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Contingent Attentional Capture

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Overview

The search and selection of information from advanced information displays typically requires sequential shifts of spatial attention, which is a cognitive resource that can be allocated to distinct objects or locations independently of eye movements. The extent to which spatial attention is allocated to information relevant to current behavioral goals and withheld from information not relevant to those goals determines the efficiency of search and selection. A substantial body of research suggests that the efficiency of this process can be compromised by a phenomenon known as attentional capture, in which attention is involuntarily shifted to the location of irrelevant or low-priority information. Understanding the nature of attentional capture is particularly relevant to display design because such shifts are, by nature, dependent on display characteristics, and can result in a loss in the efficiency of information transfer.

In work sponsored by previous Consortium grants (NCA2-390; NCA2-491), we have been developing a model of involuntary attention allocation. Whereas previous models have focused primarily on determining the stimulus properties that produce capture such as abrupt visual onset, our work has explored the interaction between stimulus properties and behavioral goals in attentional capture. Contrary to previous claims that attentional capture is limited to the occurrence of abrupt visual onsets under conditions of spatial uncertainty, our work indicates that attentional capture can be produced by properties other than abrupt onset and, more importantly, that attentional capture is contingent on the attentional "set" of the observer. According to this model, the mechanisms of attentional capture are analogous to a thermostat, where the set-point is programmed (off-line) on the basis of top-down goals, but the on-line response of the device to a temperature change is bottom-up or stimulus-driven. High-level cognitive processes determine how the attentional control system is set, but given that setting, the on-line response to events is purely stimulus-driven, with no role played by high-level cognitive processes.

The purpose of the present Interchange was to further explore the nature of top-down control over attentional capture. In this context we addressed to general issues. First, we conducted a number

of experiments exploring the "functional architecture" of attentional control settings. That is, we explored the functional classes and specificity of top-down attentional "sets". The results, which reported in the manuscripts in Appendix A and B, suggest that attentional control settings can be instantiated either at the level of feature values (Appendix A), or at the level of dimensional "singletons" (Appendix B), depending on the demands of the task. These results represent a refinement of our previous work which suggested that control settings may be limited to the distinction between static and dynamic discontinuities. The work reported in the manuscripts has been presented at several national conferences and will be submitted for publication in the near future.

The second general issue addressed concerns the underlying mechanisms of attentional control. Specifically, we conducted experiments to determine if attentional control is instantiated through the inhibition of irrelevant stimulus properties or by the facilitation of relevant properties. This work, which is reported in Appendix C, involved manipulating subjects' knowledge of the location of irrelevant stimuli. The results suggest that attentional control settings are instantiated through the facilitation of relevant properties, at least with respect to stimulus location. The work reported in Appendix C was presented as an invited address at a national conference, and has been published in an edited volume based on the conference.

Implications for Systems Design

Modeling the underlying mechanisms responsible for the allocation of spatial attention, as well as how those mechanisms interact with display characteristics, is crucial to the development of displays that ensure efficient transfer of information from display to operator. The ability to predict the conditions under which particular display events will and will not capture attention can allow a designer to present high priority information in a format that will be likely to capture the operator's attention, and low priority information in a format that will be less likely to capture attention. The studies reported here represent a significant advance in the development of this model.

Appendix A

Running head: SELECTIVITY IN ATTENTIONAL CAPTURE

Selectivity in Attentional Capture by Featural Singletons

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Abstract

Four experiments address the degree of top-down selectivity in attentional capture by featural singletons through manipulations of the spatial relationship and featural similarity of target and distractor singletons in a modified spatial cuing paradigm. Contrary to previous studies, all four experiments show that when searching for a singleton target, an irrelevant featural singleton captures attention only when defined by the same feature value as the target. Experiments 2, 3, and 4 provide a potential explanation for this empirical discrepancy by showing that irrelevant singletons can produce distraction effects that are independent of shifts of spatial attention. The results further support the notion that attentional capture is contingent on top-down attentional control settings but indicates that such settings can be instantiated at the level of feature values.

Selectivity in Attentional Capture by Featural Singletons

A spate of research over the past several years has been concerned with identifying the conditions that produce involuntary shifts of spatial attention, a phenomenon known as attentional capture. This research has led to a debate over the extent to which attentional capture can be modulated by "top-down" factors. Some have argued that all attentional allocation is completely stimulus-driven or involuntary, with virtually no top-down modulation (Theeuwes, 1991; 1992; 1994; 1996). Others have argued that attentional capture is unique to only certain stimulus properties, such as abrupt visual onset (Yantis, 1993; 1996; Yantis & Hillstrom, 1994; Yantis & Jonides, 1990). Still others have proposed that the ability of any stimulus property to capture attention is contingent on the establishment of a top-down "attentional control setting" for that property (Folk & Annette, 1994; Folk & Remington, 1994; 1996; Folk, Remington & Johnston, 1992; 1993; Folk, Remington, & Wright, 1994).

Despite this theoretical debate, a consensus has emerged that at least one particular set of conditions produces attentional capture that is relatively impervious to top-down effects. Specifically, when the target in a visual search task is a "singleton" in a given feature dimension (e.g., a single red character among a collection of green characters or a square among circles), an irrelevant singleton, if salient enough, will capture attention even when defined by a different feature value or dimension (Bacon & Egeth, 1994; Folk, et al., 1992, Exp. 4; Joseph & Opticon, 1996; Theeuwes, 1992; Yantis, 1994; 1996). This is an important conclusion, in that it suggests that at the very least, there are limits on the specificity of top-down control over attentional capture.

In the following, we first critically evaluate the evidence for singleton-based attentional capture. We then report a series of experiments showing that, contrary to the results of previous studies, top-down selectivity in attentional capture is possible even when target and distractor are both singletons. Finally, we show that irrelevant singletons can have distracting effects that are independent of shifts in spatial attention and that it is these "non-spatial" distraction effects that may have been reflected in previous studies of singleton-based attentional capture.

Singleton-Based Attentional Capture

The majority of studies concerning the distracting effects of irrelevant featural singetons have used a visual search task in which performance for a singleton target presented alone is compared with performance when the target is presented in the context of an irrelevant singleton (Bacon & Egeth, 1994; Theeuwes, 1991; 1992; 1994). For example, in an important series of studies, Theeuwes (1991; 1992) presented subjects with displays consisting of varying numbers of colored circles or diamonds appearing on the circumference of an imaginary circle. A line segment varying in orientation appeared inside each shape, and subjects had to determine the orientation (horizontal or vertical) of a segment inside a target shape. In one condition, the target shape was defined as a singleton in form, such as a single green diamond among green circles. In another condition, the target shape was defined as a singleton in color, such as a single red square among green squares. Half of the trials in each condition contained an irrelevant singleton distractor in the other dimension. For example, when looking for a green diamond among green circles, an irrelevant red circle would be present. Theeuwes (1991) found that the presence of an irrelevant singleton in one dimension produced a significant elevation in response time when looking for a target singleton in the other dimension. This effect, however, was dependent on the relative salience of the singletons; it only appeared when the irrelevant singleton was of greater salience than the target singleton. In addition, Theeuwes (1992) showed that the distraction effect occurred even when subjects had full knowledge of the specific feature value defining the target singleton (i.e., whether the target would be a diamond or circle, red or green).

On the basis of these results, Theeuwes argued that the allocation of attention to display elements is driven entirely by the relative bottom-up salience of the elements. Attention is captured by the most salient singleton in the display, regardless of whether the property defining that singleton is relevant or not. In other words, the results suggest that when searching for a singleton, top-down selectivity based on stimulus values (e.g., green or red) or even stimulus dimensions (e.g., color or shape) is not possible.

Bacon and Egeth (1994) replicated the results of Theeuwes (1991), showing that search for a

target defined by a singleton in form is disrupted by the presence of an irrelevant singleton in color. More importantly, they found that the interference produced by an irrelevant singleton is crucially dependent on whether the target of search is also a singleton. In a modification Theeuwes' paradigm, the heterogeneity of shapes in the target display was manipulated such that, in the critical condition, subjects searched for a target consisting of a green diamond among varying numbers of green circles and green squares. Thus, the target was no longer specified by a singleton in form, but rather only by a specific value along the form dimension (i.e., "diamond"). Under these conditions, the effect of an irrelevant color singleton was completely eliminated. Bacon and Egeth (1994) proposed that when the target of search is not a singleton, subjects are forced to adopt a top-down search strategy for a specific feature value, and thus irrelevant singletons in a different dimension no longer produce capture. When the target of search is a singleton, however, subjects presumably enter "singleton detection mode" even when the dimension specifying the target is known. In this mode, any singleton, even when defined by a different feature dimension or value, will produce capture.

The conclusions of Bacon and Egeth (1994) are consistent with a recent proposal by Folk, Remington, and Johnston (1992; 1993; Folk, et al., 1994). These authors have argued that attentional capture is ultimately contingent on whether an attention-capturing stimulus is consistent with top-down attentional control settings that are established "off-line" on the basis of current behavioral goals. According to Folk and colleagues, the nature of the task to be performed results in an "off-line", top-down configuration of the attention allocation system, such that stimulus properties that match the top-down control settings will result in the "on-line" involuntary allocation of spatial attention to the stimulus exhibiting those properties. Moreover, stimuli that do not match the top-down control settings will not capture attention. In this context, the "singleton detection mode" proposed by Bacon and Egeth (1994) represents a particular attentional control setting. That is, when the target of search is a singleton, the allocation system is configured to respond to singletons, and any singleton will therefore capture attention, even if defined by an irrelevant feature dimension or value.

Do Irrelevant Singletons Capture Spatial Attention?

An underlying assumption of all of the studies discussed thus far is that any disruption in performance when an irrelevant singleton distractor is present versus when a distractor is not present reflects an involuntary shift of spatial attention to the location of the singleton distractor, i.e., attentional capture. None of these studies, however, have established that the observed cost associated with the presence of an irrelevant singelton is, in fact, specific to spatial attention. It is possible that the costs reflect some form of "central" disruption rather than a shift in the locus of spatial attention. Suppose, for example, that singletons are represented as objects against an otherwise uniform texture. When a distractor singleton is present, two objects are present in the display, whereas only one object (i.e., the target singleton) is present in a no-distractor condition. Perhaps the presence of two objects incurs a central "filtering cost" (Kahneman, Treisman, & Burkell, 1983) that is independent of shifts of spatial attention. If so, the conclusion that attentional capture by an irrelevant singleton is inevitable when searching for a target defined by a singleton may be unfounded.

One way of establishing that the distracting effects of an irrelevant singleton are linked to spatial attention would be to show that they are spatially specific. That is, if irrelevant singletons truly capture spatial attention, then one would expect that the magnitude of the disruption should vary with the relationship between the distractor location and target location. Specifically, the effect should be large when the distractor and target are at different locations and should diminish when the two are in close spatial proximity.

There is, in fact, at least one study in which the spatial relationship between a distractor singleton and target singleton have been varied. Folk, et al. (1992, Experiment 4) had subjects search for a target singleton defined as a single red character among three white characters and determine whether the target singleton was an "X" or an "=". The characters appeared in four boxes arranged on an imaginary cross centered on fixation. A distractor display appeared at various stimulus onset asynchronies (SOAs) prior to the presentation of this target display. The distractor display consisted of sets of four small circles, each set arranged in a cross and surrounding one of the four boxes. One set

circles (the distractor singleton) was green and the remaining three sets were white. The relationship

between the distractor location and the target location was systematically varied across three conditions.

In one condition, the distractor and target always appeared at the same location. In another condition

they always appeared at different locations. In a third condition, no distractor was presented - all the

advance circles were white.

Folk et al. (1992) found that, relative to the no distractor condition, a distractor at the same

location produced a benefit in response time and a distractor at a different location produced a cost in

response time. This result suggests that a distracting singleton defined by an irrelevant feature value

(the color green), does indeed produce an involuntary shift of spatial attention when searching for a

target singleton defined by a different color value (the color red). In other words, this result is consistent

with the notion that irrelevant singletons produce attentional capture when searching for a target

singleton defined by a different feature value.

There is a problem with this interpretation, however. The conditions were blocked such that

subjects knew with absolute certainty whether the target would be at the distractor location or not. The

logic of the design was that any costs obtained when the distractor appeared at a different location than

the target would provide a strong index of an involuntary attention shift because subjects knew that the

target would not appear at the distractor location. It was assumed that such a cost, in combination with

a concomitant benefit when the target and distractor shared the same location, would provide evidence

of involuntary shifts of spatial attention. Note, however, that when the target and distractor appeared at

the same location, subjects may have <u>voluntarily</u> shifted attention to the distractor location since they

knew with certainty that the target would subsequently appear there. Thus, as with the visual search

studies described above, the strongest conclusion that can be drawn from this study is that an irrelevant

singleton with a different feature value than the target produces a cost relative to a no distractor

condition. That is, the study still provides no strong evidence that the cost is specific to spatial attention.

<u>Focus of the Present Studies</u>

The present studies were conducted to provide a critical test of the generally accepted

hypothesis that when searching for a target singleton defined by a particular feature value, a distractor

singleton defined by an irrelevant feature value will produce an involuntary shift in spatial attention. The

basic approach was to systematically vary both the featural similarity and location congruence between

a singleton target and singleton distractor. The methodology was similar to that used by Folk et al.

(1992) in which subjects responded to the identity of a color singleton target preceded by a color

singleton distractor that did or did not match the specific color of the target. In contrast to Folk et al.

(1992), however, the spatial relationship between distractor and target location was varied <u>within</u> rather

than across blocks. Specifically, within a block, the target appeared at the same location as the

distractor on 25% of the trials, and at a different location from distractor on 75% of the trials. With only

four possible locations, this design ensures that the location of the distractor and the location of the

target are completely uncorrelated. As such, subjects have no reason to voluntarily shift attention to the

distractor and any effect of distractor location can be assumed to reflect an involuntary shift of <u>spatial</u>

attention or attentional capture.

Experiment 1

To address the degree of top-down control over singleton capture, the first experiment

manipulated the relationship between the distractor color and the target color. Specifically, the color of

the distractor singleton either matched that of the target singleton, or it did not. In addition, a

manipulation similar to that used by Bacon and Egeth (1994) was incorporated into the design. For one

group of subjects, the color target was a singleton, in that it appeared among three white characters.

For a different group of subjects, the color target was a non-singleton, in that it appeared among a

heterogeneous display of two white characters and one other, different-colored, character.   Based

on the results of Bacon and Egeth (1994), it was expected that when the target display contained

multiple colors, subjects would be forced from "singleton detection mode" into "feature search mode",

because the target is not a color singleton. Thus, attentional capture by the distractor (as defined by a

distractor location effect) should only be apparent when the distractor color matches the target color.

The critical condition is when the target is indeed a singleton. If, as is generally held, top-down selectivity based on feature value (i.e., color) is not possible when the distractor and target are both singletons, then attentional capture should be apparent regardless of whether the distractor and target singletons are the same color or not. If, however, top-down selectivity based on feature values is possible even in singleton search, then attentional capture should only be apparent when the color of the distractor singleton matches that of the target singleton.

Method

Subjects. Twenty-eight subjects from the Villanova University Human Subjects Pool participated in this study in partial fulfillment of a class requirement. Subjects ranged in age from 18 - 21 years and were tested for normal or corrected-to-normal near visual acuity (20/30 or better at a viewing distance of 14 inches binocularly) and normal color vision using a Titmus II vision tester.

