

# Isoluminant motion onset captures attention

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In their 2003 article, Abrams and Christ found that the onset of motion captured attention more effectively than either the offset of motion or continuous motion. Abrams and Christ conceptualized the capture to be occurring at a level higher than does detection of luminance changes in the stimulus. To examine this claim, in the present experiments we replicated their critical experiment but used isoluminant stimuli, which do not produce the low-level luminance transients typically associated with motion. Under isoluminant conditions, we found a pattern of results very similar to that found previously with luminance-defined stimuli, indicating that attention can be prioritized on the basis of perceived motion onset by an object in the absence of low-level luminance transients. This may reflect an evolutionary adaptation to bias attention toward objects that exhibit characteristics of animacy, such as abruptly changing from a static to a dynamic state.

One of the continuing controversies in visual cognition concerns the nature of the stimuli and the circumstances that generate reflexive shifts of attention (e.g., Theeuwes, 1991; Yantis & Jonides, 1984). At the core of this issue is a seemingly simple question: What captures attention? The answer to this question has, perhaps unexpectedly, become quite complicated, with a wide variety of findings arising from a myriad of different paradigms. Whereas most of the studies of attentional capture have focused on changes in luminance and/or the appearance of new objects in the visual field, Abrams and Christ (2003) tested the hypothesis that the onset of motion captures attention. Prior to that time, studies of capture by motion per se failed to find any supporting evidence (e.g., Yantis & Egeth, 1999). Using a search task, Abrams and Christ showed that subjects found a target faster when it underwent a motion onset than when target items underwent a motion offset, remained static, or were constantly in motion. Abrams and Christ concluded that the onset of motion by a previously static object will reflexively capture attention. Furthermore, they proposed that motion onset is inherently valuable for a visual system to detect because it is a clue of animacy; it alerts the organism to predators and prey, because such entities are likely to be the initiators of motion.

What could be the mechanism responsible for this reflexive capture of attention? One area likely to be involved is the superior colliculus (SC). The SC has cells in its superficial layers sensitive to luminance-transient

and movement-related retinal input, and plays a key role in shifting both covert and overt attention (Posner & Petersen, 1990; Wurtz & Albano, 1980). The SC receives primarily luminance-sensitive magnocellular input from the retina, and is relatively insensitive to isoluminant chromatic borders (Marrocco & Li, 1977; Sparks, 1986). Although the SC relies on cortical input and requires cortical input from area MT to detect more complex stimuli, such as relative motion between two moving targets, it is capable of detecting motion even when cortical inputs are removed by disconnection or by cortical lesions (Davidson, Joly, & Bender, 1992; Joly & Bender, 1997).

In the cortex, the perception of motion by the early visual system is localized primarily in the dorsal, magnocellular system, which is sensitive predominantly to luminance (Livingstone & Hubel, 1988). Many forms of apparent motion (e.g., the motion seen on film, TV, and computer screens) weaken or fail at isoluminance levels, such as illusory motion stripes that appear to stop (Anstis & Cavanagh, 1983), 3-D shapes defined by random dot motion that move aimlessly (Livingstone & Hubel, 1988), and random dot kinematograms that fail to achieve figure-ground separation (Ramachandran & Gregory, 1978).

Even without considering motion, the removal of luminance transients has been shown to prevent capture by some stimuli, while leaving capture by other stimuli intact (cf. Theeuwes, 1995; Yantis & Hillstrom, 1994). Isoluminant motion displays, therefore, pose an interesting ques-

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tion for attention capture: Do motion stimuli deprived of luminance transients with regard to the background still capture attention, despite the fact that such stimuli bypass the SC and are difficult for the low-level motion-detection systems of the brain? In other words, is the onset associated with motion sufficient to capture attention even when there is no traditionally defined “onset capture” (i.e., a luminance transient)? If little or no capture is found with isoluminant stimuli, then the motion-onset attentional capture found by Abrams and Christ (2003) may likely be due to low-level transients. Conversely, if isoluminant stimuli yield robust attentional capture, then the results will support Abrams and Christ’s notion that motion onsets capture attention due to higher level processes associated with the detection of animacy.

