

Characteristics of Covert and Overt Visual Orienting: Evidence From Attentional and Oculomotor Capture

Shu-Chieh Wu and Roger W. Remington
National Aeronautics and Space Administration
Ames Research Center

Five visual search experiments found oculomotor and attentional capture consistent with predictions of contingent orienting, contrary to claims that oculomotor capture is purely stimulus driven. Separate saccade and attend-only conditions contained a color target appearing either singly, with an onset or color distractor, or both. In singleton mode, onsets produced oculomotor and attentional capture. In feature mode, capture was absent or greatly reduced, providing evidence for top-down modulation of both types of capture. Although attentional capture by color distractors was present throughout, oculomotor capture by color occurred only when accompanied by transient change, providing evidence for a dissociation between oculomotor and attentional capture. Oculomotor and attentional capture appear to be mediated by top-down attentional control settings, but transient change may be necessary for oculomotor capture.

Orienting in the visual world is accomplished by overt shifts of eye fixation in coordination with covert shifts of spatial attention (e.g., Posner, 1980). Several lines of evidence suggest that the two are controlled by a common set of mechanisms. For example, attention and saccades are closely coupled in everyday activities, such as reading (e.g., Rayner & Pollatsek, 1989). Although attention can be shifted while the eyes remain fixated, it cannot be shifted independently when a saccade is made. Attention has been observed to move ahead of voluntary saccades to the saccade target, even when the incentive is to withhold the shift or to shift attention to another location (Hoffman & Subramaniam, 1995; Irwin & Gordon, 1998; Kowler, Anderson, Doshier, & Blaser, 1995; Posner, 1980; Remington, 1980; for a review, see Hoffman, 1998). The locus of attention has also been shown to bias saccade trajectories (Sheliga, Riggio, Craighero, & Rizzolatti, 1995; Sheliga, Riggio, & Rizzolatti, 1994) and may even play an active role in saccade target localization (Kowler et al., 1995). These behavioral observations converge with neurophysiological and neuropsychological findings that show overlapping brain areas activated by both attention and saccades (e.g., Andersen, 1995; Bushnell, Goldberg, & Robinson, 1981; Corbetta, 1998; Corbetta et al., 1998; Nobre, Gitelman, Dias, & Mesulam, 2000; Wurtz, Sommer,

Pare, & Ferraina, 2001). The close coupling between attention and saccades is reflected in premotor theories of covert attention, which argue that spatial attention is controlled by the same mechanisms that govern saccades (Klein, 1980; Klein & Pontefract, 1994; Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Rizzolatti, Riggio, & Sheliga, 1994).

However, the strong behavioral evidence for common control of saccades and attention has come essentially from dual-task conditions demonstrating an inability to attend to one target concurrent with a saccade to another (e.g., Hoffman & Subramaniam, 1995; Kowler et al., 1995). An inability to independently allocate attention and execute saccades need not imply a common control mechanism but could reflect conflict for a common resource, such as a common spatial map, that need not be involved directly in the control. Indeed, interference is often observed in dual-task conditions even when the control of the respective responses is independent to a large degree, as when a vocal response to one task is paired with a manual response to the other (e.g., McCann, Remington, & Van Selst, 2000). It is difficult to see how dual-task methods that require simultaneous, incompatible shifts of the eyes and attention would allow one to dissociate interference arising from common control mechanisms as opposed to a shared common resource.

Here we approach the issue of common control by examining whether involuntary responses of saccades and attention are sensitive to the same stimulus conditions. Visual search (e.g., Theeuwes, 1991; Yantis & Jonides, 1984) and spatial cuing (e.g., Folk, Remington, & Johnston, 1992) experiments have shown that under some conditions an irrelevant peripheral stimulus will involuntarily capture spatial attention, causing it to be shifted to the location of the distracting stimulus. If the same control mechanism underlies attention and saccades, then stimulus properties that elicit involuntary attention shifts should also elicit involuntary saccades. Conversely, stimulus conditions that fail to elicit capture from one should also fail to elicit capture from the other. Following this logic, the experiments reported here test whether the same contingencies that affect attentional capture also affect oculomotor

Portions of this article were presented at the 42nd Annual Meeting of the Psychonomic Society, Orlando, Florida, November 2001. This research was supported by a postdoctoral fellowship from the National Research Council and by funding from the Airspace Operations Systems Project of the National Aeronautics and Space Administration's (NASA) Airspace Systems Program.

We thank Brad Gibson, Richard Godijn, Joel Lachter, Jim Johnston, and an anonymous reviewer for helpful comments on earlier versions of this article. We also thank Jeff Mulligan and Lee Stone for their technical assistance.

Correspondence concerning this article should be addressed to Shu-Chieh Wu or Roger W. Remington, NASA Ames Research Center, Mail Stop 262-4, Moffett Field, California 94035. E-mail: scwu@mail.arc.nasa.gov or rremington@mail.arc.nasa.gov

capture. Folk et al. (1992) have shown that task goals actively influence which stimuli will capture attention and which will not. According to Folk et al., capture is not a completely stimulus-driven process in response to particular stimulus features such as abrupt onsets (Yantis & Jonides, 1984) or to salience (Theeuwes, 1991) but is contingent on behavioral goals. For example, they showed that abrupt onsets would capture attention when the target was also defined by onset but not when the target was defined as a color singleton. If saccades and attention are controlled by the same mechanisms, then the same contingencies should be observed when saccades are involuntarily elicited by a peripheral stimulus. In particular, it would be expected that top-down and bottom-up factors that affect the capture of attention would affect the capture of saccades.

Attentional and Oculomotor Capture

The issue of common control bears directly on the debate over the role of top-down modulation of attentional capture. Recent results by Theeuwes and colleagues (Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999) have been interpreted as support for the hypothesis that attentional capture is purely stimulus driven and not modulated by top-down goals. For example, Theeuwes et al. (1998) found that, in a visual search task that required a saccade to a uniquely colored target, half of the initial saccades were directed instead toward a task-irrelevant onset distractor. Theeuwes et al. (1999) argued that this oculomotor capture reflected involuntary shifts of attention to the abrupt onset object, as evidenced by further increased response times (RTs) when the onset distractor was associated with a response incompatible with the target response. Irwin, Colcombe, Kramer, and Hahn (2000) found that new objects defined by abrupt onsets produced more oculomotor capture than luminance increments of existing objects but found no capture by color singletons. Theeuwes et al. and Irwin et al. argued that abrupt onsets define new objects that will capture attention and the eyes involuntarily despite a top-down attentional set for color singletons.

Because the target property in Theeuwes et al.'s (1998, 1999) and Irwin et al.'s (2000) experiments was color, not onset, those authors used the results to challenge the contingent orienting theory of Folk et al. (1992). This challenge relies on the assumption that oculomotor capture is a direct reflection of attentional capture. In particular, it rests on the twin assumptions that the eyes are captured because attention is captured and that the requirement to saccade or remain fixated has no effect on the conditions that will elicit attentional capture. Neither assumption has yet been tested. Although attention and saccade tasks recruit a highly overlapping network of cortical areas, there is evidence that these areas are utilized to different degrees in each task (e.g., Corbetta et al., 1998; Nobre et al., 2000), suggesting some separation of functional control mechanisms. If the control mechanisms of saccades and attention were separable, then it is possible that response characteristics observed under saccade conditions reflect the behavior of the saccade control system rather than the spatial attention control system. This would mean that properties that elicit involuntary saccades (and accompanying attention shifts) would not necessarily elicit attentional capture. Thus, patterns of oculomotor capture would not necessarily be indicative of failure of top-down control of attention.

The challenge to contingent capture posed by the oculomotor capture results can be criticized on other grounds as well. The procedures used by Theeuwes et al. (1998, 1999) and Irwin et al. (2000) are similar to an earlier study by Theeuwes (1992, Experiment 1) in which participants displayed attentional capture by irrelevant color singletons when searching for a form singleton. Bacon and Egeth (1994) showed that this method promotes a singleton detection strategy in which participants respond to the presence of any unique singleton stimulus even when in another dimension. When they removed the singleton status of the target in Theeuwes's design, color singletons no longer captured attention. On the basis of those results, they proposed a distinction between feature search and singleton detection modes. Not only do Bacon and Egeth's results clearly demonstrate that feature singletons do not necessarily capture attention in a stimulus-driven manner, they may also provide an explanation for the oculomotor capture by abrupt onsets observed by Theeuwes et al. (1998, 1999) and Irwin et al. (2000). It is possible that abrupt onsets captured attention and the eyes in those studies because they fit an attentional set for singletons, not because they defined new objects. This possibility may also explain why Theeuwes et al. (1999) found an attention shift toward oculomotor distractors even though some evidence suggests that attention may not precede involuntary saccades such as those characteristic of oculomotor capture (Mokler, Deubel, & Fischer, 2000). Oculomotor capture has yet to be tested under feature search conditions as defined by Bacon and Egeth (1994).

Present Experiments

In the experiments reported here, we explore the relationship between attention and saccades by examining whether oculomotor and attentional capture respond similarly to the same stimulus conditions. Specifically, the experiments attempted to answer three related questions:

1. Do abrupt onsets have a unique ability to elicit attentional and oculomotor capture, so that they will do so when conditions for singleton detection mode are removed?
2. Will feature singleton distractors, such as color singletons, elicit oculomotor capture?
3. Are the eliciting conditions for oculomotor capture identical to those for attentional capture?

Each of these questions is a part of the larger question of whether oculomotor capture, like attentional capture, is subject to top-down modulation or whether it is purely stimulus driven. Evidence that oculomotor capture is purely stimulus driven and that a clear link exists between it and attentional capture would strengthen the case for stimulus-driven attentional capture as well as for a common control mechanism for attention and saccades.

To address these issues, we compare rates of oculomotor capture in saccade conditions with the RT effects in no-saccade conditions. Thus, all experiments reported here included two parallel task conditions, attention and saccade, with identical designs. The logic of the experiments was to manipulate the amount of attentional capture through experimental designs that encourage different modes of search and then evaluate the impact on the occurrence of oculomotor capture.

Experiment 1

Experiment 1 included a saccade task condition that replicated the experiment of Theeuwes et al. (1998) save for the choice of colors. In addition, we collected RT data from a parallel condition of identical experimental design that required no saccades.

Method

Participants. Twenty undergraduate students recruited from local colleges near NASA Ames Research Center (Moffett Field, CA) participated either for course credit or for moderate monetary compensations. Twelve completed the attention task condition; 8 completed the saccade task condition. All of the participants reported normal or corrected-to-normal vision and no color blindness.

Apparatus. An IBM-compatible Pentium II personal computer controlled display of stimuli on a 21-in. (53.34-cm) SVGA monitor, collection of keyboard responses, and storage of data. Participants were seated in a comfortable chair with their head secured on a head-and-chin rest placed 53.5 cm in front of the monitor. They made manual responses with index and middle fingers of their right hand using the "." and "/" keys on a PC keyboard. Eye movements were recorded with an infrared video-based eye tracking system (ISCAN), which outputs data at a temporal resolution of 120 Hz and a spatial resolution of approximately 0.5° visual angle. The system tracked eye positions by computing the distance between the centers of the pupil and cornea reflection of the left eye. The experiment was carried out in a dedicated, sound-attenuated booth.