Apparatus. Stimulus displays were presented on a Princeton Graphics Ultrasync monitor driven by a Zenith 286 microcomputer equipped with a Sigma Design, Color 400 high-resolution (680 x 400) graphics board. The monitor was placed at eye level

placed inside a black wooden viewing box 50 cm from lenseless goggles attached to a porthole in the front of the box. All but the screen of the monitor was occluded by a black baffle inside the box.

Stimuli. A fixation display, a distractor display and a target display were presented on each trial (see Figure 1). The fixation display consisted of a fixation square (.34 x .34° visual angle) surrounded by four peripheral boxes (1.15 x 1.15°) placed 4.1° above, below, to the left, and to the right of fixation. All boxes were light gray (IBM color designation #8) against the black background of the CRT screen.

The distractor display consisted of the fixation display with the addition of sets of four small circles (.23° in diameter) in a diamond configuration, surrounding each of the four peripheral boxes. Three of the sets of circles were white (IBM color #15), and one set of circles was either red (IBM color #12) or green (IBM color #10). Note that, given this color assignment, the distractor was always defined as a singleton.

The target display consisted of the fixation display with the addition of an "X" or "=" in each of the peripheral boxes. These characters subtending approximately .57° visual angle in height and width. In the singleton target condition, three of the characters were white and one was either red or green. In the non-singleton target condition, two of the characters were white, one was green, and one was red (see Figure 1).

Design. Twelve subjects participated in the singleton-target condition, and sixteen in the non-singleton target condition. Within each of these target-type conditions, distractor color (red vs. green) and target color (red vs. green) were factorially combined to create four conditions: red distractor - red target, green distractor - red target, red distrator - green target, and green distractor - green target. Target color was varied across subjects (half the subjects searched for a red target, and half searched for a green target) and distractor color was varied across blocks within subjects, with the order of distractor color condition balanced across subjects.

Each distractor color condition consisted of four blocks of 32 trials. Within each block, each target (i.e., X or =) appeared equally often in each of the four possible locations. The distractor also appeared equally often at each location, but its location was uncorrelated with target location. Specifically, the target and distractor appeared at the same location on 8 (25%) of the trials within a block and at different locations on the remaining 24 (75%) of the trials. On the latter trials, distractor locations were chosen with the constraint that distractors appear equally often in each of the three possible non-target locations for each possible target location. The identity of the characters (X or =) that appeared in the three non-target locations was chosen randomly on each trial.

Procedure. Subjects were tested in one 60-min session in a dimly lit laboratory room. Written and oral descriptions of the stimuli and procedures were provided to familiarize subjects with the task. Subjects were instructed to respond "as quickly as you can but also to make as few errors as possible". Maintaining fixation on the central cross was highly stressed and subjects were told that shifting their eyes would impair performance overall. Subjects were also fully informed of the relationship between distractor location and target location and were told that they should "ignore the distractor".

At the beginning of each block of trials, a message on the CRT screen indicated which of the two distractor colors (i.e., red or green) would appear in that particular block of trials. Subjects pressed the "enter" key to start the block. At the end of a block, a "rest" message appeared on the display screen.

At the beginning of each individual trial sequence, the central fixation cross and four surrounding boxes were presented for 500 ms. The fixation cross then blinked off for 100 ms then back on for a randomly varying foreperiod of either 1000, 1100, 1200, 1300, or 1400 ms. The distractor display then appeared for 50 ms, followed by the fixation display for 100 ms. The target display then appeared for 50 ms followed once again by the fixation display. The next trial sequence was initiated 1000 ms after a response was made. Phenomenally, the four display boxes and the fixation cross appeared to remain on the CRT screen for the duration of each trial, as well as the intertrial interval. The SOA between cue and target was 150 ms making contamination of response times by eye movements unlikely.

Subjects made a forced-choice target identification by pressing the "." and "0" keys on the numeric keypad of the keyboard for "X" and "=" targets, respectively (the keys were appropriately labelled). The "X" response was assigned to the right index finger and the "=" response to the left index finger. Response time was measured from the onset of the target display. If a response was not initiated within 1500 ms, an error was scored and the next trial sequence initiated. Incorrect responses elicited a 500 ms, 1000-hz computer tone, and were followed by a "buffer" trial with parameters drawn randomly from the set for that block. Response times for error and buffer trials were not included in the data analysis.

Results

Mean response times and error rates for the non-singleton and singleton target conditions are shown in Figures 2 and 3, respectively. The data from each of these conditions were subjected to separate mixed analyses of variance (ANOVAs) with target color (red vs. green) the single between-subjects variable and distractor color (red vs. green) and distractor-target locations (same vs. different) the two within-subjects variables.

Non-singleton targets. Overall, response times were significantly longer when the distractor appeared at a different location from the target than when it appeared at the same location, $F(1, 14)$ = 40.90, p < .001. This effect was qualified, however, by a significant three-way interaction with target color and distractor color, $F(1, 14)$ = 50.66, p < .001. No other main effects or interactions were significant.

As is quite evident in Figure 2, the three-way interaction confirms that the effect of target-distractor locations varied depending on whether the distractor and target were the same color or not. Planned pairwise comparisons revealed that when the target was red, a red distractor produced a significant location effect, $t(7)$ = 8.91, p < .05, and a green distractor did not, $t(7)$ = 0.53, p > .05. When the target was green, however, the same red distractor produced no location effect, $t(7)$ = 1.20, p > .05, and the same green distractor now produced a significant location effect, $t(7)$ = 7.1, p < .05. The overall error rate averaged 4.6%. Error proportions were positively correlated with response times, although not significantly so, $r(6)$ = .25, p > .05.

Singleton targets. The overall effect of distractor-target locations was significant, F (1, 10) = 56.28, p < .001, with longer response times occurring when target and distractor appeared at different locations. This effect was significantly larger for subjects searching for green targets than for subjects searching for red targets, as indicated by an interaction between target color and target distractor locations, F (1, 10) = 7.44, p < .05. These location effects were again qualified, however, by a significant three-way interaction with target color and distractor color F (1, 10) = 19.37, p < .01.

Figure 3 shows that the significant three-way interaction takes the same form as that observed in the non-singleton target condition. Specifically, the effect of target-distractor locations again varied depending on whether the target and distractor were the same color or not. Planned pairwise comparisons revealed a significant location effect when the target and distractor were both red, $t(5)$ = 4.32, p < .01, and when they were both green, $t(5)$ = 5.93, p < .01. No location effect was evident when the target and distractor were different colors, $t(5)$ = 0.69, p > .05, and $t(5)$ = 0.62, p < .05, for green distrator - red target and red distractor - green target, respectively. The overall error rate

averaged 2.6%. Error proportions were positively correlated with response times, $r(6)$ = .71, p < .05.

Discussion

Consistent with the results of Bacon & Egeth (1994), the effect of an irrelevant distractor in the non-singleton condition (i.e., when the target appeared in the context of other colored characters) was contingent on whether the distractor and target shared the same defining feature. Attentional capture, defined by a significant effect of distractor location, was evident when the target and distractor were the same color, but was completely eliminated when they were defined by different colors. This result is consistent with the notion that the non-singleton status of the targets forced subjects into adopting "feature-search" mode. The critical result, however, is that a similar pattern was obtained in the singleton target condition; attentional capture was evident only when the target and distractor shared the same color.

The results of this experiment have at least two important implications. First, they provide strong evidence against pure bottom-up models of attentional allocation (Theeuwes, 1991; 1992). In both the singleton and non-singleton conditions, clear selectivity in attentional capture was observed as a function of the similarity between the target and distractor color. In other words, the exact same distractor had different effects depending on the color of the target subjects were searching for, suggesting that attention allocation is influenced by top-down attentional set.

On might argue, however, that even pure bottom-up models can produce apparent selectivity depending on the relative salience of the target and distractors. For example, Theeuwes (1992), has shown that a given distractor can produce significant interference when paired with a target of equal salience but no interference when paired with a target of higher salience. In the present study, the lack of attentional capture when the target and distractor were different colors can not, in fact, be accounted for by differences in the relative salience of colored distractors and targets. Suppose, for example, red singletons are more salient than green singletons. On the salience account, a green distractor should not capture attention when the target is red. A red distractor, on the other hand, should capture attention when the target is green. In other words, there should be an asymmetry in the pattern of

selectivity across target colors. As is clearly evident in Figure 3, no such asymmetry is apparent. Thus, the results are uniquely consistent with top-down contingencies in attentional capture that can be instantiated at the level of feature values.

The second important implication of the present results is that they challenge the claim that irrelevant singletons will always capture attention if the target of search is a singleton (e.g., Yantis, 1996). Clear evidence of selectivity in capture was obtained even in the singleton target condition.

How can we account for the discrepancy between the present results and those obtained in previous studies of singleton target search? One possibility is that some aspect of the present paradigm encouraged subjects to adopt feature search mode even in the singleton target condition. For example, perhaps the introduction of a distractor color singleton in close temporal proximity to the target singleton encouraged feature search. Another possibility, however, is that the lack of selectivity in previous studies of singleton search might reflect a different form of distraction than that observed in the present studies. Specifically, assuming the effects of location congruence between distractor and target in the present study reflect true shifts of spatial attention, the different pattern of distraction effects found in previous studies of singleton search (in which spatial congruence of distractor and target was not manipulated) may reflect some non-spatial form of distraction, such as the object filtering cost suggested in the introduction. The second experiment was conducted to address this latter possibility.

Experiment 2

Experiment 2 was conducted to test the hypothesis that irrelevant featural singletons can produce interference effects that are independent of shifts of spatial attention. The singleton target condition of Experiment 1 was replicated with the addition of a "no distractor" baseline condition in which distractor displays containing no color singletons were included in the design. This no distractor display is similar to the baseline conditions used in previous studies of singleton search. If irrelevant singletons can produce intereference that is independent of shifts of spatial attention, then distractors that are a different color than the target should produce a cost relative to the no distractor condition

even when the same distractor produces no evidence of attentional capture (i.e., no location congruence effect).

Method

Subjects. Twenty-four subjects from the Villanova University Human Subjects Pool participated in this study in partial fulfillment of a class requirement. Subjects ranged in age from 18 - 20 and all had normal or corrected-to-normal near visual acuity and color vision.

Apparatus and Stimuli. Apparatus and displays were identical to those used in the singleton target condition of Experiment 1. In addition, a no-distractor display was incorporated into the design. This display was identical to the distractor displays used in Experiment 1, except all the sets of circles surrounding the four peripheral boxes were white (IBM color #15). That is, the no-distractor display contained no color singletons.

Design and Procedure. Half the subjects searched for a red target, half for a green. Within each of these target color conditions, distractor condition (red, green, no distractor) was blocked, with order balanced across subjects. Each distractor condition consisted of three contiguous blocks of 32 trials. In all other respects, the design and procedure was identical to that used in Experiment 1.

Results

Mean response times and error rates for each of the target color conditions are shown in Figure 4. To determine if the present results replicate those of Experiment 1, a mixed ANOVA was first conducted on the data excluding the no distractor conditions. The analysis included target color, distractor color, and distractor-target locations as factors. The overall effect of distractor-target locations was significant, F (1, 22) = 83.20, p < .001, with longer response times occurring when target and distractor appeared at different locations. As in Experiment 1, this location effect was qualified by significant three-way interaction with target color and distractor color, F (1, 22) = 34.33, p < .001. Planned pairwise comparisons revealed significant location effects when the target and distractor were both red, t(11) = 4.77, p < .001, and when they were both green, t(11) = 10.24, p < .001, and no such effects when the target and distractor were different colors, t(11) = 0.98, p > .05, and t(11) = 0.01, p >

.05, for green distrator - red target and red distractor - green target, respectively. The overall error rate averaged 1.5%. Error proportions were positively correlated with response times, $r(6)$ = .34, p > .05.

We now turn to the primary question of the present study: Do distractors that produce no evidence of spatial attentional capture still produce a cost in performance relative to the no distractor control? To answer this question, the data from the conditions in which distractor and target color did not match (i.e., the conditions that produced no location congruence effects) were collapsed across target-distractor locations and entered into a planned comparison with response time in the no distractor condition. The resulting mixed ANOVA included target color (red vs. green) as a between-subjects variable and distractor condition (no distractor vs. distractor) as a within-subjects variable. Overall, the presence of a distractor produced a significant 26 ms cost relative to the no distractor baseline, $F(1, 22)$ = 4.76, p < .05 for the main effect of distractor condition. The main effect of target color and the interaction of target color with distractor condition did not approach significance.

Discussion

The results of this experiment replicate those of Experiment 1, in that when searching for a singleton target, an irrelevant singleton distractor only produced evidence of attentional capture when it matched the target color. More importantly, the results show that irrelevant singletons producing no evidence of attentional capture nonetheless produce a cost in performance relative to a no-distractor baseline. In other words, the results indicate that irrelevant singleton distractors can have two dissociable effects on performance. If the distractor shares the defining property of the target singleton, it can produce an involuntary shift of spatial attention. If it does not share the defining property of the target it can still produce a non-spatial distraction effect.

It has been pointed out, however, that blocking experimental manipulations can produce strategic effects that confound the interpretation of benefits and costs in performance (Jonides & Mack, 1984). To address any such confounds, a third experiment was conducted in which the three distractor conditions (i.e., target and distractor same color, target and distractor different colors, and no distractor) were mixed randomly within blocks.

Experiment 3

Method

Subjects. Sixteen subjects from the Villanova University Human Subjects Pool participated in this study in partial fulfillment of a class requirement. Subjects ranged in age from 18 - 21 and all had normal or corrected-to-normal near visual acuity and color vision.

Apparatus and Stimuli. Apparatus and displays were identical to those used in Experiment 2.

Design and Procedure. Half the subjects searched for a red target, half for a green. Each of these target color conditions consisted of three contiguous blocks of 48 trials. Within each block, each of the three distractor types (red, green, no distractor) occurred equally often. In all other respects, the design and procedure was identical to that used in Experiment 2.

Results

Mean response times and error rates for each of the target color conditions are shown in Figure 5. A mixed ANOVA confirmed the effects of distractor-target similarity found in the previous two experiments as the three-way interaction between target color, distractor color, and distractor-target locations was significant, F (1, 22) = 34.33, p < .001. Planned comparisons once again revealed significant location effects when the target and distractor were the same color ($t(7)$ = 4.68, p < .01, and $t(7)$ = 6.43, p < .001, for red - red and green - green conditions, respectively) but not when the target and distractor were different colors ($t(7)$ = 1.39, p > .05, and $t(7)$ = 0.37, p > .05, for green - red target and red - green conditions, respectively). The overall error rate averaged 2.9%. Error proportions were positively correlated with response times, $r(6)$ = .65, p > .05.

To assess non-spatial distraction, response times for the "different color" conditions were collapsed across target-distractor locations and entered into a planned comparison with response time in the no distractor condition. As in Experiment 2, the presence of a distractor produced a significant cost relative to the no distractor baseline, $F(1, 14)$ = 6.26, p < .05 for the main effect of distractor condition. This effect did not vary across target color as neither the main effect of target color nor the interaction of target color with distractor condition approached significance.