## EXPERIMENT 1

In order to examine whether or not the capture of attention that occurs with the onset of motion is dependent on luminance transients, we first attempted to replicate Experiment 1 of Abrams and Christ (2003), but with isoluminant stimuli. To obtain isoluminance in this experiment, we employed the commonly used apparent flicker minimization (flicker fusion) procedure (see, e.g., Lambert, Wells, & Kean, 2003). As with Abrams and Christ, four figure-eight objects appeared on the screen, two in motion and two static. When the figure eights changed to letters (with one letter in the display being the target), one of the static objects came into motion and one of the moving objects came to a stop. Thus, the target could appear at either a continuously static, continuously moving, motion-stopped, or motion-started object. If motion onsets capture attention, objects that have recently undergone a motion onset would be identified more quickly than objects that underwent a motion offset, maintained continuous motion, or remained static. In other words, we wanted to know if motion onset would prioritize the target when all four motion types were present and the target was equally likely to undergo one of the four motion types.

### Method

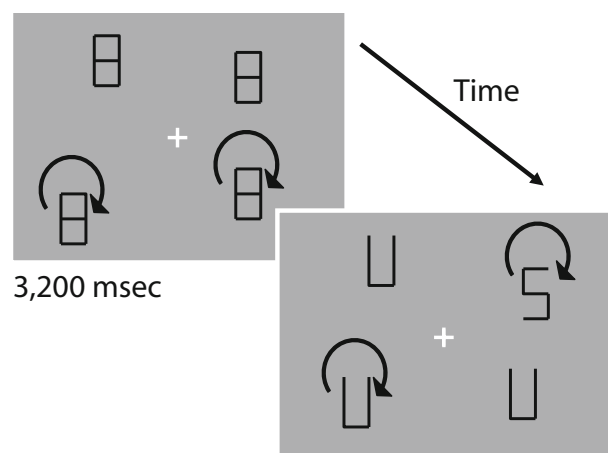
**Subjects.** Ten undergraduate students from the University of Toronto participated in the experiment for course credit. All of the subjects were naive to the purpose of the experiment.

**Apparatus.** Subjects were tested using an IBM-compatible computer with a CRT monitor in a dimly lit room. A head- and chinrest were used to maintain a constant viewing distance of 43 cm. Stimuli were drawn using the Microsoft Windows GDI+ tool kit in real time with a temporal resolution no longer than 6 msec, even for the most complicated displays. The monitor refresh rate was 75 Hz.

**Procedure.** For the isoluminance calibration task, subjects were presented with a display of rectangles composed of two colors, a red (RGB = 170, 0, 0; luminance = 6.51 cd/m<sup>2</sup>,  $x = .600$ ,  $y = .325$ ) and a green (RGB = 0,  $g$ , 0, where the value of  $g$  is an integer from 0 to 255, representing the green component brightness and adjusted as described below). The display was a large square, 12° in width, divided along the vertical meridian, with one half being green and the other half being red. The colors of this square alternated at a rate of 15 Hz. At the center of the square was another square, 2° in width, divided along the vertical meridian, with one side permanently red and the other permanently the adjustable green. While this animated display was shown, subjects used the left and right arrow keys on

the keyboard to change the brightness of the green component (by increasing or decreasing its  $g$  value) until the flicker of the screen was minimized; when they were certain that they had achieved minimal flicker, they pressed the Enter key to end the adjustment trial. The initial  $g$  value was 1 on even adjustment trials and 255 on odd adjustment trials. Subjects were presented with a black screen between trials and told to press the space bar to continue. The average  $g$  value of eight adjustment trials was considered to be subjectively isoluminant to the predetermined red color.

