Research Article

EVIDENCE FOR ATTENTIONAL CAPTURE BY A SURPRISING COLOR SINGLETON IN VISUAL SEARCH

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Abstract—*Three experiments were conducted to investigate whether surprising color singletons capture attention. Participants performed a visual search task in which a target letter had to be detected among distractor letters. Experiments 1 and 2 assessed accuracy as the dependent variable. In Experiment 1, the unannounced presentation of a color singleton 500 ms prior to the letters (and in the same position as the target letter) resulted in better performance than in the preceding conjunction search segment, in which no singleton was presented, and performance was as good in this surprise-singleton trial as in the following feature search segment, in which the singleton always coincided with the target. In contrast, no improvement was observed when the color singleton was presented simultaneously with the letters in Experiment 2, indicating that attentional capture occurred later in the surprise trial than in the feature search segment. In Experiment 3, set size was varied, and reaction time was the dependent variable. Reaction time depended on set size in the conjunction search segment, but not in the surprise trial nor in the feature search segment. The results of the three experiments support the view that surprising color singletons capture attention independently of a corresponding attentional set.*

The hypothesis that surprising events capture attention is an old one. It is evident in the writings of ancient Greek philosophers (cf. Desai, 1939), as well as in the early (e.g., Darwin, 1872/1965) and in the recent (e.g., Meyer, Reisenzein, & Schützwohl, 1997) psychological literature. Stated briefly, this *surprise-attention* hypothesis entails that unexpected events (more precisely, events that deviate from activated cognitive schemas; cf. Neisser, 1976; Rumelhart, 1984) elicit surprise. Surprise, in turn, is conceived as a response syndrome that includes the orienting of attention toward the surprising event in order to promote subsequent decision-level processing of that event.

The surprise-attention hypothesis received initial experimental support from a study by Meyer, Niepel, Rudolph, and Schützwohl (1991; see also Niepel, Rudolph, Schützwohl, & Meyer, 1994; Schützwohl, 1998). In this study, the participants' task was to respond to the position of a dot appearing above or below two vertically arranged words. In 29 trials, both words were presented in black against a white background, and surprise was induced on the following critical trial by the unannounced presentation of one word in white letters against a black rectangle. Recall of the white-lettered word was much better than in a control condition, indicating that the word was attended to. Furthermore, reaction times (RTs) to the dot were inflated on the critical trial, indicating interference from decision-level processing of the surprising event. Interference was stronger when the surprising event was presented 500 ms prior to the dot rather than simultaneously with it, possibly because the surprise response took some time to develop.

A recent study by Gibson and Jiang (1998), however, does not support the surprise-attention hypothesis. Their study investigated whether feature singletons (e.g., one red element among several green elements) capture attention in a purely stimulus-driven fashion (see Yantis & Egeth, 1999, for a recent literature review). Attentional capture is proven, for example, if the time to find the target of a search task is independent of the number of simultaneously presented nontargets. Attentional capture is said to be stimulus-driven, exogenous, or unintentional if it does not depend on an intention to attend to the singleton (Yantis, 1993). Stimulus-driven attentional capture has been proposed for onset singletons (Jonides, 1981; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984; but see the controversy between Folk, Remington, & Johnston, 1992, 1993, and Yantis, 1993, and Gibson & Kelsey, 1998). In contrast, feature singletons (elements unique in color, brightness, or size) have been shown to capture attention only if observers know that these singletons indicate the target position, but not if they are task-irrelevant (e.g., Bacon & Egeth, 1994; Folk et al., 1992; Jonides & Yantis, 1988; Yantis & Egeth, 1999). Attentional capture by feature singletons is thus conditional on an intention and is therefore not purely stimulus-driven.

Gibson and Jiang (1998) pointed out that previous experiments might have failed to find evidence for attentional capture because attentional capture habituates quickly to repeated presentations of task-irrelevant singletons. They proposed that the critical test for this habituation hypothesis[1] involves the first presentation of a singleton (to prevent habituation from eliminating attentional capture) without prior announcement (to eliminate the possibility of an intention to attend to the singleton). In each trial of their experiment, eight different letters arranged in a circle were displayed for 86 ms, and the task was to indicate which of two possible target letters was present. The experiment comprised three segments. In the first, *conjunction search*, all letters were white, whereas in the following *surprise-singleton* trial and the subsequent *feature search* segment, the target letter appeared as a red singleton. Participants were not informed about the appearance of the singleton. Because surprise-related decision-level processes can inflate RTs (e.g., Meyer et al., 1991), accuracy was the dependent variable. Mean proportion correct was not significantly lower in conjunction search (.69) than in the surprise-singleton trial (.78), whereas it was much higher in feature search (.93), indicating that the color singleton improved performance only after the participants became aware of its occurrence and its utility for the search task.

