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The dynamic events that capture visual attention: A reply to Abrams and Christ (2005)

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We recently demonstrated that, contrary to previous findings, some types of irrelevant motion are capable of capturing our attention (Franconeri & Simons, 2003). Strikingly, whereas *simulated looming* (a dynamic increase in object size) captured attention, *simulated receding* (a decrease in object size) did not. Abrams and Christ (2003, 2005) have provided a different interpretation of this evidence, arguing that in each case attention was captured by the onset of motion rather than by motion per se. They argued that the only published finding inconsistent with their motion onset account is our evidence that simulated receding motion failed to capture attention. Abrams and Christ (2005) presented a receding object stereoscopically and found that it did capture attention, leading them to conclude that the motion onset account explains existing data more parsimoniously than our account does. Our reply has three parts. First, we argue that evidence of capture by receding motion is interesting but irrelevant to the debate over whether capture by motion requires a motion onset. Second, we show that the original empirical evidence in support of the motion onset claim (Abrams & Christ, 2003) put the motion-only condition at a critical disadvantage. We present a new experiment that demonstrates strong capture by motion in the absence of a motion onset, showing that motion onsets are not necessary for attention capture by dynamic events. Finally, we outline what is known about the set of dynamic events that capture attention.

Our visual system uses several mechanisms to select potentially important information from the visual field for further processing, including the reflexive orienting of attention toward some types of unique stimuli. In a typical study of this *attention capture*, observers search through a visual display for a target letter that is embedded among distractor letters. On each trial, one randomly selected letter is unique—for example, it might have a different shape or it might suddenly flash or change color. Given that the unique feature does not predict the target location, if observers find the target more efficiently when it happens to be the unique item, then the unique item must have "captured" the observer's attention. Somewhat surprisingly, a large number of studies conducted over more than 20 years suggested that only the abrupt appearance of a new object in the display reliably captured attention; unique colors and even unique motions did not (see Yantis, 1996, for a review).

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Recently, we modified this paradigm slightly to improve its sensitivity and found that object motion can capture attention in visual search tasks (Franconeri & Simons, 2003). Strikingly, we found that *simulated looming* (a dynamic increase in object size) captured attention but *simulated receding* (a decrease in object size) did not, suggesting that only some types of motion capture attention. Given that in naturalistic contexts looming objects are more likely than receding objects to require an immediate reaction, we speculated that the potential behavioral urgency of a stimulus might contribute to whether or not it captures attention. At about the same time, Abrams and Christ (2003) also challenged the standard notion that only the abrupt onset of a new object captures attention. However, their conclusion was subtly different from ours. Whereas we argued that some forms of motion capture attention, they claimed that it is the onset of motion rather than motion per se that captures attention. That is, attention is drawn to a static object that suddenly begins to move, but not to an already moving object.

In an empirical response to our claim that some types of motion can capture attention, Abrams and Christ (2005) noted that the only evidence in the literature that is inconsistent with their motion onset account was our finding that receding motion, which included a motion onset, did not capture attention. They showed that receding motion does capture attention when it is presented with stereoscopic depth cues, leading them to conclude that the motion onset hypothesis more parsimoniously explains all prior evidence of attention capture by dynamic events. Although their experimental conditions did not closely replicate ours, their results suggest that, at least under some conditions, receding motion captures attention.

Determining the signals that capture attention is central to understanding how our visual system prioritizes information, a process that has theoretical implications for the mechanisms of attentional selection as well as practical ramifications for human–computer interaction (e.g., user interface design). In this brief reply, we argue that evidence of capture by receding objects is interesting, but that it provides no direct support for the motion onset account. Second, we examine the original evidence used to show capture by motion onset but not by motion (Abrams & Christ, 2003) and argue that this asymmetry was due to the relative timing of the two types of dynamic events. Specifically, motion-onset singletons started moving freshly at the beginning of a search, but the control motion singletons had been moving for over 3 sec before the search began. This long delay likely undermined the ability of motion to capture attention. We present a new experiment that removes this confound, and we find that motion strongly captures attention even in the absence of a motion onset. We conclude by discussing the sorts of dynamic events that capture attention.