Stimuli. The stimulus display consisted of a 0.54° central fixation cross, a 1.5° circle surrounding the fixation (to serve as a warning signal), and six circles arranged with equal spacing along the circumference of a large imaginary circle centered at fixation. The six circles appeared at angular 0° , 60° , 120° , 180° , 240° , and 300° from straight right. Each circle contained a stimulus figure. In the saccade task, the radius of the large circle was 10.08° of visual angle, for the color circles 1.48° , and for the stimulus figures 0.4° . In the attention task, the radius of the large circle was 3.4° , for the color circles 0.7° , and for the stimulus figures 0.8° . Colors used in the experiment, green and red, were prematched for luminance using a homemade program, which displays a spinning wheel consisting of pie pieces in alternating colors (in this case, red and green) and creates an illusion of apparent spinning motion when the two colors are unequal in luminance. Equiluminance was achieved by adjusting the RGB values of each color to annul that illusion. The wheel configuration was presented foveally.

Design. There were two task conditions, *attention* and *saccade*. In both task conditions, half of the trials contained an abrupt onset distractor. Targets appeared equally often in all six locations. The onset distractor, when present, could appear at 90° , 150° , 210° , or 270° counterclockwise away from the target, resulting in angular distances 90° and 150° . In Euclidean distances, these distances corresponded to 14.25° and 19.47° of visual angle in the saccade task condition and 4.81° and 6.57° in the attention task condition, respectively. The onset distractor was inserted between two circles along the large imaginary circle.

All circles contained a letter *O* as a placeholder when a trial began. When the target location was revealed through color change, an arc segment was removed from each of the letter *O* placeholders. In the target circle, an arc segment was removed from either the right or left side of the letter *O*, resulting in figures resembling a *C* or a reversed *C*. Nontarget circles, including the circle appearing with the onset distractor, had a segment removed from either the top or bottom of the letter *O*, resulting in figures resembling a *C* rotated in 90° or 270° . The two possible probe directions, forward or reversed *C*, appeared equally often. There were a total of 384 trials divided into three blocks in each task condition. Trials within a task condition across different trial conditions were completely randomized and presented to each participant in a different order.

Procedure. Prior to the first block of the attention and the saccade task, participants received 36 practice trials. Each of the following two blocks was preceded by three dummy trials from which data were discarded. The attention task condition lasted about 15 min; the saccade task condition lasted between 20 and 40 min.

A calibration procedure was administered before each block of trials in the saccade task condition. Participants fixated two sets of nine calibration targets (crosshairs) presented serially in a 3×3 grid in a random order across the display. After the first set, calibration parameters that mapped eye positions to screen coordinates in pixels were computed using a nonlinear algorithm. Screen pixel coordinates for each fixation measured in the second set were then computed using these parameters and compared against the actual locations of the targets in view. Calibration continued until no measured position was more than 1.5° away from the actual position.

In both attention and saccade task conditions, participants were required to determine whether the stimulus figure inside the target circle was a forward or reversed *C*. For the forward *C*, participants responded by pressing the "/" key with the middle finger of the right hand; for the reversed *C*, they pressed the "." key with the index finger of the right hand. To minimize the tendency to base responses on the distinction between alphabet and nonalphabet, we avoided reference to the letter *C* in the instruction and instead told participants to determine the opening of a small circle inside the target circle. Eye movements were not monitored in the attention task condition, but participants were asked to maintain fixation at the center cross.

The attention and saccade tasks contained a common sequence of events (Figure 1) but with different timing. In the attention task condition, a trial began with an initial display of a white fixation cross, a small white circle surrounding the cross, and six green circles arranged along a large imaginary circle centering at fixation. Inside each of the six circles was a green letter *O* serving as placeholder for the upcoming stimulus. The initial display was presented for 1 s, followed by the removal of the central circle to signal the forthcoming target display. After 500 ms five of the six green circles turned red, revealing the target display. On half of the trials an onset distractor (an additional red circle) was presented simultaneously with the change to the target display. Simultaneously with the color change, a small arc segment from each of the letter *O*s was removed, and the altered characters remained on for 200 ms before being erased. Participants were told to report the location of the opening in the character inside the remaining green circle. They were instructed to shift attention to the

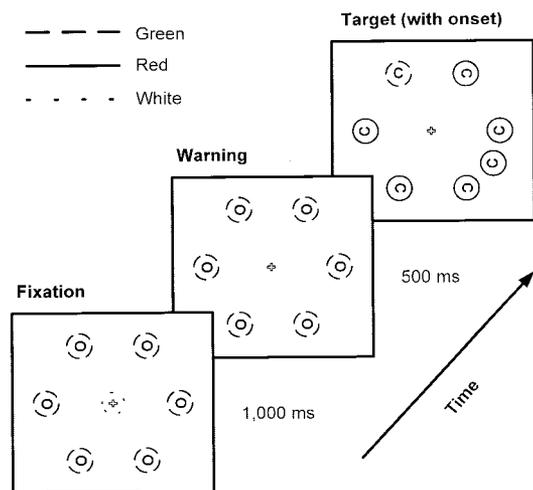


Figure 1. Sequence of events within a trial for Experiment 1. The target display shown here contains an abrupt onset distractor.

remaining green circle without shifting their gaze from the central fixation marker.

In the saccade condition, the initial display remained until participants had maintained fixation within 6° radius around the fixation cross for a full 1 s. Stimulus figures inside the color circles remained visible until the end of a trial.

Results and Discussion

For the attention task condition, trials with incorrect responses or RTs longer than 1,000 ms were excluded from further analyses; such trials accounted for 6% of total trials. For the saccade task condition, trials with incorrect manual responses (2%) or of indeterminate eye movement patterns (8%) were excluded. As a result, 9% of total trials in the saccade task condition were discarded and not analyzed further.

To evaluate the influence of onset distractors on saccades, for each trial, we categorized the end point of the initial saccade exiting the central fixation with respect to one of the locations of potential destinations (target, onset distractor, or elsewhere). In general, a saccade was said to be made toward a particular location if the first fixation landed within $\pm 30^\circ$ angular distance from the direct path to that location. On the basis of this coding scheme, we found a significant proportion, 27%, of first saccades erroneously went to the onset distractor (plotted in Figure 2, upper left panel for later comparison), consistent with previous experiments (Irwin et al., 2000; Theeuwes et al., 1998, 1999). The presence of the onset distractor also affected manual responses in the saccade condition. Averaged mean manual RT (plotted in the leftmost panel of Figure 3) was significantly lengthened from 927 to 955 ms by onset distractors, $t(7) = 3.49$, $p < .01$.

Saccade trajectories are known to curve away from visual stimuli to which covert attention has been directed (e.g., Doyle & Walker, 2001, 2002; Godijn & Theeuwes, 2002; Sheliga et al.,

1994, 1995). If oculomotor capture is associated with an attention shift, saccade trajectories should curve away from onset distractors. To test for curvature, we compared the trajectories of correct saccades to oblique targets (i.e., targets at 60° , 120° , 240° , or 300°) in the no-onset condition with trajectories for the same oblique targets in the presence of an onset at 90° . Saccade curvature was determined for each trial by first calculating the amplitude of the most direct path from fixation to the end point of the first saccade. Then, the peak deviation was calculated by determining the largest perpendicular distance between any eye sample on the actual trajectory and the direct path. Trials were excluded if their deviation angle, the angle subtended by the peak deviation, was greater than 30° , because these saccades likely underwent a change in course instead. Finally, a curvature index was calculated by dividing peak deviation by saccade amplitude. This procedure results in a measure of curvature per unit amplitude, which could rule out curvature variation pertaining to saccade amplitude only (Doyle & Walker, 2001). Curvature measures were assigned positive or negative signs to indicate their direction. Saccades that curved toward the hemifield where the target was (considered the ipsilateral hemifield) were given negative signs; those curved toward the opposite hemifield (considered the contralateral hemifield) from the target were given positive signs.

Results of averaged median saccade curvatures are summarized in Figure 4. The baseline curvature of saccades made without distractors is depicted by the position of the vertically aligned reference line. Its negative value is reminiscent of curvature typically observed for oblique saccades, which extends first horizontally then vertically (e.g., Viviani, Berthoz, & Tracey, 1977). Because of the existence of baseline curvature, analysis of saccade curvature focused on the difference in curvature between conditions with and without distractors. Differences in curvature caused by ipsilateral and contralateral onset distractors are represented in

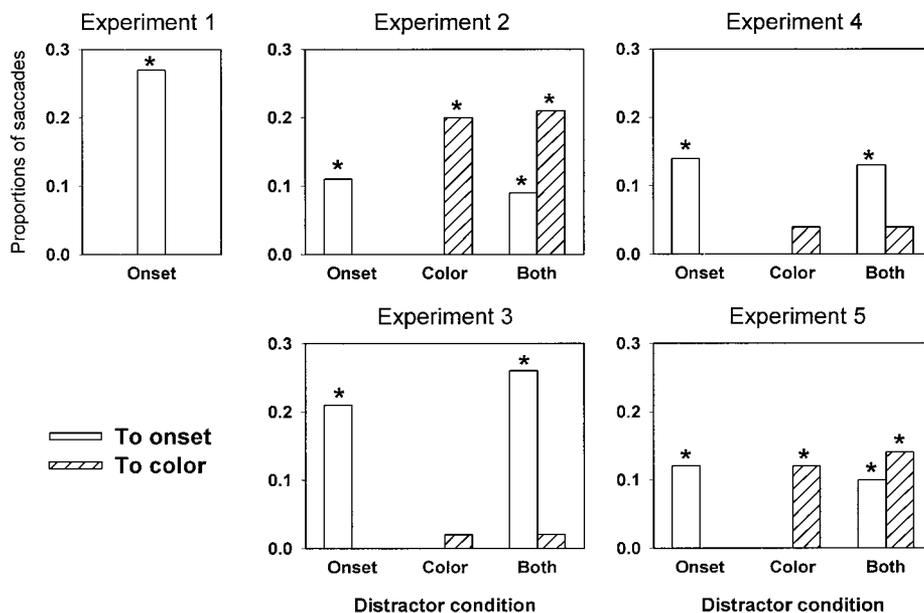


Figure 2. Proportions of saccades made toward onset and color distractors by distractor conditions in Experiments 1–5. Asterisks indicate proportions that exceeded chance level ($p < .05$, one-tailed t tests).

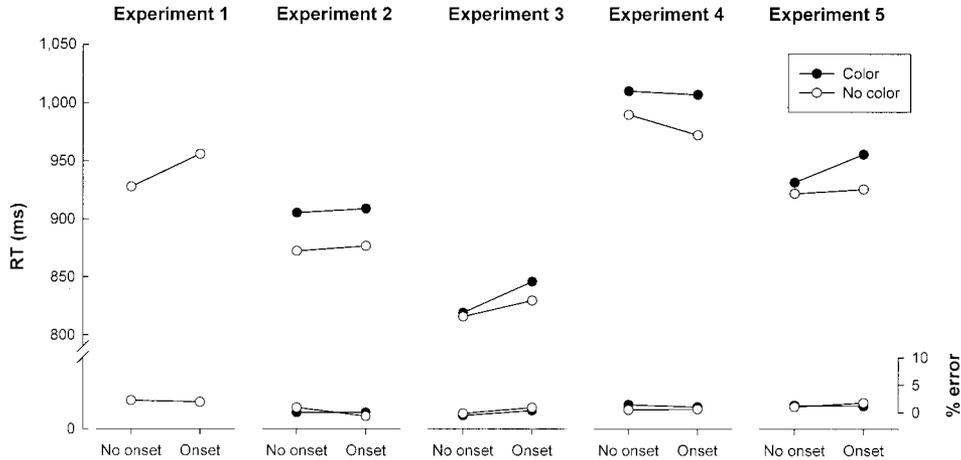


Figure 3. Manual response times (RTs) and error rates of the saccade task condition in Experiments 1–5.

Figure 4 by horizontal bars. If onsets cause saccades to curve away, onsets located ipsilaterally to the target should result in contralateral curvature deviation, and vice versa. Indeed, separate one-tailed *t*-test results showed that onsets, whether placed ipsilaterally or contralaterally to a target, significantly curved saccades away ($ps < .05$).

