## Research Article

# MOTION ONSET CAPTURES ATTENTION

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**Abstract**—*Although visual motion may seem salient, motion per se does not automatically attract attention. We show here, however, that the onset of motion does indeed attract attention. In three experiments, subjects identified target letters in displays that contained targets and distractors. There was no advantage for moving letters among static ones, but there was an advantage for objects that had recently started to move despite the fact that the motion was uninformative. If some additional time was allowed to elapse after motion onset, inhibition of return slowed responding to the item that had started to move—a further sign that the motion onset had captured attention. Finally, detection of target letters was found to be independent of the number of distractors in the display if the target had undergone motion onset, also indicative of attentional capture. We discuss the adaptive significance of sensitivity to onsets in the presence of a relative insensitivity to ongoing motion.*

The 19th-century physiologist and philosopher William James was probably not the first to state what must have seemed a truism: that "moving things" will attract attention (James, 1890/1950). Yet more than 100 years later, although much has been learned about the exquisite sensitivity of the human brain to motion (for reviews, see Andersen, 1997; Sekuler, Watamaniuk, & Blake, 2002), it has yet to be shown that motion will attract attention reflexively. Indeed, moving objects *seem* salient, and motion can be willfully selected as a to-be-attended dimension in a scene (Hillstrom & Yantis, 1994; McLeod, Driver, Dienes, & Crisp, 1991; Yantis & Egeth, 1999). But motion does not attract attention if the motion serves no purpose in the subject's task: A moving object might be no more noticeable than a single red object among objects of many colors.[1] If, however, motion of an object causes a regrouping, or new interpretation of a scene, such as when one member of a set of aligned elements moves out of line, then the newly appearing element will indeed capture attention (Hillstrom & Yantis, 1994). In this case, it may not be the motion that captures attention, but rather the sudden appearance of a new object in the scene (if a new object appears through some other means, it too will capture attention; e.g., Oonk & Abrams, 1998; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984).

Yet although motion per se does not attract attention, we propose that the *onset* of motion does attract attention, and in the present article we present evidence in support of that possibility. Indeed, there is already some reason to suspect that motion onsets might be especially noticeable. For example, motion onset may play an important role in the categorization of objects as being animate as opposed to inanimate. Such categorization is thought to be important in the detection of prey and predators, and is thought by some researchers to rely on a relatively low-level processing of motion cues in a scene (as opposed to being driven by some higher cognitive processes; Scholl & Tremoulet, 2000). Objects that accelerate, such as those that have just begun to move, are more likely to be seen as animate than objects that undergo a deceleration (Tremoulet & Feldman, 2000). Thus, sensitivity to motion onsets (but not necessarily to decelerative or constant-velocity motion) may help an animal detect the other animals that are nearby—a useful attribute of a visual system.

In our experiments, subjects searched for target letters in displays in which letters underwent a variety of different types of motion. The nature of the motion did not help predict the location or identity of the target—but the subjects' reaction times indicate the types of motion that were more or less effective at attracting attention. We found that targets are most easily detected in objects that have recently started to move, compared with objects that are not moving or that have been moving continuously for some time.

## EXPERIMENTS 1A AND 1B

In our first experiment, subjects were asked to identify the target letter present in a display that contained one target and three distractors. The four items in each display began the trial as placeholders, but later changed to letters. Each underwent a different type of motion: One item was always in motion from the time it first appeared; one item never moved; one item began the trial in motion but then stopped; and finally, one item was static at the beginning of the trial but began to move during the trial.[2] The location at which the target could appear was uncorrelated with motion type. We measured the latency needed to correctly identify the target letter for each of the types of motion.

### Method

#### *Subjects*

Ten undergraduates participated in Experiment 1a, and 12 participated in Experiment 1b. All were experimentally naive and received course credit in return for their efforts.

