

Stimulus-Driven Capture and Attentional Set: Selective Search for Color and Visual Abrupt Onsets

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Recent evidence suggests that attentional capture is contingent on the attentional control setting induced by the task demands (C. L. Folk, R. Remington, & J. C. Johnston, 1992). Because the experiments on which these conclusions are based can be criticized for several reasons, the contingent capture hypothesis was tested using 2 visual search tasks in which subjects searched multielement displays in which a color singleton and onset singleton were simultaneously present. Both experiments show that the contingent capture hypothesis does not hold: Irrespective of attentional set, attention was captured by the most salient singleton. The findings suggest a stimulus-driven model of performance in which selection is basically determined by the properties of the featural singletons present in the visual field.

Among the most fundamental issues of visual attention research is the extent to which visual selection is controlled by the properties of the stimulus or by the intentions, goals, and beliefs of the observer (see e.g., Yantis, 1993). It is generally assumed that visual selective attention can be controlled in either a goal-directed or a stimulus-driven manner. Selection is thought to occur in a goal-directed, voluntary manner when the observer intentionally selects only those objects required to perform the task at hand. Selection is thought to occur in a stimulus-driven, involuntary manner when selection is determined by the specific properties of the objects present in the visual field, irrespective of the intentions or goals of the observer.

For visual selection to be involved, it is required that different sources of information are simultaneously present in the visual field. Selective attention controls which objects embedded in an array of other objects are selected for further processing. Before selective attention operates, preattentive processes perform some basic analyses segmenting the visual field into functional perceptual units. A unit is thought to be selected if spatial attention is directed toward it (e.g., Broadbent, 1958, 1982). It is commonly assumed that this preattentive segmentation is limited to a set of primitive features or properties of objects such as color, shape, size, and brightness (e.g., Treisman & Gelade, 1980). Because visual search for these properties is independent of the number of elements in the display, the preattentive segmentation process is thought to operate without capacity limitations and in parallel across the visual field (e.g., Broadbent, 1958; Neisser, 1967). The preattentive segmentation process provides the perceptual units; the crucial question is whether the subsequent allocation of attention to

these perceptual units is controlled by stimulation or by the strategic plans of the observer (e.g., Neumann, 1984).

In the absence of a deliberate state of attentional readiness on the part of the observer, Jonides and Yantis (1988) and Theeuwes (1990) showed that, in a visual search task, the mere presence of a featural singleton in color, brightness, or shape was not enough to capture attention involuntarily. When searching for a target that could not be detected preattentively (e.g., Jonides & Yantis, 1988: searching for a target letter between other letters), the irrelevant featural singleton was simply ignored and the time to find the target increased linearly with the number of elements in the display. On the other hand, even in the absence of a deliberate state of attentional readiness, abrupt changes in luminance over time—abrupt onsets (Jonides, 1981; Jonides & Yantis, 1988; Müller & Rabbitt, 1989; Posner, 1980; Yantis & Jonides, 1984) and offsets (Miller, 1989; Theeuwes, 1991a)—can generate involuntary shifts of attention. Jonides and Yantis (1988), for example, showed that in a visual search task, a letter with abrupt onset was always selected first, even when there was no benefit to the observer to intentionally allocate attention to the onsetting item. These results suggest that dynamic discontinuities defined as changes in luminance over time (e.g., onsets, offsets, motion) are capable of capturing attention involuntarily. Static discontinuities that do not change in luminance over time do not elicit such shifts.

Recently, Yantis and Jonides (1990) and Theeuwes (1991a) showed that when search is eliminated by cuing with absolute certainty the spatial location of the impending target, even dynamic discontinuities (e.g., abrupt onsets and offsets) elsewhere in the visual field do not capture attention. Such a result was predicted because, in anticipation of the target event, spatial attention was already directed to the location of the impending target, suggesting that visual selection—controlling which object embedded in an array of other objects is selected for further processing—took place before the search display came on. Because the cuing procedure eliminates spatial uncertainty, it is not required to

I thank David E. Irwin, James C. Johnston, Odmir Neumann, and Steven Yantis for their excellent comments and suggestions on an earlier draft of this article.

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select a target object among other objects. The consequence is that the preattentive parallel segmentation stage that normally precedes the selection stage does not occur.