Several procedural differences might have contributed to the diverging results obtained by Gibson and Jiang (1998) and Meyer et al. (1991). One difference is that the surprise stimulus Meyer et al. used probably was more conspicuous than Gibson and Jiang's surprise singleton, because it covered a larger area and was displayed longer. Also,

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1. The surprise-attention hypothesis is essentially a variant of this habituation hypothesis, because the ability of the singleton to elicit surprise should decrease rapidly after its first presentation.

Gibson and Jiang's procedure presupposed that attentional capture in the surprise trial occurred within about 86 ms. Thus, if attentional capture had been slower in the surprise trial than in feature search, their procedure would have been insensitive to attentional capture. Two findings corroborate this concern. Meyer et al. (1991) found that their surprising event was apparently attended to later than a simultaneously presented target stimulus. Additionally, Cheal and Chastain (1998) found that with multiple-element precues, in which the position of the target was cued by the position of a singleton, performance was better when observers knew the dimension of the singleton (e.g., color or brightness) in advance than when they did not have such advance knowledge. Because the dimension of the surprise singleton in Gibson and Jiang's study was known in feature search but not in the surprise trial, performance might have been impaired in the surprise trial.

The present study's goal was to test the surprise-attention hypothesis within a visual search paradigm using stimuli optimized for eliciting surprise and a procedure more sensitive to attentional capture than the one used by Gibson and Jiang (1998). Experiments 1 and 2 used Gibson and Jiang's experimental design, but the possible slowness of surprise-induced attentional capture was taken into account by displaying the color singleton 500 ms in advance of the search display in Experiment 1 (see also Chastain & Cheal, 1998). Experiment 2 was an attempt to replicate Gibson and Jiang's results with the stimuli and trial structure used in Experiment 1, but without the 500-ms preview of the surprise singleton. Experiment 3 took a more common approach to attentional capture, using set size (number of nontargets) as an independent variable and RT as the dependent variable.

EXPERIMENT 1

Method

Participants

Participants were 34 students from the University of Bielefeld, Bielefeld, Germany. Compensation was approximately $1.

Design and procedure

The experiment comprised the same three segments as Gibson and Jiang's (1998) Experiment 1. Trial structure (see Fig. 1) was slightly changed in order to present the surprising color singleton prior to the target display. Following the fixation cross, 12 colored squares (1.2° × 1.2°; viewing distance of 57 cm) appeared on the 12 clock positions of a circle 6.7° in diameter. After 500 ms, 12 black (0 cd/m^2) letters (0.7° × 0.8°), composed of horizontal and vertical line segments only, were presented in the squares for 86 ms. The squares remained visible until a response was registered.

The participants' task was to determine which of two possible target letters (*H* or *U*) appeared, and to press a key accordingly. The instructions emphasized accuracy of the response and explained that speed was only of secondary importance. Errors were immediately followed by error feedback, consisting of a 100-Hz, 100-ms tone. In the *conjunction search segment*, which comprised 48 experimental trials preceded by 12 practice trials, all squares were of the same color. This

