Motion onset does not capture attention when subsequent motion is "smooth"

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Abstract

Previous research on the attentional effects of moving objects has shown that motion per se does not capture attention. However, in later studies it was argued that the onset of motion does capture attention. Here we show that this motion-onset effect critically depends on motion jerkiness, that is, the rate at which the moving stimulus is refreshed. Experiment 1 used search displays with a static, a motion-onset and an abrupt-onset stimulus, while systematically varying the refresh rate of the moving stimulus. Results show that motion onset only captures attention when subsequent motion is jerky (8 and 17 Hertz), not when it is smooth (33 and 100 Hertz). Experiment 2 replaced motion onset with continuous motion, showing that motion jerkiness does not affect how continuous motion is processed. These findings do not support accounts assuming a special role for motion onset, but they are in line with the more general unique-event account.

Motion in the visual field carries important information that is critical for an observer to successfully deal with every day events (Gibson, 1950), such as a suddenly approaching car or a waving hand. The human visual system is known to have specialized motion processing capabilities, and one might suspect that motion automatically attracts attention, in order to prioritize the processing of the information associated with the motion. However, research in the laboratory has, in general not supported this idea (e.g., Hillstrom & Yantis 1994; Yantis & Egeth, 1999; for a review see Rauschenberger, 2003; or Theeuwes, 2010). For example, Hillstrom and Yantis used a visual search task and showed that a moving stimulus (or a stimulus containing a moving texture) was not easier to find than a stationary stimulus unless the motion was predictive of the target's location or the motion resulted in the appearance of a new object.

However, these ideas have been contested by a number of studies showing, for example, that motion can have an effect on attention under certain conditions. For example, capture occurred when motion was used as a cue for a motion-defined target, but not for a target that was defined in another dimension, such as color or abrupt onset (Folk, Remington, & Wright, 1994). Others have suggested that attention capture occurs only with certain types of motion, like linear motion, oscillating motion, and looming motion (Franconeri & Simons, 2003; von Mühlenen & Lleras, 2007; Skarratt, Cole & Gellatly, 2009). Moreover, von Mühlenen, Rempel, and Enns (2005) argued that capture does not solely depend on motion type, but also on the timing of motion (e.g., motion starts 150 ms before search begins).

Finally, Abrams and Christ (2003) supported Hillstrom and Yantis (1994) finding that motion per se does not capture attention, but instead argued that it is the onset of motion that captures attention. They used a placeholder search paradigm with four stimuli, each having a task-irrelevant motion attribute: continuous motion, motion onset, motion offset and static. They showed that although a continuously moving target was not easier to find than a static target, a motion onset target was, supporting their Motion-Onset Account. In two other studies they replicated this benefit for a motion onset when comparing it with abrupt onsets (Christ & Abrams, 2008) and also when testing older people (Christ, Castel, & Abrams, 2008). The reasoning behind the motion-onset account is that continuous motion as such is far too common in our natural environment to be informative of behaviourally urgent events. But, the onset of motion can be important for the categorization of objects as being animate as opposed to inanimate, which, in evolutionary terms might be vital for the detection of prey and predators (e.g., Scholl & Tremoulet, 2000).

Von Mühlenen et al. (2005) also found that the onset of motion (and not motion per se) captures attention, but only if it is temporally unique. According to this Unique-Event Account any sudden change is capable of capturing attention as long as it occurs at a time when nothing else is happening in the visual field. While the motion-onset account assumes that motion onset enjoys a special status in attention capture (like abrupt onsets), the unique-event account assumes that motion onset is like any other sudden change (i.e., color changes, luminance changes, or shape changes) that captures attention only when it is temporally unique.

Contradictory to von Mühlenen et al.'s (2005) finding, Abrams and Christ (2003) found capture for motion onset when it was not unique, for example, when it co-occurred with display transition – where figure-eight placeholders changed to letters. There were a number of notable differences between the two studies: First, in von Mühlenen et al's (2005) study, motion attributes were varied across different experiments, whereas in Abrams and Christ's (2003) study motion attributes co-occurred within the same trial. Second, von Mühlenen et al. used slope differences (search RT as a function of display size) as a measure for attentional capture, whereas Abrams and Christ primarily used differences in the RTs. Finally, and we believe most critically, von Mühlenen et al used relatively smooth motion (85

Hz), whereas Abrams and Christ used rather jerky motion (15 Hz). Perhaps this form of crude motion used by Abrams and Christ (2003, as well as by Christ & Abrams, 2008 and Christ et al., 2008) produced abrupt changes that captured attention. If this were the case, capture would occur only with jerky but not with smooth motion.