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1. It is important to distinguish between the salience of an object, such as a moving one, and the ability of that object to capture attention in a bottom-up manner. Yantis and Egeth (1999) have shown that elements such as color or motion singletons may be very salient, as evidenced by efficient detection of the target when it is known to coincide with the singleton. However, the very same stimuli can yield inefficient target detection under conditions in which the singleton coincides with the target only by chance. The true test of attentional capture occurs in the latter case. In particular, attention can be said to be captured in a stimulus-driven, bottom-up manner only if a target that coincides with the singleton is detected efficiently even under conditions in which the target and singleton are uncorrelated. It is this latter test that we conducted in the present study, for elements that underwent motion onsets.

2. It is the inclusion of this last type of motion that distinguishes the present experiment from those that have been conducted previously by other researchers (e.g., Hillstrom & Yantis, 1994).

  

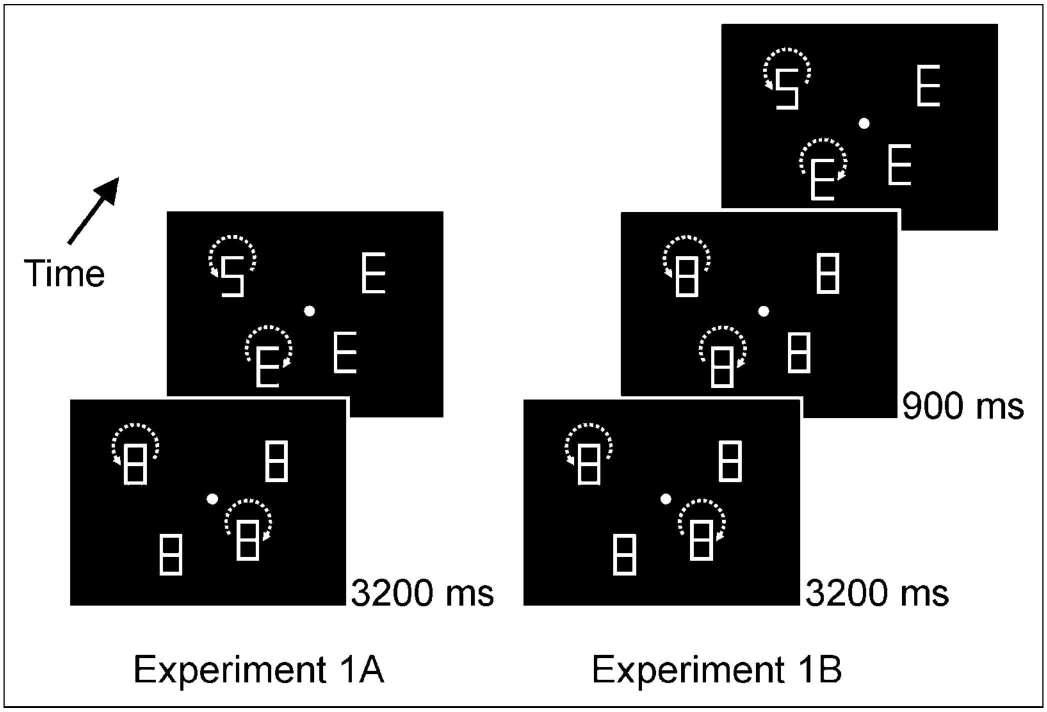


**Fig. 1.** Sequence of events on a trial in Experiment 1a (left) and Experiment 1b (right). Four figure-eight placeholders, two of them moving, were visible for 3,200 ms prior to a movement transition, at which point one moving placeholder stopped moving and a static placeholder began to move. In Experiment 1a, the placeholders then changed immediately into letters to be searched. In Experiment 1b, a 900-ms delay was imposed prior to presentation of the search items. The subject's task was to identify the target letter present (either an *S* or an *H*). The location of the target was uncorrelated with the motion of the elements. Arrows indicate elements in motion and were not visible on the display.