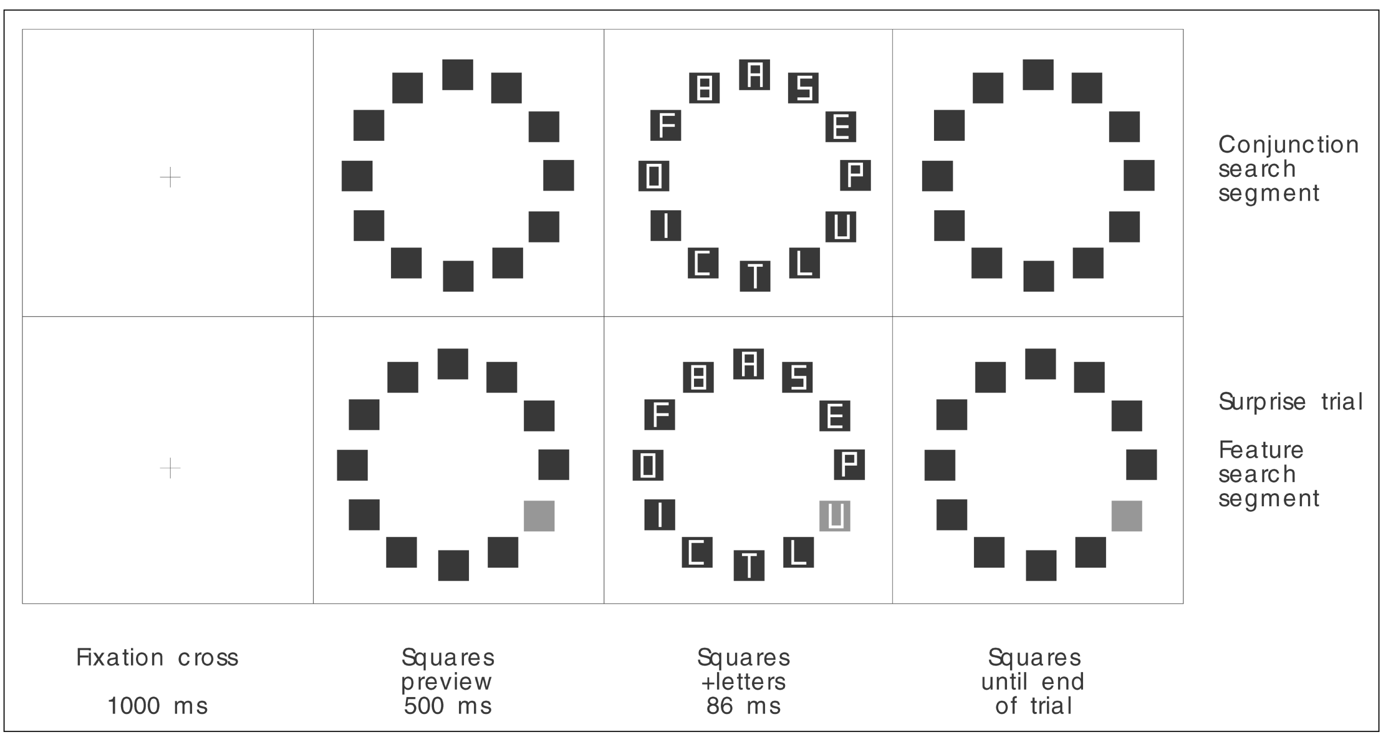

Fig. 1. Trial structure in Experiment 1. Time runs from left to right. In the experiment, the background and the letters were black, and the squares were red or green (indicated here by black vs. gray). The only difference between the conjunction search segment (upper panel) and the surprise trial plus the feature search segment (lower panel) was that only in the latter trials there was a color singleton (in the same position as the target) in each trial. (Note that the figure is not drawn to scale.)

segment was followed by 48 trials in which one square appeared in a different color. The positions of this singleton square and the target letter always coincided. The first trial with a singleton square was the *surprise-singleton trial.* The *feature search segment* comprised the following 47 trials. Each target appeared equally often in each position, and a new random sequence was used for each subject. The experiment flowed continuously from one segment to another, and the participants were not informed that one square would be presented in a different color or that it indicated the target position.

For half of the participants, the singleton square was red and the remaining squares were green; for the other half, the color assignment was reversed. The two colors were not matched for luminance (green: 87 cd/m^2; red: 18 cd/m^2), which is common practice in research on color singletons (e.g., Folk et al., 1992; Gibson & Jiang, 1998; Jonides & Yantis, 1988). Instead, it was assumed that the subjectively large difference in color would be more important (cf. Folk et al., 1992).

Results and Discussion

Figure 2, upper panel, shows the proportion correct for each trial. Mean proportion correct was considerably lower for the conjunction search segment (M = .65, SD = .09) than for the feature search segment (M = .96, SD = .03). Proportion correct in the surprise trial was .91, a value similar to the mean for the feature search segment. Color assignment affected performance neither in the surprise trial, $\chi^2(1, N = 34) < 1$, nor in the conjunction search or the feature search segment, $ts(32) < 1$.