Do Receding Stimuli Capture Attention?

In their commentary, Abrams and Christ (2005) acknowledged that the failure of receding items to capture attention in our study was inconsistent with the motion onset hypothesis, because our receding object did have a motion onset. They correctly note that our "receding" motion was actually a shrinking motion because it did not involve a change in depth, and that when they presented a unique object receding in depth stereoscopically, it did capture attention. On the basis of this evidence that receding motion captures attention, they argued that the motion onset hypothesis can explain all evidence in the literature for attention capture by dynamic events.

The finding that receding motion captures attention when presented as a change in depth is potentially important for determining the set of events that capture attention. However, this finding is irrelevant to the distinction between capture by motion and capture by motion onsets. Whether or not our motion event was perceived as receding or as shrinking, it did contain a motion onset (i.e., a change at a luminance edge) and failed to capture attention. Why should our receding condition fail to capture attention according to the motion onset hypothesis? One possibility is that our receding event did not involve translation, but just shrinking, and translation may be necessary for capture by a motion onset. However, by that logic, our looming condition should not have captured attention either, because it did not involve translation, just expansion. Given this dissociation, the motion onset hypothesis must be modified to acknowledge that some forms of motion onset capture attention and others do not, which is no more parsimonious than our claim that some forms of motion capture attention and others do not.[1]

Evidence that stereoscopically presented receding motion captures attention is interesting and important because it weakens our speculation that only behaviorally urgent events capture attention. However, our own attempts to determine whether stereoscopically presented receding motion captures attention raised several concerns about the evidence presented by Abrams and Christ (2005). First, we noticed that our untrained observers frequently made eye movements to the one "close" object in the display, presumably to reduce disparity, see it clearly, and watch it recede. An eye movement to the receding object prior to the receding motion could produce results similar to prioritization, even if the receding motion itself did not capture attention. To conclude that receding motion captures attention, a control is needed to show that depth singletons do not, and eye movements should be monitored to show that subjects are not fixating the object before it begins to recede. Second, changes in binocular disparity require *monocular horizontal motion*. That is, although objects do not translate binocularly, if observers closed one eye they would see horizontal motion. We already know that horizontal motion captures attention (Franconeri & Simons, 2003). To argue that binocularly presented receding motion captures attention, it would be necessary to argue as well that monocular motion detection mechanisms cannot account for the attentional priorization.

Next, we briefly examine the original evidence used to support the motion onset hypothesis (Abrams & Christ, 2003) and present an experiment showing that attention capture by motion can occur in the absence of a motion onset.

Motion Versus Motion Onset: Reexamining the Evidence

In a visual search experiment designed to determine whether motion and/or motion onsets capture attention (Abrams & Christ, 2003), subjects initially viewed a display in which the target letter and distractor letters were masked. During this preview period, one of the search letters moved in a circular pattern and two other letters were static.[2] After 3,200 msec, the masks were removed from the letters. At the same time, one of the static letters began to move (a motion onset) and the other remained static. The letter that had already been moving for 3,200 msec continued moving. This item was intended to test whether motion alone can capture attention, because it had not undergone a recent motion onset. In this experiment, the motion onset letter was searched with priority (relative to the static letter) but the already moving object was not, leading to the conclusion that motion onset captures attention but motion does not (or, to put it more precisely, a motion onset is necessary for motion to capture attention).

Although this finding is consistent with the motion onset account, the experiment did not provide a fair test of the hypothesis that motion can capture attention in the absence of a motion onset. Whereas the motion onset occurred at the start of the search, the "merely moving" letter started moving 3,200 msec earlier. Extensive evidence on transient shifts of attention shows that proper timing is critical for a dynamic cue to have a positive effect on search performance. Once a dynamic cue is presented, the cued item receives a processing benefit for a limited time (about 300 msec), after which the cued item is actually *inhibited* (see, e.g., Abrams & Christ, 2005; Posner & Cohen, 1984). Consequently, we should not expect any signal to attract attention 3,200 msec after it began. Perhaps because ongoing motion occurs continuously, it should be expected to continue to draw attention. However, even a strong luminance change, presented repeatedly every 133 msec, loses its ability to exogenously cue attention after about 300 msec (Nakayama & Mackeben, 1989). Thus, in a fair test of whether motion can capture attention in the absence of a motion onset, the motion must not be presented long before the start of the search array.