The letter search task (Figure 1) was a colored version of the white-on-black Abrams and Christ (2003) motion-onset letter search task, with the letters being the adjusted solid green and the background being the predetermined solid red. This created a subjectively isoluminant display. The initial display consisted of the red background. After 500 msec, a 1°-wide white fixation cross appeared at the center of the display, and subjects were instructed to fixate on the cross until the search array was presented. Following another 500 msec, four green placeholders appeared. Each placeholder was a block figure eight measuring 1° wide × 2° high, with the line segments being 0.16° wide. The placeholders were randomly placed within an imaginary square 18° wide, so that no two placeholders were horizontally or vertically aligned with each other, and would never move within 1° of each other or the center cross. Two of the placeholders appeared moving clockwise along their own circular paths 2° in diameter, starting at random locations along the circle, while the other two placeholders were static. After 3,200 msec, segments of the placeholders were removed to reveal the search array, and at the same time the movements of the placeholders (now search items) changed: One of the moving placeholders stopped moving (*motion offset*), while the other remained in motion (*constant motion*). One of the static placeholders began moving in a circular path (*motion onset*), while the other remained static (*still*). When segments were removed, one of the placeholders turned into the target letter (“S” or “H”), whereas the other placeholders turned into distractors (all “E”s or all “U”s). Subjects were told to press one of two keys (“z” or “/”) in response to the identity of the target letter. The search display remained on screen until subjects responded or 3,200 msec elapsed. A message told the subject whether his or her response was correct, wrong, irrelevant (if other keys were pressed), or too slow, along with a reminder of what the correct keys were. Between trials, the screen appeared black for 2,000 msec, after which the



**Figure 1.** The sequence of events on a letter search trial in Experiment 1. At the start of each trial, two placeholders were in circular motion while the other two were static. When the line segments were removed to reveal the target and distractors, one of the moving objects stopped while one of the static objects began to move. The background color was red and the line segments were drawn in an isoluminant green. Circular arrows indicate motion, and were not present in the actual display.

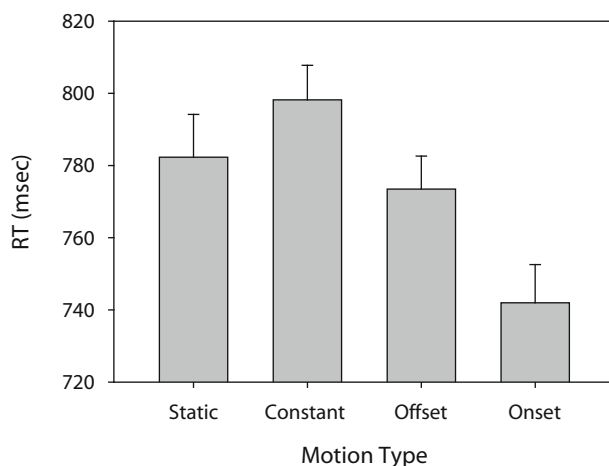
next trial began automatically. Subjects were given a short break every 48 trials.

**Design.** Subjects first performed eight practice isoluminance adjustments and 16 practice search trials, followed by eight experimental isoluminance adjustments and 288 experimental search trials. Across each session, the target was equally likely to appear at the still, constant-motion, motion-onset, and motion-offset objects. The two targets (S/H) were equally likely to occur, as were the two distractors (E/U). The assignment of response keys to targets was counterbalanced across subjects.

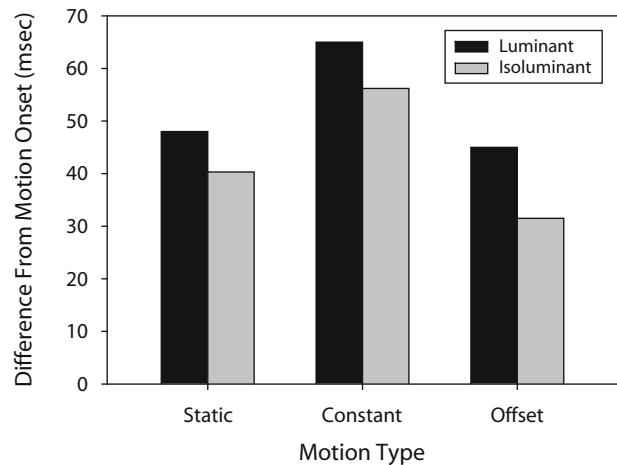
## Results and Discussion

Overall, the mean green component value that subjects selected as isoluminant was 100 RGB units (i.e., RGB = 0, 100, 0; producing a green with luminance = 8.15 cd/m<sup>2</sup>,  $x = .295, y = .562$ ), with a standard deviation of 22.2 RGB units. Trials in which reaction time (RT) was less than 50 msec or greater than 1,400 msec were eliminated from the analysis, and only trials with correct responses were considered for analysis (this removed 2.2% of the trials). From the remaining trials, mean RTs were calculated for each subject and condition, and these were analyzed using a within-subjects, one-way (still, constant motion, motion onset, motion offset) ANOVA; see Figure 2. A main effect for motion condition was found [ $F(3,27) = 6.5, p < .01$ ], and planned comparisons showed that subjects responded significantly faster to motion-onset targets than to (A) still targets [ $t(9) = 3.2, p < .06$ ], (B) constant-motion targets [ $t(9) = 3.7, p < .01$ ], and (C) motion-offset targets [ $t(9) = 2.2, p < .03$ ]. The error rate for each motion condition was at most 6.4%, and did not depend on the motion type of the target [ $F(3,36) < 1$ ].