Because of possible serial order effects, direct comparisons of the segments are problematic. For this reason, as in Gibson and Jiang (1998), proportion correct was regressed on trial number, separately for the conjunction search segment (slope = 0.0003, intercept = .65) and the feature search segment (slope = 0.0006; intercept = .92). A 95% confidence interval for the population proportion correct in the surprise trial was computed. It ranged between .77 and .97 and included the proportion correct predicted on the basis of the regression parameters of the feature search segment (y = .95), but not of the conjunction search segment (y = .66).

These results clearly support the surprise-attention hypothesis. The first unannounced presentation of a color singleton resulted in improved performance, indicating an attentional response to the singleton. Moreover, performance was as good in the surprise trial as in feature search, in which the participants probably expected the singleton and knew about its predictive value. This indicates that attentional capture by unexpected color singletons is as efficient as attentional capture by expected color singletons.

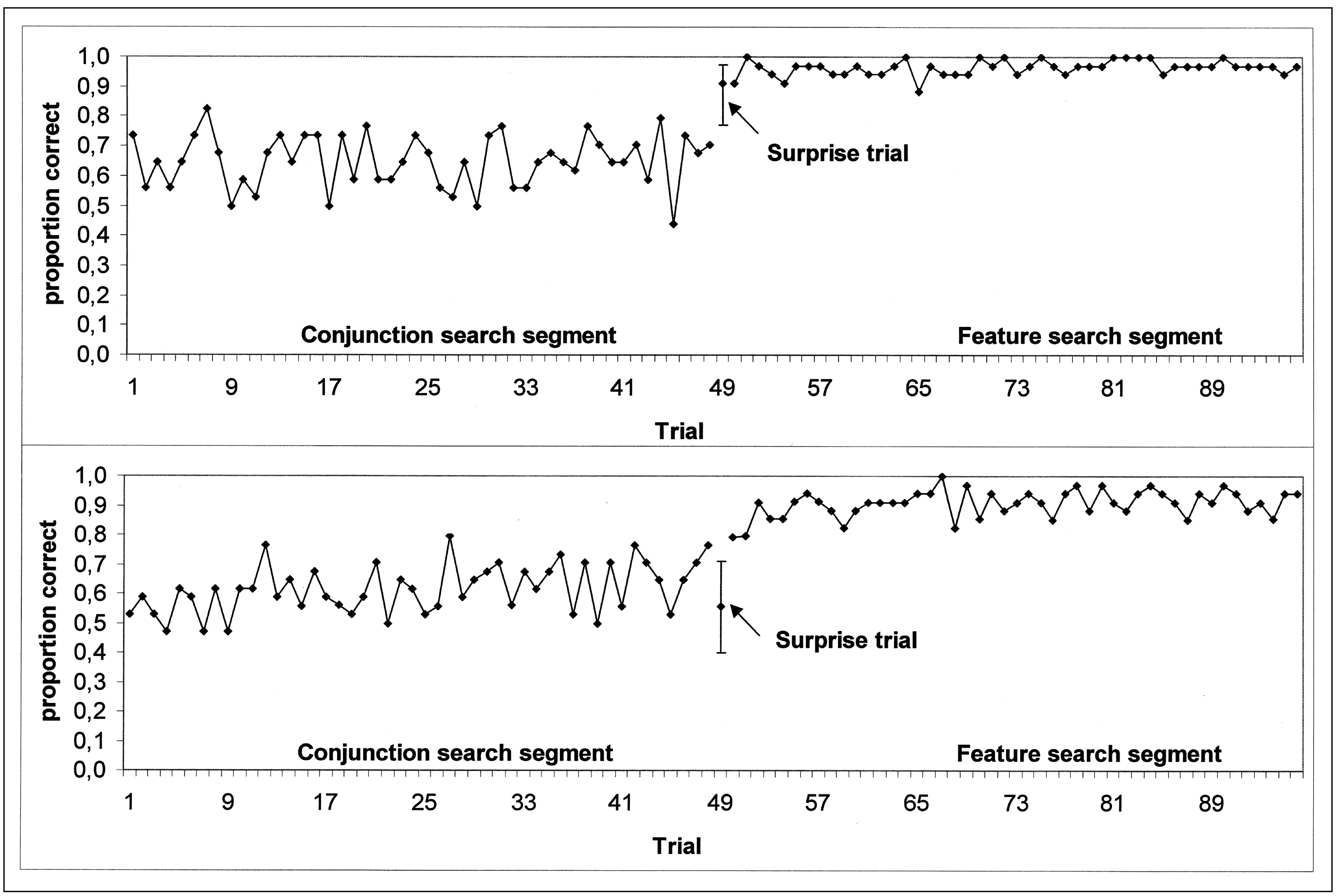

Fig. 2. Proportion correct in the conjunction search segment (Trials 1–48), the surprise trial (Trial 49), and the feature search segment (Trials 50–96) of Experiment 1 (upper panel) and Experiment 2 (lower panel). The error bars for the surprise trial indicate the 95% confidence interval for the population mean proportion correct in that trial.

As Gibson and Jiang (1998) pointed out, the design of their (and accordingly, of the present) experiment meets the criteria for establishing attentional capture: During the first segment, the participants should have been set to detect only the identity of the two target stimuli and the onset of the display as a whole; however, they should not have been intentionally looking for color when the singleton appeared unexpectedly.

EXPERIMENT 2

Because Experiment 1 did not replicate Gibson and Jiang's (1998) negative results, the question arises whether the critical differences between the two studies concern the temporal parameters or other stimulus and procedural differences. For this reason, in Experiment 2 there was no preview of the squares allowed, to be consistent with Gibson and Jiang's procedure, while everything else was unchanged relative to Experiment 1.

Method

Participants

Participants were 34 students from the University of Bielefeld. Compensation was approximately $1.

Design and procedure

The design and procedure were the same in Experiment 2 as in Experiment 1 with only one exception: Instead of the 500-ms preview of the colored squares (see Fig. 1, second frame), colored dots (1×1 pixel in height and width) in the nonsingleton color were presented at the 12 clock positions. Note that these dots served as spatial and temporal cues to the target display, and in this way were comparable to the squares in Experiment 1.