Discussion

The results of this experiment are nearly identical to those found in Experiment 2. Given that the various distractor conditions were intermixed randomly within a block, these results suggest that the apparent non-spatial cost produced by the presence of an irrelevant singleton distractor is not an artifact of blocking distractor conditions. Thus, the data provide further support for two dissociable forms of distraction produced by irrelevant singleton distractors.

There is, however, another alternative account of the apparent non-spatial distraction observed in these studies. We have interpreted the absence of a distractor-target location effect as evidence that spatial attention is not involuntarily shifted to the location of the distractor. One might argue, however, that spatial attention is attracted to the location of the distractor in all conditions, but when the distractor is a different color than the target, the system is able to "recover" or shift spatial attention back to fixation more readily than if the distractor is the same color as the target. A recovery that takes place within the 150 ms SOA between distractor and target onset could account for the lack of a location effect. Moreover, the observed cost relative to no distractor conditions might reflect this recovery operation rather than the non-spatial distraction argued for above. Indeed, Theeuwes (1994) has proposed just such a phenomenon to account for the apparent top-down selectivity in attentional capture found in our previous studies.

In the final experiment, we test this alternative account by incorporating an SOA manipulation into conditions in which target and distractor colors do not match, conditions which showed no evidence of attentional capture in the previous experiments. A no distractor condition was also included. If the recovery account is correct, then evidence of attentional capture (i.e., a location effect) should be apparent at SOAs shorter than 150 ms.

Experiment 4

Method

Subjects. Twenty-four new subjects, ranging in age from 18 - 20 years participated in this study. All had normal or corrected-to-normal near visual acuity and color vision.

Apparatus and Stimuli. Apparatus and displays were identical to those used Experiment 3.

Design and Procedure. All subjects searched for a green target preceded by either a red distractor or no distractor. Subjects were presented with eight blocks of 48 trials. Within each block, half the trials contained a distractor and half did not. As in the previous experiments, when a distractor appeared, it occurred at the target location on 1/4 of the trials and at a different location on 3/4 of the trials. In addition, the three distractor types (same location as target, different location from target, and no distractor) were crossed with three different distractor - target SOAs (50, 100, and 150 ms). In all other respects, the design and procedure was identical to that used in Experiment 3.

Results

Mean response times and error rates for the three distractor types as a function of distractor - target SOA are plotted in Figure 6. As in the previous two experiments, an analysis was first conducted excluding the data from the no distractor trials. The resulting 2 (distractor location) x 3 (SOA) repeated measureas ANOVA yielding only a significant main effect of SOA, $F(2, 46)$ = 6.28, p < .01. The main effect of distractor type and the interaction of distractor type and SOA did not approach significance, for both, F < 1. Thus, as is evident in the figure, there is little indication of any location effect, even at SOAs less than 150 ms.

To assess non-spatial distraction, the data were collapsed across distractor locations and compared to the no distractor condition at each SOA. The resulting 2 (distractor status) x 3 (SOA) repeated measures ANOVA yielded significant main effects of distractor status, $F(1, 23)$ = 14.65, p < .001, and SOA, $F(2, 46)$ = 4.69, p < .05, as well as a significant interaction, $F(2, 46)$ = 3.54, p < .05. Post-hoc comparisons yielded signficant distraction effects at 100 and 150 ms SOAs, $F(1, 23)$ = 9.49, p < .01 and $F(1, 23)$ = 13.47, p < .01, respectively. The presence of a distractor failed to produce a reliable effect at the 50 ms SOA, F < 1.

Error rate averaged just over 1% and did not vary systematically across conditions.

Discussion

The present results replicate the results of the previous studies, showing that at a 150 ms

distractor - target SOA, there is no effect of distractor location, but a significant effect of distractor

presence. More importantly, the fact that no significant location effect is apparent at the 50 and 100 ms

SOAs provides strong evidence against the possibility that attention is actually captured by a dissimilar

distractor, but then recovers within 150 ms.

One might argue, however, that the figure shows a trend toward a location effect at the 50 ms

SOA. There are several reasons why this trend is unlikely to reflect attentional capture. First, the 15 ms

effect did not approach significance, nor is it anywhere near the magnitude of the location effects

observed in the previous experiments when distractor and target were the same color. Second, if the

distractor were capturing attention at 50 ms, then response times for different location trials should be

higher at 50 ms than at 150 ms, since performance at the latter SOA would represent complete recovery

(attention in a spatially neutral state). This is clearly not the case. Instead, the 15 ms effect is driven

almost entirely by a reduction in response time on same location trials, a point that is addressed in more

detail below.

The results of the present experiment also show that non-spatial distraction effects are present at

100 ms SOA, but do not occur at the 50 ms SOA. At first glance, this would appear to conflict with the

results of experiments showing distraction effects even with simultaneous presentation (e.g., Theeuwes,

1991). As noted above, however, the reduction in the distraction effect at 50 ms SOA is driven almost

entirely by same location trials. We suspect that when SOA is short, and the distractor appears at the

same location as the target, it is integrated with the target into a single "object". Thus, there is no cost

associated with "filtering" an irrelevant object. At longer SOAs, however, the distractor is coded as a

distinct object, thereby produced a filtering cost. Consistent with this notion, Yantis and Gibson (1994)

have recently shown that the formation of new object files is associated with temporal discontinuities of

100 ms or more.

General Discussion

The present series of experiments were conducted to explore the degree of top-down selectivity

in singleton search. Contrary to previous claims, we have shown that selectivity based on feature values

is possible even when the target of search is a singleton. Specifically, all four experiments showed that

when searching for a singleton target defined by a particular color, an irrelevant singleton distractor

defined by a different color produced no evidence of attentional capture. The results of Experiment 4 in

which SOA was systematically manipulated confirmed that this effect does not simply reflect rapid

recovery from capture. Combined with evidence of capture when target and distractor color match,

these results provide clear evidence of top-down selectivity in singleton search.

The present experiments also provide evidence for a form of distraction that is dissociable from

the capture of spatial attention. Specifically, Experiments 2 - 4 showed that a distractor can produce no

evidence of attentional capture, and yet produce significant costs in performance relative to trials on

which no distractor appeared. Experiment 3 confirmed that this non-spatial cost is not a strategic

artifact of blocking distractor and no distractor trials.

Contingent Attentional Capture

There are a number of important theoretical implications associated with the present results.

First, the results provide further evidence against a strictly bottom-up model of attention allocation (e.g.,

Theeuwes, 1994). According to the bottom-up model, within each feature dimension (e.g., color or

shape) preattentive processes calculate differences in feature values across space. Attention is then

allocated to objects or locations in order of the magnitude of the preattentively defined "difference

signals". It is only after attention has been allocated is the featural source of the difference signal

identified. Moreover, the difference signals themselves are assumed to be impervious to top-down

modulation. Thus, attention allocation is driven entirely by the relative salience of the objects in the

display.

According to such a model, one of two possible patterns should have emerged in conditions

where target and distractor color did not match. If red and green singletons were of roughly equal

salience, then capture should have occurred regardless of color assignment. If, however, one type of

singleton were more salient than the other, then capture effects should have been asymmetric, with

capture occurring for one color assignment, but not the other (e.g., a red distractor might produce

capture for a less green target, but not vice versa). Neither of these patterns emerged, however. Instead, evidence of spatial attention capture was entirely contingent on whether the distractor and target shared the same specific color value. Moreover, this selectivity in capture was evident even at short (50 ms) SOAs, suggesting that the effect cannot be accounted for by a rapid recovery from capture. Thus, the present results, along with several other recent studies of visual conjunction search (Bacon & Egeth, in press; Kaptein, Theeuwes, & Van der Heijden, 1995) provide evidence that is clearly inconsistent with a strict bottom-up model of attention allocation.

On the other hand, the present results are quite consistent with a model in which attention allocation is contingent on top-down "control settings" that reflect current behavioral goals (Folk, et al., 1992; 1993; 1994). These variable control settings are assumed to influence what types of stimulus events attract attention. In the context of the present studies, the control setting is determined by the defining feature of the target. Thus, distractors sharing that feature will attract attention, even when the subject "knows" the distractor is irrelevant.

Specificity of Control

A second important implication of the present results concerns the specificity of attentional control settings. We have proposed previously that the specificity of attentional control settings may be limited to two broad classes of stimulus properties, namely static versus dynamic discontinuities. This conclusion was based largely on work showing little evidence of selectivity between targets and distractors defined by onset and motion (Folk, et al., 1994) which are both different forms of dynamic discontinuity. In addition, we originally found no evidence of selectivity based on specific color values (Folk et al., 1992).

In contrast, the present results provide clear evidence that even in singleton search subjects are, in fact, able to adopt attentional control settings for specific feature values, at least in the color domain. A similar conclusion has recently been reached by Hendel and Egeth (1996). Given these new results, it appears that the cost associated with irrelevant color singletons in our previous work (Folk et al., 1992) most likely reflected non-spatial distraction rather than true attentional capture. It should be noted that

evidence for color selectivity at the feature level is quite consistent with current computational models of visual search (e.g., Bundesen, 1990; Cave & Wolfe, 1990). It remains to be seen, however, whether featural selectivity is possible in stimulus dimensions other than color. Indeed, our work with motion and onset (Folk et al., 1994) suggests that even dimensional selectivity is limited within the realm of dynamic discontinuities. Perhaps this pattern reflects differences in the top-down penetrability of underlying physiological pathways. Specifically, the magnocellular pathway, which carries particularly important ecological information regarding dynamic changes, may be more impervious to top-down influence than the parvocellular system, which tends to carry information regarding static discontinuities such as color singletons (Livingstone & Hubel, 1988).

Singleton Detection Mode

A third implication of the present results concerns the notion of a "singleton detection mode" as proposed by Bacon & Egeth (1994). These authors proposed that when the target of visual search is a singleton, subjects appear to be "forced" into adopting an attentional set for singletons, even when the task would be more efficiently carried out by establishing a featural set (i.e., when irrelevant singletons are defined by a different feature dimension or value). In contrast, the present results show that singleton detection mode is not a mandatory consequent of a singleton-defined target. Moreover, given that previous studies of singleton search failed to distinguish between the capture of spatial attention and non-spatial distraction, one might argue that the notion of singleton detection mode is unnecessary. That is, it is possible that featural selectivity was, in fact, occurring in previous studies, and that the observed costs were similar to the non-spatial distraction observed in Experiments 2 - 4 of the present work.

On the other hand, there are several reasons it may be premature to dismiss singleton detection mode as a important theoretical construct. First, there are many procedural differences between the present studies and the work of Bacon and Egeth (1994). For example, the asynchronous presentation of distractor and target in the present studies may have encouraged the establishment of singleton detection mode in a way that the simultaneous presentation of Bacon and Egeth (1994) does not.

Second, the notion of singleton search may be quite appropriate when the nature of the task truly encourages a set for singletons. For example, if the target is a singleton, but the defining feature of target is uncertain from trial to trial, then it would be quite appropriate to establish an attentional control setting for singletons in general. Indeed, we have recently reported work consistent with this hypothesis (Remington & Folk, 1994).

Non–Spatial Distraction

The final implication of the present work is the demonstration of a source of distraction in singleton search that is dissociable from shifts of spatial attention. Although the precise nature of this form of distraction is unclear, we speculate that it is related to the segmentation of displays into perceptual objects. Specifically, when a distractor singleton appears, it is encoded as an object distinct from the target singleton. Even though this irrelevant object may not draw spatial attention to itself, it may, if salient enough, nonetheless compete for selection, ultimately slowing down responses to the target. Such competition among perceptual objects has been documented previously as a "filtering cost" (Treisman, Kahneman, & Burkell (1983).

In the context of attentional capture in singleton search, the most important aspect of non-spatial distraction is that it can confound the interpretation of experiments in which converging evidence for shifts of spatial attention (e.g., spatial congruency effects) is not present. This potential confound may help to account for some of the empirical discrepancies in the literature on attentional capture. For example, Theeuwes (1994) reported no evidence of selectivity in capture between color and onset singletons in a visual search task in which target and distractor were presented simultaneously. This appears to be in direct contradiction to the results of Folk, et al. (1992), who showed strong evidence of top-down selectivity between color and onset in a paradigm similar to that used in the present studies. In the Theeuwes study, however, there was no manipulation of the spatial congruence of target and distractor singleton; capture was defined by cost on distractor trials relative to no distractor trials. Thus, it is possible that Theeuwes' (1994) results reflect a filtering cost rather than true attentional capture.

Arguing against this possiblity, Theeuwes (1996) more recently found evidence of response

competition effects based on the identity of an irrelevant distractor singleton, suggesting that attention

may have indeed have been drawn to the location of the distractor. Unfortunatley it is not clear whether

the response competition effects observed were necessarily specific to the distractor singleton. Clearly

further research is necessary to identify the nature of distraction effects in singleton search.

Nonetheless, given the present results, it would appear essential that any future research provide

converging evidence for shifts of spatial attention before attributing performance costs to attentional

capture.

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Figure Captions

Figure 1. Examples of target and distractor displays for Experiment 1. Note: open characters were white, black characters were red, and hashed characters were green.

Figure 2. Average mean response times and error rates as a function of target color, distractor color and target - distractor location in the non-singleton target condition of Experiment 1.

Figure 3. Average mean response times and error rates as a function of target color, distractor color and target - distractor location in the singleton target condition of Experiment 1.

Figure 4. Average mean response times and error rates as a function of target color, distractor types and target - distractor location in Experiment 2.