The finding that motion-onset letter targets were identified most quickly replicates the previous finding of Abrams and Christ (2003), who used luminance-defined stimuli. Moreover, we computed the benefit afforded by the isoluminant motion onset in the present experiment by subtracting RTs in the motion-onset condition from those in each of the other conditions. These differences, shown in Figure 3, reveal that the magnitude of the advantage conferred by motion onset



**Figure 2.** Mean reaction times when the target underwent each of the four types of motion, from Experiment 1. Error bars represent standard errors.



**Figure 3.** Response time benefit due to motion onset by the target compared with the other three movement types, for both luminance-defined (from Abrams & Christ, 2003) and isoluminant stimuli (the present experiment).

is almost identical to that found with the luminance-defined stimuli used by Abrams and Christ. Thus, not only does the onset of motion capture attention when isoluminant stimuli are used, the capture effect is virtually the same as that seen when luminance transients are present.

The similarity between the findings of our isoluminance experiment and the previous luminant experiment of Abrams and Christ (2003) is evidence that the capture of attention through motion onset is not due to low-level transients. There is, however, an alternative explanation: Our isoluminant procedure was simply not accurate, and sufficient transients remained to produce effects similar to those in the Abrams and Christ study. This is particularly important given that the magnocellular system is very sensitive (see, e.g., Livingstone & Hubel, 1988) and would pick up small residual luminance differences. Furthermore, we did not use a control task to verify whether isoluminance was achieved. We therefore devised a second experiment using a more sophisticated adjustment method in order to provide converging evidence for our initial findings.

## EXPERIMENT 2

Whereas the results of the first experiment clearly show attentional capture from the motion-onset objects, the conclusions we have drawn depend on the objects' being isoluminant with the background. To provide important converging evidence that motion onset captures attention in isoluminant displays, we conducted a second experiment that improved several aspects of our isoluminance procedures. One change was that the isoluminance adjustment was done by using a forced-choice illusory motion adjustment procedure, followed by a testing phase in which we interpolated for the subject's true isoluminance point. The resulting procedure is significantly more complicated than the flicker fusion procedure typically used in creating isoluminant stimuli, but it is a more rigorous method of isoluminance adjustment. The illusory motion

stripe is an illusion in which four square-wave gratings are presented one after another, with two gratings composed of black and white, whereas the other gratings are composed of the two colors to be equated in luminance. The illusion created is that the stripe appears to be scrolling in one direction, and that direction depends on the relative brightnesses of the two colors. The direction of motion is maximally ambiguous at isoluminance. This illusion, originally described by Anstis and Cavanagh (1983), is more suitable for our purposes than the flicker minimization method because it relies on the failure of an involuntary illusion at isoluminance while indicating to the viewer, through the direction of illusory motion, how to make further adjustments. The technique has been used reliably to identify colorblind individuals, who have different isoluminance points (Anstis & Cavanagh, 1983), as well as to determine relative perceived brightness of red and green in nonverbal subjects such as babies (Anstis et al., 1986) and guppy fish (Anstis, Hutahajan, & Cavanagh, 1998). In our experiment, each response was set up so that it would adjust the green value for the subsequent trial, causing the green value to ultimately converge on the isoluminant value. This guaranteed that subjects would perform the task properly, since the task ended only when there was no net adjustment over the most recent 10 trials.

Another improvement to the method of the first experiment was the addition of luminance noise in the letter search display for both colors. The addition of dynamic pixelwise brightness noise was intended to make small residual deviations from isoluminance in the display uninformative. This method has been used in the past by Snowden (2002) to make uninformative any residual luminance differences in the display, particularly those resulting from color borders and high spatial frequencies. To create the noise, two predetermined brightnesses of red were used in this experiment to define the limits of the noise range, with one being the darkest possible red and one being the brightest possible red. The noise was then randomized in steps of 1/255 RGB units within that range. In order to ensure that the noise range of the green was similar to that of the predetermined red, two sets of forced-choice illusory motion adjustments were performed.