In the following experiment, we provide such a test. We designed a search task in which a moving letter was present on each display, but observers could not see the moving letter until the start of the search task. We asked the observers to make an eye movement to a search display containing an already moving letter, so that they did not see the onset of the motion but did see the resulting motion. If the moving object still captures attention, then motion onsets are not necessary for motion to capture attention. To preview our findings, motion can strongly capture attention in a visual search task even in the absence of a motion onset.

EXPERIMENT

Our search task was similar to those used in our previous study (Franconeri & Simons, 2003) and by Abrams and Christ (2003), with one major change: We introduced each new search display while subjects were making an eye movement to a point below the computer monitor. The new array contained an item moving continuously in a circular pattern. Because the new array appeared during the eye movement, the subjects never saw the motion onset.[3] At least 800 msec later, the observers saccaded back to the fixation point at the center of the search array and began their search. If the moving object captures attention, then motion onsets are not necessary and motion alone is sufficient for attention capture.

Method

Subjects. Sixteen subjects participated in the experiment in return for course credit.

Apparatus and Procedure. Stimuli were displayed on a CRT monitor (16-in. diagonal viewable area) running at 85 Hz. Search displays were created by a Macintosh G3 computer using custom software written using the VisionShell C libraries (www.visionshell.com). Viewing position was stabilized by a chinrest placed 50 cm from the monitor. From this viewing distance, the monitor's display was 36º wide and 27º high. Figure 1 depicts a typical search display. Three or five gray (23-cd/m^2) letters (each 1.26º high and 1.26º wide, with segments 2 pixels [0.07º] thick, in Geneva Bold font) were arranged around a gray (23-cd/m^2) fixation point in a virtual circle 4.9º in radius on a black (0-cd/m^2) background. The fixation point and search display were centered on a position 4.8º above the center of the screen. The letters, chosen from among A, C, E, F, H, L, P, S, and U, were constructed from subsets of the segments that make up a block figure eight. One of the letters moved continuously around its designated position in the display, in a circular pattern (0.42º in diameter), at 2.8 revolutions/sec.

Each subject wore a head-mounted SMI EyeLink I eye tracker connected to a Pentium-based PC running EyeLink software, which transmitted eye position information to the stimulus computer. After each trial, the subject made a saccade to the base of the monitor (about 38º below the center of the search display). During the

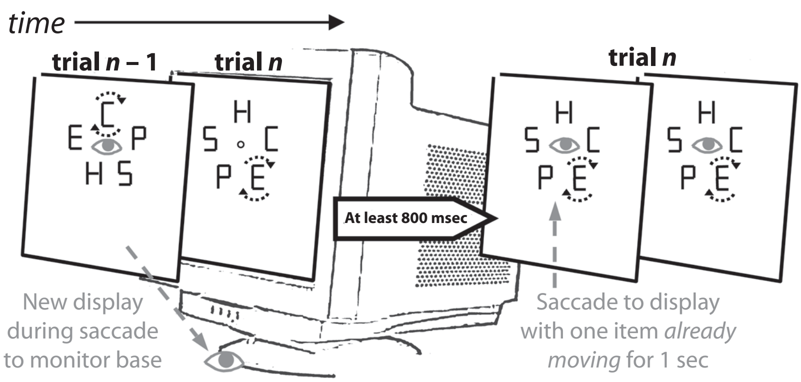

Figure 1. Display sequence for the experiment. The search display for trial *n* (containing a moving letter) appeared during the peak velocity of the subject's downward saccade after trial *n* − 1. The subjects could not look back to the new search display until at least 800 msec after the display change. Displays are not shown to scale.

approximate peak velocity of the downward saccade, the old search display was replaced with a new one, also containing a moving letter. From this peripheral view of the search display, the subject could tell that something was moving in the search display but could not discern the identity of any of the letters. When the eye position had been below the monitor for 800 msec, the computer beeped, signaling the subject to refixate the search display and begin searching. If the subject attempted to refixate the search display before 800 msec had passed, the computer issued a series of warning beeps and the trial was excluded from the data analysis. As the subject made an upward saccade to the search display, response timing began when eye position came within 4º of the central fixation point.[4] The subject determined whether each search display contained a U or an H and pressed the corresponding key on the keyboard. Both speed and accuracy were stressed, and the subject could take breaks at any time by postponing either the saccade below the monitor or the saccade back to the monitor.