Results and Discussion

The proportion correct for each trial is shown in Figure 2, lower panel. Mean proportion correct was again considerably lower for the conjunction search segment (M = .62, SD = .08) than for the feature search segment (M = .91, SD = .05). Proportion correct in the surprise trial was .56. Color assignment did not influence the results in the surprise trial, $\chi^2(1, N = 34) = 1.1$, or in the conjunction and the feature search segments, $ts(32) < 1.4$, $ps > .1$.

Slope and intercept were 0.0026 and .56, respectively, for the conjunction search segment and 0.0013 and .81, respectively, for the feature search segment. The 95% confidence interval for the population proportion correct in the surprise trial ranged between .39 and .71 and included the proportion correct predicted on the basis of the regression parameters of the conjunction search segment (y = .69), but not of the feature search segment (y = .87). Thus, Gibson and Jiang's (1998) results were replicated with the present stimuli and procedure. Given that the 500-ms preview of the squares was the only difference from Experiment 1, the critical factor for finding attentional capture in the surprise trial appears to be the relative timing of attentional capture and the onset and offset of the letters.

EXPERIMENT 3

As Gibson and Jiang (1998) pointed out, measuring RT in the surprise trial is problematic because surprise-related decision-level processes can inflate RTs. In order to disentangle the effects of attentional capture and these processes, and to assess the efficiency of attentional capture, Experiment 3 varied set size. Set-size variations have been used in numerous experiments to test the efficiency of attentional capture. The underlying rationale is as follows: If the target does not capture attention, a demanding serial search has to be performed, and detection latency should depend on set size. In contrast, if the target captures attention, detection latency should be independent of set size. The important point here is that adding a constant to RT should not change these relationships. The surprise-related decision-level processes that inflate RT can be viewed as such an additive constant, because they are located at a processing stage different from the allocation of attention (cf. Sternberg, 1969), and because there is no apparent reason to expect them to depend on set size.

The general predictions for Experiment 3 were as follows. If surprising color singletons do not capture attention (the null hypothesis), the surprise-induced RT delay would be additive to the common set-size effect on RTs in conjunction search tasks. In contrast, if surprising events do capture attention (the surprise-attention hypothesis), mean RTs in the surprise trial would not depend on set size, but would reflect only the speed of attentional capture plus the surprise-induced RT delay.