Finally, a novel testing procedure of forced-choice apparent motion judgments was added before the letter search task in order to verify that the stimuli had indeed achieved isoluminance. A series of illusory motion stripes were presented, but instead of each response adjusting the green color, each response was recorded and the probability of choosing one direction was calculated. The isoluminance point for the subsequent letter search task was then taken from interpolating the probabilities of this judgment procedure, instead of directly from the forced-choice adjustment procedure. Three green values were interpolated: one when subjects were 75% uncertain that the green brightness was below isoluminance, one when subjects were 50% uncertain (i.e., responded randomly, presumably due to isoluminance being reached), and one when subjects were 25% uncertain that the green brightness was below isoluminance. These three green luminance values were then used in the letter search task to add a factor of

luminance to the design; this allowed the effect of motion onsets to be tested at different luminances (one just at the dimmer-than-isoluminance threshold, one just at the brighter-than-isoluminance threshold, and one in between these two, which presumably is at isoluminance). If motion onset were affected by luminance, then we should expect that any effect of luminance would interact with the effect of target motion type. If motion-onset capture occurs at isoluminance, however, then the factor of luminance should not interact with the effect of target motion type.

## Method

**Subjects.** Subjects were 15 naive undergraduate students at the University of Toronto, and all received course credit for their participation. None had participated in the previous experiment.

**Apparatus.** The apparatus used was the same as in Experiment 1.

**Procedure.** Subjects first performed the adjustment phase of the calibration task, each trial of which consisted of making a forced-choice response on the direction of the illusory motion. The illusory motion stripe was composed of a sequence of four repetitive images presented at 30 frames per second. The first frame was a strip of alternating bright gray (luminance = 56.6 cd/m<sup>2</sup>) and black squares (0.3° wide) located across the horizontal meridian of the screen. The second frame was a strip of squares composed of one adjusted green and one standard red square but shifted to the left by half the width of each square. The third frame was exactly like the first frame but with the colors reversed, and the fourth was exactly like the second but with the colors reversed. When viewed, the brighter of the red and green colors appears to associate with the bright gray squares, and hence, depending on which color is brighter, the stripe will appear to move in a different direction. Subjects were told to report the direction in which the stripe was moving, and each response ended the trial. Trials from six independent adjustment threads were presented to the subject one at a time, in random order. Each adjustment thread operated independently and tracked its own adjusted green value and the responses made to its trials. Within each thread, an initial green value was randomly presented, and with each response of the subject, 3 RGB units of green were added or subtracted for the next trial in order to minimize the magnitude of the perceived motion. Eventually, the subject would pass the isoluminance point, and his or her responses would reverse direction. After five such reversals, each subsequent trial added or subtracted 1 RGB unit of green instead of 3, and the adjusted green value was saved when there was no net change in its value over the most recent 10 trials. When the green values of all six threads had been saved, two averages were produced representing the isoluminant green value for each of the two red values. Three of the threads used a dim red (RGB = 150, 0, 0; luminance = 5.17 cd/m<sup>2</sup>,  $x = .592$ ,  $y = .324$ ) and the other three used a bright red (RGB = 210, 0, 0; luminance = 11.6 cd/m<sup>2</sup>,  $x = .629$ ,  $y = .328$ ) in order to produce the noise for the letter search task.

Following a short break, subjects then performed the probability measuring phase of the calibration task, where their probability of reporting the stripe as moving rightward (i.e., the green is dimmer) was measured at 4 luminance deviations around the bright red's isoluminant point obtained from the adjustment phase (i.e., they were presented stripes with green at -20, -10, 0, +10, and +20 g units from isoluminance). For the subjects, there was no indication that the task had changed; they performed the same stripe-direction judgments. There were five threads of 40 trials each, with each thread corresponding to a degree of brightness deviation, and trials were presented from each of the threads in random order. From the psychometric function produced by this phase, luminance values when subjects reported "moving right" 25%, 50%, and 75% of the time were calculated by linear interpolation.