The subjects completed one practice block of 32 trials and then seven experimental blocks of 32 trials each. Item motion was not correlated with the location of the target, and trials of set sizes 3 and 5 were intermixed in each block. For set size 5, each block contained 16 trials in which a distractor moved and 4 trials in which the target moved. For set size 3, each block contained 8 trials in which a distractor moved and 4 trials in which the target moved. Target identity (H or U) and target location were randomly chosen for each trial.

Results

A trial was excluded from the analysis if the subject looked back up to the search display before 800 msec had elapsed (6% of all trials). Trials with incorrect responses (1.2% of all trials) or with response times (RTs) over 4 sec (1% of all trials) were counted as errors and were excluded from the RT analyses. Total error rates did not differ significantly among conditions, and there was no indication of a speed–accuracy trade-off.

Average RTs are shown in Figure 2. Responses were faster for set size 3 trials (618 msec) than for set size 5 trials [652 msec; $t(15) = 2.8$, $p = .014$]. The subjects also responded more quickly when the moving item was the target (607 msec) than when it was a distractor [663 msec; $t(15) = 3.2$, $p < .006$]. In this task, the most important measure of attention capture is whether the search rate was more efficient when the moving item was the target than when it was a distractor (see Franconeri & Simons, 2003, for a discussion). Search should be slower when the moving item is a distractor and faster when the moving item is the target. Ideally, if motion strongly captures attention, then in trials in which the moving item is the target, the slope of the function relating set size to RT should be flat (i.e., 0 msec/item), suggesting that, regardless of the number of items in the display, the moving target was searched first. In our study, when the target was moving the slope was −3 msec/item, but when a distractor was moving the slope was 37 msec/item [$t(15) = 4.4$, $p < .001$]. The moving item was searched first, suggesting that motion captures attention even without a visible motion onset.

CONCLUSIONS

Our earlier studies of attention capture by dynamic events showed that many forms of newly introduced motion (within about 150 msec of the start of the search) captured attention. Abrams and Christ (2003) argued instead that only the *onset* of motion captures attention and that motion per se does not. In their studies, however, observers had viewed the moving item for 3 sec before the start of the search task. Even if motion did capture attention in their experiment, their design would not reveal it because of the short time course of exogenous cuing (about 300 msec; see, e.g., Nakayama & Mackeben, 1989). By requiring our subjects to make an eye movement to a display containing an already moving object, we showed that motion does capture attention even when the motion does not have a visible onset. Given these considerations about the time course of exogenously cued attention, the present experiment is the first to distinguish between the claim that motion onsets are needed for capture by motion and the claim that some forms of motion are sufficient for attention capture, even in the absence of a perceived motion onset.

What Kinds of Dynamic Signals Capture Attention?

Our initial evidence for capture by dynamic events showed that looming stimuli capture attention but receding stimuli do not (Franconeri & Simons, 2003), leading to the speculation that the potential behavioral urgency of a stimulus might help govern attention capture by dynamic events. This conjecture is weakened by evidence that stereoscopically receding objects do capture attention (Abrams & Christ, 2005) and that if this capture resulted purely from receding motion and not from monocular motion signals, then our speculative hypothesis would be undermined (but see von Mühlenen & Lleras, 2003, for additional evidence that looming captures attention but receding does not). In any case, behavioral urgency will not explain all aspects of attention capture. Many factors likely determine whether an irrelevant dynamic event will attract attention. For instance, the type