Method

Participants

Participants were 25 students from the University of Bielefeld. Compensation was approximately $1.50.

Design

The participants were randomly assigned to one of two set-size conditions (4 vs. 12 letters). Note that the between-subjects variation of set size, although introducing irrelevant variance, was inevitable because there was only one surprise trial for each participant.

Stimuli and procedure

The experiment comprised the same three segments as Experiment 1. Trial structure was the same in all segments: After a 1,000-ms presentation of a fixation cross, an *H* or a *U* plus 3 or 11 distractor letters (depending on set size) appeared for up to 4,000 ms. The letters were presented as lit objects against a black background, as in Gibson and Jiang (1998). Which of the two target letters appeared, its position, and the positions of the distractor letters were randomly determined, with a new random sequence computed for each subject. Each target letter appeared on half of the trials, and each appeared equally often in each position. The letters were the same as in Experiments 1 and 2. In the set-size 12 condition, they appeared in the 12 clock positions of a 4.5° circle; in the set-size 4 condition, they appeared in the 3-, 6-, 9-, and 12-o'clock position of a 1.7° circle. The different eccentricities were intended to hold constant the proximity of adjacent letters, a variable assumed to influence saliency (cf. Yantis & Egeth, 1999). Eccentricity per se affects RTs in visual search only slightly, given that targets and nontargets are presented at equal eccentricities (Wolfe, O'Neill, & Bennett, 1998).

The participants' task was to indicate the identity of the target letter with a key press. Instructions emphasized speed and accuracy. RT was measured from the onset of the search display. The search display disappeared upon the registration of the response, and error feedback was given if the response was false. In the 24 practice trials and the following 72 experimental trials of the conjunction search segment, all letters were green (87 cd/m^2). In the surprise trial and the following 23 trials of the feature search segment, the target letter was always white (118 cd/m^2).

Results and Discussion

Trials with errors or RTs greater than 3,000 ms were excluded from the RT analysis, resulting in a loss of 4.9% of the experimental trials, one of them a surprise trial; this reduced the number of participants to 24, 12 in each group.

Figure 3 shows the mean RTs and percentage of errors for the two groups in the three segments. RTs were analyzed by means of a 2 (set size: 4 vs. 12) × 3 (trial type: conjunction search vs. surprise singleton vs. feature search) analysis of variance (ANOVA). Both main effects were significant, $F(1, 22) = 11.2, p < .01$, for set size and $F(2, 44) = 36.5, p < .001$, for trial type. The Set Size × Trial Type interaction was also significant, $F(2, 44) = 15.2, p < .001$.

A corresponding error analysis revealed a significant main effect for trial type only, $F(2, 44) = 20.8, p < .001$. The effects for set size, $F(1, 22) = 2.6, p > .1$, and the Trial Type × Set Size interaction, $F(1, 44) < 1$, were not significant. Fewer errors occurred in the surprise trial (0.0%) than in conjunction search (3.8%) and in feature search (6.0%), indicating that observers traded speed for accuracy in the surprise trial. This trade-off, however, does not complicate the interpretation of the RTs, because the main effect for trial type is not essential in the present analysis.

The main prediction concerned whether the effect of set size was different for the conjunction search segment versus the surprise trial. A 2 (set size: 4 vs. 12) × 2 (trial type: conjunction search segment vs. surprise trial) ANOVA revealed the predicted Set Size × Trial Type interaction, $F(1, 22) = 16.0, p < .001$; the two main effects were also significant, $F(1, 22) = 12.7, p < .01$, for set size and $F(1, 22) = 6.3, p < .05$, for trial type.

The results of planned comparisons were consistent with the surprise-attention hypothesis: The set-size effect was significant in the conjunction search segment, $t(22) = 7.9, p < .001$, but not in the surprise trial, $t(22) < 1$. In the conjunction search segment, RT depended on set size because the target letter was not salient and, therefore, did not allow efficient search. In contrast, the surprise singleton did capture attention; for this reason, the set-size effect was dramatically reduced on this trial (see Fig. 3); however, because of the surprise-induced RT delay, the RTs in the surprise trial were relatively long.