Theeuwes (1991b, 1992) showed that in visual search tasks in which the observer adopted an attentional set for a singleton (i.e., the defining attribute of the target was a featural singleton), performance was disrupted by irrelevant featural singletons in a different dimension as the relevant singleton (see also Bacon & Egeth, in press, Experiment 1; Pashler, 1988, Experiment 6). For example, in Theeuwes (1992), observers had an attentional set for a shape singleton because they searched for a green circle among green squares. When on some trials, an irrelevant color singleton was present (i.e., when one of the squares was red), search performance was disrupted. Even though observers had a clear attentional set to attend to a shape singleton, the irrelevant color singleton captured attention involuntarily. Theeuwes (1991b, 1992) showed that selectivity depended solely on the relative saliency of the stimulus attributes: When the shape singleton was more discriminable than the color singleton, the shape singleton interfered with search for the color singleton, and vice versa. It was concluded that in visual search tasks in which a preattentive segmentation process is required to detect the target, the attentional set cannot override the stimulus-driven capture that arises due to the appearance of a more salient stimulus attribute. Theeuwes (1991b, 1992) claimed that in visual tasks in which the defining attribute is a singleton, selection occurs in purely stimulus-driven fashion.

In a recent article, Folk, Remington, and Johnston (1992) challenged this claim and suggested that the control of attention is never purely stimulus driven. They claimed that the stimulus-driven control exerted by the objects present in the visual field depends on the observer's state of attentional readiness. Folk et al. used a paradigm involving the presentation of cues to be ignored immediately prior to the presentation of the target display. They showed that under conditions of spatial uncertainty, an onset singleton serving as a cue does not capture attention when observers adopt an attentional set for color singletons. On the other hand, when observers are set to identify a color singleton, they cannot ignore another color singleton known to be irrelevant (the cue). Folk et al. conclude that all attentional shifts are mediated by "programmable" control settings. Their conclusions are important; Yantis (1993) acknowledged that "the central point made by Folk et al. (1992)—that the bottom-up control of attention by stimuli interacts with the observer's state of attentional readiness—provides an important foundation for further developments in attentional theory" (p. 676).

It should be realized, however, that Folk et al.'s (1992) conclusions are based on a cuing paradigm with possible difficulties (e.g., Yantis, 1993). For example, in some conditions the task used was not really a search task because the target element was the only element present in the visual field (see also Yantis, 1993, Footnote 3). In addition, the task did not allow a check on whether subjects divided their attention over the visual field. If in some conditions subjects focussed their attention on a (random) location in the visual

field before display onset, it is likely that the distracting effects of events falling outside the attended area are attenuated (Theeuwes, 1991a; Yantis & Jonides, 1990).

Because Folk et al.'s (1992) conclusions are important, it is crucial to test their hypothesis with an uncomplicated visual search task. In the present study, subjects had to search selectively for either a color (attentional set for color singleton) or an onset singleton (attentional set for onset) embedded among three or six nontarget items in the visual field. Variation of display size enabled a check on whether search was performed in parallel or serially. When subjects had an attentional set for a color singleton, on some trials another location contained an irrelevant onset. In addition, when subjects had an attentional set for onset, on some trials another location contained an irrelevant color singleton. The task was designed such that subjects needed to attend to the location that was cued by the singleton of the attentional set.

According to the Folk et al. (1992) hypothesis that involuntary capture of attention is dependent on the control settings, it is expected that an abrupt onset does not capture attention when subjects have an attentional set for a color singleton. Time to identify the target signaled by the color singleton should not be affected by the presence of an irrelevant onset. In addition, when subjects have a clear attentional set for onset, the presence of an irrelevant color singleton should not affect performance.

Alternatively, Theeuwes's (1991b, 1992) hypothesis that visual selection depends on the relative saliency of the singletons present in the visual field, predicts that irrespective of attentional set a singleton with high saliency disrupts search for a less salient singleton.

Experiment 1

Method

Subjects. Eight right-handed subjects, ranging in age from 18 to 23 years, participated as paid volunteers. All had normal or corrected-to-normal vision and reported having no color vision defects.

Apparatus and stimuli. An SX-386 personal computer (G2) with an NEC Multisync 3D VGA color screen (resolution 640 × 350) using Micro-Experimental Laboratory software package controlled the timing of the events, generated pictures, and recorded reaction times (RTs). The "f" key and the z key of the computer keyboard were used as response buttons. Each subject was tested in a sound-attenuated, dimly lit room; a chin rest was used to stabilize the head. The CRT was located at eye level, 115 cm from the chin rest.