Other measures associated with onset capture were also computed. Median latency for the first saccade in each condition was computed for each participant. The overall averaged latency of erroneous saccades toward the distractor (207 ms) was significantly shorter than that of correct saccades (294 ms) in the same condition, $t(7) = 4.27, p < .01$. Oculomotor capture is also signified by short fixation durations on the distractor before a corrective saccade is made toward the target; the durations are usually shorter than what is required to program a saccade anew (200 ms; see Salthouse & Ellis, 1980). In the present experiment, averaged median fixation duration was only 112 ms, comparable with similar measures reported previously (Irwin et al., 2000; Theeuwes et al., 1998, 1999).

In the attention task condition, abrupt onsets significantly delayed responses to the target, from 604 ms to 612 ms, $t(11) = 2.03, p < .05$ (see Figure 5, leftmost panel). The increase in RT cannot

be attributed to speed–accuracy trade-offs, because abrupt onsets correspondingly increased error rate from 4.6% to 7.4%, $t(11) = 2.97, p < .01$. In sum, results from the saccade condition replicated those reported by Theeuwes et al. (1998) and showed clear evidence of oculomotor capture. Results from the attention condition suggest that the same design also induces attentional capture.

Experiment 2

Experiment 2 examined whether distractors, abrupt onsets or color singletons, would elicit attentional and oculomotor capture in a design that discouraged broad singleton detection mode. Following the logic of Bacon and Egeth (1994), we discouraged singleton detection mode by including trials with a color distractor and tested participants in saccade and no-saccade conditions as in Experiment 1. If successful, there should be no attentional capture by abrupt onsets. This outcome would be consistent with contingent orienting and would strengthen the case for the distinction between feature and singleton search modes. Furthermore, because Experiment 2 contained trials in which the only distractor was an onset singleton, we can compare rates of oculomotor capture with

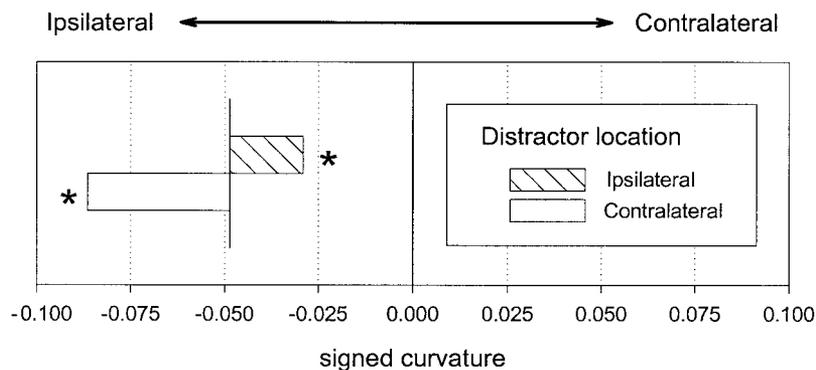


Figure 4. Differences in the curvature of saccade trajectories caused by ipsilateral and contralateral distractors in Experiment 1. Asterisks indicate the results of one-tailed *t* tests with *p* values less than .05.

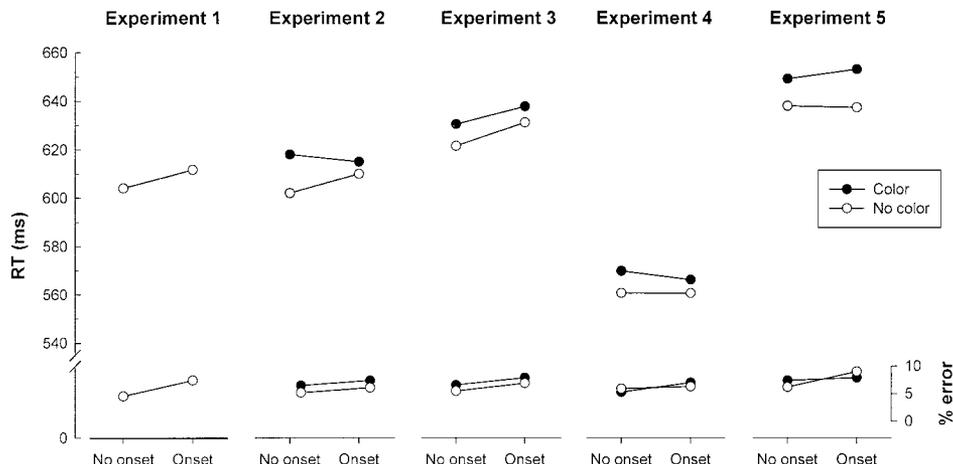


Figure 5. Manual response times (RTs) and error rates of the attention task condition in Experiments 1–5. In Experiment 5, RTs were based on fixated trials only.

those in Experiment 1 under the same stimulus conditions. If both oculomotor and attentional capture are modulated by task goals, the adoption of feature mode should have corresponding effects on the rate of oculomotor capture and the amount of attentional capture measured in no-saccade conditions.

Method

Participants. Twenty-six individuals participated in the experiment, including one of the authors (SCW). Eight completed both attention and saccade task conditions; 18 completed only the attention condition. Among those who completed both tasks, 5 of the participants were staff members of the lab. All other participants were undergraduate students recruited from the same participant pool as Experiment 1. All participants met the same requirements specified in Experiment 1. Five of the participants in the saccade task condition had participated in similar experiments but, except for the author, they were naive to the purpose of the present experiment.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1 except the addition of the color blue, whose luminance was matched to those of red and green using the same procedure described in Experiment 1.

Design. The design of Experiment 2 was identical to that of Experiment 1 except that half of the trials contained a blue color distractor on the target display. As a result, there were four sets of 96 trials: no distractor, onset distractor only, color distractor only, or both onset and color distractors (see Figure 6). Trials of different types were intermixed and presented to each participant in a different randomized order. The onset distractor, when present, could appear at 90°, 150°, 210°, or 270° counterclockwise away from the target, resulting in two possible angular distances, 90° and 150°. The color distractor, when present, could appear at any one of the five nontarget locations, resulting in three possible angular distances, 60°, 120°, and 180°. In Euclidean distances, these corresponded to 10.08°, 17.46°, and 20.16° of visual angle in the saccade task condition and 3.4°, 5.89°, and 6.8° in the attention task condition, respectively. When both color and onset distractors were present, certain restrictions in their placement were maintained, depending on the angular distance between the onset distractor and the target. When the target and the onset distractor were 90° apart, the color distractor would not appear in between them. When the target and onset distractor were 150° apart, the color distractor would appear at neither the location in between them nor 60° away from the target.

Procedure. The procedure used in Experiment 2 was identical to that used in Experiment 1 except for those participants who completed both tasks. To avoid unwanted transfer of eye movement responses between tasks, we always presented the attention task first. Three participants completed both tasks in the same day; the other 5 completed the saccade task condition after 1 to 7 days.

Results

Location of first fixation and manual RT data were analyzed with respect to two variables: presence of an onset distractor and presence of a color distractor. For the attention condition, incorrect trials and RTs longer than 1,000 ms were excluded; such trials accounted for 7% of total trials. For the saccade condition, trials with incorrect manual responses (2%) or of indeterminate eye movement patterns (1.3%) were excluded. As a result, 3.3% of total trials in the saccade condition were discarded.

Manual RT of attention task condition. RTs of correct trials were further trimmed to exclude those over three standard deviations. Mean RTs of the remaining trials for each trial type in the attention task condition are summarized in the middle left panel of Figure 5. A 2 × 2 analysis of variance (ANOVA) with variables of onset and color on data from 26 participants revealed a main effect of color, $F(1, 25) = 18.53$, $MSE = 150.5703$, $p < .001$, and an interaction between color and onset, $F(1, 25) = 6.98$, $MSE = 124.3538$, $p < .05$. Analyses of simple effects showed that the interaction was due to a significant delay (8 ms) caused by onsets on trials with no color distractor, $F(1, 25) = 8.01$, $MSE = 124.3538$, $p < .01$, that was absent on trials with a color distractor ($p > .3$). In addition, the presence of a color distractor also significantly reduced response accuracy, $F(1, 25) = 5.62$, $MSE = 0.0009$, $p < .01$. No other effect was found in the accuracy results.

Saccade paths. Saccade paths were computed as in Experiment 1 and are summarized in the left panel of Table 1 and the upper middle panel of Figure 2. In the no-distractor condition, about 80% of saccades were correctly made toward the target. In the onset-only distractor condition, approximately 10% of first

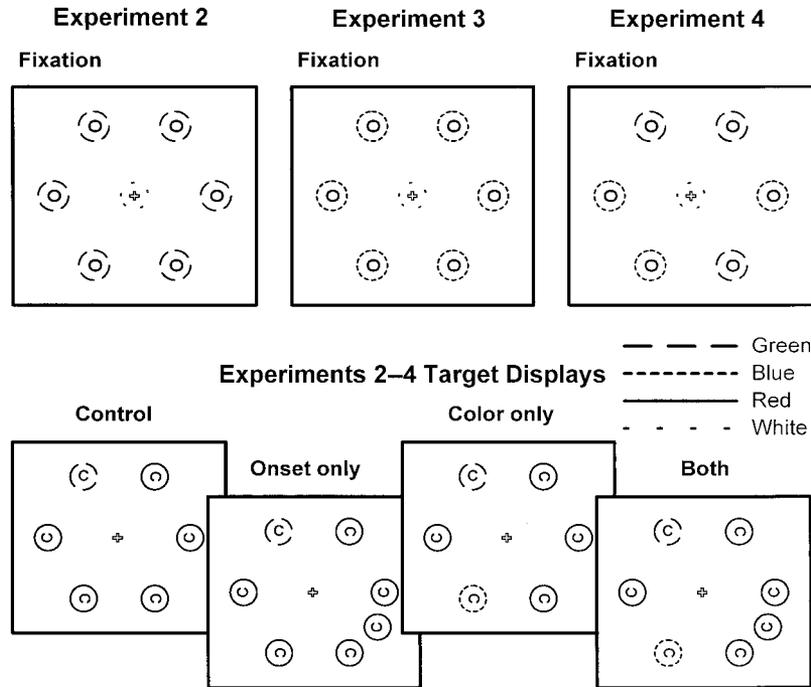


Figure 6. Fixation and target displays for Experiments 2–4. Note that Experiments 2–4 had identical target displays; they differed only in the composition of the fixation display.

fixations fell near the path toward the distractor. In the color-only distractor condition, approximately 20% of first fixations fell near the path toward the color distractor. When both onset and color distractors were present, color distractors attracted significantly more saccades (21%) than onset distractors (9%), $t(7) = 3.47, p < .05$.¹

Saccade latency. Table 2 shows averaged median latency results by distractor condition and saccade destination. A 2×2 ANOVA with variables of color and onset found a main effect of color, $F(1, 7) = 6.24, MSE = 68.1974, p < .05$; the presence of a color distractor delayed saccades made correctly toward the target. In all conditions when oculomotor capture by distractors occurred, latencies of the erroneous saccades regardless of distractor type were always significantly shorter than those made correctly toward the target; for the onset-only condition, $t(7) = 4.49, p < .01$, and for the color-only condition, $t(7) = 5.40, p > .005$. In the condition in which both distractors were present, latencies of saccades toward onset distractors appeared to be shorter than those of saccades toward color distractors, but the difference did not reach statistical significance, $t(7) = 2.21, p > .05$.

Fixation duration following captured saccades. Fixation duration measured the time elapsed between the end of an erroneous saccade toward a distractor and the onset of the subsequent correction saccade toward the target. Averaged median latency results are summarized next to their respective fixation targets in Table 2. It is evident that most of these durations were shorter than what is usually required for the programming of a voluntary saccade.