Was attentional capture as efficient in the surprise trial as in feature search? Search appeared to be slower in the surprise trial (12.5 ms/letter) than in feature search (3.6 ms/letter). If this difference were reliable, it would be more appropriate to speak of "attentional misguidance" (Todd & Kramer, 1994) than of attentional capture, in order to reserve the latter term only for cases in which the slope of the search function is zero. Efficient search predicts a main effect of type of trial (surprise trial vs. feature search) only, reflecting the surprise-induced RT delay. A corresponding ANOVA revealed exactly that pattern: The significant main effect of trial type, $F(1, 22) = 47.7, p < .001$, reflected a 360-ms reduction of RTs in the feature search segment relative to the surprise

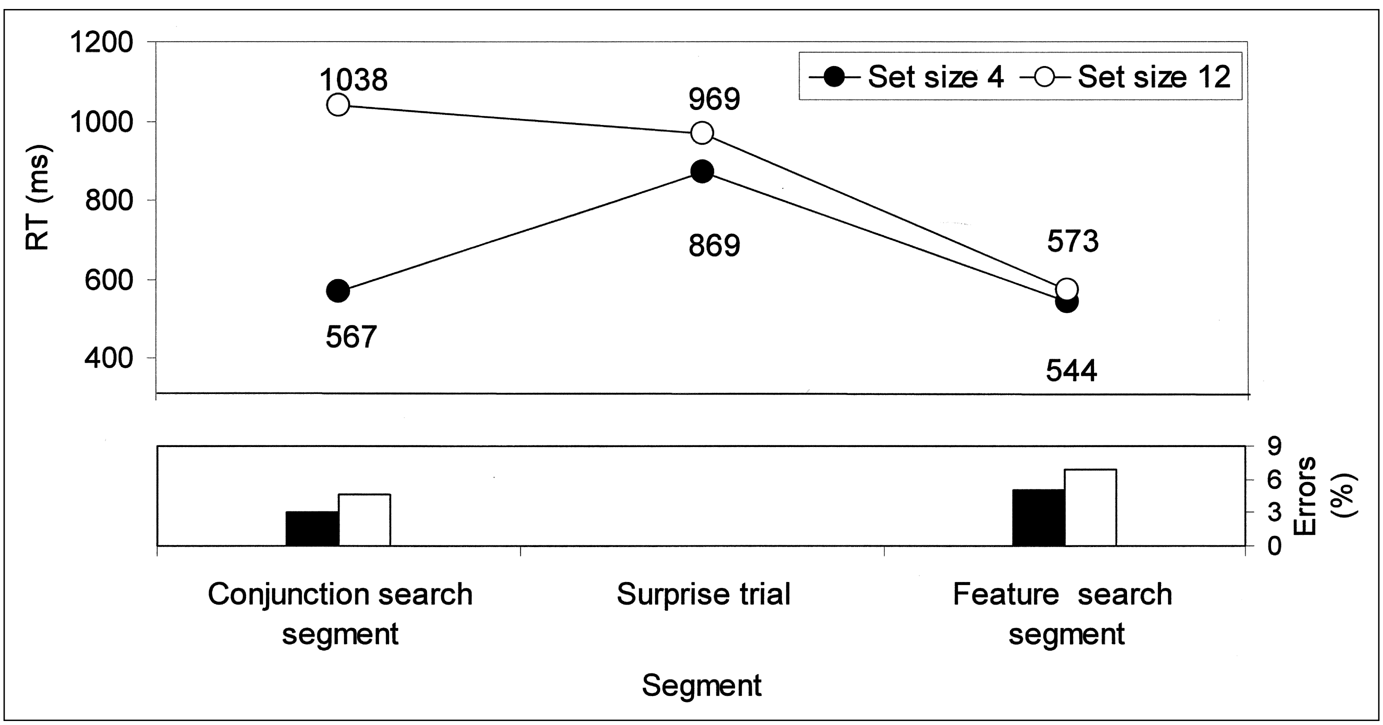

Fig. 3. Mean reaction times (RTs) and percentage errors for the set-size 4 condition (black symbols) and the set-size 12 condition (white symbols) for the conjunction search segment, the surprise trial, and the feature search segment of Experiment 3.

trial, while the remaining effects were not significant, *F*s < 1, indicating that type of trial did not affect search rates. Thus, the present results suggest that search in the surprise trial was as efficient as feature search. Furthermore, although the slope in the surprise trial was nonzero, it was smaller than the attentional misguidance effect (about 20 ms/item) reported by Todd and Kramer (1994).