The display elements consisted of green (CIE x,y chromaticity coordinates of .303/.594) or red (coordinates of .630/.353) outline circles that were matched for luminance (16.5 cd/m²). The fixation cross and the line segments were presented in white (33.0 cd/m²) on a black background (0.5 cd/m²). The colorimetric and photometric measurements were carried out by means of a spectroradiometer (Photo Research, type: PR 703 A/M). The detector head of this device was directed toward the color patches used in this experiment, which were displayed at the center of the computer screen.

Procedure. The task (similar to the one used in Theeuwes, 1991b, 1992) consisted of a visual search task in which there is a

clear separation between the defining and reported attribute of the target. Subjects responded to the orientation (horizontal or vertical) of a line segment appearing inside a red circle embedded among green circles (color condition) or in a red outline circle with abrupt onset embedded among no-onset circles (onset condition). Because subjects responded to the orientation of a target line segment located among slightly tilted nontarget line segments, the task required focal attention (Theeuwes, 1991b; Treisman & Gormican, 1988) but not a high spatial acuity. The no-onset and onset stimuli were constructed analogously to Jonides and Yantis (1988), in which onset stimuli were presented in previously blank locations, and no-onset stimuli were camouflaged by premask.

The trial events are shown in Figure 1. At the beginning of a trial a central dot appeared, on which subjects remained fixated throughout a trial. After 700 ms, the standard premask was presented consisting of three or six green outline circles (1.2° of diameter), which were equally spaced around the fixation point on an imaginary circle whose radius was 3.4° . The six circles formed a hexagon; the three circles formed either an upward pointing or downward pointing equilateral triangle. Each circle contained six line segments (0.5°), one vertical, one horizontal, and four tilted 20° to either side of the horizontal and vertical plane. After a 1,000-ms premask the stimulus field was presented. At the end of the 1,000-ms premask period, five of the six line segments in each of the circles were extinguished, revealing line segments that were tilted 20° to either side of the horizontal or vertical plane. The orientations were randomly distributed in a display. In only one circle, the extinguished line segments revealed a line segment oriented either horizontally or vertically; the orientation determined the appropriate response key (the "f" key for vertical and the z key for horizontal). In the color condition, at the end of the 1,000-ms premask period, one of the green circles changed into an equiluminant red circle, which contained the horizontal or vertical target line segment. In the onset condition, at the end of the 1,000-ms premask period, a green circle containing the target line segment was presented at one of the six previously blank locations of the 3.4° imaginary circle. The stimulus field remained present for no more than 2 s until a response was given.

In the color condition, subjects received two conditions: (a) a no-distractor condition, in which the red circle containing the target line segment was presented with three or six green circles, and (b) a distractor condition, in which one of the three or six green circles had abrupt onset. In the onset condition subjects received two conditions as well: (a) a no-distractor condition, in which the green circle with abrupt onset was surrounded by three or six green circles, and (b) a distractor condition, in which one of these green circles was red. When searching for a uniquely colored red circle, the distracting element was a green circle with abrupt onset, and when searching for a green circle with abrupt onset the distracting element was a uniquely colored red circle. The position of the red target circle in the stimulus display was randomized from trial to trial. It always replaced one of the circles from the premask display. The position of the onset circle, which was randomized as well, was presented at one of the six blank locations. At the end of the premask period, in all except one condition, a circle with abrupt onset was added to the three or six circles of the premask display, creating a stimulus field consisting of four or seven circles. In the no-distractor color condition, however, no circle with abrupt onset was added at the end of the premask period. To keep an equal number of elements in the stimulus display, the premask in this condition consisted of the standard three or six circles with an additional circle at one of the locations that contained an abrupt onset circle in the other conditions.

Each subject performed both a color and an onset session. Both the color condition session and the onset condition session consisted of 96 practice trials (half of the trials in the no-distractor condition, the other half in the distractor condition), followed by a block of 144 trials in the no-distractor condition and 144 trials in the distractor condition. Half of the subjects started with the color session, the other half with the onset session. Within the color and onset sessions, half of the subjects started with the no-distractor condition, the other half with the distractor condition. Display size (4 or 7) was randomized within blocks. Each subject performed a total of 576 trials—that is, a total of 72 trials in each display-size distractor condition.