Figure 5. Average mean response times and error rates as a function of target color, distractor types and target - distractor location in Experiment 3.
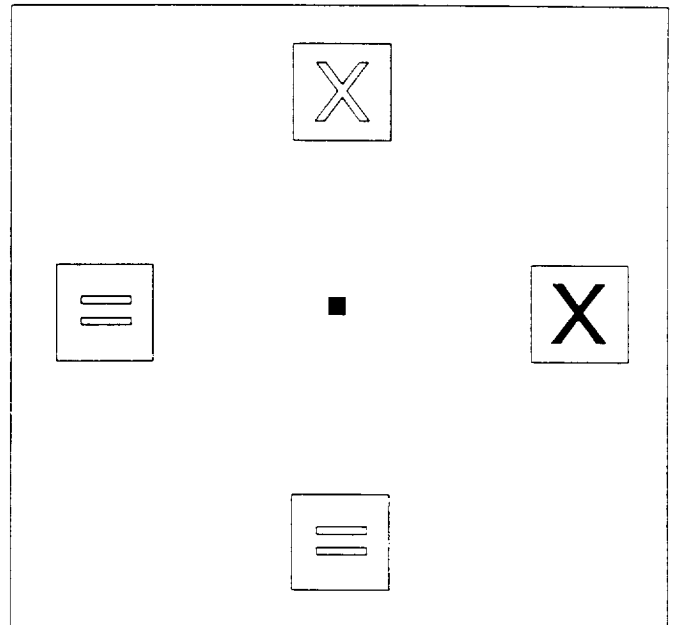
Figure 6. Average mean response times and error rates as a function of distractor condition and SOA in Experiment 4.
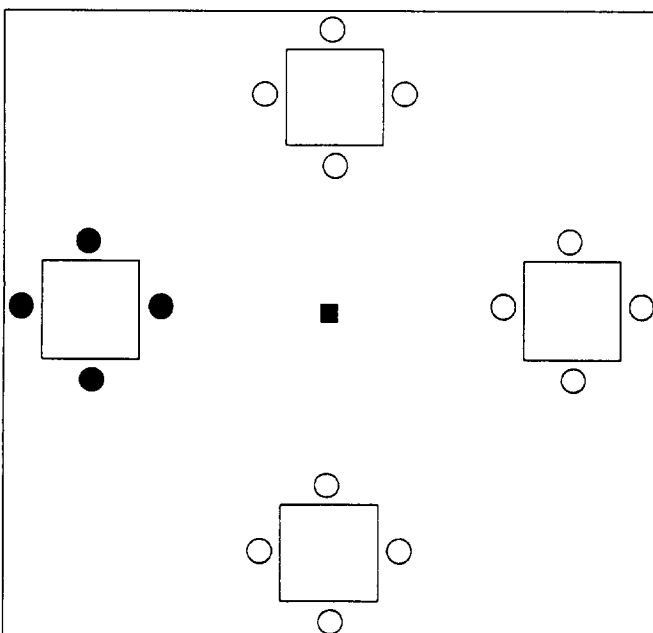
TARGET DISPLAYS

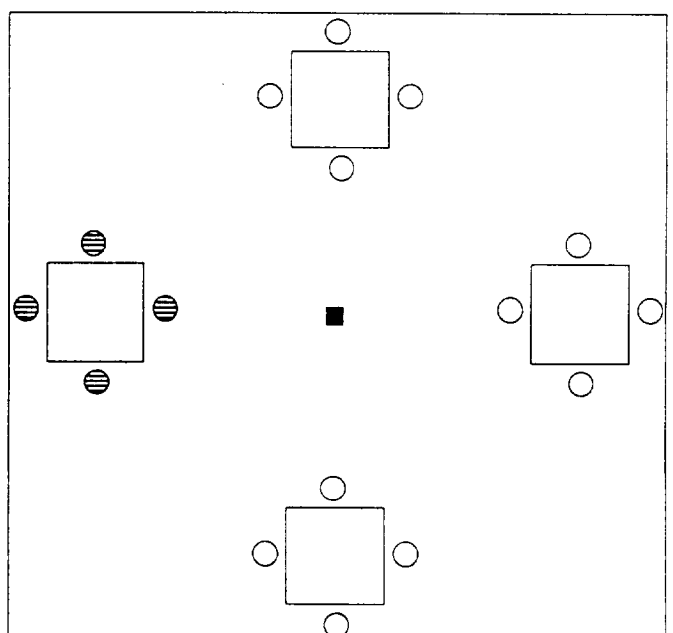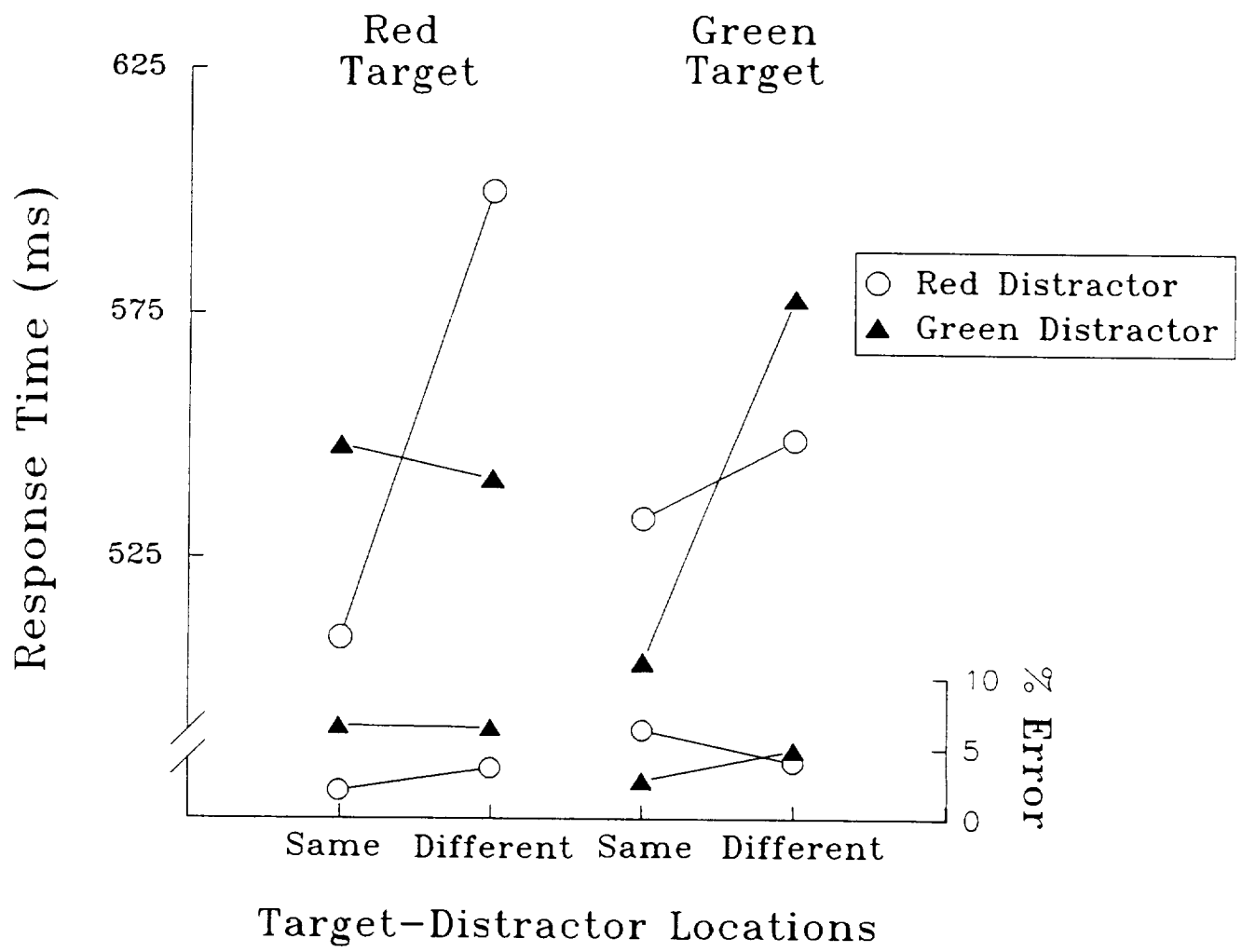## Non - Singleton Target
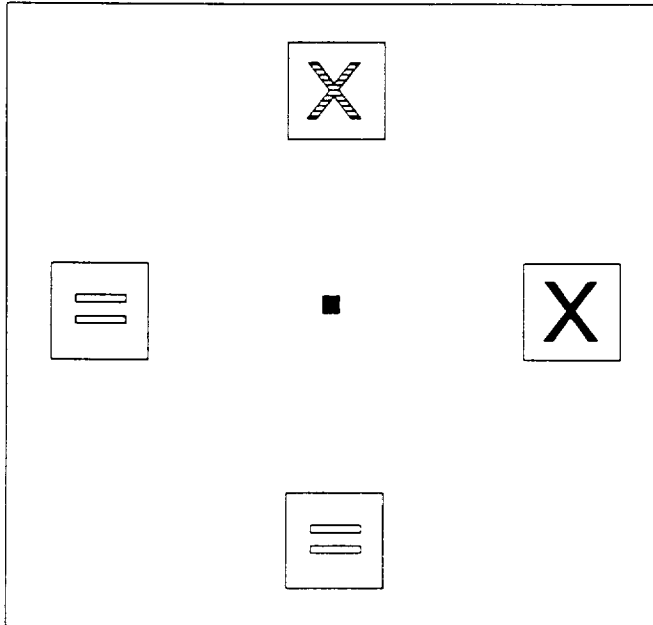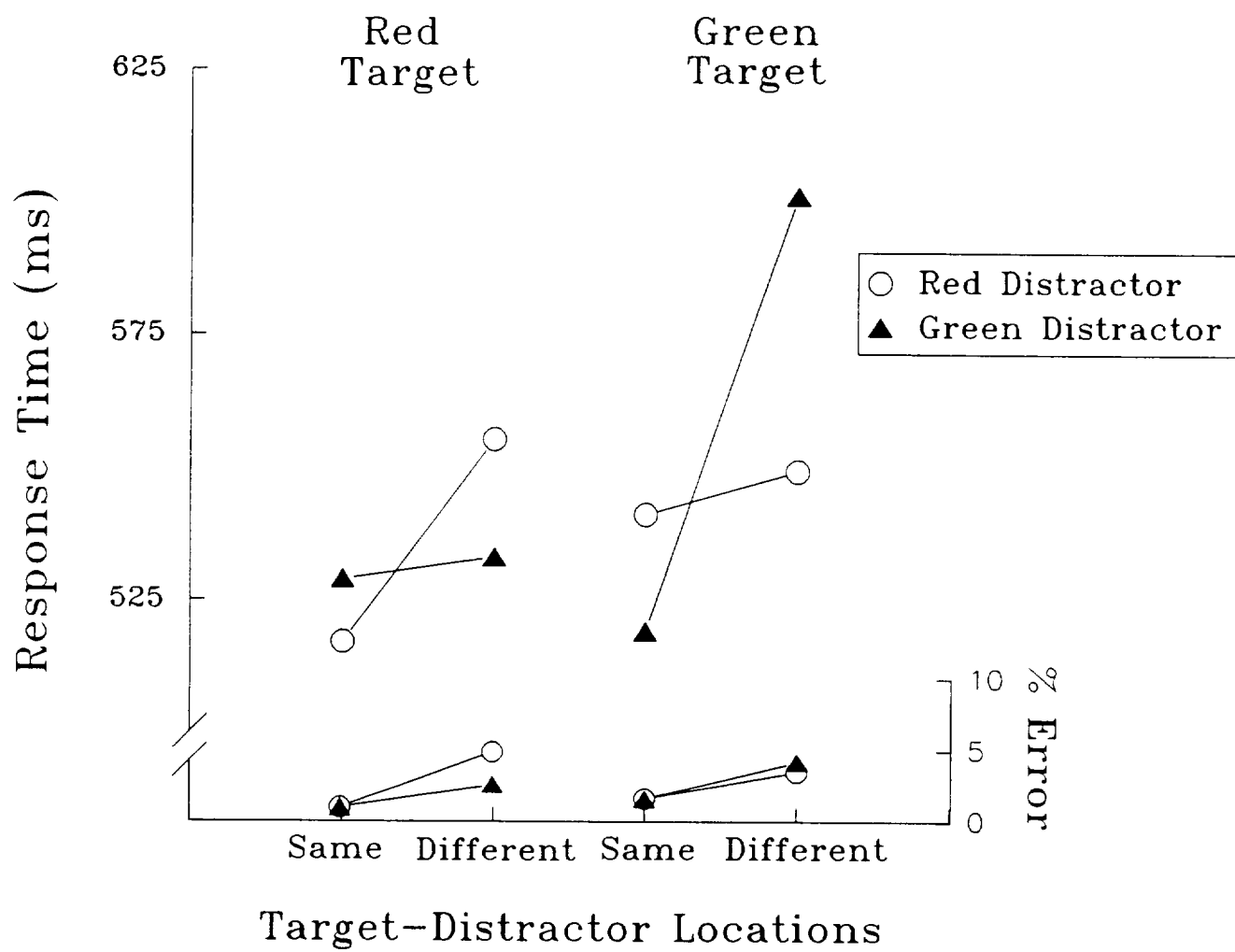
Singleton Target