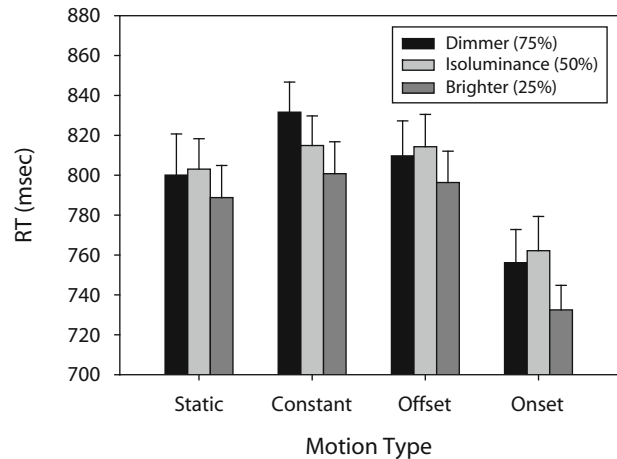
Subjects were then given another brief break, after which they performed the motion-onset task. There were two differences from Experiment 1. First, luminance noise was added to the search letters as

well as the background. The background was created by displaying 1 of 30 randomly chosen prerendered noisy red bitmaps on each frame, while the placeholders and letters were drawn with randomly selected areas of a large green noise bitmap generated immediately following isoluminance calibration, using the averaged bright and dim green values. The noise was pixelwise and dynamic, such that neither two adjacent pixels of the same frame nor the same screen pixel across different frames was likely to remain the same brightness. The animation of the noise was necessary to ensure that the luminance changes arising from the edges of the moving noise patches were not informative. If this were not the case, pixels at the edges of the moving figure would be replaced by pixels of the opposite color that were not necessarily isoluminant, which would produce a moving luminance-defined outline. Second, there was an additional factor of luminance, with 3 levels of luminance: 75% (i.e., the green value at which subjects reported an illusory stripe drawn with it to move right 75% of the time), 50% (i.e., isoluminant), and 25%. The noise range for each brightness condition was determined by the difference between the average bright green and the average dim green value obtained from the calibration task. Trials from three threads corresponding to each of the green brightnesses were presented in random order. The only other aspect of this task that differed from Experiment 1 is that the number of trials was different: Subjects performed 576 trials in a 3 (green brightness levels)  $\times$  4 (target motion type) design. As before, the target was equally likely to undergo each of the four motion changes, and the two targets (S/H) and distractors (E/U) were equally likely to occur. Subjects received a break every 48 trials.

## Results and Discussion

Trials for which RTs were not between 50 and 1,400 msec or that had wrong responses were trimmed, removing 2.5% of the total trials. Error rates did not exceed 5% for each of the 12 conditions. Overall, mean green values and standard deviations for the 25%, 50%, and 75% luminance conditions were found to be  $114 \pm 13.4$  RGB units (producing  $11.4 \text{ cd/m}^2$ ,  $x = .295$ ,  $y = .571$ ),  $108 \pm 10.1$  RGB units ( $9.99 \text{ cd/m}^2$ ,  $x = .295$ ,  $y = .566$ ), and  $97 \pm 13.2$  RGB units ( $8.18 \text{ cd/m}^2$ ,  $x = .295$ ,  $y = .557$ ), respectively. Mean RTs were calculated for each subject and condition, and analyzed with a 3 (luminance: 25%, 50%, 75%)  $\times$  4 (target motion type: still, constant motion, motion onset, motion offset) ANOVA. The overall mean RTs for each condition are shown in Figure 4. A main effect was found for luminance [ $F(2,28) = 4.0$ ,  $p < .030$ ]; as expected, luminance had an effect on RT. A main effect was also found for target motion type [ $F(3,42) = 29.0$ ,  $p < .001$ ], and there was no interaction between luminance and target motion type [ $F(6,84) < 1$ ]. Comparisons between the motion-onset condition and each of the other three motion-change conditions using separate 2 (motion onset vs. either constant motion, motion offset, or static)  $\times$  3 (25%, 50%, 75%) ANOVAs showed that target motion type had a consistent effect, with [ $F(1,14) > 18.2$ ,  $p < .001$ ] for all three; motion-onset targets were detected significantly faster than were targets in the other motion conditions. There was also no interaction between luminance and target motion type for all three comparisons [ $F(2,28) < 1$ ].