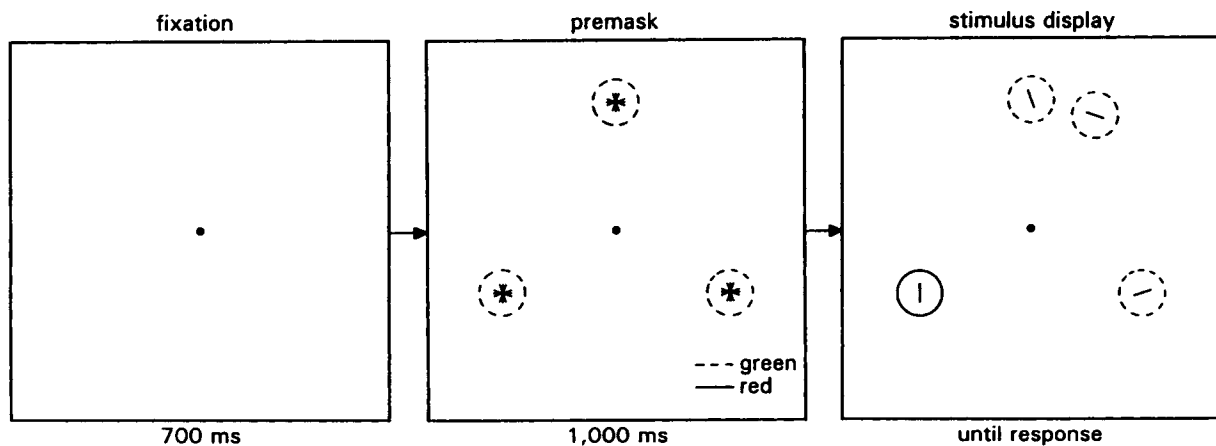


Figure 1. Trial events in Experiment 1. This diagram illustrates the color distractor condition, in which subjects have an attentional set for a color singleton. At stimulus display onset, one of the red circles (dotted outlines) changes into a green circle (continuous outlines), constituting the color singleton. At the same time, an irrelevant green circle is added to the display, constituting the abrupt onset distractor. The color singleton contains the target line segment which in this example is vertical.

A session lasted approximately 40 min, with a 15-min break between the sessions. Within a session, there were short breaks after 72 trials in which subjects received feedback about their performance (percentage errors and mean RT) on the preceding block of trials. Prior to the start of the experiment subjects were instructed to search for the horizontal or vertical target line segment and to press the appropriate response key with their index fingers, which were resting on the "f" and z keys. Before each session, the subjects were informed about the relationship between the location of the target line segment and the unique display element. In the color condition, subjects were told that the target line segment was always located in the uniquely colored red circle. In the onset condition they were told that the target line segment was always located in the circle with abrupt onset. They were instructed to use this information. It was emphasized that subjects should fixate the central dot and not move their eyes during the course of any trial. It was stressed that a steady fixation would reduce RT and make the task easier. Both speed and accuracy were emphasized. A warning beep informed subjects that an error had been committed. If no response was made after 2 s, subjects were informed that they had committed an error.

Results

All RTs lasting longer than 1 s were counted as errors, which led to a loss of well under 1% of the trials. Figure 2 presents the subjects' mean RT and error percentages in the four conditions. The individual mean RTs were submitted to an analysis of variance with attentional set (search for color or search for onset), display size (4 or 7), and distractor as factors.

There was a main effect on RT for both display size and distractor; $F(1, 7) = 6.3, p < .05$, for display size; and $F(1,$

$7) = 29.2, p < .01$, for distractor. The mean slopes for the color condition were 4.7 ms and 2.6 ms for the no-distractor and distractor conditions, respectively. For the onset condition, these figures were 0.6 ms and 5.5 ms, respectively. Only the slope of 4.7 ms was significantly different from zero, $t(7) = 3.8, p < .01$. All slopes were small and within the range that suggests parallel preattentive search across all items in the display (e.g., Treisman & Gormican, 1988). Inspection of the RT data reveals that when subjects are searching for a uniquely colored red circle, they are distracted by the abrupt onset. In addition, when subjects are searching for an abrupt onset, they are distracted by the uniquely colored red circle.