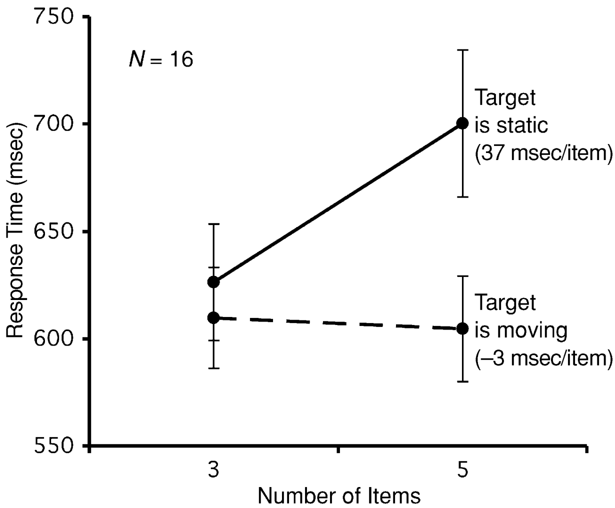

Figure 2. Average response times in the experiment.

of dynamic signal may be critical. Some sort of sensory transient seems to be required; new objects that appear without a unique local transient do not capture attention (Franconeri, Hollingworth, & Simons, 2005; but see Cole, Kentridge, & Heywood, 2005). As we have noted, the timing of the dynamic event relative to the start of search is also critical (see, e.g., Nakayama & Mackeben, 1989; Posner & Cohen, 1984). The difficulty of the primary task (search, in this case) also affects capture, with capture by both dynamic and static stimuli being reduced as search tasks become more difficult (Franconeri, Alvarez, & Bemis, 2005; Proulx & Egeth, 2002). Also, attention capture by dynamic events can be impeded by the presence of competing dynamic events in a display (Franconeri & Simons, 2003; Martin-Emerson & Kramer, 1997; Miller, 1989; von Mühlenen, Rempel, & Enns, in press). Perhaps most important, the strength of the dynamic signal itself likely influences its ability to attract attention. It is easy to miss a single swaying blade of grass, but, as Yantis and Hillstrom (1994) noted, it is hard to miss the lights turning on at Fenway Park. Perhaps even a receding stimulus would attract attention if the size change were large enough.

There is now little evidence of a qualitative division between dynamic events that capture attention and those that do not (the division between looming and receding is now hanging by a thread). However, some dynamic signals may capture more strongly than others (see Franconeri & Simons, 2003, for a discussion). It is also certainly possible that motion accompanied by a motion onset captures attention more strongly than does motion alone. However, our evidence shows that motion onsets are not necessary for strong capture by motion. The challenge in comparing the abilities of various dynamic events to capture attention is to equate qualitatively different stimuli on the basis of their "signal strength," perhaps using perceptibility among noise as an operationalization of signal (see Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001, for an attempt to account for different levels of signal in a study of attention capture). We hope that future research will produce a better characterization of attention capture through examination of the relative prioritization of different classes of dynamic events.

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NOTES

1. Technically, a motion onset is an instantaneous event—the moment a stimulus transitions from static to dynamic. Consequently, if motion onsets per se capture attention, the nature of the subsequent stimulus motion should be irrelevant. Unfortunately, it is not possible to present a motion onset in the absence of motion, making it impossible to test whether motion onsets in isolation capture attention. Therefore, it is more precise to define the motion onset hypothesis as the claim that motion does not capture attention unless it is accompanied by a motion onset.

2. There was also a "motion offset" letter, which moved before the search and then stopped moving, but this type of motion is not relevant to the current debate. In addition, the critique we present here is of Abrams and Christ's (2003) Experiment 1, but it also applies to their Experiment 2.

3. Even if the observers could have seen the motion onset, the search did not begin for at least another 800 msec. Given this lag, if attention were captured only by the motion onset, then observers should experience inhibition of return to the moving item, not attention capture (Abrams & Christ, 2003).

4. If the subjects had fixated the moving letter instead of the fixation point, any evidence of priority for the moving letter might have been due to better visibility rather than to attention capture. The experimenter monitored each subject's eye movements and ensured that the upward saccade landed at the fixation point and remained there. An analysis of the subjects' eye movements revealed that the subjects were able to saccade to the fixation point with an average error of 0.93° and that this error was not correlated with either the horizontal ($r^2 = .026$) or the vertical ($r^2 = .004$) component of the moving item's position relative to the fixation point.

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