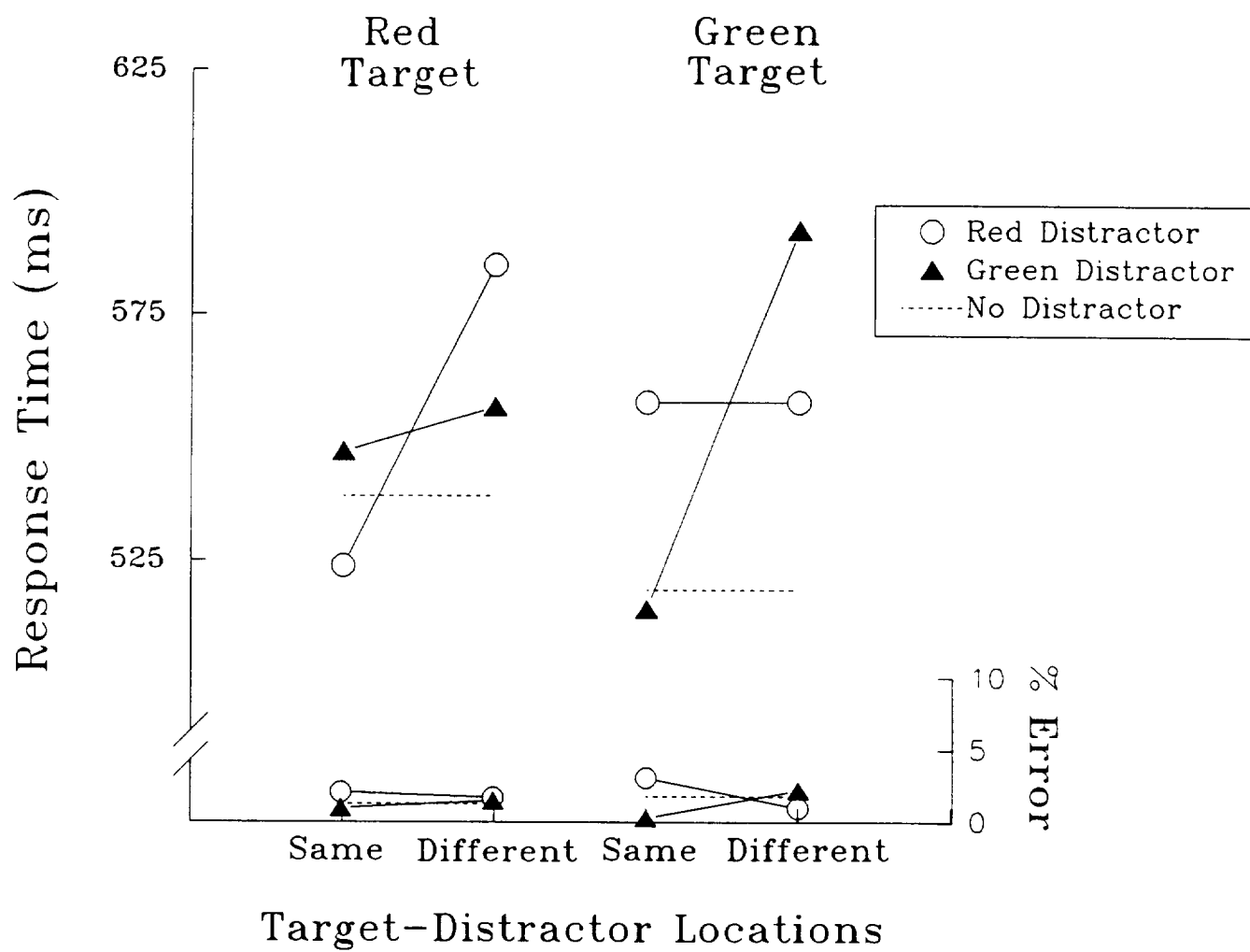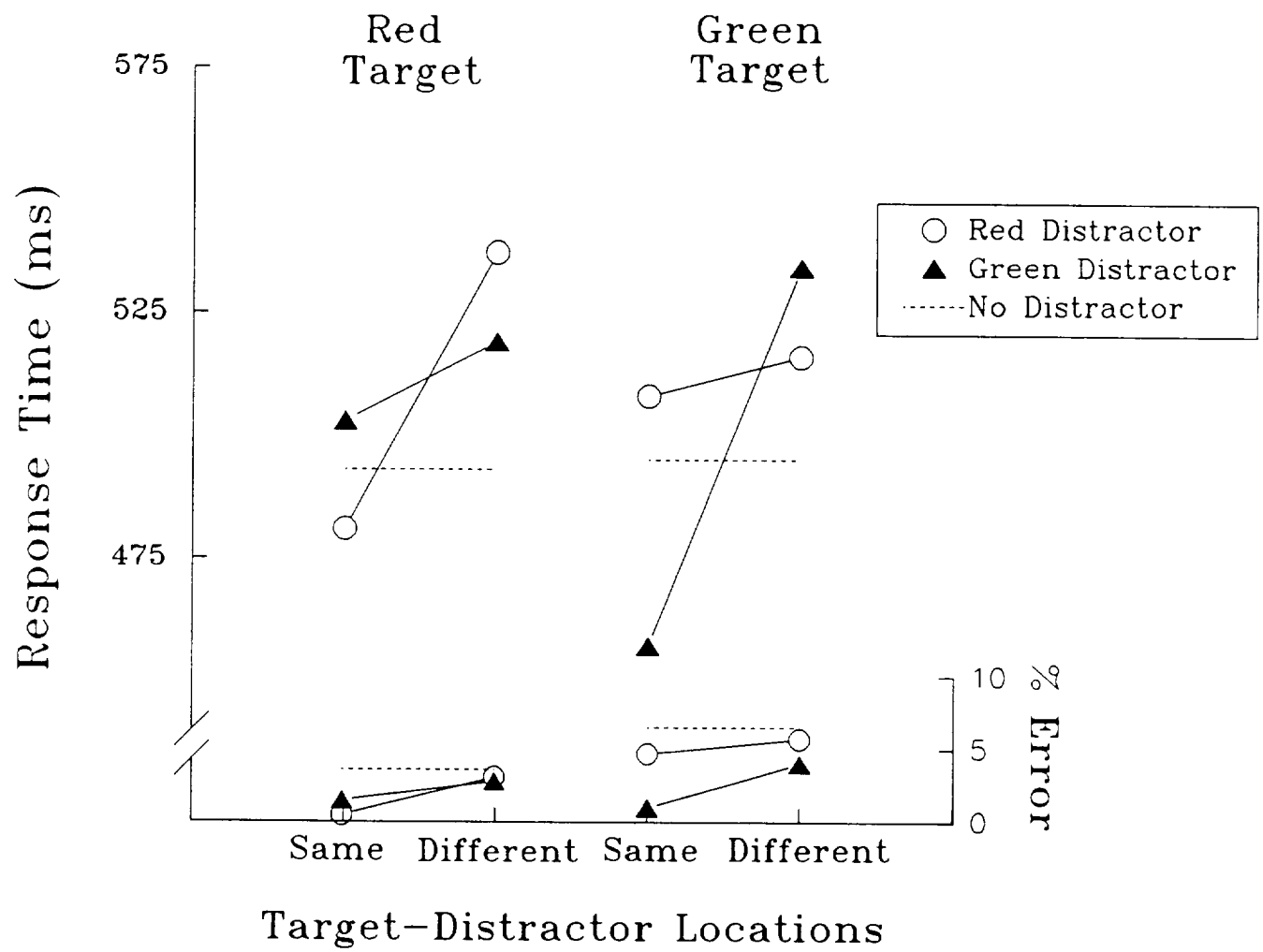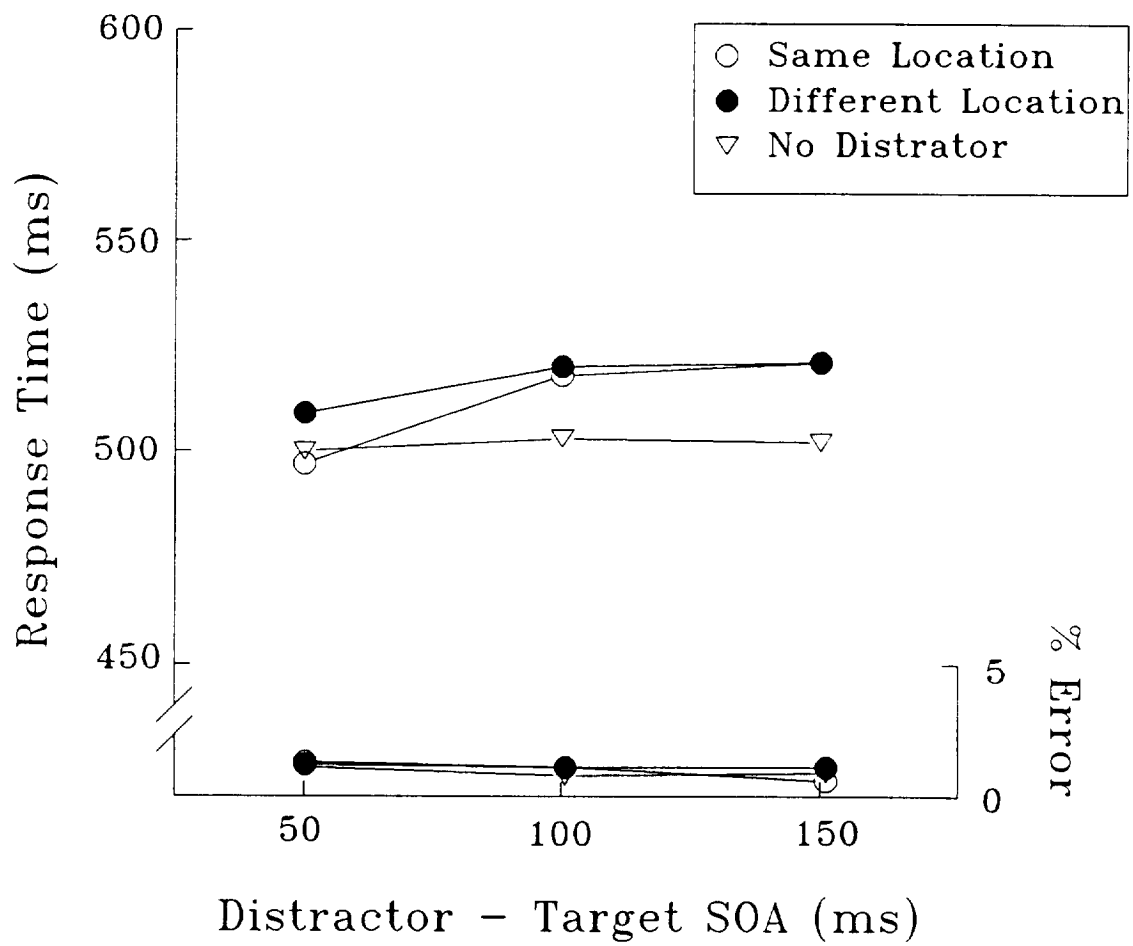# DISTRACTOR DISPLAYS

Red Distractor

Green Distractor

Appendix B

The Effect of Perceptual Categories on the Voluntary Control of Visual Attention

by

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Introduction

The distinction between voluntary and involuntary behavior is at times fuzzy, but nonetheless critical to understanding the complexity of human behavior. Voluntary control of behavior functions to set and accomplish our plans and intentions. Such behaviors include planning and reasoning as well as more molecular behaviors such as controlled visual search. In contrast, there are numerous systems in the brain devoted to regulating sleep, alertness, orienting to external events, temperature, and other activities of which we are not usually aware. These regulatory activities are involuntary in the sense that we cannot, or at least often do not, voluntarily execute them or control them once executed.

One important function under involuntary control is the orienting to potentially important external events. The world is only partially predictable. As a consequence, an organism without a mechanism to alert it to important external events would quickly perish at the hands of predators. An involuntary alerting mechanism would have the advantage that it could interrupt ongoing activity without the need for continuous deliberate monitoring of the external world. The interrupt driven routines of computer systems have been arrived at by similar logic. It is cumbersome to interleave the monitoring of the world with whatever program is trying to be executed. Instead, it is

better to have a separate independent system capable of detecting external events and then of interrupting ongoing activity if the event proves salient.

For human behavior, interruption occurs when an external event reorients attention away from its current focus to that of the interrupting event. It is assumed that attention is required for the execution of voluntary behaviors, so that if attention has been captured by the external event, the reorienting of attention results in suspension of the prior task. In practice, attentional capture has been studied primarily with visual stimuli where the reorienting amounts to a change in the spatial location of visual attention.

Theoretical accounts of voluntary and involuntary control of attention can be distinguished largely by how they treat the involuntary attentional response to external events. Yantis and colleagues (Yantis & Jonides, 1984; Jonides & Yantis, 1988; Yantis & Jonides, 1990; Yantis & Hillstrom, 1994) have argued that attention is directed involuntarily to stimuli with specific physical properties. That is, attention is summoned involuntarily by certain signal properties of the visual input. Yantis & Jonides (1984; Jonides & Yantis, 1988; Yantis & Jonides, 1990) argued that abrupt transient onset is the special signal feature of signal. They found no set size effects in search for a target that was abruptly onset in a background of distracters revealed by the removal of camouflage. This is consistent with visual attention being drawn involuntarily to the onset target. More recently, Yantis & Hillstrom (1994) have argued that it is the appearance of a new object not the transient onset that captures attention. They found that targets defined by properties other than transient onset, for example motion, showed no set size effects when they were new objects. It has long been known that novelty is a key element in eliciting the orienting response (Sokolov, 1963; Siddle, Stephenson, & Spinks, 1983). It is difficult, however, to define what constitutes a novel stimulus. The move away from specific sensory features to the concept of new objectness is a significant departure. It means that internal variables such as expectation play a role in an involuntary response. The theoretical position of Yantis and colleagues now comes quite close to the contingent involuntary capture theory of Folk, Remington, & Johnston (1993; Folk, Remington, & Wright, 1994) discussed below.

A different account has been advanced by Theeuwes (1992). He argues that stimulus-driven control of attention is dependent solely on stimulus salience. In this account there is no special class of stimuli that elicits involuntary attention orienting. Instead, attention is summoned by highly salient stimuli. In support of this, Theeuwes

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(1992) demonstrated that in displays consisting of simultaneous color and onset singletons, attention can be involuntarily summoned with either one by altering relative stimulus strength (salience). While the salience account treats the competition between external events for the control of attention, it does not treat the resolution of conflicts between external and internal demands for attention. Further, since exogenous control depends solely on salience, there is no place for goal-directed resolution of conflicting demands from two separate external stimuli.

We (Folk, Remington, & Johnston, 1993) have argued for an alternative account of attentional control we call contingent involuntary orienting (Folk, et al. 1993; Folk, et al., 1994). Contingent involuntary orienting posits something akin to a programmable interrupt system, in which putative attentional control settings maintain a set of stimulus properties of current relevance. An external stimulus will elicit an involuntary attention response whenever its properties match the current attentional control settings. Attentional control settings are established either through deliberate intentions (e.g., "I am looking for red objects") or with practice can come to be set by the context without deliberate intention. The point is that even involuntary control of attention is responding to immediate goals and contextual knowledge. In its strong form the hypothesis rejects the notion of a purely stimulus-driven control of attention. If certain stimulus properties prove useful in a wide range of circumstances, over time they can be adopted in a wide range of circumstances either by generalization over similar contexts, or as default settings.

Support for the contingent involuntary orienting hypothesis comes from experiments showing that a precue will capture attention only when it shares a feature with the target that is important for locating the target. For example, in Folk, et al. (1993), Experiment 3, a 50 ms distracter stimulus was presented prior to the 50 ms presentation of the target stimulus with an interstimulus interval of 100 ms. On 75% of the trials the distracter occurred in a different location than the subsequent target; on 25% of the trials it was in the same location. If the distracter attracted attention involuntarily, then attention should be drawn to the wrong location on different location (DL) trials, but to the target location on same location (SL) trials. Thus, attentional capture would result in faster responses to SL trials than DL trials. We refer to the increase in response times for the DL condition over the SL condition (DL - SL) as the distracter effect.

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In Folk et. al. (1993), we varied the distracter-target relationship in separate blocks. Onset and color distracters were paired with both onset and color targets. The results showed clearly that the distracter effect occurred only when both distracter and target were color singletons or both were onsets. Mixed conditions showed no distracter effect. Onset distracters had no effect on color targets, nor did color distracters on onset targets. Attention was involuntarily captured by singleton distracters only if those distracters shared properties of the target. Onset distracters captured attention when subjects were looking for onset targets, but not when subjects were looking for a color singleton; color-singleton distracters captured attention when subjects were looking for color singleton targets, not when they were looking for onset targets. We argued that subjects could tune attentional control settings to the demands of the search task. Once tuned, the response would be automatic, involuntary, but the tuning was done in response to task demands.

The contingent involuntary orienting hypothesis is unique among the three accounts in providing a cogent explanation for how high-level goals can alter the involuntary attentional response to exogenous events. It does not, however, deny a role for special features or for salience. As discussed above, stimulus features, such as motion or transient onset, that have general utility can come to be adopted as attentional control settings in a wide range of circumstances. Salience may in fact play a role in determining which of two stimuli will be attended to when both have properties matching the attentional control settings. The unique contribution of the hypothesis is its recognition that even involuntary behavior can be under the control of higher-order goals.

To refine the contingent involuntary orienting hypothesis, we focused our research on identifying the properties for which attentional control settings could be set. Since the attentional response to an external stimulus depends on the match between perceptual features and current goals, it is important to determine the specificity of the perceptual units that constitute an attentional control setting. In Folk, Remington, & Johnston (1993) we speculated that attentional settings were broadly tuned. In particular, we thought there might be a setting for a dynamic discontinuity -- such as onset or motion -- and another setting for a spatial discontinuity -- such as a singleton in color or texture. The results of Folk, Remington, & Wright (1994) seemed to confirm this. Those experiments paired distractors and targets from a dynamic dimension (motion and onset) and a static dimension (color). When the target finding property was motion, either motion or onset distracters interfered, but not color; conversely, when the target finding

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property was color, color distracters interfered, but not motion or onset. Motion and onset are processed similarly in early stages of visual analysis in magnocellular pathways, whereas color is distinguished from both early on, being processed in the parvocellular pathways. One interpretation of our results was that dynamic discontinuities such as motion and onset comprised one set of attentional control settings, spatial discontinuities like color another. Attention could be broadly tuned for these properties. Since the distinction between parvocellular and magnocellular occurs early in processing, such a broad tuning seemed to fit the need for an alerting signal that could be processed preattentively.

However, experiments by Bacon & Egeth (1994) showed that attention can be more narrowly tuned than our results suggest. They found that subjects could adopt at least two distinct modes in visual search: feature value mode in which they were set for a particular property such as a specific color (e.g., red), or a singleton mode in which they set for a unique item on any feature dimension. In feature search mode a stimulus will capture attention if it contains a particular feature value, such as red, or round, etc. In singleton search mode a discrepant item will capture attention irrespective of dimension -- color or luminance onset. It is not impossible that our results could be accounted for by feature search mode only. In the bulk of our experiments using color targets, target color is held constant within a block of trials. This would allow subjects to adopt a set for a particular color value instead of for a more broadly tuned setting such as color singleton. Even the capture of motion by onset and vice versa could be seen as a feature setting for transient singleton. Since the transient plays an important role in both motion and onset, the set would generalize resulting in capture.