An additional analysis showed that distraction effect on RT did not depend on the order of the presentation of the color and onset sessions. The interaction between presentation order and distractor was not significant, $F(1, 6) < 1$, suggesting that the distraction effect is not due to some transfer from one condition to the next.

To achieve homogeneity of the error rate variance, the mean error rates per cell were transformed by means of an arcsine transformation. There was only a main effect for distractor, $F(1, 7) = 11.7, p < .05$. Because this analysis indicates that error differences are nonsignificant or tend to mimic RT, differences in response latencies are not due to a speed-accuracy trade-off.

Discussion

The results of this experiment are fairly clear: When subjects have an attentional set for a color singleton (a static discontinuity), an abrupt onset (a dynamic discontinuity) captures attention involuntarily, as evidenced by a prolonged RT to identify the target line segment inside the color singleton. In addition, when subjects have an attentional set for an abrupt onset, a color singleton also captures attention involuntarily. The results indicate that Folk et al.'s (1992) hypothesis that involuntary capture of attention is dependent on the control settings does not hold: Even when subjects have a clear attentional set for a static discontinuity, a dynamic discontinuity interferes, and vice versa.

The results agree with Theeuwes's (1991b, 1992) hypothesis that visual selection depends on the relative saliency of the singletons present in the visual field. In conditions in which there is only one singleton present (i.e., the no-distractor condition), the mean RT represents the relative saliency of the singleton; that is, it depicts the time it takes for attention to be captured by the singleton. As evident in Figure 2, the RT analysis indicates that the mean RTs averaged over display size for the no-distractor conditions color and onset were not different (550 ms for color and 535 ms for onset), suggesting that they did not differ in their saliency. In line with the Theeuwes hypothesis, comparable interferences for the color and onset conditions were expected and observed.

The finding that for all search functions, RT did not increase with display size, indicates that search for the color singleton and abrupt onset was performed in parallel. The

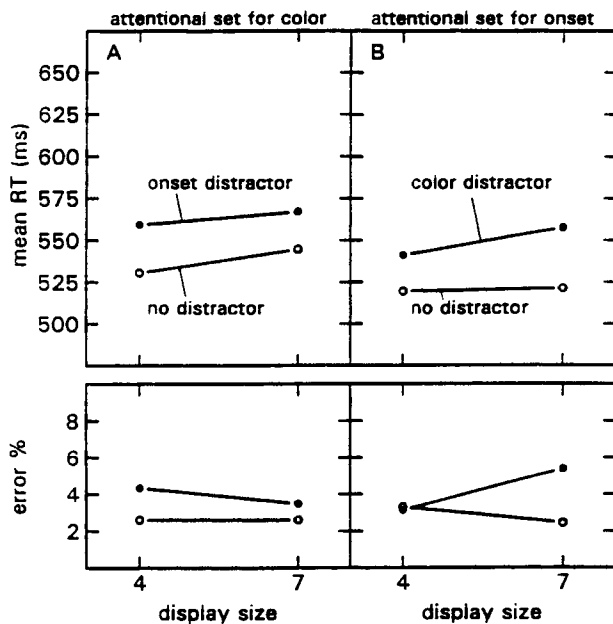


Figure 2. Experiment 1: Mean reaction time (RT) and error percentages for search with or without a distractor for the color (Panel A) and onset (Panel B) conditions. (Open circles = no distractor condition; filled circles = distractor condition.)

finding that search is not serial ensures that, prior to display onset, subjects did not focus their attention on some restricted area in the visual field. As indicated, focussing attention to one or a few items will give serial search that might attenuate the distracting effect of the irrelevant item.

The present findings showing that an attentional set for a static discontinuity cannot override the stimulus-driven capture of the dynamic discontinuity and vice versa might contain a confound because at stimulus presentation two elements are changed. The color of one element was changed from green to an isoluminant red, and one element was added. Although there is evidence showing that isoluminant color changes are perceived as being static (Cavanagh, Tyler, & Favreau, 1984) and moving elements presented on an isoluminant background do not pop out (Lüschow & Nothdurft, 1992), it is theoretically feasible that subjects attended to "change" irrespective of whether it is a color change or a luminance change. If subjects adopted such an attentional set for "change," interferences as found in Experiment 1 can be expected.