### *Apparatus and procedure*

Subjects were seated in front of a computer monitor in a dimly lit room. The sequence of events on each trial is shown in Figure 1. Each trial began with a fixation display that contained a central dot and four placeholder stimuli. Each placeholder was a figure eight that was 2° high and 1° wide. The placeholders were randomly distributed within an imaginary 18° square centered on the central dot, with the following constraints: None of the placeholders were aligned either vertically or horizontally with each other, and no placeholder appeared within 1° of another placeholder or the central dot. When the display initially appeared, two of the placeholders were moving along a tight circular path (2° diameter), and the other two were stationary.[3] Motion continued for 3,200 ms, at which time a movement transition occurred, producing four different motion conditions: One of the moving placeholders stopped moving (motion offset); one of the previously static placeholders began moving (motion onset); one static placeholder remained stationary (static); and one moving placeholder continued moving (continuous motion).

It is important to note that the placeholders were visible for several seconds prior to the movement transition. In this way, the transient associated with the motion onset was separated in time from that associated with the appearance of the objects themselves. Indeed, it has been shown that visual evoked potentials to motion onset are attenuated if the onset occurs within 300 ms of the appearance of the display (Torriente, Valdes-Sosa, Ramirez, & Bobes, 1999).[4]

In Experiment 1a, the movement transition coincided with the presentation of the search array. At that time, elements of each placeholder were removed to reveal letters. One of the placeholders became the letter *S* or *H*, representing the target stimulus. All remaining placeholders were replaced by distractor letters (either all *E*s or all *U*s). Subjects were instructed to respond to the target's identity as quickly as possible by pressing one of two keys (i.e., "z" or "/") on the keyboard. All four types of motion were present on every trial, but for convenience we refer to a given motion condition to mean the trials on which the target appeared in the object that underwent that sort of motion. For example, by *motion-onset condition*, we mean those trials in

3. Movement began (or ended) with each placeholder in the lowest possible position along its path. The motion was accomplished by displaying each placeholder (and subsequently, any moving letters in the search array) for 67 ms at each of 16 evenly spaced positions along its movement path. When the moving placeholders first appeared, one was moving in a clockwise direction, and the other was moving counterclockwise.

4. This reduction in evoked potential magnitude shortly after display onset may explain why previous researchers have not detected attentional capture by motion onset. For example, in Hillstrom and Yantis's (1994) Experiment 1, the moving object was in motion at the time the search array initially appeared. Thus, the onset of the search array may have attenuated any response to a motion onset that occurred around the same time.

which the target happened to appear in the object that had experienced motion onset.

Experiment 1b was identical to Experiment 1a with one important exception: A 900-ms delay was inserted after the movement transition but before presentation of the search array (see Fig. 1). If any of the events that occurred at the movement transition captured attention in a stimulus-driven manner, then in Experiment 1b subjects would be expected to be *slower* to detect targets at the captured location than at the other locations. Such a slowing is referred to as *inhibition of return* (Posner & Cohen, 1984). The explanation of the phenomenon is as follows. A transient event may capture attention and produce a benefit at the captured location for a brief time. However, if subjects believe that the transient is uninformative with respect to the upcoming target location, they will remove their attention from the location of the transient and return to a diffuse attentional state. The removal of attention is believed to leave in its wake inhibition, which slows responding to events at the location in question. Inhibition of return has been observed to occur as early as 300 ms after the cue, although typical cue-target delays are about 900 ms, as in Experiment 1b.

In both experiments, the search array remained visible until the subject responded. If a subject responded incorrectly, a brief tone followed by the message "Wrong Response" was presented. A tone and the message "Too Early" or "Too Slow" was presented if a subject responded less than 300 ms after array onset or failed to respond within 3,000 ms, respectively. After each block, subjects were informed of their mean reaction time and number of errors.

### *Design*

Following 24 practice trials, subjects served in 288 experimental trials. Trial presentation was balanced such that the target was equally likely to appear in each of the four different types of objects, the distractor letters were equally likely to be *E* or *U*, and the target letter was equally likely to be *S* or *H*. The target-to-response key mapping was counterbalanced across subjects. Trial types were randomly mixed. At intervals of 48 trials, subjects were given the opportunity to take a break.