Manual RT of saccade task condition. Because manual responses could only be made after gaze has reached the target, manual RTs in the saccade task condition are to a large extent

contingent on the pattern of eye movements on a given trial. RTs should be longer when the eyes went first to a nontarget location. This was exactly what happened; manual RTs were 830 ms following correct saccades to the target and delayed by another 100 ms if the eyes initially went to a distractor. No other difference was found in manual RTs following correct saccades in different distractor conditions. RTs were also analyzed according to distractor conditions with no regard to first saccade destinations, in a way analogous to the analysis of manual RTs in the attention task condition. Mean RTs (three standard deviations trimmed) of correct responses for each distractor condition in the saccade task condition are summarized in the middle left panel of Figure 3. A 2×2 ANOVA with variables of onset and color found only a main effect of color, $F(1, 7) = 17.07, MSE = 495.2427, p < .005$. Color distractors not only captured the eyes on a proportion of trials but also delayed manual responses overall.

Discussion

Experiment 2 found little evidence of attentional capture by abrupt onsets when conditions favored feature search mode. The presence of an onset distractor failed to produce attentional capture when the color target lost its singleton status as a result of the inclusion of trials containing another uniquely colored item. The

¹ Because of the addition of color distractor conditions, it was not possible to obtain sufficient observations among oblique saccades to provide reliable trajectory information. Saccade trajectories were therefore not analyzed in subsequent experiments.

Table 1
Proportions of First Saccades Directed Toward the Target and Elsewhere (Else) by Distractor Conditions in Experiments 2–5

Distractor condition	Experiment 2		Experiment 3		Experiment 4		Experiment 5	
	Target	Else	Target	Else	Target	Else	Target	Else
Control	0.81	0.19	0.83	0.17	0.78	0.22	0.79	0.21
Onset only	0.69	0.20	0.69	0.10	0.68	0.18	0.72	0.15
Color only	0.60	0.20	0.84	0.14	0.78	0.18	0.71	0.18
Both	0.53	0.17	0.64	0.08	0.68	0.15	0.60	0.16

contingency on task goals observed here supports other findings showing that onsets only capture attention when they fit the current attentional control settings and extends Bacon and Egeth's (1994) findings based on color distractors and form targets. This result suggests that previous findings of attentional capture by onset distractors (Irwin et al., 2000; Theeuwes, 1994; Theeuwes et al., 1998) can be attributed to singleton detection mode rather than pure stimulus-driven capture.

Despite the elimination of attentional capture, results from the saccade task showed evidence of reduced but residual oculomotor capture by abrupt onsets. Compared with Experiment 1, oculomotor capture was reduced, from 27% (Experiment 1) to 10%, but not completely eliminated.² On the one hand, this correspondence between the magnitude of attentional capture and the rate of oculomotor capture indicates that oculomotor capture is also in part contingent on attentional control settings. On the other hand, the residual oculomotor capture despite the absence of attentional capture is evidence of a dissociation between attention and oculomotor capture. The persistence of oculomotor capture by abrupt onsets in conditions analogous to those that produce no attentional capture suggests that the saccade system may be more sensitive to transients than the attention system. Apparently, top-down modulation due to the instruction to saccade produces an attentional and oculomotor set that differs from that produced when the instruction is to attend only. The relationship of this form of top-down modulation and that associated with singleton and feature modes is not yet known.

Analysis of the trials that showed oculomotor capture indicates that characteristics of the erroneous saccades were similar to those observed previously (Irwin et al., 2000; Theeuwes et al., 1998, 1999). Latencies of saccades made toward the abrupt onset were uniformly shorter than those made toward the target. Once a

saccadic error occurred, the gaze generally remained on the onset item for a period of time shorter than what would be needed for the programming of a new saccade.

It is assumed that the elimination of attentional capture and the reduction of oculomotor capture by abrupt onsets were due to the use of feature search mode. To be qualified as a mode of operation, feature search should be characteristic of all trials within a block, regardless of whether the target is a singleton or nonsingleton. Empirically, this held true in the saccade condition, as reflected in the similarly small proportion of saccades captured by onsets with and without a color distractor, and in the absence of delays in manual responses by onsets in the same conditions. However, in the attention condition we observed capture by onsets on trials with a singleton target (i.e., no color distractor) that was not present on trials with a nonsingleton target (i.e., with a color distractor). Because the attention task condition was always presented first, it is possible that attentional capture by onsets was present only early in practice. We tested for practice effects by comparing data from the first and second half of the session. Mean RTs are depicted in Figure 7. It is evident that significant attentional capture by onset distractors in singleton conditions occurred only in the first half of the session. A 2×2 ANOVA on the second half of the data that showed only a main effect of color, $F(1, 25) = 14.94$, $MSE = 227.4051$, $p < .001$, confirmed this observation. This finding argues that the distinction between singleton and feature search mode can be generalized to different stimulus properties and applied to attentional as well as oculomotor capture. In addition, the adoption of a particular mode of search appears to be a gradual rather than instantaneous process. The absence of attentional and oculomotor capture on trials with no color distractors also argues against any heterogeneity-based accounts. With the addition of a color distractor on nonsingleton target trials, increased heterogeneity among nontarget items may have rendered abrupt onsets less salient and consequently reduced their ability to capture attention and the eyes. No such argument can be made for singleton target trials. Abrupt onsets on these trials appeared against the same homogeneous background, just as in Experiment 1, and yet produced no capture. This finding supports the existence of a top-down attentional mode based on features, which

Table 2
Saccade Latencies (in Milliseconds) by Direction of First Saccades and Distractor Conditions and Fixation Duration (in Parentheses) by Distractor Type in Experiment 2

Distractor condition	Direction of first saccades			
	Target	Onset	Color	Elsewhere
Control	286	—	—	174
Onset only	271	203 (73)	—	209
Color only	289	—	223 (50)	236
Both	283	194 (87)	220 (74)	225

Note. Dashes indicate that the saccade latency was not measured.

² In the control condition, the eyes went elsewhere on about 20% of the trials. That is, each nontarget location has a base rate of 4% to 5% to be the destination of a saccade. Elimination of oculomotor capture means that the proportion of saccades that goes to a particular distractor item does not exceed chance level.

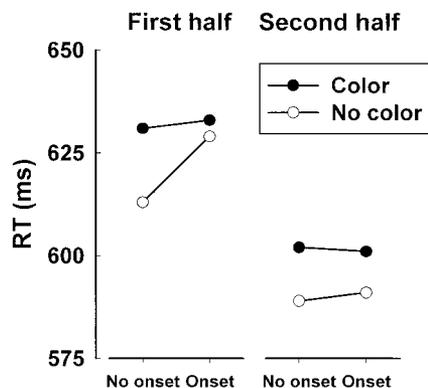


Figure 7. Manual response times (RTs) of the attention task condition in Experiment 2, broken down by first and second halves of session.

is capable of overriding stimulus-driven attentional and oculomotor capture and can be sustained over trials.

The logic of encouraging feature search mode applied by Bacon and Egeth (1994) concerns making singleton detection strategy ineffective. In theory, singleton strategy would be ineffective if either the target or singleton distractor lost its singleton status. Empirical evidence shows, however, that singleton detection mode could only be rendered ineffective by removing the singleton status of the target. In an oculomotor capture experiment with a design similar to that of Theeuwes et al. (1998, 1999), Kramer, Cassavaugh, Irwin, Peterson, and Hahn (2001) asked participants to search for a color singleton target in the presence of either zero, one, or two irrelevant onset distractors. They found that oculomotor capture occurred on 21% to 26% of the trials with two onsets, comparable with and not statistically different from the 25% to 31% rates found for trials with one onset. In our Experiment 2, adding a color singleton greatly reduced the rate of oculomotor capture. It is clear that adding another onset singleton did not have the same effect as adding a unique color singleton. This finding suggests that in the present experiments, it is setting attention for features that prevented capture by onsets, not simply removing conditions favoring singleton detection.

Insofar as there exists an attentional mode based on features, the question remains whether it is based on target feature value. The presence of a color distractor on a proportion of trials meant that uniqueness in color dimension was an unreliable predictor of target location. In theory, attention would operate more efficiently if set for the target color value. The finding that the color distractor caused significant interference in attention and saccade conditions, however, suggests the set adopted could not always reliably distinguish between different unique colors. Thus, the feature-based mode exhibited in the present results does not seem to fit the existent definition of feature search mode, which according to Bacon and Egeth (1994) refers to a mode wherein observers monitor "a specific feature map that codes for the presence of the relevant feature" (p. 486). However, it is questionable whether feature search mode was ever attained in Bacon and Egeth's results. For example, in their Experiment 3, observers searched for a specific form (circle) in the presence of up to two unique forms (square and triangle) among a background of diamond forms. Although the search process appeared to proceed in parallel even

with increasing numbers of diamonds, the overall search process was delayed with increasing numbers of unique forms. Bacon and Egeth (1994) regarded this effect as a consequence of increasing distractor heterogeneity (cf. Duncan & Humphreys, 1989). Nevertheless, if attention was indeed set on the target feature value (circle), the search process should have remained parallel even with increasing numbers of unique forms.

Based on the similarity between the findings from the present research and those of Bacon and Egeth's (1994), we use the term *feature search mode* to describe the set adopted for nonsingleton targets, even though the set appears to be for feature category rather than value. It is not clear why participants were not able to set for the target feature value in the present research, especially because Folk and Remington (1998) reported color selectivity in the search for color singleton targets. We think the discrepancy may be rooted in the different ways in which distractors are implemented in these two studies. Further research is required to clarify this inconsistency.

As the feature mode adopted by participants appeared to be based on feature category, interference caused by color distractors could then naturally be viewed as capture. Characteristics of the observed erroneous saccades are also in accord with involuntary capture; saccades made toward the color distractors were fast with very brief fixations before subsequent correction saccades, just as those signifying oculomotor capture by abrupt onsets (cf. Theeuwes et al., 1998). Our findings that irrelevant color distractors can capture attention and the eyes are at odds with Irwin et al.'s (2000) results. The discrepancy may be attributed to the fact that for those experiments in which Irwin et al. failed to observe color capture, the targets were onset singletons. Because the saccade system appears to be especially susceptible to abrupt onsets, as the present results suggest, it is possible that the combination of bottom-up and top-down emphasis on onsets precluded interference from otherwise salient distractors. The effect of transients on saccades and attention is explored further in the following experiments.

Experiment 3

Experiment 2 found attentional and oculomotor capture by color distractors that we attributed to a match between the stimulus property of the distractor and the attentional control setting adopted in feature search mode. There is an alternative explanation, however. The color distractor involved a transient change in color. There is evidence that equiluminant chromatic changes capture attention even when the target is defined by onset (Snowden, 2002). One could also argue that the color distractor captured attention and the eyes not simply because it fitted the attentional set for color but because its color change rendered it more salient than the target or the onset. This account is consistent with Theeuwes (1992, 1994), who has argued that attentional capture is determined by the relative salience between the distractor and the target. Theeuwes (1994) reported that when abrupt onsets defined targets, transient color singleton distractors produced attentional capture but static ones did not. On the basis of these results, one could conclude that transient color singletons and abrupt onsets exude a higher level of salience than static color singletons.

Experiment 3 was designed to investigate the role of salience by eliminating transient change as a property of the color distractor. In

Experiment 3, the initial circles were the color of the color distractor (blue) instead of the color of the target (green). The target was still in the green circle among red ones. On some trials a blue color distractor was present. As a result, the target appeared through a transient change in color from blue to green, whereas the color distractor, when presented, remained statically blue. Hence their relative salience should be reversed from that in Experiment 2.