Experiment 2 was designed to test this possibility. Rather than changing the color of a single circle, the color of all except the target circle was changed so that an attentional set for change per se was not an appropriate strategy. In addition, to test Theeuwes's hypothesis, the color difference was made smaller so that the onsetting element had a higher saliency than the color singleton. According to Folk et al.'s (1992) hypothesis, the time to identify the target signaled by the less salient color singleton is not affected by the irrelevant onsetting element. According to Theeuwes's (1991b, 1992) hypothesis, attention is automatically captured by the most salient element, suggesting that the time to identify the target signaled by the less salient color singleton is prolonged. On the other hand, search for the abrupt onset with a relatively high saliency is not affected by the presence of the less salient color singleton.

Experiment 2

Method

Subjects. Eight subjects ranging in age between 20 and 25 years participated in the experiment.

Apparatus. The apparatus was identical to Experiment 1. The premask consisted of gray circles. Rather than changing the color of one of the circles as in Experiment 1, at the end of the premask period, the color of all of the circles except one was changed into an equiluminant red¹ (CIE *x,y* chromaticity coordinates of .265/.278 for gray and .628/.352 for red; luminance of 17.3 cd/m²).

Procedure. The task was identical to Experiment 1.

Results

RTs longer than 1 s were counted as errors, which led to a loss of well under 1% of the trials. Mean RT and error percentages are shown in Figure 3.

There was a main effect on RT for attentional set, $F(1, 7) = 25.0, p < .01$, and distractor, $F(1, 7) = 9.0, p < .05$. Also, the interaction between these variables and the inter-

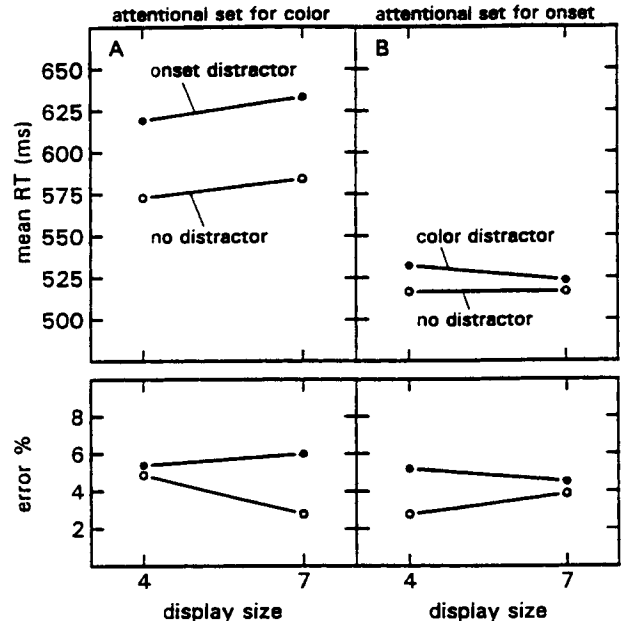


Figure 3. Experiment 2: Mean reaction time (RT) and error percentages for search with or without a distractor for the color (Panel A) and onset (Panel B) conditions. (Open circles = no distractor condition; filled circles = distractor condition.)

action between attentional set and display size were reliable, $F(1, 7) = 6.0, p < .05$, and $F(1, 7) = 11.5, p < .05$, respectively. The mean slopes for the color condition were 3.7 ms and 4.4 ms for the no-distractor and distractor conditions, respectively. For the onset condition, these figures were -0.04 ms and -3.0 ms, respectively. Only the slope of 4.4 ms was significantly different from zero, $t(7) = 3.2, p < .01$. The slopes were small, reflecting parallel preattentive search across all items in the display. For the color condition, planned comparisons showed a significant difference between the mean RTs of the no-distractor condition and the distractor condition, $F(1, 7) = 12.6, p < .01$, implying that search for the uniquely colored gray circle is slowed down by the abrupt onset circle. The same comparison for the onset condition shows that search for the abrupt onset circle is not affected by the presence of the uniquely colored gray circle, $F(1, 7) < 1$. Again, the distraction effect on RT did not depend on order of the presentation of the

¹ The color gray was chosen for the premask because, due to the steady fixation, colors such as green, red, or blue will induce a local chromatic adaptation (see Theeuwes & Lucassen, 1993). Due to this chromatic adaptation, the color of the circles of the stimulus field presented at exactly the same location as the circles of the premask appear to have a color that is slightly different from the color of the circle presented at a new location (i.e., the circle with onset). This might give a confound because the onsetting circle not only has onset but also a color that is slightly different from the rest. This effect does not occur with the color gray because this color consists of red, green, and blue simulating the red, green, and blue cones about equally.

color and onset sessions; the Order \times Distractor interaction was insignificant, $F(1, 6) < 1$.