In order to test this hypothesis, we designed an experiment that both replicates Abrams and Christ's finding and manipulates the motion refresh rate. In contrast to von Mühlenen et al. (2005), we decided not to vary display size in this study, in order to prevent the number of trials from escalating, and because we consider it to be less critical for the purpose of our study. Consequently, absolute RT differences are used as an indicator for attentional capture, which are generally considered to be less reliable than slope differences (e.g., Simons, 2000). However, this seemed a justifiable compromise, given that our primary concern was to see whether the RT difference in Abrams and Christ's studies – irrespective of whether it indicates attention capture or not – critically depends on the jerky motion that they used.

Experiment 1

Experiment 1 used the same basic methodology as Christ and Abrams (2008). The trial sequence showed two figure-eight placeholders followed by three letter stimuli (a static, an onset, and a moving stimulus).[1] The moving stimulus was refreshed either at 100, 33, 17 or 8Hz, leaving intervals of 10, 30, 60 or 120 ms respectively, between consecutive frames. In Experiment 1 the moving stimulus started moving at the display transition (from figure eight

[1] Abrams and Christ (2008) used a fourth stimulus type termed "new moving object", where the target was a moving abrupt-onset stimulus. We did not include this stimulus type because their results in this condition did not differ from the static abrupt-onset condition.

to letters). We predict that the RT difference between static and moving target type would critically depend on motion refresh rate.

Method

Participants. Fourteen undergraduates (5 male, mean age 18.5) from the University of Warwick participated in return for course credit. All of them reported normal or corrected to normal vision and were naïve to the purpose of the experiment.

Apparatus and Stimuli. The participants were seated in a dimly lit sound attenuated room in front of a 19” CRT monitor at a distance of approximately 57 cm. The monitor was driven at 100 Hz at a resolution of 1024 x 786 pixels. The experiment was controlled by an IBM-PC compatible computer using custom written software. Participants’ responses were recorded using left and right arrow keys on a standard keyboard. Stimuli consisted of a fixation cross, figure-eight placeholders, and letters, presented in grey (luminance 8.5 cd/m2) drawn on black background (0.02 cd/m2). The fixation cross had a size of 0.6° of visual angle and was presented at the centre of the screen. The figure-eight placeholders and letters subtended 1° by 2° and were made of seven line segments (length 1.0°, thickness 0.13°). The letters were ‘H’, ‘U’, ‘S’ and ‘E’ and were made by removing the corresponding line segments from the figure eight. Stimuli were placed on the three imaginary corners of a randomly oriented equilateral triangle centred on fixation (fixation-letter distance was 12.5°). Letters in the search display were stationary or moving on a circular path (radius = 1.3°) at a constant speed of 8.7°/s, at which a full rotation took 960 ms (see Figure 1). Moving direction was randomly varied between clockwise and anti-clockwise. The refresh rate of the moving stimulus was systematically varied from 100, 33, 17 to 8Hz. For example, a 100-Hz stimulus was updated every 10 ms (displaced by 0.09°), producing the impression of smooth motion, whereas an 8-Hz stimulus was updated every 120 ms (displaced by 1.05°), producing the impression of jerky motion. This means that motion speed was held constant while motion quality was systematically varied.

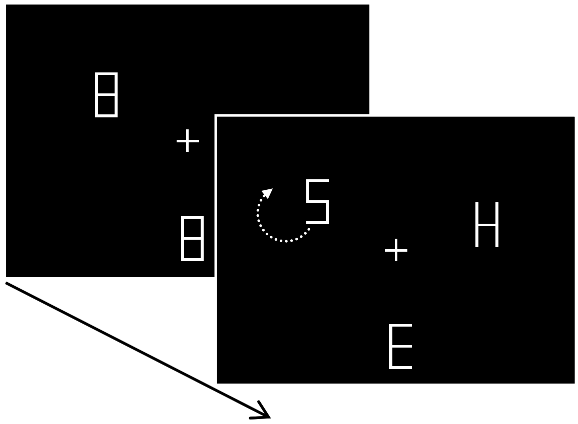

Figure 1. Example display in Experiment 1. Stimulus movement began when the placeholders changed to the letter stimuli.

Procedure and Design. A trial started with the presentation of a placeholder display that consisted of a fixation cross and two figure-eight placeholders. After 960 ms, the placeholder display was followed by the search display which always contained three letters. The static and moving letters were revealed by deleting the irrelevant line segments from the corresponding place-holders, whereas the onset letter appeared at the previously unoccupied location. Stimulus movement began when the placeholders changed to letters (see Figure 1).

Participants were asked to look for ‘H’ and ‘U’ targets among ‘S’ and ‘E’ distractors and to respond with the arrow keys. Half of the participants used the left arrow for H and right arrow for U, and vice versa for the other half. They were instructed to respond to the target as fast as they could whilst trying to not make more than 5% errors. The search display stayed on until the participant responded or 10 seconds had elapsed. In the instance of wrong responses immediate feedback was given on the screen saying “error” and participants had to press the space bar to continue the experiment. Otherwise the next trial started after an interval of 1 second. Each participant completed 20 practice trials followed by 480 experimental trials. The experimental trials were divided into 10 blocks of 48 trials each, with short breaks between blocks.