There could be a number of outcomes surrounding the color distractor. First, if visual salience is essential to the capture of attention and saccades by color distractors in Experiment 2, this modified procedure should virtually eliminate that capture. If color contingency is a critical property of the operative set, color capture should remain. As for the onset distractor, according to the contingent capture theory, it should now elicit attentional capture because the emergence of the target involves change, as does the emergence of the abrupt onset items. There should also be a correspondingly higher rate of oculomotor capture than observed in the previous experiment.

Method

Participants. Twenty-six new individuals participated in the experiment. Eighteen completed the attention task condition; 8 completed the saccade task condition. All of the participants met the same requirements as in Experiment 1.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Design and procedure. The design and procedure were identical to those of Experiment 2 except that the circles in the initial display were blue instead of green (see Figure 6, upper middle panel). As a result, the color target went through a transient change from blue to green and the color distractor remained statically blue.

Results

For the attention task condition, trials with incorrect responses or RTs longer than 1,000 ms were excluded from further analyses; such trials accounted for 9% of total trials. For the saccade condition, trials with incorrect manual responses (2%) or of indecipherable eye movement patterns (3%) were excluded. As a result, 5.4% of total trials in the saccade condition were discarded and not analyzed further.

Manual RT of attention task condition. Mean RTs of correct responses for each trial type in the attention task condition are summarized in Figure 5. A 2×2 ANOVA with variables of onset and color distractors on data from 18 participants revealed main effects of color, $F(1, 17) = 9.18$, $MSE = 118.7813$, $p < .01$, as well as onset, $F(1, 17) = 5.42$, $MSE = 236.9449$, $p < .05$. No interaction was found between the two variables. No effect was found either in the accuracy results, also shown in Figure 5.

Saccade paths. The middle panel of Table 1 and the lower middle panel of Figure 2 present, in each distractor condition, the proportions of first saccades made toward each of the four possible destinations. The results showed clear oculomotor capture by onset distractors (23%), none by color.

Saccade latency. Averaged median latency results by distractor condition and saccade destination are summarized in Table 3. There was no difference between latencies of saccade made directly toward the target in different distractor conditions. Latencies

Table 3
Saccade Latencies (in Milliseconds) by Direction of First Saccades and Distractor Conditions and Fixation Duration (in Parentheses) by Distractor Type in Experiment 3

Distractor condition	Direction of first saccades			
	Target	Onset	Color	Elsewhere
Control	241	—	—	218
Onset only	240	204 (69)	—	223
Color only	242	—	—	218
Both	239	189 (71)	—	223

Note. Dashes indicate that the saccade latency was not measured.

of saccade directed toward the onset distractor were uniformly shorter than those toward the target, regardless of the state of the color distractor.

Manual RT of saccade task condition. Mean manual RTs were 790 ms following correct saccades and delayed by 90 ms when the eyes went initially to the onset distractor. No difference was found following correct saccades in different distractor conditions. When analyzed by distractor conditions without regard to first saccade destinations (data shown in Figure 3, middle panel), results of a 2×2 ANOVA with variables of onset and color revealed a main effect of onset, $F(1, 7) = 7.83$, $MSE = 422.5241$, $p < .05$. The presence of onset distractors caused oculomotor capture on a significant proportion of trials, which led to the overall lengthening of manual RTs in respective conditions.

Discussion

Results of the attention task condition challenge the contribution of visual salience to attentional capture. Attention was captured by an unchanged unique color item even when the intended target was prominently signaled by a transient change into another unique color. Consistent with predictions of contingent capture, abrupt onset items now produced significant attentional capture. This outcome is similar to Folk et al.'s (1992) finding that identity discrimination targets presented as onsets are susceptible to interference from onset distractors. The color distractor shared color but not change with the target, whereas the onset distractor shared change but not color. Because both color and onset distractors produced capture, we conclude that a complete match between stimulus and attentional control settings is not necessary to elicit capture.

The saccade task condition returned some rather unexpected outcomes. In previous research, oculomotor capture has always been observed in conjunction with attentional capture, supporting theories of oculomotor capture that hypothesize that the programming and execution of reflexive saccades are initiated by reflexive shifts of attention (e.g., Theeuwes et al., 1999). The present experiments found positive support for this hypothesis from the finding that both the eyes and attention were captured by singleton distractors when they were consistent with task goals. However, Experiment 2 and Experiment 3 both found dissociations between attention and saccades. In Experiment 2, onset distractors produced a residual oculomotor capture in saccade conditions but failed to produce attentional capture in no-saccade conditions. In

Experiment 3, static color distractors produced significant attentional capture but no oculomotor capture. A similar dissociation between attention capture and inhibition of return has been observed by Gibson and Amelio (2000); singleton color cues that fitted attentional control settings and produced significant attentional capture failed to elicit inhibition of return. Saccades, and perhaps inhibition of return, exhibit a dependency on and sensitivity to transients not characteristic of attention.

Experiment 4

Experiment 3 showed that unique color distractors captured attention under an attentional set for color even when they appeared static and undoubtedly less salient than the target, but the capture of attention was not accompanied by a corresponding capture of the eyes. We hypothesize that the triggering of oculomotor capture requires transient changes in distractors. There is, however, another possibility. If the saccade system is more susceptible to the influence of salient stimulus properties, then having a target that was more salient than the distractor may simply have prevented oculomotor capture by the weaker color distractor. Experiment 4 was conducted to distinguish between these two possibilities.

In Experiment 4, salience of the target and distractor was equated by making both of them static. This was achieved by modifying the initial display to consist of an equal number of green and blue circles. The target display emerged when both nontarget and nondistractor circles turned red. The task still required the search for a green target circle among red ones, in the likely presence of a blue distractor and a red onset. The target was chosen from one of the original green circles, and the color distractor from one of the original blue circles. As a result, on trials with a color distractor, both target and distractor remained unchanged throughout the trial. Because the target now was a color singleton but had no transient change associated with it, contingent capture theory would predict attentional capture by the color distractor but not by the onset distractor. Conversely, a salience account would predict strong capture by the onset because, with both the target and color distractors being static, the onset distractor became the most salient unique item on the display. If oculomotor capture follows the same pattern as attentional capture, the static color distractor should produce oculomotor capture. If, however, a transient change is critical to triggering oculomotor capture, the onset distractor should elicit involuntary saccades, and we should observe a dissociation between attention capture and oculomotor capture.

Method

Participants. Twenty-eight individuals participated in the experiment. Twenty completed the attention task condition; 8 completed the saccade task condition. All of the participants met the same requirements as in Experiment 1.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Design and procedure. The design and procedure were identical to those of Experiment 2 except that the circles on the initial display were mixes of equal numbers of blue and green (see Figure 6, upper right panel). It was constrained so that no three consecutive circles were of the same color. The target and distractor appeared at locations previously occupied by the same color. The arrangement allowed both the target and distractor

to remain static. The participants were only told to locate the green target; they were not informed of its relation with the three initial green circles.

Results

For the attention task condition, trials with incorrect responses or RTs longer than 1,000 ms were excluded from further analyses; such trials accounted for 8% of total trials. For the saccade condition, trials with incorrect manual responses (3%) or of indecipherable eye movement patterns (9%) were excluded. As a result, 12% of total trials in the saccade condition were discarded and not analyzed further.

Manual RT of attention task condition. Mean RTs of correct responses for each trial type in the attention task condition are summarized in the right panel of Figure 5. A 2 × 2 ANOVA with variables of onset and color distractors on data from 20 participants revealed a main effect of color, $F(1, 19) = 6.76$, $MSE = 161.8963$, $p < .05$. No other effect was found. In the accuracy results, also shown in Figure 5, a 2 × 2 ANOVA with variables of onset and color revealed a main effect of onset, $F(1, 19) = 4.75$, $MSE = 0.0004$, $p < .05$; onset distractors significantly reduced response accuracy.

Saccade paths. The upper right panel of Figure 2 and the right panel of Table 1 present, in each distractor condition, the proportions of first saccades made toward each of the four possible destinations. The results showed a clear influence by onset distractors and none above chance by color. The presence of an onset item distracted around 13% of saccades on average.

Saccade latency. Averaged median latency results by distractor condition and saccade destination are summarized in Table 4. Latencies of saccades made toward the target were affected by the presence of an onset distractor, revealed by a 2 × 2 ANOVA with variables of onset and color, $F(1, 7) = 6.76$, $MSE = 349.4179$, $p < .05$. Correct saccades toward the target were faster in the presence of onset distractors. Latencies of saccade directed toward the onset distractor were uniformly shorter than those toward the target, regardless of the state of the color distractor.

Manual RT of saccade task condition. Mean manual RTs were 910 ms following correct saccades and delayed by 180 ms if the eyes went initially to the onset distractor. No difference was found in manual RTs following correct saccades in different distractor conditions. When analyzed according to distractor conditions with no regard to first saccade destinations, results of a 2 × 2 ANOVA with variables of onset and color revealed a main effect of color,

Table 4
Saccade Latencies (in Milliseconds) by Direction of First Saccades and Distractor Conditions and Fixation Duration (in Parentheses) by Distractor Type in Experiment 4

Distractor condition	Direction of first saccades			
	Target	Onset	Color	Elsewhere
Control	334	—	—	313
Onset only	315	264 (114)	—	271
Color only	338	—	—	260
Both	323	265 (121)	—	264

Note. Dashes indicate that the saccade latency was not measured.

$F(1, 7) = 6.10$, $MSE = 1,002.6422$, $p < .05$. The presence of color distractors, although causing no significant oculomotor capture, delayed manual responses.

Discussion

The pattern of RT results from the attention task condition was similar to the second half of Experiment 2. Consistent with the contingent capture theory, there was attentional capture by color distractors but not by onset distractors. The pattern for oculomotor capture differs from the pattern for attentional capture. Color distractors failed to produce oculomotor capture, replicating Experiment 3 and confirming the crucial involvement of transient changes in triggering oculomotor capture. Onset distractors produced minimal oculomotor capture, replicating that of Experiment 2 and demonstrating again that oculomotor capture is contingent on attentional control settings. The fact that onset distractors in the present experiment were most salient on the display and produced little interference in the absence of any other substantial distraction strengthens the case for contingent capture even further. The presence of residual oculomotor capture by abrupt onsets here and in Experiment 2, despite an absence of attentional capture, suggests that transient change has a heightened effect on orienting when participants are prepared to make a saccade.

As shown in Figures 3 and 5, Experiment 4 found faster manual responses in the attention task condition and slower latencies in the saccade task condition than observed in our earlier experiments. A possible explanation for the difference is the reduced uncertainty regarding target location. Although the participants were not explicitly informed of the special relation between the target and the composition of the initial display, nothing prevented them from realizing the relation and using that knowledge. If participants could restrict their attention to a reduced set of items by focusing on target color, they would be able to locate and respond to the target faster. This explanation would be consistent with the finding of faster RTs in the attention task condition. However, as uncertainty about target location was reduced, uncertainty about the location of the color distractor was reduced as well. If the uncertainty levels associated with target and distractor locations were to have any effect, they should work to reduce attentional capture by color distractors. The fact that attentional capture by color distractors remained at approximately the same level suggests that this aspect of the design did not cause spurious results.