The arcsine transformed error data showed that there was no reliable effect of distractor, indicating that the increase in RT caused by the onset distractor cannot be attributed to a speed-accuracy trade-off.

Discussion

The no-distractor conditions show that an onset is more salient than a gray circle between red circles (averaged over display size, no-distractor condition: 602 ms for color and 522 ms for onset). In line with the hypothesis of Theeuwes (1991b, 1992), the present data indicate that selectivity depends on the relative saliency of the singletons present in the visual field: Search for an onset was not hindered by the presence of a less salient color singleton. On the other hand, the salient onset interfered strongly with search for the color singleton. Again, the attentional set could not override the stimulus-driven capture of the more salient onset, a finding that challenges Folk et al.'s (1992) hypothesis.

General Discussion

Two experiments were conducted to test the hypothesis that the control of attention is never purely stimulus driven as suggested by Folk et al. (1992). According to their hypothesis involuntary orienting of attention to a stimulus event is contingent on the attentional set of the observer. Thus, if an observer has an attentional set for a static discontinuity (a color singleton), other static singletons capture attention, whereas dynamic discontinuity (abrupt onsets) can simply be ignored. Both experiments reported here show that this hypothesis does not hold: An attentional set for a static discontinuity cannot override the attentional capture of an abrupt onset.

The present findings together with those of Theeuwes (1991b, 1992) suggest a model of performance that assumes that the extent to which singletons capture attention is basically determined by the relative saliency of the singletons present in the visual field. In case spatial attention is unfocused, irrespective of the attentional set, spatial attention is automatically and involuntarily captured by the most salient singleton. The shift of spatial attention to the location of the singleton implies that the singleton is selected for further processing. If this singleton is the target containing the target line segment, a response is given. If it is not the target, attention is automatically switched to the next salient singleton. Because the saliency of the color and onset singleton were about equal in Experiment 1, attention was sometimes captured by the target and sometimes by the distractor, giving interferences for both the color and onset condition. Because the color difference was made smaller in Experiment 2, the onset singleton was always the most salient one, and therefore always selected first. As a consequence, search for the onset singleton was not hindered by the presence of the color singleton, whereas the onset singleton always interfered with search for the color singleton.

The present approach assumes that the local differences, which are detected by the preattentive process, are used to drive the attentional focus from one location having a high local difference signal to the next. It is assumed that the local activations caused by the differences among the elements are preserved. For example, as suggested by Yantis and Johnson (1990), a priority map representing the current priority tag strength of each element in the scene might drive focal attention through a scene (see also Ullman, 1984). After directing attention to one of the tagged locations, information regarding the item at that location (e.g., its identity, color, brightness, etc.) becomes available, and the priority tag of that element will be purged. This purging ensures that the element is not selected again.

According to Theeuwes's model (1993), in an unfocused state of attention, the preattentive process simply calculates differences in features within dimensions, resulting in patterns of activation at different locations, followed by an automatic shift of spatial attention to the location with the highest difference signal. In this model, selection operates irrespective of the task demands. The automatic shifts of attention can be considered the result of relatively inflexible, "hardwired" mechanisms that are triggered by the presence of specific stimulus properties. In line with Sagi and Julesz (1985) and Ullman (1984), for example, it is assumed that the parallel process can only perform a local mismatch detection followed by a serial stage in which the most mismatching areas are selected for further analysis.

It is recognized that the operation of the "hardwired" capturing mechanism can be stopped voluntarily by focusing attention on a restricted area in the visual field (e.g., Theeuwes, 1991a; Yantis & Jonides, 1990). It is assumed that no preattentive processing occurs outside the area to which attention is directed. Thus, if serial search through a display is necessary in order to detect the target (search for a target letter between other letters as, for example, in Jonides & Yantis, 1988), subjects may adopt a sequential focussed search mode in which attention is focussed, encompassing individual items. As a consequence of this focussed attention strategy, irrelevant featural singletons outside the attentional focus will not capture attention, as for example shown by Jonides and Yantis (1988). In the present study, however, focussing attention on individual items was not an adequate strategy because such a strategy would imply that also the task-relevant feature would not be capable of capturing attention. Therefore, in order to detect the task-relevant feature by parallel processing, subjects were required to divide their attention over the whole visual field, with the consequence that the task-irrelevant feature was also capable of capturing attention.

