after the relevance of the color singleton became known.

Note, however, that it is also possible that feature search was performed more efficiently than conjunction search in Experiment 1 simply because the red letter was more visible following the bright masks than were the white letters. To address this concern, we conducted a control experiment in which 25 different observers performed the same conjunction search task as in Experiment 1, except that the target display could appear either all white or all red; the masks were always white. The results were inconsistent with the masking hypothesis: Mean accuracy was identical in the white- and red-target display conditions (both  $M_s = .74$ ),  $F(1, 24) < 1$ . Hence, it is unlikely that observers were more accurate during feature search than during conjunction search in Experiment 1 simply because the red target was more visible than the white target.

In addition, although the difference observed between the feature search and conjunction search conditions in Experiment 1 suggests that the target could be selected more efficiently when it was consistently associated with the red singleton, this conclusion was based on only a single display size. To address this concern, we conducted a second control experiment to assess the efficiency of visual search across a range of display sizes. The procedure in this control experiment was also similar to that in Experiment 1, except that only the first (conjunction search) and third (feature search) segments were included, and the display could contain either two, four, or eight elements. The 24 observers in this experiment viewed 64 trials in each of six conditions (3 display sizes  $\times$  2 tasks), and accuracy was averaged over both trials and observers in each condition. As expected, during the initial conjunction search task, visual search efficiency decreased as display size increased: Mean accuracy was found to be .93, .86, and .75 for display sizes of two, four, and eight, respectively. This decrease in visual search efficiency was reflected by a significant main effect of display size in the conjunction search task,  $F(2, 46) = 79.42$ ,  $MSE = 26.29$ ,  $p < .0001$ . Also as expected, visual search was performed overall more efficiently in the feature search task than in the conjunction search task,  $F(1, 23) = 54.31$ ,  $MSE = 119.60$ ,  $p < .0001$ . More important, unlike in the conjunction search task, visual search was equally efficient across display size in the feature search task: Mean accuracy was identical ( $M = .98$ ) for the three display sizes, leading to a nonsignificant main effect of display size in the feature search task,  $F(2, 46) = 1.00$ ,  $MSE = 3.46$ ,  $p > .35$ . This differential effect of display size as a function of task was reflected by a significant Display Size  $\times$  Task interaction,  $F(2, 46) = 69.79$ ,  $MSE = 13.87$ ,  $p < .0001$ . These findings corroborate the findings obtained in Experiment 1 and suggest that the red singleton can be selected first on each trial when it is consistently associated with the target.

Having shown that visual search can become highly efficient when the target is known to be a color singleton, we next considered the main question of whether the appearance of the color singleton could improve the efficiency of visual search when the singleton was unexpected, and hence its relevance was unknown. This capture hypothesis required an estimate of performance in both the conjunction search and feature search tasks at the precise point in the experiment at which the surprise trial occurred. Recall that the surprise trial occurred unexpectedly at the end of the conjunction search task, but just before the feature search tri-



**Fig. 2.** Proportion of observers in Experiment 1 who responded correctly on each of the conjunction search, surprise, and feature search trials. Best-fitting regression lines are shown for the conjunction search and feature search conditions, and the error bars shown for the surprise condition represent a 95% confidence interval.

als. Thus, the surprise trial occurred at a point when observers had already gained a great deal of experience with the conjunction search task, but before they had gained any experience with the feature search task. Consequently, observers likely would have been performing at near

peak efficiency on the conjunction search task, and at less than peak efficiency on the feature search task. Hence, unbiased comparisons between the surprise condition and both the conjunction search and the feature search conditions required that these differences in prior experience be controlled. Accordingly, the capture hypothesis was evaluated by comparing actual performance on the surprise trial with predicted performance on the conjunction search task following 192 previous trials, and with predicted performance on the feature search task without any previous experience using the color singleton to guide visual search.