Experiment 5

Experiment 5 was designed to ensure that the pattern of results from the previous experiments would be observed when noncritical design features were changed. One concern is that to avoid confusion over the categorization of saccade destination, abrupt onsets have so far never appeared at the 30° locations next to a target. This manipulation may have reduced the uncertainty of target location if onsets were detected first and therefore inadvertently facilitated target localization. As a result, attentional and oculomotor capture may have been reduced not because of the use of feature search mode but rather the use of voluntary allocation of attention (e.g., Theeuwes et al., 1998, Experiment 2). To address this, Experiment 5 lifted the restriction on where abrupt onsets

could appear in relation to a target. A second concern is that in all previous experiments the target circle contained a letter *C* rotated in either 0° or 180° while the rest of the circles contained a letter *C* rotated either 90° or 270°. It may be argued that the difference in gap orientation served as a preattentive cue that helped localize the target, thus reducing the effectiveness of onset (but apparently not color) cues. In Experiment 5, all circles contained a letter *C* rotated 0° or 180°; hence the target could only be located through its unique color. Finally, in previous experiments eye positions were not monitored in the attention task condition, though brief exposure time was used to minimize potential eye movements. In this experiment we monitored eye positions in the attention condition to ensure that the observed effects in the attention condition were not due in fact to eye movements.

Method

Participants. Twenty-eight individuals participated in the experiment. Twenty completed the attention task condition; 8 completed the saccade task condition. All were recruited from the same participant pool and met the same requirements as in Experiment 1.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Design and procedure. The design and procedure were identical to those of Experiment 2 except for the following changes. First, the onset distractor could appear 30°, 90°, 150°, 210°, 270°, or 330° counterclockwise from the target, resulting in angular distances 30°, 90°, and 150°. The 30° distance corresponded to 5.22° of visual angle in the saccade task condition and 1.76° in the attention task condition. Second, on target displays, all circles contained a letter *C* rotated either 0° or 180°. Third, eye position was monitored in the attention condition.³

Results

For the attention task condition, trials with incorrect responses or RTs longer than 1,000 ms were excluded from further analyses; such trials accounted for 7.7% of total trials. For the saccade condition, trials with incorrect manual responses (1%) or of indecipherable eye movement patterns (3%) were excluded. As a result, 4% of total trials in the saccade condition were discarded and not analyzed further. In addition, trials with onsets at 30° were excluded from analyses in both task conditions to maintain comparability of the present results with those of previous experiments.

Manual RT of attention task condition. Mean RTs of correct responses for each trial type in the attention task condition are summarized in the right panel of Figure 5. A 2 × 2 ANOVA with variables of onset and color distractors on data from 20 participants revealed a main effect of color, $F(1, 19) = 15.82$, $MSE = 241.5857$, $p < .001$. No other effect was found. An additional 2 × 2 ANOVA was carried out for trials on which fixation was

³ During the course of the study, we realized that some participants had difficulty maintaining fixation at the central cross; thus the last 5 of the 20 participants in the attention condition were run in a modified version of the experimental program that issued warnings of deviated eye fixation should such instance occur three trials in a row.

maintained.⁴ Results again showed only a main effect of color, $F(1, 19) = 17.78$, $MSE = 202.2948$, $p < .001$. The accuracy results, also shown in Figure 5, are based on all trials with no regard to eye positions, as in previous experiments. A 2×2 ANOVA with variables of onset and color revealed a main effect of onset, $F(1, 19) = 5.21$, $MSE = 0.0010$, $p < .05$, and an interaction between onset and color, $F(1, 19) = 4.88$, $MSE = 0.0005$, $p < .05$. The nature of the interaction was explored with analyses of the simple effects; results showed that the interaction was due to significant performance decrement caused by onsets on trials with no color distractors, $F(1, 19) = 13.75$, $MSE = 0.0005$, $p < .005$. This accuracy effect appeared to be confined to 3 participants whose accuracy dropped 10% in the onset-only condition. When data from those 3 participants were excluded, accuracy effects disappeared, but the RT data continued to show effects of color, $F(1, 16) = 12.73$, $MSE = 228.9614$, $p < .005$, with no effect of onset.

Saccade paths. The results of saccade path analyses are summarized in the rightmost panel of Table 1 and the lower right panel of Figure 2. Similar to Experiment 2, about 80% of saccades were correctly made toward the target in the control conditions. Onset and color distractors captured approximately 12% of saccades when presented singly. When presented jointly, onset and color distractors captured approximately 10% and 14% of saccades, respectively, and a marginally significant difference was found between their rates of capture ($p < .09$).

Saccade latency. Averaged median latency results by distractor condition and saccade destination are summarized in Table 5. There was no difference between latencies of saccade made directly toward the target in different distractor conditions. Erroneous saccades directed toward distractors, whether onset or color, had latencies significantly shorter than correct saccades in the same conditions; $t(7) = 5.40$, $p < .001$, for the onset-only condition, and $t(7) = 3.72$, $p < .01$, for the color-only condition. In the condition in which both distractors were present, latencies of saccades toward onset distractors appeared to be shorter than those of saccades toward color distractors, but the difference did not reach statistical significance, $t(7) = 1.00$, $p > .15$.

Manual RT of saccade task condition. Mean manual RTs were 880 ms following correct saccades and delayed by approximately 100 ms when the eyes went initially to a distractor. No difference was found following correct saccades in different distractor conditions. When analyzed according to distractor conditions with no

regard to first saccade destinations, results of a 2×2 ANOVA with variables of onset and color revealed a marginal effect of color, $F(1, 7) = 5.32$, $MSE = 591.2767$, $p < .06$.

Discussion

The results of Experiment 5 essentially replicated those of Experiment 2. In the attention task condition, when analyzed with no regard to eye positions as in previous experiments, results showed significant attentional capture by color distractors and none by onset distractors. The same pattern of results was obtained on those trials on which fixation was maintained within a criterion surrounding fixation. In the saccade task condition, oculomotor capture by onset distractors was again largely reduced, compared with Experiment 1. Color distractors also produced significant oculomotor capture, though the rate of capture appeared to be lower than that of Experiment 2. Together, these results again refute the notion that abrupt onsets invariably capture attention with no regard to top-down attentional control settings. Instead, the current attentional control setting determines what feature properties will capture attention.

General Discussion

The visual search experiments reported here examined the involuntary responses of the eyes and spatial attention to abrupt onset and color singleton distractors. Attentional capture was assessed by RT differences in no-saccade conditions, and oculomotor capture was assessed by the proportion of first saccades to the distractor in saccade conditions. Across the five experiments, we have shown that there are contingencies and dissociations between attentional and oculomotor capture. Although both were mediated by top-down attentional control settings, oculomotor capture was observed only for stimuli with transient properties. We discuss these results by focusing on how different visual properties, specifically abrupt onsets and color singletons, affect attentional and oculomotor capture under different search modes and task demands.

Contingencies in Oculomotor and Attentional Capture

Capture by onsets. According to Irwin et al. (2000) and Theeuwes et al. (1998, 1999), oculomotor capture occurs because attention has been captured. Hence, they interpret oculomotor capture by abrupt onsets but not color to mean that abrupt onsets are special stimuli with regard to attentional capture. However, our

Table 5
Saccade Latencies (in Milliseconds) by Direction of First Saccades and Distractor Conditions and Fixation Duration (in Parentheses) by Distractor Type in Experiment 5

Distractor condition	Direction of first saccades			
	Target	Onset	Color	Elsewhere
Control	300	—	—	277
Onset only ^a	296	222 (81)	—	266
Color only	292	—	245 (70)	268
Both ^a	294	230 (76)	234 (71)	271

Note. Dashes indicate that the saccade latency was not measured.

^a Trials with onsets at 30° were not included.

⁴ Fixation was considered maintained when no saccadic eye movement was detected, or when detected, the endpoint of the first movement from fixation did not go beyond one half of the display radius (3.4°). The proportions of fixated trials varied from 55% to 95% among participants. We analyzed the distribution of eye movement endpoints on fixated (included) and moved (excluded) trials in the onset-only condition to determine whether the excluded trials consisted of mostly trials with eye movements to onsets. The analysis was conducted on the basis of the collective data from all participants. On fixated trials with detected saccadic eye movements (~31%), 53% of the eye movements went to target, 7% to onset, and 40% to elsewhere. On moved trials, 49% of the eye movements went to target, 14% to onset, and 37% to elsewhere. It is evident that on most excluded trials the eyes went to the target.

results showed that abrupt onsets captured attention only when they conformed to behavioral goals. Specifically, the significant attentional capture observed under singleton detection mode (Experiment 1) was eliminated simply by the presence of another uniquely colored singleton distractor (Experiments 2, 4, and 5). Note that the modulating effects of target–distractor contingencies in Experiments 2, 4, and 5 can be confidently attributed to a set adopted by the participants; the same onset distractor displays that elicited capture in Experiment 1 failed to do so when intermixed with color singleton distractor trials. Further, the extent to which the additional color distractor modulated attentional capture by abrupt onsets depended on target properties. The same static color distractor that eliminated capture in Experiment 4 exhibited no modulating effects when the color target was accompanied by a transient change in Experiment 3.

Oculomotor capture for onsets followed a pattern similar to attentional capture. The rate of oculomotor capture by abrupt onsets in saccade conditions varied according to the magnitude of attentional capture measured in no-saccade conditions. When attention was captured by abrupt onsets (Experiments 1 and 3), oculomotor capture by abrupt onsets was substantial. When attention was not captured by onsets (Experiments 2, 4, and 5), oculomotor capture by onsets was greatly reduced. These results suggest that oculomotor capture is also modulated by top-down attentional control settings. However, saccadic control appears to be more sensitive than attention to luminance transients; residual oculomotor capture by abrupt onset distractors persisted despite the absence of attentional capture in corresponding no-saccade conditions. We discuss below the failure of static stimuli to elicit oculomotor capture even when they elicit attentional capture.

Overall, the modulation of the capture produced by abrupt onsets for both attention and saccades follows a pattern of contingent capture similar to that observed in spatial cuing experiments (Folk et al., 1992). Here we demonstrate the same contingencies in visual search experiments. The design of our experiments follows closely those conditions from which claims of stimulus-driven capture have been based (e.g., Irwin et al., 2000; Theeuwes et al., 1998, 1999). By altering the composition of trials, we found that abrupt onsets only capture attention when they share relevant properties with the target, which could be a singleton status (Experiment 1) or a property reliably associated with the target (Experiment 3) in feature search mode. By demonstrating contingencies in a visual search paradigm, we have countered possible objections to contingent capture arising from the use of the spatial cuing paradigm.

Capture by color singletons. Attentional capture by color singletons observed in Experiments 2–5 is consistent with contingent capture predictions, given that feature mode was expressed here not in terms of feature value but feature dimension (color). The case for contingent attentional capture in general is further strengthened by findings in the present study that salience per se did not determine whether the distractor would capture attention. We use salience here to refer to the physical distinctiveness of the stimulus, which includes the magnitude of luminance change for onset, as well as uniqueness on the color dimension. Though no metric exists for equating the salience of onsets versus color singletons, our results show no pattern that could be easily interpreted as support for salience in determining capture. For example, it would be reasonable to expect that static color singletons should

be less salient than transient color singletons produced by changing the color from the previous display. Nonetheless, in Experiment 3, static color distractors captured attention when the target was prominently defined by a transient color change. The luminance change associated with abrupt onsets would be expected to make them more salient than the static color singletons. Yet, in Experiment 4, the onset distractor failed to elicit any attentional capture, though again it did produce a residual oculomotor capture. It is clear that the physical properties of the stimulus alone do not appear sufficient to produce involuntary covert orienting, at least within the limits of intensity and color differences used here. Indeed, evidence from single neuron recording in primate visual cortex (area V4) shows that salience may be determined not simply by physical properties but also by top-down set (see Treue, 2001, for a review).