## Results and Discussion

Mean reaction times for each type of motion are shown in Figure 2, separately for Experiments 1a (no delay after movement transition) and 1b (900-ms delay after movement transition). An overall analysis of variance across both experiments revealed no main effect of movement condition, $F(3, 60) = 2.3$, n.s., but a reliable interaction between movement condition and experiment, $F(3, 60) = 13.1$, $p < .001$. Individual analyses confirmed the details of the interaction. In Experiment 1a, subjects were fastest to identify the target when it appeared in the object that had just started to move (i.e., in the motion-onset condition), $F(3, 27) = 10.8$, $p < .001$. Post hoc *t* tests confirmed that latencies in the motion-onset condition were faster than those in the static condition, $t(9) = 5.8$, $p < .001$; continuous-motion condition, $t(9) = 4.6$, $p < .005$; and motion-offset condition, $t(9) = 3.0$, $p < .05$. The results show clearly that attention was captured by the onset of motion, leading to speeded target identification when the target was in the object that had started moving.

A very different pattern of results was observed in Experiment 1b. As in Experiment 1a, there were significant differences in reaction times across conditions, $F(3, 33) = 4.8$, $p < .01$, but in this case, reaction times were slowest, not fastest, in the motion-onset condition.

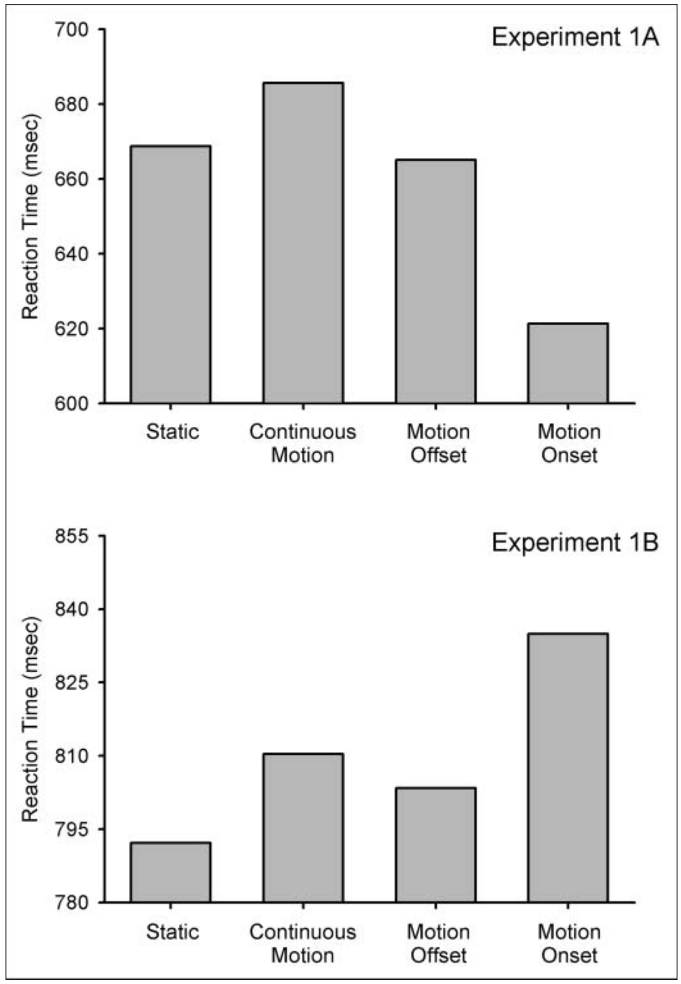


**Fig. 2.** Mean reaction times for each of the four types of movement in Experiments 1a (top panel) and 1b (bottom panel). In Experiment 1a, the search letters were revealed coincident with the movement transition. In Experiment 1b, a 900-ms delay was inserted after the movement transition but before appearance of the search letters.