Proportion correct was regressed on trial number in both the conjunction search and the feature search tasks of Experiment 1 to obtain the necessary estimates of performance (see Fig. 2 and Table 1). Predicted performance on the conjunction search task following 192 previous trials was estimated to be .75, whereas predicted performance on the feature search task without any previous experience using the color singleton to guide visual search was estimated to be .91. In comparison, performance on the surprise trial was found to be .78 in this experiment, suggesting that visual search for the target letter was less efficient in the surprise condition than in the feature search condition, and that it was about equally efficient in the surprise and conjunction search conditions. Note, however, that although the predicted values

**Table 1.** Summary statistics for Experiment 1

Statistic	Search condition		
	Conjunction search	Surprise	Feature search
Proportion correct			
Mean	.69	.78	.93
Standard deviation	.11	—	.04
95% confidence interval	—	.88-.63	—
Regression of proportion correct on trial number			
Slope	.0007	—	.0002
Intercept	.62	—	.91

based on conjunction search and feature search should remain relatively stable from one experiment to the next (given that they are both based on 192 trials), the value observed in the surprise condition is likely to be more variable, based as it is on only a single trial. In order to obtain a more reliable estimate of performance in the surprise condition, we computed a 95% confidence interval around the observed value of .78 following the procedure described in Hays (1973, pp. 378–380). As shown in Figure 2, this confidence interval, which ranged from .88 to .63, included the value estimated from the regression line in the conjunction search condition (.75) but not the value estimated from the regression line in the feature search condition (.91). Together, the present results suggest that visual search is performed less efficiently in the surprise condition than in the feature search condition.

## EXPERIMENT 2

The results obtained in Experiment 1 suggest that unexpected color singletons are not selected first and therefore do not capture attention. However, the results of Experiment 1 are also consistent with the hypothesis that unexpected color singletons do capture attention, but that the beneficial effects of this capture can be offset by other detrimental effects that are also associated with surprise. For instance, it was assumed in Experiment 1 that stimuli were identified just as efficiently following their selection on the surprise trial as they were following their selection on conjunction search trials. However, it is possible that the sudden appearance of the unexpected red letter disrupted target detection processes by causing processing resources to be focused on the color of the singleton rather than on its shape. If so, then it is possible that the red letter was in fact selected first on the surprise trial (as predicted by the capture hypothesis), but was not identified as efficiently on this trial as selected stimuli were on previous trials. According to this modified capture hypothesis, the pattern of results obtained in Experiment 1 can be interpreted to show that a combination of relatively efficient visual selection together with relatively inefficient target processing (as in the surprise condition) leads to approximately the same level of performance as a combination of relatively inefficient visual selection together with relatively efficient target processing (as in the conjunction search condition). To test this modified capture hypothesis, we conducted a second experiment in which the unexpected color singleton was never the target. In this situation, this hypothesis predicts that the ability to identify the target correctly will be significantly worse on the surprise trial than during preceding conjunction search trials because the target suffers from two detrimental effects in the surprise trial: Not only is the identification of selected elements performed less efficiently because of the element of surprise, but the display element with the highest selection priority (i.e., the red singleton) is never the target.

### Method

#### Subjects

The subjects were 64 students from the University of Notre Dame who participated for course credit.

#### Design and procedure

The second experiment was identical to the first experiment in all relevant respects except that the color singleton was never the target. In addition, eight different random orders were generated in Experiment 2 so that for any given trial number, the target appeared in each of

the eight possible locations across each set of 8 observers. Because the only difference between the first and third segments of the present experiment was the presence of an irrelevant color singleton, they were both conjunction search tasks, and we refer to these segments as *distractor-absent* and *distractor-present* conditions, respectively.