Patterns of oculomotor capture to color singletons did not show such a clear contingency on task goals as observed with onset singletons. Oculomotor capture by color singletons occurred only when the color singleton had a transient property, as when it changed color. Our data indicate that color alone is not an effective stimulus for eliciting involuntary saccades. However, color must have some effect in modulating oculomotor capture. If oculomotor capture responds only to transients, there should have been no effect of the color of a transient stimulus; capture should occur to the strongest transient, likely the onset. There is no evidence for this in our data. Oculomotor capture by onsets in feature search conditions never exceeded that of the transient color distractor. In Experiment 2, the capture rates for transient color singletons were ~20%, compared with ~11% for abrupt onsets. In Experiment 5, the proportions of capture by onsets and transient color singletons were approximately equal. Why do we not see more oculomotor capture to the more salient transient onset? One explanation is that the contingencies associated with attention are modulating the response of the oculomotor system. Because attention responds to the color, in accord with task goals, it inhibits the tendency to move the eyes to the onset.

Summary. The present results provide answers to the three questions outlined earlier. Our results do not support the claim that onsets are special in the sense of being sufficient to capture attention regardless of attentional set. Our results, however, do support a special role for transient stimulation (luminance transients or color change) in producing oculomotor capture. Residual rates of oculomotor capture by onsets suggest a heightened sensitivity to onsets in eye movement conditions. The presence of substantial oculomotor capture to transient color singletons but not static color singletons suggests that transient change may be a necessary condition. Hence, the stimulus properties that elicit oculomotor capture are not identical to those that elicit attentional capture. Although both are contingent on top-down settings, attention and saccades can be dissociated in the patterns of their involuntary responses to static and transient stimuli. In summary, our results do not support the claim that oculomotor capture (and hence attentional capture) is purely stimulus driven. We argue that earlier claims for an absence of top-down modulation (Irwin et al., 2000; Theeuwes et al., 1998, 1999) failed to consider the effects of search mode on attentional control settings.

One issue worth further discussion is the small effect size (around 10 ms) of attentional capture found consistently throughout all of the experiments, especially in Experiment 1. Theeuwes

(1994) reported an effect size of 50 ms for attentional capture by onset distractors in the search for a static color singleton target. Others have reported effect sizes around 25 ms for singleton capture conditions that involved form targets and color distractors (Bacon & Egeth, 1994, Experiment 1; Theeuwes, 1992, Experiment 1). However, all those effects were found in singleton detection mode. Effect sizes comparable with the present ones have been reported by Bacon and Egeth (1994, Experiment 3), which read between 10 and 20 ms based on their figure depictions. A likely explanation for reduced capture effects is that the more stringent set adopted in feature mode is effective in eliminating capture on a greater proportion of trials. As for the small effect size of singleton capture reported in Experiment 1, Theeuwes and Godijn (2001) observed that the effect of attentional capture is attenuated as the distance between target and distractor increases. Theeuwes and Godijn estimated about 60 ms for the nearest distractor (2.3° of visual angle away) and 20 ms for the farthest distractor (9.2° away). We found a similar distance effect by onset distractors in the attention task condition of Experiment 5 (see Figure 8).⁵ A one-way ANOVA found an overall difference in RT to the target related to the distance between the target and onset, $F(2, 38) = 18.25$, $MSE = 470.2602$, $p < .0005$; the difference was primarily due to a significant increase in RT when the onset was at 30° away (1.76° visual angle) from the target, $t(19) = 4.34$, $p < .0005$. It is possible that the effect size in Experiment 1 was relatively small because onset distractors never appeared at 30° away from a target. Because the closest distance between a target and color distractor was 60° (3.4° visual angle), shorter than the closest analyzed distance between a target and onset distractor, it is possible that the observed color capture effects were simply due to this distance advantage. The suspicion can be put to rest as the result of a one-way ANOVA on data from the color-only attention condition of Experiment 5 (also shown in Figure 8) showed no effect of distance, $F(2, 38) = 2.08$, $MSE = 385.2256$, $p > .1$. Although Theeuwes and Godijn have offered an explanation of the distance effect in terms of local inhibition surrounding a distractor that captures attention, it is not clear why attending to the distractor should produce only a local inhibitory effect instead of the ex-

pected cost when attention is diverted from the target regardless of the distance. In any case, the phenomenon has not been thoroughly explored. We must leave it to future research to reconcile distance effects with top-down and bottom-up accounts of attentional capture.

Control of Attention and Saccades in Involuntary Orienting

It is clear from the different responses to transient and static distractors that oculomotor capture is not simply an overt form of attentional capture, in which the eyes are captured because spatial attention has been captured (e.g., Irwin et al., 2000; Theeuwes et al., 1998, 1999). This dissociation is also inconsistent with the claim of some premotor theories (e.g., Rizzolatti et al., 1994) that spatial attention is simply a saccade whose motor output has been inhibited. If only the motor act were inhibited, then the stimulus properties that elicit capture should have been the same for saccade and no-saccade conditions. Instead, our results suggest an involuntary orienting system whose behavior results from an interaction between attention and saccade control centers. This interaction is mediated by task-related processes that determine whether or not to move the eyes (*task set*) and for which stimulus properties attention should be set (*target set*).

The contingencies and dissociations we observe here must have some correspondence with activity in neural circuits associated with saccades and attention. Some indication of how target sets modulate orienting as described by contingent orienting is found in research on the brain mechanisms underlying saccades and attention. For attention, goal-related top-down modulation is observed in area V4 (see Treue, 2001, for a review). Sensitivity of V4 neurons to a particular stimulus is increased when the stimulus is attended, either by being located within an attended spatial region (Reynolds, Pasternak, & Desimone, 2000) or by possessing attended features (Motter, 1994). Response of a V4 neuron is driven by the neuron's response to the attended stimulus, even when the attended stimulus is otherwise ineffective and presented along with an effective (preferred) and salient stimulus in the receptive field (Reynolds, Chelazzi, & Desimone, 1999; Reynolds & Desimone, 2003). These findings demonstrate that, at the level of V4, visual salience appears to be an interactive product of top-down and bottom-up factors, and its ability to elicit neuronal responses is modulated by surrounding stimuli and current attentional settings.

For saccades, behavioral relevance of target sets is reflected in at least two cortical areas: the intraparietal area (LIP) and the frontal eye fields (FEF). Cells in LIP (Colby, Duhamel, & Goldberg, 1996; Pare & Wurtz, 2001; Wurtz et al., 2001) and FEF (Schall, Hanes, Thompson, & King, 1995) show enhanced activity time-locked to the presentation of a stimulus to which a saccade is intended. The firing rate of neurons in FEF is higher to distractors that share features with the target (Bichot & Schall, 1999a, 1999b). This selective activation mirrors the attentional control settings proposed by Folk et al. (1992). Both FEF and LIP interact with subcortical neurons in the superior colliculus (SC) to generate

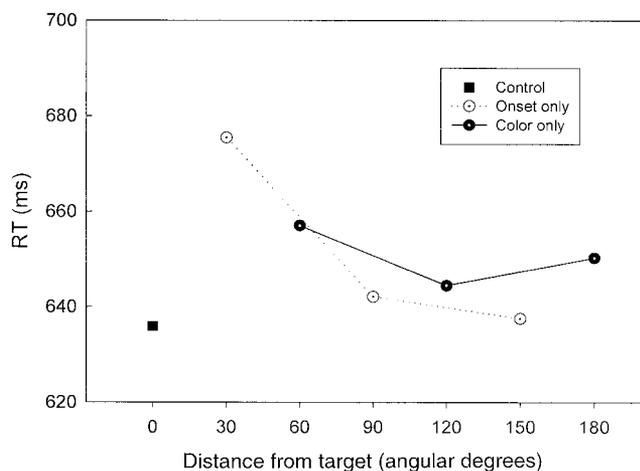


Figure 8. Distance effect of manual response times (RTs) of the attention task condition in Experiment 5.

⁵ The distance effect analysis was based on all valid trials with no regard to eye position to attain a workable number of observations at each angular distance.

saccades. Given the interconnections between FEF and LIP (e.g., Stanton, Bruce, & Goldberg, 1995) and between LIP and V4 (e.g., Blatt, Andersen, & Stoner, 1990), it is likely that all of these cortical areas have a role in determining relevant stimuli for shifting spatial attention and saccadic eye movements that corresponds to the contingency on target sets observed here.

Patterns of connectivity and interaction among FEF, LIP, and SC lay out the basis of underlying brain mechanisms that could give rise to the observed patterns of results related to task sets. It is generally thought that the SC is responsible for involuntary, reflexive saccades (see, e.g., Bichot, 2001). Superficial areas receive direct input from visual cortex as well as from the retina that presumably provides rapid information of the location of transient events (e.g., abrupt onsets) in the visual world (Bichot, 2001; Lee, Helms, Augustine, & Hall, 1997; Munoz, Dorris, Pare, & Everling, 2000). In contrast, color information is processed in areas that receive input from striate cortex but do not have direct connection to SC (see Ottes, Van Gisbergen, & Eggermont, 1987). Consistent with this, we found the latency of saccades to onset distractors reliably shorter than to color distractors.

How can task sets (instructions to fixate or saccade) alter the effectiveness of transient stimuli to capture attention or elicit involuntary eye movements? In the case of instructions to fixate or saccade, there can be no preparation for particular stimulus properties. One way for the same stimulus property to elicit differing responses according to instructions is to modulate the response differently in each condition. Assuming that transient stimuli can elicit involuntary responses via the direct retinal-collicular pathways, we conjecture that such bottom-up influences are countered by cortical pathways operating via FEF, which convey top-down information specified by task demands. In SC, eye movements are generated by saccade neurons, each tuned to a specific direction and amplitude. The task goal of maintaining fixation could lead to strong cortical input from FEF to fixation neurons in SC whose firing inhibits saccade neurons in SC (e.g., Munoz & Wurtz, 1993), as well as from FEF to omnipause neurons in the pons whose tonic discharge during active fixation inhibits the brain stem saccade burst generator (e.g., Segraves, 1992). To trigger an involuntary saccade, sensory inputs from the retina and striate cortex that signal the abrupt onset would have to overcome the low resting level of activation in saccade cells as well as the gating by omnipause neurons on the burst generator. Indeed, Tse, Sheinberg, and Logothetis (2002) showed that abrupt onsets caused no systematic saccades, microsaccades, or deviations in fixational eye movements when the intent was to remain fixated. This could explain why, in the no-saccade condition, transient stimuli do not elicit saccades despite direct input. Target-related feature information, however, is processed by the ventral visual pathway, which presumably would not be affected by the dampened activity of the saccade system. As a result, abrupt onsets will be able to elicit involuntary attention shifts when they are part of the target set.

In the saccade condition, the goal of making a rapid saccade would discourage strong inhibition of saccade neurons in SC, which consequently would have higher activation levels than in no-saccade conditions. The increased activity of SC neurons increases the likelihood that direct input from early visual processing would result in an occasional erroneous saccade to transient events. There is also evidence that LIP neurons respond to transients in their receptive field even when those onsets are not the

saccade target (Colby et al., 1996; Gottlieb, Kusunoki, & Goldberg, 1998). Given the delays in processing and communicating information about the presence of color singletons, SC could be preparing to make a saccade to the onset before information about the target location has accumulated. The differential response of FEF neurons to relevant and irrelevant distractor properties does not appear until 50–100 ms following the first initial FEF activity (Bichot & Schall, 1999a, 1999b). The same general considerations suggest why static color singletons fail to capture the eyes. The lack of a direct link between color centers and SC deprives saccade neurons in SC with the rapid source of activation provided by abrupt onsets. Static singletons should also fail to excite LIP, because cells in LIP do not fire to preexisting stimuli unless they are behaviorally significant (Colby et al., 1996; Gottlieb et al., 1998), and so cannot activate SC through that pathway.