To examine this we constructed conditions in which the target finding property was a color singleton whose color was unpredictable from trial to trial. With target color uncertain from trial-to-trial, control settings for spatial attention would have to adopt a more general set. This could be for any singleton, static discontinuity, or color singleton. The distracter in all conditions was a red color singleton; the targets could either be red, blue, or green color singletons. On each trial only one target color was presented. We compare pure blocks, in which the target color is held constant, to mixed blocks, in which target color varies from trial to trial.

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Experiment 1

Method

Each trial began with the presentation of 4 boxes arranged at the ends of an imaginary cross centered around a fixation marker. There followed a random foreperiod of 1000-1400 ms, terminated by the 50 ms presentation of the distracter frame. The distracter frame consists of 4 small circular markers surrounding each of the 4 target boxes. Three of the boxes were surrounded by white circles, one by red circles. We refer to the red circles as the distracter singleton. After 60 ms the distracter frame was extinguished. This was followed by a blank interval of 100 ms, terminated by the 60 ms presentation of the target frame.

The target frame consisted of either an "X" or an "=" in each of the four boxes. Three of the characters were white, one was in color -- either red, green, or blue. Subjects made a speeded response to indicate whether the colored item was an "X" or "=".

The critical comparison for capture is between trials in which the distracter and target are at the same location (SL) and trials in which they occur at different locations (DL). On each trial, the locations of the distracters and target item were chosen pseudorandomly with the constraints that (1) both the distracter singleton and the target singleton occurred equally often at each location, and (2) the probability of a SL trial was .25.

The experiment consisted of 576 trials divided into two equal sessions. In the pure block session, target color was held constant for 96 trials. In one condition, for example, subjects were tested on 96 trials in which the target color was green, followed by 96 trials in which it was red, followed by 96 trials in which it was blue. In the mixed block session, target color was chosen pseudorandomly on each trial. In both sessions, each color -- red, blue, green -- occurred equally often. Subjects were randomly assigned to one of two order conditions -- mixed - pure, or pure - mixed. Within the pure-block session there were three additional order conditions corresponding to relative order of presentation of red, blue, and green targets. Subjects were assigned randomly to each of these orders.

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Prior to testing, subjects were told that the location of the distracters would provide no information as to the location of the subsequent target and that they should ignore the distracters.

Results

An ANOVA with block type, color, and distracter-target location showed significant effects of block type (F[1,17] = 18.6, p < .001) and distracter-target location (F[1,17] = 60.6, p < .001). Response times were faster in pure blocks (555 ms) than in mixed blocks (615 ms); SL trials (571 ms) were faster on average than DL trials (599 ms). Separate analyses were done on pure blocks and mixed blocks to look more closely at the effects of distracter-target location on specific colors.

For pure blocks there was a small but significant effect of color (F[2,34] = 3.9, p < .05) and a significant interaction between color and distracter-target location (F[2,34] = 64.8, p < .001). For red targets, mean response time on SL trials was 529 ms compared to 601 ms on DL trials. There was no distracter effect for blue or green. For green, mean response time on SL trials was 548 ms compared to 533 on DL trials. For blue targets, mean response time on SL trials was 555 ms compared to 560 ms on DL trials.

For mixed blocks there was a small but significant interaction of color with distracter-target location (F[2,34] = 3.7, p < .05). For red targets, mean response time on SL trials was 602 ms compared to 626 ms on DL trials. For green, mean response time on SL trials was 603 ms compared to 639 on DL trials. For blue targets, mean response time on SL trials was 586 ms compared to 636 ms on DL trials.In the main, all three colors show faster RTs for the SL condition than the DL condition.

Discussion

In the pure blocks we obtained a pattern of results consistent with the hypothesis that an involuntary attentional response to the distracter was contingent on a setting for the distracter color (red). When target and distracter had the same feature value (red), the uninformative distracter elicited an involuntary shift of visual attention, leading to elevated response times on DL trials. Consistent with our previous work, these results show that attentional control settings can be set on the basis of feature value. In the mixed blocks however the pattern suggests that subjects could not withhold an attentional

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response to the red distracter when target color was not known in advance. Whereas blue and green targets in pure blocks showed no difference between SL and DL trials -- thus no evidence of capture -- the difference is significant for all three colors in mixed blocks. This suggests that some other setting, perhaps a singleton mode setting (Bacon & Egeth, 1994) was in place. The obvious objection to this experiment is that in the mixed condition one of the target colors (red) was the same as the distracter color. This may not have given subjects the opportunity to achieve any attentional setting other than for an odd-man-out.

Experiment 2

In Experiment 2 we selected a set of target colors all of which were different from the distracter. The distracter color was certain (red), but the target colors were uncertain and all differed from the distracter (orange, violet, and green). One advantage of this is that it allows us to see whether attention can be set to exclude the target color (a not-red setting).

Method

Experiment 2 differed from Experiment 1 in the target colors. The red and blue targets were replaced by orange and violet targets. The green target was unchanged.

Subjects

Sixteen subjects recruited from local universities and junior colleges were tested. All subjects had normal or corrected to normal vision, normal color vision, and were between 18-40 yrs of age.

Results

The results are shown graphically in Figure 5. The overall ANOVA showed significant main effects of block type ($F[1,15] = 7.3$, $p < .05$) and distracter-target location ($F[1,15] = 26$, $p < .001$). Mean response time was significantly faster in pure blocks (570 ms) than in mixed blocks (595 ms), and SL response times (571 ms) were faster than DL response times (594 ms). No other effects were significant. A separate analysis of pure blocks showed no effects of color ($F[2,30] = 0.5$, $p < .7$) nor of the color

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by distracter-target location effects seen in Experiment 1 (F[2,30] = .5, p < .7). For blue targets, mean SL response times were 556 ms, DL times were 574 ms. For orange, mean SL times were 565 ms, DL times were 581 ms. For green, mean SL times were 567 ms. DL times were 576 ms. There was a significant effect of distracter-target location (F[1,15] = 12.5, p < .01). Mean SL response time was 563 ms, mean DL response time was 577 ms.

For mixed blocks there was also a significant effect of distracter-target location (F[1,15] = 16.8, p < .001). The average DL-SL difference was 32 ms. Mean SL response time was 579 ms compared to 611 for DL. There was also a significant effect of color (F[2,30] = 4.0, p < .05), but no interaction of color with distracter-target location (F[2,30] = 0.9, p < .5).

Discussion

The results of Experiment 2 are consistent with those of Experiment 1. In pure blocks, no distracter effect was observed for targets different in color from the distractor. However, like the mixed block condition of Experiment 1, there were consistent effects of distracter-target location for all three colors -- none of which were the target color. Our tentative conclusion is that subjects are not able to set for the negation of the distracter color, but must set for specific colors. In the absence of a predictable, known target feature, search is either by dimension or by singleton.

Both experiments found a larger DL-SL difference in mixed blocks than in pure blocks. In Experiment 2 this effect is over twice as much for mixed as for pure blocks. However, there is a small but significant DL-SL effect in the pure blocks of Experiment 2. This effect may be the result of the specific colors used. The violet and orange colors in Experiment 2 contain some input from the red color gun of the monitor. Thus, if set for orange or violet, red would produce some activation of each, possibly enough to draw attention on some trials. Green is the only color that contains no red (defined by the gun mixture). Note that even though the DL-SL effect for green in the pure blocks of Experiment 2 is quite a bit larger than in Experiment 1, it is only 9 ms, compared to 17 & 16 ms for orange and violet respectively. Nonetheless, in Experiment 3 we selecting colors that are more equally distributed in the color space in order to test for the possibility that color similarity influenced capture in Experiment 2.

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Experiment 3

In Experiment 3 we selected three new target colors and one new distracter color with the constraint the chromaticity and luminance of the three target distracters be approximately equally discriminable from the distracter color. In this way we can examine whether the interference in the mixed condition of previous experiments was due to interference of specific colors with the distracter, or due, as we claim, to the capture of attention when target value is uncertain.

Method:

To make the target colors approximately equally discriminable from the cue color we first selected a set of four colors spaced widely in the CIE color space. Then for each color we generated u' and v' values in the 1976 CIE color space from which a measure of color difference measure, delta-E, could be calculated for each pair of colors (Silverstein & Merrifield, 1985). The discriminability measure was used to reselect colors to be more equally different from the cue color. We then viewed the new colors to get a subjective impression of distinctness and recomputed the delta-E scores. This procedure was repeated until we had colors that were subjectively equidistant from the and could find no further adjustments that would equalize measure color differences. The chosen values are given as Color (x, y, L) where x and y are the CIE coordinates, and L is the luminance: Red = (.48, .33, 21); Green = (.29, .52, 33.5); Blue = (.25, .29, 34); Yellow = (.39, .42, 44). The Delta-E values are: Red - Green = 217; Red - Blue = 184; Red - Yellow = 117.

The procedure in Experiment 3 was identical to the mixed condition of Experiment 2 save for the change of colors. There were three color assignment conditions each of which used two of the three possible target colors. Each subject was assigned to a color condition.

Subjects

Twenty-one subjects aged 18 - 35 recruited from the NASA Ames subject pool were tested. All had normal or corrected to normal vision. None had participated in either of the previous experiments.

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Results

Correct response times were analyzed in a repeated measure analysis of variance with target colors. A significant distraction effect was observed ($F[1.18] = 32.26$; $p <= 0.001$). Mean response time for SL trials was 586 ms, for DL trials 625 ms. There was no effect of target color assignment nor any interaction of cue-target location with color.

Discussion

Experiment 3 is strong evidence that capture with uncertain target color values is not due to color selection artifacts. Instead, it supports our earlier finding that attentional control settings are based on positive stimulus attributes. When stimuli differ on the values within a feature dimension, capture by uninformative precues will occur unless the value of the target is known on each trial.

Thus far we have shown that uncertainty about the target feature value produces an attentional control setting that elicits an involuntary response to the red distracter color. In this respect, we have shown an important limitation on the flexibility of attention within the color domain. Apparently it is not possible to set for the negation of a feature value.

The results of our mixed conditions are consistent with subjects having adopted a singleton search mode when the specific target feature was unpredictable. Because the attentional control settings could not be set for a specific color, color singletons in the distracter frame elicited an involuntary attentional response. However, did the featural uncertainty in the target result in a setting for singleton, so that any singleton would elicit an attentional response? Or, was it a specific set for color singleton, so that only color singletons would draw attention?

Experiment 4

Experiment 4 tested this by replacing the red color singleton distracter with an onset singleton distracter. In both Folk, Remington, & Johnston (1993) and Folk, Remington, & Wright, 1994 we have shown that onset singletons will not capture visual attention when subjects are looking for a color target. However, in those experiments the color value was known with certainty. In Experiment 4 we repeat this test using

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uncertain color values. If subjects can adopt a feature dimension search mode then they should still be set for color and the onset should not capture attention. If. however. in the absence of a known target feature a singleton search mode must be adopted. there should be significant capture for the onset singleton even though the target is a color singleton.

Method

The onset distracter is a single set of white circles surrounding one of the 4 possible target locations. The location of the onset distracter was chosen randomly on each trial with the constraints that it occur equally often at all possible target locations and that it occur at the same location as the subsequent target on 25% of the trials. Sixteen new subjects selected from local universities and colleges were given course credit for participation. If attention is set to respond to any singleton. the onset singleton should capture attention and a distracter effect will be observed. However. if attention is set to respond to a color singleton -- or if it is possible to ignore the onset -- then no distracter effect will be observed.

Results

There was a small but significant distraction effect in both pure (F[1,15] = 7.0; p < .02) and mixed blocks (F[1,15] = 29.07; p < .001). For pure blocks. mean response time on SL trials was 524 ms. on DL trials 536 ms. For mixed blocks. mean response time on SL trials was 538 ms. on DL trials 555 ms. The trial type (block vs. mixed) by validity interaction was not significant (F[1,15] = 1.74; p < .21).

Discussion

Our results tentatively support two conclusions. First. the presence of a significant distracter effect in the mixed conditions suggests that it was not possible to ignore the cue in the absence of a positive set for a feature value. For example, in Experiment 2, if attention could have been set to "not-red" no distracter effect would have been observed.

Second, our results are in agreement with Bacon & Egeth (1994) in showing evidence for both feature value mode and singleton mode. We found no evidence that intermediate modes were possible. For example. we failed to observe in Experiment 3

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any evidence that selection could be based on the presence of a color singleton to the exclusion of non-color singletons.

General Discussion

What are possible modes for attentional control? With the present results we can begin to answer this question. First, in accord with Bacon & Egeth (1994), we found evidence for a Singleton search mode. Experiment 4 showed that capture occurs with target uncertainty even when the singleton comes from a completely independent dimension, one shown not to produce capture with a predictable target feature.

Our experiments also provide evidence that attention can be set to orient to specific target features. When target and distracter had the same color value, capture was observed. When target and distracter were not the same color and the target value was predictable from trial to trial, no capture was observed. Thus, it appears that subjects can set for a specific known feature value.

Our experiment fail to find evidence for an attentional set to a complete feature dimension. If so, then no capture should have been observed in Experiment 4. However, caution is needed in concluding this. The distracter effect was very small in the mixed condition, only 17 ms. Moreover, there was a significant 12 ms effect in the pure block condition, in conflict with several earlier findings (Folk, Remington, & Johnston, 1993, Folk, Remington, & Wright, 1994). Thus, we could be observing the effects of some as yet unknown artifact. It remains to be seen whether dimensional set is truly impossible.

Conclusions

The results are consistent with the hypothesis that the ability to selectively filter distracters depends on the presence of an attentional set for a specific feature value present in the target.

In the absence of a consistently predictable target property, attention is broadly set to respond to any singleton.

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Certain knowledge of specific distracter feature values is of little or no use in controlling attention.

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Appendix C

When Knowledge Does Not Help: Limitations on the Flexibility of Attentional Control

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Running Head: MECHANISMS OF ATTENTIONAL CONTROL

When Knowledge Doesn't Help: Limitations on the Flexibility of Attentional Control

Mechanisms for allocating spatial attention must satisfy to two competing goals. On the one hand, efficiency requires the selective allocation of limited resources only to those objects or events important to the current goals of the organism. On the other hand, adaptability requires the allocation of resources to new objects or events that, although potentially irrelevant to current behavioral goals, may nonetheless hold important ecological information requiring the establishment of a new goal. Historically, these two goals have been mapped on to two distinct modes of attentional control, referred to as endogenous (goal-directed) and exogenous (stimulus-driven) control, respectively (Eriksen & Hoffman, 1972; Jonides, 1981; Posner, 1980). The latter has also been referred to as "attentional capture" (Yantis & Jonides, 1984).

Recent evidence suggests that these two modes of control can more appropriately be considered endpoints on a continuum, occurring in their pure form only under very limited conditions, it at all (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Folk, Remington & Wright, 1994; Yantis & Jonides, 1990; Yantis, 1993). This implies that attentional deployment is normally the result of an interaction between endogenous and exogenous factors. Indeed, the notion of such an interaction is a dominant aspect of many current models of attention allocation (Bundesen, 1990; Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Folk, Remington & Johnston, 1993; Koch & Ullman, 1985; Treisman & Sato, 1990).