Post hoc comparisons confirmed that reaction times were slower in the motion-onset condition than in the static condition, $t(11) = 3.4$, $p < .01$; continuous-motion condition, $t(11) = 2.5$, $p < .05$; and motion-offset condition, $t(11) = 2.3$, $p < .05$. Recall that a 900-ms delay was introduced between the onset of motion and the conversion of the placeholders into letters in Experiment 1b. Such a delay is sufficient to yield the inhibition-of-return effect (e.g., Abrams & Pratt, 2000; Posner & Cohen, 1984). The pattern of results suggests that motion onset attracted the subjects' attention, but because the onset was uninformative with respect to target location, subjects withdrew their attention from the motion-onset object. Their later attempt to return attention to that object while searching for the target was slowed because of inhibition of return. Indeed, the presence of inhibition of return in Experiment 1b is consistent with our conclusion that the motion onset attracted attention in a stimulus-driven manner because it has been shown that inhibition of return occurs only after exogenously attracted attention, not centrally directed attention (Posner & Cohen, 1984).

Error rates did not exceed 3.6% in any condition of either experiment, and did not depend on the motion condition, $F(3, 27) < 1$, n.s., in Experiment 1a and $F(3, 33) = 1.4$, n.s., in Experiment 1b.

It is worth noting one alternative interpretation of the present results. Because we studied objects that differed from the background in luminance, it is possible that the attentional capture we observed was due not to the onset of motion but instead to the onset of local luminance changes near the motion-onset object when it began to move. Another experiment we have conducted (Christ & Abrams, 2002) is not open to this possibility because in that experiment the motion consisted entirely of a field of randomly moving dots that suddenly began to move coherently. The onset of coherent motion attracted attention, but the onset was not accompanied by an onset of luminance change, effectively ruling out the alternative explanation of the present results.[5]

## EXPERIMENT 2

The results of Experiments 1a and 1b suggest that attention was captured by the motion-onset object, leading to enhanced target identification at a short delay between the onset and the appearance of the search array, and also leading to inhibition of return when the delay between motion onset and presentation of the search array was longer. In Experiment 2, we conducted a different test of attentional capture. If attention is captured by motion onset, then motion onset should lead to efficient search performance. That is, subjects should be able to identify a target in a motion-onset object equally fast regardless of the number of other elements in the display. This requirement reflects the load-insensitivity criterion of automaticity discussed by Yantis and Jonides (1990). Thus, in Experiment 2, we had subjects identify targets like those in Experiment 1 in displays that contained either three or six elements.

### Method

#### *Subjects*

Ten students drawn from the same population as studied earlier participated. None had served previously.

#### *Apparatus and procedure*

This experiment was similar to Experiment 1a, with the following differences. The initial display included either three or six placeholders, all of which were initially stationary. Following a 3,200-ms delay, one of the placeholders began moving (*motion-onset* condition) while the other placeholders (either two or five) remained static (*static* condition). Coincident with the onset of motion, all of the placeholders turned into letters, as they had in Experiment 1a. Subjects were instructed to identify the target in the display as quickly as possible.

#### *Design*

On a given trial, the target was equally likely to appear in any of the placeholder locations. When three items were present, the target was the motion-onset item on 33% of the trials. When six items were present, the target was the motion-onset item on 17% of the trials. Otherwise, the experimental design was identical to that used in Experiment 1.