## Results and Discussion

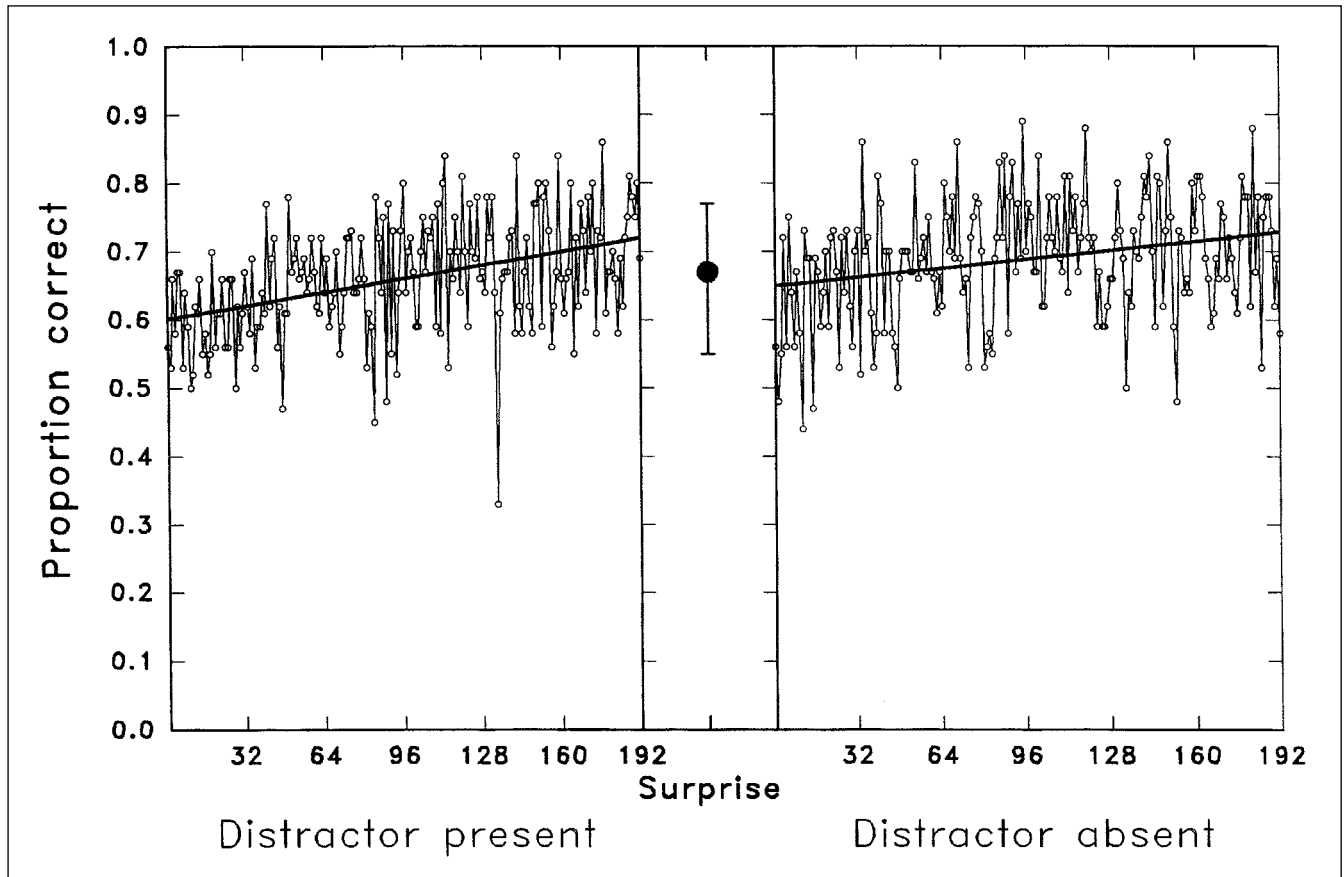
The results of this experiment are shown in Figure 3, and summary statistics are listed in Table 2. Proportion correct was regressed on trial number in both the distractor-absent and the distractor-present conditions, though only the former regression line is relevant for present purposes. Predicted performance in the initial distractor-absent condition following 192 previous trials was estimated to be .72, a value very similar to that observed in Experiment 1 (.75). In comparison, actual performance on the surprise trial was found to be .67 in this experiment. Although the observed value of .67 was less than the predicted value of .72, this predicted value was included within the 95% confidence interval (.77 to .55) computed around actual performance on the surprise singleton trial. The present results are therefore inconsistent with the modified attentional capture hypothesis described at the beginning of this experiment, which predicted a much larger difference between the distractor-absent and surprise conditions.