One clear example of the interplay between goal-directed and stimulus-driven attention allocation is the effect of advance knowledge on the ability of certain stimulus events, such as abrupt visual onsets, to produce attentional capture. Abrupt onsets have been shown to be particularly effective in producing stimulus-driven shifts of attention when no obvious attentional "set" is in effect (e.g., Jonides & Yantis, 1988; Remington, Johnston, & Yantis, 1992). In fact, it has been argued that only abrupt onsets (or, more specifically, the abrupt appearance of a new object), can produce attentional capture under such conditions (Jonides & Yantis, 1988; Yantis & Hillstrom, 1994). Given specific foreknowledge of the

defining characteristics of a "target" stimulus, however, an irrelevant, abruptly onset distractor has been shown to have virtually no effect on performance. For example, Yantis & Jonides (1990) found that when subjects were given a 200 ms precue indicating the subsequent location of a target stimulus, an irrelevant abruptly onset character no longer produced evidence of attentional capture. Similarly, Folk, et al. (1992), found that when given advance information about a defining feature of the relevant target (e.g., color), the effects of an irrelevant, abruptly onset distractor were eliminated.

Folk et al. (1992) also found that when targets were defined by a feature other than abrupt onset, such as a discontinuity or "singleton" in color, irrelevant singletons sharing the same dimension did produce evidence of attentional capture (see also Bacon & Egeth, 1994; Pashler, 1987; Theeuwes, 1992). In short, irrelevant events that shared the defining feature of the target produced attentional capture and events that did not produced no evidence of capture. These results suggest that attentional capture is dependent not on the occurrence of specific stimulus properties, as proposed by Jonides & Yantis (1988), but on the relationship between the properties of the irrelevant event and the current goals of the observer.

Contingent Attentional Capture

On the basis of these and other results, Folk et al. (1993) have argued that the existing data on attentional capture can be parsimoniously accommodated by assuming that capture is ultimately contingent on variable, endogenous "attentional control settings." These control settings are assumed to reflect high-level behavioral goals and to be instantiated "off line." Stimulus events that match the current control setting will produce an involuntary shift of attention, even if the events are known to be irrelevant. Events that do not match the current control setting will not produce a shift of attention. Thus, attentional capture is not a purely stimulus-driven phenomenon specific to certain stimulus events, but instead reflects conditions in which a conflict exists between high-level behavioral goals and specific, "on-line" goals to withhold an attentional response to a particular stimulus. Under this framework, the apparent unique ability of abrupt onsets to produce attentional capture reflects either subtle task

characteristics that encourage a control setting for onsets, or perhaps an enduring predisposition to set the allocation system for onsets.

The notion that involuntary shifts of spatial attention are contingent on an endogenous attentional set is consistent with a growing number of studies showing that otherwise involuntary or "automatic" attentional effects can be modulated by strategic factors. For example, there is evidence that the magnitude of classic Stroop effects is dependent on whether the irrelevant color words are members of the response set or not (Proctor, 1978; Tzelgov, Henik, & Berger, 1992). In addition, the magnitude of semantic priming effects have been shown to depend on the nature of the task performed on the prime stimulus (Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellogg, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994; Smith, 1979; Smith, Theodor, & Franklin, 1983). Specifically, semantic priming is eliminated when set to search for a specific letter in the prime rather than reading the prime. Similarly, Keren, O'Hara, and Skelton (1977) have shown that compatibility effects associated with irrelevant flankers in an "Eriksen-type" task depend on the level of processing required for targets. For example, the effects of irrelevant flanking noise letters that were physically similar or dissimilar to two central targets depended on whether the targets were judged on physical, categorical, or name similarity. In all of these studies, the effect of unattended, irrelevant information was dependent on whether the information was part of a task set or not. This is consistent with Logan's (1978) proposal that reaction time tasks can be considered "prepared reflexes" in which a sequence of processing operations, or attentional control settings (Folk, et al., 1992) are "programmed" or established "off-line" and then run off automatically upon stimulus presentation. Thus, the nature of "on-line" processing of a given stimulus on a given trial is contingent on the relationship between the stimulus and the task set for that trial.

Flexibility of Attentional Control

Given that advance knowledge of the task characteristics can lead to the establishment of attentional control settings or a "task set", an important issue concerns the flexibility with which control

settings can be established. How sensitive are control settings to variations in task constraints? Are there limits to the specificity of attentional control settings? Investigating such issues can lead to a more complete understanding of the underlying functional architecture of attentional control (Folk, et al., 1993), as well as the mechanisms by which attentional control settings are instantiated. For example, finding that only certain types of advance task information affect attention allocation might suggest that attentional control settings are limited to certain classes of stimulus properties, or that control settings involve the selective activation of task-relevant stimulus properties rather than the suppression of irrelevant properties.

It has recently been argued that the flexibility of top-down attentional control over attentional capture is actually quite limited (Theeuwes, 1991; 1992). In a visual search task, Theeuwes (1992) found that an irrelevant discontinuity in color (i.e., a "color singleton") produced a significant distraction effect (i.e., attentional capture) when searching for a discontinuity in shape (i.e., a "form singleton"), even when the exact shape of the target was known in advance. Theeuwes argued that subjects were unable to establish a top-down set for a specific form feature and that attentional allocation was driven entirely by the relative bottom-up salience of the singletons, independent of the features over which they were defined. Bacon and Egeth (1994), however, have recently shown that by including multiple shape discontinuities in Theeuwes' displays, the distracting effects of irrelevant color singletons are completely eliminated. Bacon and Egeth argue that their manipulation forced subjects from a "singleton search mode" with the original Theeuwes displays, into a "feature search mode" with the modified displays. In other words, with slight variations in the nature of the task, subjects were able to adopt attentional control settings for specific shape values. Similar results have been reported by Folk and Remington (1993) who found evidence for control settings for specific color values.

Focus of the Present Experiments

In the present studies, we further explore the flexibility of attentional control by investigating the nature of attentional control settings for locations in space. As discussed above, Yantis and Jonides

(1990) have shown that the ability of an irrelevant abrupt onset to capture attention is completely

eliminated if subjects are given valid advance information about the location of the target. One

interpretation of these results is that knowing the target location allows subjects to establish a control

setting for a particular location in space, thereby rendering stimuli occurring at non-target locations (i.e.,

stimuli inconsistent with the attentional control setting) incapable of capturing attention. In the present

studies we investigate whether similar effects will be observed when subjects are provided with advance

knowledge of the distractor, rather than the target, location. Our goal was to determine if the attentional

control system is flexible enough to use such information to eliminate capture by an irrelevant abrupt

onset. A related goal was to begin to address the underlying mechanisms through which control

settings are instantiated. For example, if control settings involve the suppression of irrelevant

information, then we might expect that providing advance knowledge of the location of an abrupt onset

distractor should eliminate its ability to capture attention. If, however, control settings involve only the

activation or facilitation of relevant information, then knowledge of the distractor location (with no

information about target location) might prove relatively useless, and abrupt onset distractors should still

produce attentional capture.

<div align="center">Experiment 1</div>

Method

       Subjects. Sixteen Villanova University students, ranging in age from 18 to 20 years, participated

to partially fulfill a course requirement. All reported normal or corrected-to-normal visual acuity.

       Apparatus. Stimuli were presented on a Princeton SR-12 color monitor driven by a Zenith 286

microcomputer equipped with a Sigma C400 high-resolution color graphics card.

       Task. The general task involved the speeded, forced-choice identification of a target character

(i.e., an "X" or an "=") appearing in one of four peripheral boxes centered on fixation. Four blocked,

within-subjects conditions were created by factorially combining the presence/absence of a peripheral,

abrupt onset distractor with the presence/absence of a central, symbolic cue. Distractors always

occurred at a location where the subsequent target would not appear. Thus, any cost in response time for trials containing a distractor relative to trials containing no distractor was assumed to reflect attentional capture. When a central cue was present, it always indicated the location of the subsequent distractor (in distractor conditions) or a location where the target would not appear (in no distractor conditions). The stimulus onset asynchrony (SOA) between presentation of the central cue and peripheral distractor was varied from 100 to 400 ms in an effort to explore the timecourse for the establishment of any observed attentional set for location.

Stimuli. Subjects were presented with a sequence of four basic displays consisting of a fixation display, a cue display, a distractor display and target display. Examples of each of these displays, along with their sequence of presentation are shown in Figure 1. The fixation display consisted of four

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Insert Figure 1 about here

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peripheral boxes and one central box, each measuring 1.15 degrees visual angle from a viewing distance of approximately 40 cm. The four outer boxes were located at the vertices of an imaginary diamond centered on the fifth box with a center-to-vertex distance of 4.7 degrees visual angle. The inside of the center box contained eight additional line segments arranged as a diamond surrounding a "plus" sign. All boxes were light gray (IBM color designation 8) against the black CRT screen.

The cue display consisted of the fixation display with a subset of the lines forming the central box removed. When a cue appeared, lines were removed to form a "T" oriented toward one of the peripheral boxes. When a cue did not appear, lines were removed to form a "+".

The distractor displays consisted of the cue display with the addition of four small circles, each subtending .36 degrees visual angle, around the four sides of one of the five boxes. The circles were placed such that each was centered approximately .3 degrees visual angle peripheral to its respective side of the box. The circles were high contrast white (IBM color designation 15) against the black CRT

screen. In conditions where distractors did not appear, the cue display simply remained on the screen during the distractor display interval.

Target displays consisted of the cue display with the addition of a single character appearing in one of the four peripheral boxes. This target character was either an "X" or an "=", subtended .57 degrees visual angle, and appeared as high contrast white (IBM color designation 15) against the black monitor screen.

Design. The four within-subjects conditions (i.e., no cue -no distractor, no cue - distractor, cue - no distractor, cue - distractor) were run in separate blocks of 144 trials. Condition order was varied across subjects according to a Latin Square. Within each block, the SOA between presentation of the cue display and distractor display varied randomly across six values (100, 150, 200, 250, 300, and 400 ms). Each target (i.e., X or =) appeared equally often in each of the four outer boxes, as did distractors when they appeared. Distractors and targets, however, never appeared at the same location on any given trial. Each combination of target type, target location, and distractor location occurred equally often at each of the six SOAs.

Ten practice trials were presented at the beginning of each block. In addition, after any trial on which an error was made, a "buffer" trial, chosen randomly from the set of possible trial parameters for that condition, was inserted.

Procedure. Subjects were fully informed of the fact that targets would never appear at the distractor location. In addition, they were encouraged to take advantage of the information provided by the cue if possible. Subjects were instructed to respond "as quickly as you can while making as few errors as possible." Maintaining fixation on the center box in the display was heavily stressed. The subject was seated at a distance of approximately 40 cm from the computer CRT screen.

Each condition began with the presentation of a screen indicating which of the four conditions would follow. Subjects then pressed a key to begin the sequence of trials in that condition. A message appeared at the end of each condition instructing the subject to rest before beginning the next block.

Subjects then pressed a key when they were ready to continue.

The sequence of events on a given trial began with a 250 ms "blink" of the center box, followed by a 750 ms presentation of the fixation display. The cue display was then presented for one of the six SOAs, followed by a 50 ms presentation of the distractor display. The cue display then appeared again for 100 ms, followed by a 50 ms presentation of the target display which was then replaced by the original fixation display. The next trial began 1000 ms after the subject's response.

Subjects were instructed to press the "Ins" ("0") key on the bottom of the keyboard's numeric keypad with their left index finger if an "=" was presented, and the "Del" (".") key with their right index finger if an "X" was presented. A 500 ms, 1000 hz. tone was sounded by the computer for an incorrect response. If a response was not made within 1500 ms, an error was scored and the trial sequence continued.

Response time and error status for each trial were measured and recorded by the computer. Response time was measured from the onset of the target display until a response was made. Practice trials, error trials, buffer trials, and trials on which response time was less than 200 ms were excluded from the data analysis.

Results

Mean response times and error rates as a function of condition and SOA are shown in Figure 2.

Insert Figure 2 about here

An analysis of variance (ANOVA) was conducted on the mean response times with distractor status (no distractor, distractor), cue status (no cue, cue), and SOA as within-subject factors. Distractor status produced a significant main effect, with longer response times associated with trials on which a distractor appeared, $F(1, 15) = 8.49$, $p < .01$. Overall, response times also decreased with SOA, $F(5, 75) = 3.68$, $p < .01$. The effect of SOA was only marginally dependent on cue status, $F(5, 75) = 2.46$, p

= .04. In contrast, the effect of SOA was heavily influenced by distractor status, $F(5, 75) = 3.95$, $p <$ .01, for the Distractor Status x SOA interaction. Specifically, response times remained relatively constant across SOAs on distractor trials, and decreased with SOA on no distractor trials.

Error rates averaged just under 9%. An ANOVA on the error rates revealed no significant main effects or interaction.

Discussion

The results of this experiment are relatively straightforward. The presence of an abrupt onset distractor produced evidence of attentional capture even when subjects knew where the distractor would appear. Specifically, the presence of a distractor produced a cost in response time regardless of the presence or absence of a precue identifying the impending location of the distractor. Moreover, this effect was present even when the precue preceded the distractor by nearly 500 ms.

Given the length of each condition (i.e., 144 trials), it is possible that overall means may have obscured cue effects that emerge with practice. To check this possibility, an additional analysis was conducted comparing performance in the first half of each condition to performance in the second half. Response times were significantly faster overall in the second half of each condition ($F(1, 15) = 20.49$, p < .001). There was a trend toward a reduction in the magnitude of the distractor effect in the second block, but this effect was not reliable, $F(1, 15) = 4.15$, p > .05.

In sum, the results of this experiment suggest that subjects were unable to use advance information about the location of the abrupt onset distractor to eliminate its ability to capture attention, at least within the time parameters explore. These results also suggest that the findings of Yantis and Jonides (1990), in which a 200 ms precue for the target location eliminated attentional capture by an irrelevant abrupt onset, probably reflect a facilitative effect for target location, rather than suppression of non-target locations.

Experiment 2

The inability of subjects to use distractor location information in Experiment 1 does not

necessarily imply that such information could never be used to establish a spatial control setting that would eliminate capture by the distractor. It is possible, for example, that a control setting based on distractor location requires longer than 500 ms to establish. In the second experiment, we attempted to eliminate the requirement to rapidly establish an attentional set from trial to trial. Instead of providing an advance precue on each trial, distractor location was held constant throughout each block of trials. Thus, subjects knew with absolute certainty that the distractor would appear at a particular location on every trial in a given block. A control condition was also included in which distractor location varied randomly from trial to trial.

An additional modification to the task was included. It has recently been pointed out that response time differences between distractor and no distractor conditions can reflect non-spatial distraction effects that are independent of shifts of spatial attention (Folk & Remington, 1993). To be certain that the costs produced by the distractor in Experiment 1 reflect shifts of spatial attention, an irrelevant distractor appeared on every trial, but the location of the distractor was completely uncorrelated with the location of the subsequent target. Because the distractor provided no information regarding the location of the target, subjects had no incentive to voluntarily shift attention to the distractor. Consequently, any difference in response times for trials on which the distractor appeared at the same location as the target and those on which the distractor appeared at a different location than the target must reflect an involuntary shift of spatial attention.