### Results and Discussion

Mean reaction times for motion-onset and static targets are shown in Figure 3 for the two display sizes. Subjects were slower to detect targets in static objects overall, a result consistent with attentional capture by the motion onset, $F(1, 9) = 42.6$, $p < .001$. Subjects were also slower overall when the display size was six than when it was three, $F(1, 9) = 18.3$, $p < .005$. However, the display-size effect was driven entirely by the static targets, resulting in an interaction between display size and motion condition, $F(1, 9) = 9.8$, $p < .05$. Additional $t$ tests confirmed that the 24-ms-per-item search slope in the static condition was reliably greater than zero, $t(9) = 6.3$, $p < .001$, and the 5.4-ms-per-item slope in the motion-onset condition was not, $t(9) = 1.0$, n.s. These slopes are within the ranges generally thought to indicate inefficient search (in the static condition) and efficient search (in the motion-onset condition; Wolfe, 1998).

Error rates were less than 3% in all conditions and did not depend on display size or motion type, nor was there an interaction, $F$s$(1, 9) < 1$.

The results from Experiment 2 provide support for the hypothesis that objects that have recently begun to move capture attention in a bottom-up fashion. This conclusion is possible because the location of the target was uncorrelated with the motion of the elements, yet targets were found and identified rapidly when they happened to be the

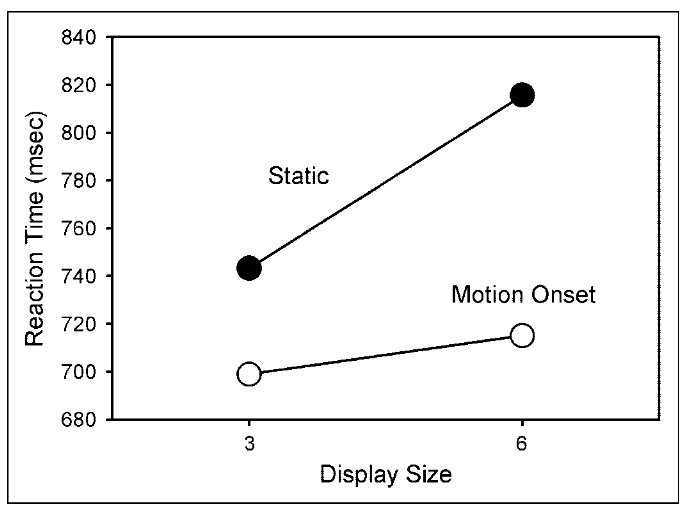


**Fig. 3.** Mean reaction times for target identification in Experiment 2, shown separately for trials on which the target was or was not the sole element that had undergone a motion onset.

5. In this other experiment (Christ & Abrams, 2002), 10 subjects viewed four placeholders identical to those used in Experiment 1. The placeholders remained fixed throughout a trial. Each placeholder was superimposed on a 3.75° square patch of 75 dots that each moved one pixel in a randomly selected direction during each video refresh (16.7 ms; dots that would exit the patch instead disappeared and reappeared on the opposite side). At the appropriate time, the dots in one randomly chosen patch began to move in the same direction, and 150 ms later the placeholders were replaced by letters. Subjects were 43 ms faster to detect the target when it appeared on the dots with coherent motion (25% of the trials) than when it appeared on the dots moving randomly, $t(9) = 4.3$, $p < .005$.

motion-onset element. The speed of target detection did not depend on display size when the target was the motion-onset element.[6]

## GENERAL DISCUSSION

We have shown that the onset of motion captures attention in a bottom-up, stimulus-driven manner. This conclusion is based on finding (a) an advantage for motion-onset elements in search despite the motion being uninformative (Experiment 1a), (b) a disadvantage for motion-onset elements in search after a 900-ms delay (Experiment 1b), and (c) rapid detection of and the absence of a display-size effect for motion-onset elements, also in a condition in which motion was not correlated with target location (Experiment 2).[7] It is important to emphasize that motion per se does not appear to attract attention, but rather it is the *onset* of motion that is important. This conclusion is possible because motion onset and continuous motion were pitted against each other in Experiment 1 (and also in Experiment 2 and the control experiment described in footnote 6), and because prior attempts to study capture by motion have not detected such capture (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999). More recently, Franconeri and Simons (in press) reported capture by some types of motion. In their experiments, however, the search array was always revealed shortly (150 ms) after motion onset, so their results could be due entirely to capture by motion onset and not motion per se.