The data-driven selection model, as described above, is not in accordance with various recent models of visual search that do assume top-down effects on visual selection (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Treisman & Sato, 1990). Generally, these models are based on data that show that attentional set (e.g., knowing that the target is a red circle) speeds up responding to this target (i.e., the red circle). In these typical visual search tasks, the item subjects are looking for during search is also the item to which they

have to respond. As a consequence, attentional set not only affects visual selection, but also affects the processes (e.g., identification, response selection) that occur after the target has been selected. The present study does not contain this confound. Because subjects responded to the orientation of the target line segment located in the perceptually discrepant item, it is ensured that the RT data reflect effects operating at the early stage of perceptual processing rather than on processing operations occurring after the item has been selected (see also Yantis, 1993).

It might be argued that top-down effects did not show up in the present study because the target and distractor were so salient that attentional set could not override the attentional capture of these salient items. This argument might be valid for the interference found in Experiment 2; yet, in Experiment 1 color and onset singletons were about equally salient. If top-down effects do exist, they should have shown up under these circumstances.

The present data are not in accordance with Folk et al.'s (1992) conclusions. There are, however, large differences between the present visual search task and the cuing task used by Folk et al. (1992). In Folk et al.'s study, subjects responded to a letter shape (X vs. $=$) which, in different conditions, had either a unique color or a unique abrupt onset. When the search display was preceded by a featural singleton to be ignored (the "cue") that matched the singleton for which they were searching ("invalid-match" trials, e.g., searching for a unique color with a cue that contains a unique color as well), the cue captured attention as evidenced by a prolonged RT to identify the target. On the other hand, if the featural singleton to be ignored did not match the singleton for which they were searching ("invalid-mismatch" trials, e.g., searching for unique color with the cue containing a unique onset), the onset did not capture attention. This contingent capturing of attention occurred for both color and onset and is considered as evidence that involuntary capture is contingent on the adoption of some attentional set and will not occur if such a set is not adopted.

In the Folk et al. (1992) study, the use of the word *cue* may be misleading. The cue and search display were presented in fast successive order (both displays within 200 ms), and it is likely that some integration took place over time. The cue and search displays will appear to be presented at approximately the same time, with the cue being slightly more salient because it is presented slightly earlier in time. The critical finding in support of Folk et al.'s conclusion is that invalid-match trials show a large performance cost compared to invalid-mismatch trials. In the invalid-match conditions, it appears to subjects that two colored (color condition) or two onsetting (onset condition) items are (almost) simultaneously present in the visual field. Attention is involuntarily switched to the location of one of the singletons (first shifted to the cue because it is presented first and is therefore more salient). If attention is shifted to the cue, disengagement of attention from that location to the target location may take extra time because the cue and target share the same target defining property. This possibility was suggested by Theeuwes (1991b, Experiments 1 and 2), who found that a distractor in the same dimension as

the target causes more interference than a distractor in a different dimension.

In the invalid-mismatch condition, two items, one with a unique color and one with a unique onset, are present in the visual field. Attention is again switched involuntarily to the more salient cue, but disengagement of attention from the cue is rapid because cue and target do not share the target defining property. The difficulty of disengaging attention was also hinted by Yantis (1993) when he suggested that the Folk et al.'s (1992) study reveals that attentional set cannot be switched over very small time scales (p. 678).

This explanation accounts for Folk et al.'s (1992) results without assuming any top-down control at the selection level: Attention is switched involuntarily to the most salient singleton in the visual field. The key assumption in this account is that disengagement from a mismatching item is faster than disengagement from a matching item. Notice, however, that this is not a top-down effect on selection but on processes occurring after the item has been selected. If this account is correct, then one need not conclude that attentional capture by visual singletons is contingent on the adoption of a particular attentional set.

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Received October 1, 1992

Revision received August 13, 1993

Accepted October 18, 1993 ■

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