Method

Subjects. Twenty-five paid volunteers, recruited from the NASA-Ames subject pool participated. All reported normal or corrected-to-normal visual acuity. Eleven subjects were run in the fixed distractor condition and thirteen in the random distractor condition (see below).

Apparatus. Stimuli were presented on a NEC 4-D display driven by a Compaq 486 computer equipped with an Orchid Wondercard VGA color graphics board.

Stimuli. The stimuli were identical to those used in the first experiment with a few exceptions.

First, on all displays, the central box was replaced by a small fixation cross measuring approximately .2 degrees visual angle. Second, in experimental blocks, a distractor appeared on every distractor display (i.e., no-distractor displays were eliminated). Finally, cue displays were eliminated from the design.

Design. Two between-subjects distractor conditions, consisting of 10 blocks of 32 trials each, were created by varying the certainty of the distractor location. In the fixed condition, the distractor appeared around the same box on every trial in a block, with the particular box varying across blocks. The order in which distractor locations were presented was varied across subjects. In the random condition, the location of the distractor varied randomly from trial to trial within a block. Each of these two conditions was preceded by 96 practice trials on which no distractor occurred.

Within a block of trials, each of the two possible targets appeared equally often in each of the four boxes. In the random condition, the distractor also appeared equally often at each location. For every block in both conditions, the target appeared at the distractor location on 1/4th of the trials and at a non-distractor location on 3/4ths of the trials. Thus, given four possible locations, the distractor provided no information about the target location.

Procedure. Subjects were fully informed of the relationship between distractor location and target location and were encouraged to ignore the distractor if possible. The were also fully informed of whether the distractor location was fixed or whether it would vary randomly.

The trial sequence began with a 250 "blink" of the fixation cross, followed by a random foreperiod defined by the hazard function of an exponential distribution with a mean of 450 ms. The distractor display then appeared for 60 ms, after which the fixation display reappeared for 60 ms. The target display then appeared for 60 ms, followed once again by the fixation display. If subjects committed an error, the word "ERROR" appeared in the middle of the screen for 500 ms, followed by the fixation display for 500 ms.

In all other respects, the procedure was identical to Experiment 1.

Results

Mean response times and error rates as a function of distractor condition (fixed vs. random) and distractor location (same vs. different from target location) are shown in Figure 3.

Insert Figure 3 about here

A 2 x 2 mixed ANOVA on the mean response times yielded a highly significant main effect of distractor location, $F(1,23) = 34.73$, $p < .0001$. Specifically, response times were, on average, 23 ms higher when the target and distractor appeared at different locations than when they appeared at the same location. This effect was evident for both the random and fixed distractor conditions, as the interaction failed to even approach significance, $F < 1$. Surprisingly, the between-subjects main effect of distractor condition also failed to reach significance, $F < 1$.

Error rates averaged 6.7% and followed the same pattern as response times. Although there was a slight trend toward higher error rates in the random condition, a mixed ANOVA yielded no significant effects.

Discussion

There are two central conclusions to be drawn from this study. First, the fact that performance varied as a function of the spatial relationship between distractor location and target location suggests that abrupt onset distractors produced shifts in the distribution of spatial attention, rather than producing some non-spatial distraction effect. Second, consistent with the results of Experiment 1, the significant effect of distractor location in the fixed distractor condition suggests that even with "chronic" knowledge of the distractor location, subjects were unable to suppress capture by the distractor appearing at that location.

As with Experiment 1, however, it is possible that mean response times for a block may obscure intrablock phenomenon such as habituation to the distractor. To test this possibility, an additional analysis was conducted in which performance on the first half of the trials in each block was compared

to performance on the last half of trials in each block. The main effect of distractor location was once again significant, $F(1, 23) = 53.22$, $p < .0001$, and there was no interaction of distractor location with block half, nor any three-way interaction of distractor location, block half and distractor condition (for both $F < 1$). This indicates that for both random and fixed distractor conditions, there was no evidence of any habituation of attentional capture as a block progressed.

Attentional capture by a distractor appearing at the same location trial after trial is clearly consistent with the notion that the attentional control system is incapable of establishing an spatial attentional set that suppresses capture by a stimulus at a known location. One could argue, however, that subjects may not be incapable of using knowledge of the distractor location to eliminate capture, they may simply be unwilling to do so, given the constraints of the task. Recall that in an effort to be certain any effects of cue location reflect true shifts of spatial attention, the target appeared at the distractor location on 25% of the trials. If the distractor location is suppressed, then rapid target processing might be compromised on 25% of the trials. The overall cost associated target processing on those 25% of trials may have been greater than the cost of attentional capture by the distractor. Thus, the apparent inability to use information about distractor location may simply reflect a conflict between two behavioral goals that are mutually exclusive -- rapid target acquisition and suppression of distractors.

Experiment 3

In the third experiment, we attempted to remove any potential conflict between the goals of distractor suppression and target acquisition. Specifically, distractors always appeared at locations in between the potential target locations, never at a target location. Given that Experiment 2 established that the distractors were indeed producing shifts of spatial attention, in the present experiment we return to measuring capture in terms of performance differences between distractor and no-distractor trials. As in Experiment 2, in one condition distractor location was fixed throughout a block of trials, and in another condition distractor location varied randomly from trial to trial.

With the present design, suppressing attentional capture at distractor locations should have no effect at all on the efficiency of target acquisition because distractors, when present, never appeared at a potential target location. Thus, if subjects are capable of establishing a spatial control setting based on knowledge of the distractor location, then attentional capture should be eliminated in the fixed location condition, but not the random location condition. If subjects are simply unable to use knowledge of the distractor location to establish a control setting, then capture should be apparent in both conditions.

Method

Subjects. Forty-two student volunteers from Villanova University participated in this study. Of these, twenty took part in the fixed distractor condition and twenty-two in the random distractor condition. All subjects received either $5 or extra credit in an undergraduate course. All had near visual acuity of 20/30 or better as measured by a Titmus II Vision Tester.

Apparatus. The apparatus was identical to that used in Experiment 1.

Stimuli. Stimuli were identical to those used in Experiment 2 with two exceptions. First, on half of the distractor displays, no distractor appeared. Second, when a distractor did appear, it was located 4.7 degrees visual angle from fixation at one of four corners of an imaginary square centered on fixation. In other words, it appeared at one of the four blank locations in between the four outer boxes.

Design. In both fixed and random location conditions, subjects received four blocks of no-distractor trials and four blocks of distractor trials. A no-distractor block was always presented first and subsequent blocks alternated between the two conditions. Each block consisted of 32 trials, with each target ("X" vs. "=") appearing equally often in each of the four outer boxes. In the fixed distractor condition, the distractor appeared at the same location on every trial in a block. The particular location varied across blocks, and the order of location was balanced across subjects using a Latin Square. In the random distractor condition, the distractor location varied randomly from trial to trial within a block, but appeared equally often at each possible distractor location.

Procedure. Subjects were informed of the difference between distractor and no distractor

blocks. In addition, they were fully informed with respect to whether the distraction location was random or fixed. The sequence of events on a given trial began with a 250 ms "blink" of the fixation cross followed by foreperiod interval randomly chosen from the set 1000, 1100, 1200, 1300, or 1400 ms. The cue display was then presented for 50 ms followed by the fixation display for 100 ms and then the target display for 50 ms. The fixation display then reappeared until the next trial began.

Results

Mean response times and error rates as a function of distractor condition (fixed vs. random) and distractor status (no distractor vs. distractor) are shown in Figure 4.

Insert Figure 4 about here

A 2 x 2 mixed ANOVA on the mean response times yielded a significant 11 ms main effect of distractor status, $F(1,23) = 7.76 \, p < .01$. The presence of a distractor had an influence in both random and fixed distractor conditions, as the interaction between distractor condition and distractor status failed to even approach significance, $F < 1$. As in Experiment 2, the between-subjects main effect of distractor condition also failed to reach significance, $F (1, 40) = 1.38, \, p > .05$.

Error rates were quite low averaging only 2.1%. Error rates were slightly higher in the no distractor condition (2.3%) than in the distractor condition (1.8%). A mixed ANOVA showed that this trend was marginally significant, $F(1, 40) = 4.35, \, p = .04$. Although suggestive of a speed-accuracy tradeoff, this small effect on errors is confounded with practice; the no distractor condition was always the first condition presented to subjects. Consistent with this interpretation is the fact that error rates for no distractor and distractor conditions differed by no more than one half of one percent (mean = .2%) in all but the first block of trials. In the first block, error rates differed by nearly 2%. Given this pattern, and the low error rates overall, it is unlikely that the response times are contaminated by a speed accuracy trade-off.

Discussion

The pattern of overall means in the present experiment is identical to that found in Experiment 2. Irrelevant abrupt onset distractors produced evidence of attentional capture regardless of whether subjects had advance knowledge of the exact location of the distractor. Moreover, this effect was evident even when distractors never occurred at potential target locations.

One obvious difference between the results of Experiment 2 and the present experiment, however, is the magnitude of the distractor effect. In Experiment 2 the distractor location effect was more than twice as large (23 ms) than the distractor effect in the present experiment (11 ms). There are several potential accounts of this difference. First, given that the no distractor condition always came first in the present experiment, practice effects may have mitigated the true magnitude of the distractor effect. Second, the distractor location effect in Experiment 2 measures the combined effect of costs produced by the distractor on different-location trials, and benefits on same-location trials. Assuming the no distractor condition in the present experiment represents a conservative baseline, the distractor effect is a conservative estimate of only costs associated with shifts of attention to non-target locations.

One final possibility is that the distraction effect may vary within a block, producing mean response times that are a mixture of "early" trials on which the distractor captured attention, and "late" trials on which it did not. To assess this possibility, a half-block analysis was conducted as in the first two experiments. This time the analysis revealed a significant interaction between block half and distractor status, $F(1, 40) = 10.76$, $p < .01$. Specifically, the presence of a distractor produced a 20 ms cost relative to no distractor trials for the first half block, and a 2 ms effect in the second half block. This pattern was evident for both the fixed and random distractor conditions as the three-way interaction was not significant, $F(1, 40) = 1.07$, $p > .05$. Thus, this analysis suggests that the distraction effect in the present experiment is just as large as in Experiment 2 for the first half of each block, but is virtually eliminated by the end of each block.

How are we to account for the reduction in the distraction effect as a block progresses? One

possibility is that with practice, subjects are indeed able to actively establish an attentional control setting that suppresses the effect of distractors at non-target locations. There are several reasons to suspect, however, that the reduction in distraction reflects a form of passive habituation rather than active suppression. First, if the effect were due to the active application of strategic control settings, then one might reasonably expect that the ability to strategically control the effect of distractors would vary depending on whether the distractor position was fixed or random. There was, however, no evidence of any difference in the nature of the half block effect as a function of distractor condition. Of course, it is possible that the same control setting might, in fact, be able to handle both fixed and random distractors. For example, subjects may learn to adopt a suppressive set for all distractor locations, rendering any distractor location, be it fixed or random, incapable of producing capture. However, if subjects learn to adopt a single control strategy, then we might expect distraction effects to show up only in the first half of the first block. That is, having learned how to establish the effective control setting in the first block, we might expect that setting to remain in effect throughout the experiment. In fact, in additional analyses, we found that the half block effect was present in each block of the experiment. Thus, we tentatively conclude that the present data are more consistent with a passive habituation process rather than the active establishment of an attentional control setting. Given little evidence of habituation in the previous experiments, however, we suspect that the conditions under which habituation occurs are directly related to what control settings are in effect, a point discussed in more detail below.

General Discussion

This series of experiments was conducted to explore the flexibility of attentional control settings for spatial location and to begin to address the underlying mechanisms by which attentional control settings are instantiated. Subjects were provided with advance information about the location of an irrelevant abruptly onset distractor through the use of trial by trial spatial cuing (Experiment 1) or by holding the distractor location constant throughout a block of trials (Experiments 2 and 3). The only

conditions in which attentional capture was eliminated was after repeated presentations of distractors that could never appear at potential target locations (Experiment 3).

How can the we account for the pattern of results across the three experiments? We propose that the results are consistent with the general notion that task characteristics determine and constrain the nature of attentional control settings in any given situation, and that attentional capture reflects conflicting behavioral goals. The primary task goal in all three experiments is to locate an abrupt onset target that can occur at one of four potential locations. To accomplish this goal, we assume that two concurrent control settings are established, one for abrupt onset, and one for potential target locations. Thus, when an abrupt onset distractor appears at a potential target location, it satisfies both control settings and therefore captures attention, even though subjects "know" where the distractor will appear. (Note that when target location is cued or known (as in Yantis & Jonides, 1990), there is no need to establish a control setting for onset, because a set for the target location eliminates the need to "find" the target. Thus, a single control setting "for" the target location satisfies the simultaneous goals of target acquisition and distractor suppression.) When the abrupt onset distractor always appears at non-target locations, as in Experiment 3, it still satisfies the abrupt onset control setting, but not the target locations setting. We propose that when the distractor does not satisfy both control settings, the attentional response to abrupt onset eventually habituates. By this logic, the lack of habituation or half-block effects in Experiments 1 and 2 reflect the fact that the distractor satisfied both settings.[1]

One underlying assumption of this model is that with respect to spatial locations, attentional control settings are instantiated through the facilitation of relevant locations rather than the suppression of attentional responses to information at irrelevant locations. The design of these experiments allowed subjects every possible opportunity to suppress shifts of attention to information at known irrelevant locations, and there was no evidence that they were able, or at the very least, willing, to do so. Thus, on the basis of the current experiments, as discussed above, we propose that the elimination of capture by distractors at irrelevant locations when relevant locations are known in advance, such as found by Yantis

and Jonides (1990), reflects a control setting "for" the relevant location rather than a setting "against" irrelevant locations.

The present studies represent an exploration of the limitations on the flexibility of attentional control. The specific model outlined above is obviously tentative, and may be specific to attentional control settings for location. Clearly further research is needed to determine if the effects observed here generalize to other forms of attentional control. For example, an obvious follow-up to the present experiments would be to determine if similar effects would be observed with stimulus properties such as discontinuities in color (Folk, et al., 1992; Folk & Remington, 1993). Nonetheless, the present studies provide converging evidence that the phenomenon of attentional capture is contingent on endogenous attentional control settings that are determined by task constraints.

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Author Notes

Footnotes

[1] One might argue that because targets never appeared at the cued location in Experiment 1, a distractor appearing at that location does not satisfy the "potential target location setting". Although on any given trial the target did not appear at the distractor location, the target and distractor locations varied across trials. Thus, a distractor location on one trial may become the target location on the next trial. We assume that given the relatively short precue duration, subjects were simply unable to alter the potential target location a set "on-line."

Figure Captions

Figure 1. Representation of trial events and stimuli in Experiment 1.

Figure 2. Average mean response times and error rates as a function of cue-distractor SOA, cue status, and distractor status in Experiment 1.

Figure 3. Average mean response times and error rates as a function of distractor location and distractor condition in Experiment 2.

Figure 4. Average mean response times and error rates as a function of distractor location and distractor condition in Experiment 3.

Target
50 ms

ISI
100 ms

Distractor
50 ms

Precue
100 - 400 ms

Fixation
750 ms

Response Time (ms)

Cue / Distractor

No Cue / Distractor

Cue / No Distractor

No Cue / No Distractor

Error Rate (%)

Cue – Target SOA (ms)