Our results may also represent the first demonstration of attentional capture uncontaminated by top-down biases that can arise from an attentional set for the displaywide changes that signal the presence of the search array (Gibson & Kelsey, 1998). In our experiments, an attentional set for movement in general, for changes in movement, or for the offset of the camouflaging placeholder segments would not have favored the motion-onset item over the motion-offset or continuous-movement items. Thus, the advantage of the motion-onset item may reflect a true bottom-up capture of attention.

What is the potential utility of a visual system in which motion onset captures attention? One possibility, mentioned earlier, is that motion onset is a cue that is indicative of object animacy. When one's survival may depend on the rapid detection of nearby predators (or prey), detection of animacy may play a key role. Thus, if attention were captured by events likely to indicate animacy, an important function would be served (a similar suggestion was made by Tipper & Weaver, 1998). Heightened sensitivity to motion onsets in particular would have a number of advantages over a system that was merely sensitive to movement in general. One such advantage, for example, would be a reduced frequency of false positives that might otherwise call attention unnecessarily to the nearly continuous retinal motion caused by one's own locomotion through the environment.

The present results may also bear on an understanding of the brain areas responsible for processing movement information, and their role in perception and attention more generally. For example, several sources of evidence suggest that new objects will capture attention in much the same way that we have shown here that motion onset captures attention (e.g., Oonk & Abrams, 1998; Yantis & Hillstrom, 1994). Thus, it may be that capture by new objects and capture by motion onset are both consequences of the operation of a single object-processing system. That possibility is consistent with recent results of Kourtzi, Bülthoff, Erb, and Grodd (2002). These researchers showed that the middle temporal and medial superior temporal brain areas (MT and MST), generally thought to be important for the perception of motion, are also involved in processing object features such as shape. Given the shared brain regions involved, it is not surprising that new objects and certain types of motion signals have similar effects on the attention system.

Whatever the specific neuroanatomical substrate, a number of potentially important functions could be facilitated by a visual system that is especially sensitive to the onset of motion, as we have shown to be true of the human visual system. Thus, as is the case with so many of his other insights, William James was at least partially correct when he stated that moving things attract attention. Perhaps if he were here today he might instead suggest that "things that have just started to move" attract attention.

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Kourtzi, Z., Bülthoff, H.H., Erb, M., & Grodd, W. (2002). Object-selective responses in the human motion area MT/MST. *Nature Neuroscience*, *5*, 17–18.

6. We also conducted a control experiment identical to Experiment 2, but with an element in continuous motion from the beginning of the trial instead of undergoing a motion onset. The 8 subjects were slower to detect targets when the display size was six compared with three, $F(1, 7) = 19.0$, $p < .005$, but there was no effect of motion condition, $F(1, 7) < 1$, nor did the effect of motion condition interact with display size, $F(1, 7) < 1$. These results effectively rule out the possibility that motion onsets in Experiment 2 captured attention because of some unknown, perhaps accidental feature of the method. If that were the case, then capture would also have been expected in the control experiment, but instead the control experiment showed a failure of continuous motion to capture attention, as has been reported by other investigators (e.g., Hillstrom & Yantis, 1994).

7. We can add to this list one additional source of evidence for attentional capture by motion onset. We recently found that inhibition of return will be reduced if a sufficiently distracting stimulus is presented in the display shortly before presentation of the to-be-detected target (Abrams & Christ, 2002). Continuous motion of an object was not distracting—it could be ignored and had no impact on the magnitude of inhibition of return. However, an object that *began* to move could not be ignored, even though subjects knew it would have no bearing on their task. As a result, onsets of motion were distracting and resulted in a decrease in inhibition of return. This finding shows that motion onsets satisfy the intentionality criterion of automatic capture identified by Yantis and Jonides (1990). Specifically, the capture of attention by motion onset does not appear to be susceptible to voluntary suppression.

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