The above account maintains the tight coupling of attention and saccades posited by premotor theories. It differs in that the inhibition is not just of the movement, controlled by brain stem mechanisms, but also of the control center for initiating saccades. As a result, the inhibition changes the response patterns by effectively damping the signal from low-level visual processes. Dampening the saccade response exposes a mode of control that is more purely attentional. In our view, the behavioral and neurophysiological evidence suggest that the cortical inputs to SC represent a later attention system whose job is to modulate the behavior of a more primitive orienting system exclusive to saccades.

The neurophysiology may also provide insight into the debate over top-down or stimulus-driven attentional capture. Essentially, there have been four proposals for what will capture attention: abrupt onsets (Yantis & Jonides, 1984), salience (Theeuwes, 1992), new objects (Yantis & Hillstrom, 1994), and contingencies established as attentional control settings (Folk et al., 1992). The neurophysiology provides some evidence for each of these. Luminance transients are conveyed directly to SC, LIP responds to new objects even if not relevant, LIP and V4 also reflect stimulus salience, and FEF, LIP, and V4 reflect the target sets that determine which stimulus properties are relevant. We suggest that differences in methods and stimuli can cause one or more pathways to dominate. Our experiments likely produce complex activity in all areas where at times one or another of these underlying pathways dominates performance. A deeper understanding of the relationship between the behavioral paradigms and the underlying brain activity may reveal modes of orienting consistent with each of the classes of explanation.

References

- Andersen, R. A. (1995). Encoding of intention and spatial location in the posterior parietal cortex. *Cerebral Cortex*, *5*, 457–469.
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, *55*, 485–496.
- Bichot, N. P. (2001). Attention, eye movements, and neurons: Linking physiology and behavior. In M. Jenkin & L. Harris (Eds.), *Vision and attention* (pp. 209–232). New York: Springer-Verlag.
- Bichot, N. P., & Schall, J. D. (1999a). Effects of similarity and history on neural mechanisms of visual selection. *Nature Neuroscience*, *2*, 549–554.
- Bichot, N. P., & Schall, J. D. (1999b). Saccade target selection in macaque during feature and conjunction visual search. *Visual Neuroscience*, *16*, 81–89.

- Blatt, G. J., Andersen, R. A., & Stoner, G. R. (1990). Visual receptive field organization and cortico-cortical connections of the lateral intraparietal area (area LIP) in the macaque. *Journal of Comparative Neurology*, *299*, 421–445.
- Bushnell, M. C., Goldberg, M. E., & Robinson, D. L. (1981). Behavioral enhancement of visual responses in monkey cerebral cortex: I. Modulation in posterior parietal cortex related to selective visual attention. *Journal of Neurophysiology*, *46*, 755–787.
- Colby, C. L., Duhamel, J.-R., & Goldberg, M. E. (1996). Visual, presaccadic, and cognitive activation of single neurons in monkey lateral intraparietal area. *Journal of Neurophysiology*, *76*, 2841–2852.
- Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independence, or overlapping neural systems? *Proceedings of the National Academy of Sciences, USA*, *95*, 831–838.
- Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., et al. (1998). A common network for functional areas for attention and eye movements. *Neuron*, *21*, 761–773.
- Doyle, M., & Walker, R. (2001). Curved saccade trajectories: Voluntary and reflexive saccades curve away from irrelevant distractors. *Experimental Brain Research*, *139*, 333–344.
- Doyle, M. C., & Walker, R. (2002). Multisensory interactions in saccade target selection: Curved saccade trajectories. *Experimental Brain Research*, *142*, 116–130.
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*, 433–458.
- Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 847–858.
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.
- Gibson, B. S., & Amelio, J. (2000). Inhibition of return and attentional control settings. *Perception & Psychophysics*, *62*, 496–504.
- Godijn, R., & Theeuwes, J. (2002). Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1039–1054.
- Gottlieb, J. P., Kusunoki, M., & Goldberg, M. E. (1998, January 29). The representation of visual salience in monkey parietal cortex. *Nature*, *391*, 481–484.
- Hoffman, J. E. (1998). Visual attention and eye movements. In H. Pashler (Ed.), *Attention* (pp. 119–154). Hove, England: Psychology Press.
- Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics*, *57*, 787–795.
- Irwin, D. E., Colcombe, A. M., Kramer, A. F., & Hahn, S. (2000). Attentional and oculomotor capture by onset, luminance, and color singletons. *Vision Research*, *40*, 1443–1458.
- Irwin, D. E., & Gordon, R. D. (1998). Eye movements, attention, and trans-saccadic memory. *Visual Cognition*, *5*, 127–155.
- Klein, R. (1980). Does oculomotor readiness mediate cognitive control of visual attention? In R. S. Nickerson (Ed.), *Attention and performance VIII* (pp. 259–276). Hillsdale, NJ: Erlbaum.
- Klein, R., & Pontefract, A. (1994). Does oculomotor capture readiness mediate cognitive control of visual attention? Revisited! In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 333–350). Cambridge, MA: MIT Press.
- Kowler, E., Anderson, E., Doshier, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research*, *35*, 1897–1916.
- Kramer, A. F., Cassavaugh, N. D., Irwin, D. E., Peterson, M. S., & Hahn, S. (2001). Influence of single and multiple onset distractors on visual search on singleton targets. *Perception & Psychophysics*, *63*, 952–968.
- Lee, P. H., Helms, M. C., Augustine, G. J., & Hall, W. C. (1997). Role of intrinsic synaptic circuitry in collicular sensorimotor integration. *Proceedings of the National Academy of Sciences, USA*, *94*, 13299–13304.
- McCann, R. S., Remington, R. W., & Van Selst, M. (2000). A dual-task investigation of automaticity in visual word processing. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1352–1370.
- Mokler, A., Deubel, H., & Fischer, B. (2000, August). *Unintended saccades can be executed without presaccadic attention shift*. Poster session presented at the 23rd European Conference on Visual Perception, Groningen, the Netherlands.
- Motter, B. C. (1994). Neural correlates of attentive selection for color or luminance in extrastriate area V4. *Journal of Neuroscience*, *14*, 2178–2189.
- Munoz, D. P., Dorris, M. C., Pare, M., & Everling, S. (2000). On your mark, get set: Brainstem circuitry underlying saccadic initiation. *Canadian Journal of Physiological Pharmacology*, *78*, 934–944.
- Munoz, D. P., & Wurtz, R. H. (1993). Fixation cells in monkey superior colliculus: I. Characteristics of cell discharge. *Journal of Neurophysiology*, *70*, 559–575.
- Nobre, A. C., Gitelman, D. R., Dias, E. C., & Mesulam, M. M. (2000). Covert visual spatial orienting and saccades: Overlapping neural systems. *NeuroImage*, *11*, 210–216.
- Ottes, F. P., Van Gisbergen, J. A. M., & Eggemont, J. J. (1987). Collicular involvement in a saccadic colour discrimination task. *Experimental Brain Research*, *66*, 465–478.
- Pare, M., & Wurtz, R. H. (2001). Progression in neuronal processing for saccadic eye movements from parietal cortex area LIP to superior colliculus. *Journal of Neurophysiology*, *85*, 2545–2562.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.
- Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice-Hall.
- Remington, R. W. (1980). Attention and saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, *6*, 726–744.
- Reynolds, J. H., Chelazzi, L., & Desimone, R. (1999). Competitive mechanisms subserve attention in macaque areas V2 and V4. *Journal of Neurophysiology*, *19*, 1736–1753.
- Reynolds, J. H., & Desimone, R. (2003). Interacting roles of attention and visual salience in V4. *Neuron*, *37*, 853–863.
- Reynolds, J. H., Pasternak, T., & Desimone, R. (2000). Attention increases sensitivity of V4 neurons. *Neuron*, *26*, 703–714.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*, 31–40.
- Rizzolatti, G., Riggio, L., & Sheliga, B. M. (1994). Space and selective attention. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 231–265). Cambridge, MA: MIT Press.
- Salthouse, T. A., & Ellis, C. L. (1980). Determinants of eye-fixation duration. *American Journal of Psychology*, *93*, 207–234.
- Schall, J. D., Hanes, D. P., Thompson, K. G., & King, D. J. (1995). Saccade target selection in frontal eye field of macaque: I. Visual and premovement activation. *Journal of Neuroscience*, *15*, 6905–6918.
- Segraves, M. A. (1992). Activity of monkey frontal eye field neurons projecting to oculomotor regions in the pons. *Journal of Neurophysiology*, *68*, 1967–1985.
- Sheliga, B. M., Riggio, L., Craighero, L., & Rizzolatti, G. (1995). Spatial attention-determined modifications in saccade trajectories. *NeuroReport*, *6*, 585–588.

- Sheliga, B. M., Riggio, L., & Rizzolatti, G. (1994). Orienting of attention and eye movements. *Experimental Brain Research*, *98*, 507–522.
- Snowden, R. J. (2002). Visual attention to color: Parvocellular guidance of attentional resources? *Psychological Science*, *13*, 180–184.
- Stanton, G. B., Bruce, C. J., & Goldberg, M. E. (1995). Topography of projections to posterior cortical areas from the macaque frontal eye fields. *Journal of Comparative Neurology*, *353*, 291–305.
- Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics*, *49*, 83–90.
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*, 599–606.
- Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 799–806.
- Theeuwes, J., & Godijn, R. (2001). Attentional and oculomotor capture. In C. L. Folk & B. S. Gibson (Eds.), *Attraction, distraction and action: Multiple perspectives on attentional capture* (pp. 121–149). Amsterdam: Elsevier.
- Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science*, *9*, 379–385.
- Theeuwes, J., Kramer, A. F., Hahn, S., Irwin, D. E., & Zelinsky, G. J. (1999). Influence of attentional capture on oculomotor control. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1595–1608.
- Treue, S. (2001). Neural correlates of attention in primate visual cortex. *Trends in Neuroscience*, *24*, 295–300.
- Tse, P. U., Sheinberg, D. L., & Logothetis, N. K. (2002). Fixational eye movements are not affected by abrupt onsets that capture attention. *Vision Research*, *42*, 1663–1669.
- Viviani, P., Berthoz, A., & Tracey, D. (1977). The curvature of oblique saccades. *Vision Research*, *17*, 661–664.
- Wurtz, R. H., Sommer, M. A., Pare, M., & Ferraina, S. (2001). Signal transformations from cerebral cortex to superior colliculus for the generation of saccades. *Vision Research*, *41*, 3399–3412.
- Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 95–107.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601–620.

Received March 28, 2002

Revision received May 7, 2003

Accepted May 18, 2003 ■

Call for Nominations: *Rehabilitation Psychology*

The APA Publications and Communications (P&C) Board has opened nominations for the editorship of *Rehabilitation Psychology* for the years 2006–2011. Bruce Caplan, PhD, is the incumbent editor.

Candidates should be members of APA and should be available to start receiving manuscripts in early 2005 to prepare for issues published in 2006. Please note that the P&C Board encourages participation by members of underrepresented groups in the publication process and would particularly welcome such nominees. Self-nominations are also encouraged.

Rehabilitation Psychology will transition from a division publication to an “all APA” journal in 2006, and the successful candidate will be involved in making suggestions to the P&C Board and APA Journals staff about the transition process.

Gary R. VandenBos, PhD, and Mark Appelbaum, PhD, have been appointed as cochairs for this search.

To nominate candidates, prepare a statement of one page or less in support of each candidate. Address all nominations to

Rehabilitation Psychology Search Committee

Karen Sellman, Search Liaison

Room 2004

American Psychological Association

750 First Street, NE

Washington, DC 20002-4242

The first review of nominations will begin December 8, 2003. The deadline for accepting nominations is **December 15, 2003**.