This experiment differed from Experiment 1 in that the color singleton was a feature of the target letter in this experiment, but was a feature of a different object in Experiment 1. Given that attentional capture was evident in both experiments, this difference seems not to be crucial for attentional capture. This conclusion is also relevant to comparisons between Experiment 1 and Gibson and Jiang's (1998) study, because their surprise singleton was also a feature of the target letter.

GENERAL DISCUSSION

The present results are consistent with the theoretical and experimental literature on surprise in supporting the hypothesis that surprising singletons capture attention (e.g., Meyer et al., 1991). Surprise singletons thus differ from expected color singletons in that they capture attention independently of an intention. This result is inconsistent with a strong version of the contingent-capture hypothesis (Folk et al., 1992), according to which attentional capture is always contingent on an intention, and it also deviates from Yantis and Jonides's (1984) view that only onset singletons capture attention unintentionally.

How should the diverging results and hypotheses be reconciled? I propose that expected and unexpected singletons are processed differently. Whereas expected singletons (except, perhaps, onsets) capture attention only if their selection is intended, unexpected singletons capture attention if they deviate significantly from those stimuli whose perception is expected, explicitly or implicitly. Explicit expectations are generated and maintained consciously on the basis of considerations or verbal instructions in some situations. Additionally, implicit expectations are always generated automatically on the basis of knowledge acquired in similar situations. Expectations, as viewed here, are best conceived as based on, and subsequently incorporated into, the dynamic model of the situation that guides the observer's actions. This notion of expectations is thus similar to Neisser's (1976) schemas and Rumelhart's (1984) activated schemas. Stimuli that significantly deviate from schematic expectations elicit surprise and capture attention.

The surprise-attention hypothesis suggests itself as a necessary complement to present models of attentional capture. If attentional capture were always conditional on an intention, organisms would perceive only what they intended to see (plus whatever incidentally has similar features); other events would rarely be recognized, and threats would be frequently overlooked.

The results of Experiments 1 and 2 suggest that attentional capture was slower in the surprise trial than in feature search. This could be accounted for by additional processes that precede the orienting; such processes would include, at least, the detection of the expectancy discrepancy and the initiation of the surprise response. Note that "slow" in this context is being used in a relative sense (i.e., relative to feature search). How slow attentional capture by surprising singletons is can be determined only by time-course analyses (e.g., Chastain & Cheal, 1998). Time-course analysis may reveal additional information about the process. For example, Chastain and Cheal (1998) found that the time course of attentional capture by color singletons differs from that of onset singletons in a way indicating that color singletons are detected automatically but are attended to voluntarily. Future experiments should use time-course analyses to compare the characteristics of intended and unintended attentional capture.

The present results relate to the phenomenon of inattentional blindness (IB; e.g., Mack & Rock, 1998; Most et al., 2001): Observers frequently fail to detect task-irrelevant stimuli that are presented without prior announcement. It is important to note that there is no inconsistency between experiments on IB and surprise. Mack and Rock (1998) reported that IB typically occurred in about 25% of their observers. In the present experiments, IB was not assessed; however, Meyer et al. (1991) found similar rates (about 20%) of IB in their surprise trials. This implies that IB and surprise, although probably mutually exclusive states of mind, can co-occur within the same experiment for different observers. A surprise-theoretical perspective suggests that one factor that determines whether surprise or IB results is whether the degree of expectancy discrepancy is high or low, respectively. Future experiments should examine the conditions in which IB versus surprise occurs.

A final question to be addressed is whether attentional capture induced by surprising singletons is indeed purely stimulus-driven. If "stimulus-driven" is used with the meaning of "unintentional" (e.g., Gibson & Jiang, 1998), attentional capture by surprising singletons is stimulus-driven, because observers did not intend to attend to the singleton in the surprise trial. In contrast, if stimulus-driven means "purely bottom-up," the present results do not reflect stimulus-driven processes, because surprise always implies top-down processes like expectancies. Surprise is best conceived of as resulting from an interaction of expectancy-based and stimulus-driven processes.

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