The luminance of the letters, though it did have an effect on RT, did not interact with the effect of target motion type. This suggests that motion onsets are not influenced by how strongly they are defined by luminance; motion onsets are just as effective at capturing attention when they are isoluminant as they are when they depart slightly



**Figure 4.** Mean reaction times when the target underwent each of the four types of motion, in each of the three green brightness conditions, from Experiment 2. Error bars represent standard errors.

from isoluminance. The present results thus replicate those from Experiment 1, and are consistent with the view that motion onset captures attention even in the absence of luminance-defined contours.

## GENERAL DISCUSSION

A consistent RT advantage for motion onset was found in both experiments, despite the differences in the methods of obtaining isoluminance. It is possible that Experiment 1 might have shown the motion-onset capture effect because of a failure to achieve isoluminance. In Experiment 2, however, not only did the elimination of luminance differences fail to weaken the motion-onset capture effect, but also changes in luminance, while influencing global RTs, failed to influence the motion-onset effect altogether. Together, our findings indicate that isoluminant motion onsets capture attention relative to constant motion, motion-offset, or no-motion conditions.

The finding of attentional capture with isoluminant motion onsets also indicates that the SC is not necessary for attentional capture by motion onset, because the SC is relatively insensitive to isoluminant color changes, and we did not observe a loss of capture at isoluminance. This conclusion is in line with the literature suggesting that the SC is not necessary in attention orienting. For example, Sumner, Adamjee, and Mollon (2002) reported that isoluminant distractors, which were invisible to the SC as shown by their inability to distract saccadic eye movements, could still produce exogenous cuing effects. Similarly, Cole, Kentridge, and Heywood (2005) reported that attention could be captured with the onset of a new isoluminant object, but not by an old isoluminant object that changed color. In both of these studies, the removal of low-level luminance transients alone, by using isoluminant stimuli, had no influence on attentional capture. It is worth noting that although we found that isoluminant motion onset captures attention relative to isoluminant motion offset and constant motion,

the latter types of motion-capture attention would likely capture attention if they were singleton events among a field of static objects. Whether or not luminance transients would be required for such capture is an open question.

The present results are also consistent with the idea that attention capture can depend on higher level perceptual representations. For example, Yantis and Hillstrom (1994) used non-color-based isoluminant displays to show that capture produced by new objects was a result of the object onset, not the luminance change associated with the onset. Cole et al. (2005) found that a color change at isoluminance was insufficient for capture, but when the initial color of an object was the background color, so that the color change of that object produced the percept of a new object's onset, the color change produced capture. With regard to isoluminant stimuli, Burr, Fiorentini, and Morrone (1998) showed that RTs to the motion onset of isoluminant gratings depended on the perceived speed, as influenced by the degree of isoluminance, and not the actual physical speed of the stimulus. In light of these studies, our results support the idea that attention can be prioritized on the basis of the onset of perceived *object* motion—that is, the perception that a previously static object is now moving—even in the absence of low-level evidence typically associated with such motion (such as changes at luminance edges).

Why might motion onset be so important as to generate reflexive attentional capture even when coded at only a relatively high level? Abrams and Christ (2003) speculated that the onset of motion indicates that the object in question has its own internal power source, and hence is a powerful cue to animacy—that is, the object may be alive. Clearly, throughout evolution it has been advantageous to be especially sensitive to the presence of nearby living things, which could have been either predator or prey. Indeed, evidence that humans are sensitive to potentially alive objects in our visual field comes from research showing that static pictures of animals produce ultrarapid saccadic responses (Kirchner & Thorpe, 2006). It has been shown that even simple geometric dots moving in unpredictable patterns across computer screens can be interpreted as animate (a phenomenon classified as perceptual animacy; see, e.g., Tremoulet & Feldman, 2000). Moreover, it has been shown that objects that have larger changes in speed or direction show greater perceptual animacy (Tremoulet & Feldman, 2000), leading to the prediction that the amount of capture found with our motion-onset stimuli might depend on the speed of rotation (and that the speed of rotation would affect the capture that occurs with motion offset and constant motion when they appear as singletons). In the present article, we have shown that such sensitivity can be maintained even in the absence of low-level sensory information that is typically associated with moving objects.

#### AUTHOR NOTE

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