In addition, it is important to point out that, as expected, overall performance was more accurate in the subsequent distractor-present condition (.69) than in the initial distractor-absent condition (.66),  $F(1, 63) = 12.76$ ,  $MSE = 12.76$ ,  $p < .001$ . This result corroborates previous research (e.g., Jonides & Yantis, 1988) by showing that a singleton that is known to be irrelevant does not capture attention. However, it is also important to point out that performance did decline initially in the distractor-present condition (as shown by the regression line in Fig. 3), though this decline in performance cannot be interpreted as evidence for attentional capture because following the surprise trial, it is likely that observers intentionally looked for the red singleton, at least initially, in order to establish its relevance.

## GENERAL DISCUSSION

Stimulus-driven attentional capture refers to a form of attentional control in which visual events are given high selection priority despite being independent of current behavioral goals. Because there has been very little evidence provided in support of this form of attentional control, the present study used a new procedure to measure the occurrence of stimulus-driven attentional capture. Unlike previous studies (e.g., Jonides & Yantis, 1988), which manipulated observers' intentions toward featural singletons by using singletons that were known to be irrelevant to the target, the present study used an unexpected color singleton whose relevance was unknown at the time of test. This new procedure was used to investigate the possibility that attentional capture occurs only on the initial encounter with a salient visual event. If so, then performance in the surprise condition would be expected to be similar to an estimate of performance in a feature search condition because in both situations the singleton would be selected first.

Nevertheless, despite the important procedural changes introduced in the present study, the result was very similar to what previous studies have found. As expected, visual search was highly efficient when the target was consistently associated with the color singleton in the feature search condition. However, the appearance of the unexpected



**Fig. 3.** Proportion of observers in Experiment 2 who responded correctly on each of the distractor-absent, surprise, and distractor-present trials. Best-fitting regression lines are shown for the distractor-present and distractor-absent conditions, and the error bars shown for the surprise condition represent a 95% confidence interval.

color singleton did not increase the efficiency of visual search to the level predicted on the basis of the feature search condition. In fact, visual search was about as efficient in the surprise condition as it was predicted to be when no singletons appeared in the display (as in the conjunction search condition). Moreover, the findings obtained in Experiment 2 suggest that the lower-than-expected performance

observed in the surprise condition of Experiment 1 cannot be attributed to a combined effect in which the color singleton both increased the selection priority of the target and decreased the efficiency of post-selection, target detection processes. The present findings are therefore contrary to models of visual search which contend that stimulus salience alone is sufficient for highly efficient visual search (Cave & Wolfe, 1990; Koch & Ullman, 1985). Rather, highly efficient visual search appears to depend critically on the development of an intention to use the singleton to guide visual search (Folk et al., 1992; Gibson & Kelsey, in press).

What, then, is the status of stimulus-driven attentional control? To date, the existence of a pure form of stimulus-driven attentional control has been aligned exclusively with the existence of attentional capture. However, it remains possible that a visual event might influence visual search in a purely stimulus-driven fashion without necessarily being the first element selected. Indeed, a comparison of the two surprise conditions in Experiments 1 and 2 indicated that accuracy was 11% better when the singleton was associated with the target than when it was associated with one of the distractors. Moreover, performance in the surprise condition of Experiment 1 (.78) fell outside the 95% confidence interval established for the surprise condition in Experiment 2 (see Table 2), though performance in the surprise condition of Experiment 2 (.67) remained within the 95%

**Table 2.** Summary statistics for Experiment 2

Statistic	Search condition		
	Distractor absent	Surprise	Distractor present
Proportion correct			
Mean	.66	.67	.69
Standard deviation	.08	—	.09
95% confidence interval	—	.77–.55	—
Regression of proportion correct on trial number			
Slope	.0006	—	.0004
Intercept	.60	—	.65

## Attentional Capture

confidence interval established for the surprise condition in Experiment 1 (see Table 1). Thus, although performance in the conjunction search and surprise conditions could not be distinguished in the present study, more direct comparisons between the two surprise conditions suggest that the sudden appearance of an unexpected color singleton can have a small influence on visual search performance, without producing attentional capture. Whether this influence reflects a purely stimulus-driven effect on spatial selection, or whether it might also reflect stimulus-driven effects that occur following spatial selection (e.g., effects on target detection processes), remains to be determined.

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