The experiment systematically varied three factors: target identity (H or U), target type (static, onset, moving), and motion refresh rate (100, 33, 17, 8 Hz). All possible factor combinations were presented in random order. For the analysis, target identity was not further considered.

Results

RTs. Mean correct RTs were calculated separately for each participant and factor combination, excluding outlier trials with RTs smaller than 200 ms or larger than 2000 ms (1.6% of all trials). Figure 2 shows the averaged RTs as a function of motion refresh rate with separate lines for each target type. As can be seen, a moving target was found as quickly as an onset target or as slowly as a static target depending on the motion refresh rate.

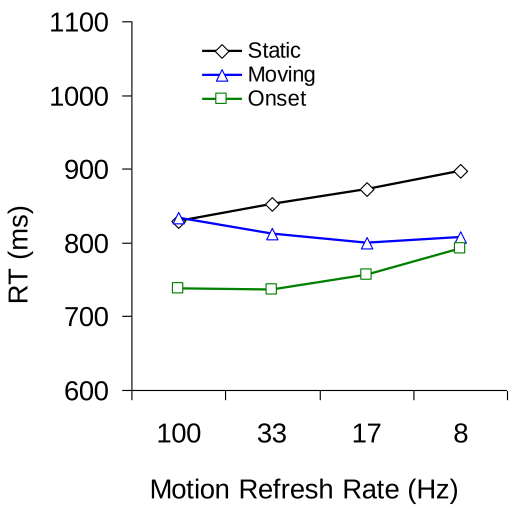

Figure 2. Mean correct RTs as a function of motion refresh rate in Experiment 1, with separate lines for each target type.

Individual mean RTs were submitted to a 3x4 repeated measures ANOVA with the factors target type (static, onset, moving), and motion refresh rate (100, 33, 17, 8 Hz).[2] There was a significant main effect of target type, $F(2,26) = 23.16$; $p < .001$: Posthoc LSD tests revealed that onset targets were found significantly faster than moving targets, which in turn were found significantly faster than static targets (756, 813, and 862 ms, respectively). There was also a significant main effect for motion refresh rate, $F(3,39) = 5.64$, $p < .01$: LSD tests revealed that RTs in the 8-Hz condition were significantly slower (on average 29 ms) than RTs in the other three conditions. The two-way interaction was also significant, $F(6,78) = 3.13$, $p = .01$.

To further explore the 2-way interaction, three separate 2x4 split-up ANOVAs were conducted comparing each possible pair of target type levels. A significant target type x motion refresh rate interaction was found in the static/moving pair, $F(3,39) = 4.9$, $p < .01$, and in the onset/moving pair, $F(3,39) = 3.85$, $p = .01$, but not in the static/onset pair ($F<1$). As can be seen from Figure 2, the static line appears parallel to the onset line, but not to the moving line. Separate Bonferroni adjusted t-tests revealed that moving targets were found significantly faster than static targets at 8 Hz and 17 Hz but significantly slower than onset targets at 33 Hz and 100 Hz (all $p < .01$). To summarize, a rather “smoothly” (100 and 33 Hz) moving target was not found any faster than a static target, whereas a rather “jerkily” (17 and 8 Hz) moving target was found as quickly as an onset target.

<u>Errors.</u> Mean percentage errors (see Table 1) were calculated separately for each participant and variable combination. A 3x4 ANOVA with the factors target type and motion

[2] At the suggestion of one of the reviewers we ran two more participants, which increased the chances of a type-I error. In order to adjust for this, we have changed our level of significance from .05 to .01, in accordance with Frick’s (1998) sequential stopping rule for multiple statistical tests.

refresh rate revealed a significant main effect for target type, $F(2,26) = 5.68$; $p < .01$, due to fewer errors in the onset condition than in the static and moving condition (2.9 vs. 5.5 and 4.8%, respectively). While the two-way interaction was not significant, $F(6,78) = 1.13$, ns, errors showed overall a very similar pattern to the RTs, suggesting that the RTs are not confounded by speed-accuracy tradeoffs.

Table 1. Mean Percentage Errors in Experiment 1 and Experiment 2

	Target Type		
Motion Refresh Rate	Static	Onset	Moving
Experiment 1			
100 Hz	5.7	2.7	5.7
33 Hz	5.5	2.5	4.5
17 Hz	6.3	3.8	3.8
8 Hz	4.5	2.7	5.4
Experiment 2			
100 Hz	4.4	4.8	5.0
33 Hz	6.9	3.3	5.0
17 Hz	3.3	3.1	3.1
8 Hz	3.8	2.9	5.0

Discussion

The results show that a moving target is easier to find than a static target only when the motion refresh rate is low. This perfectly corresponds with previous findings: On the one hand, the results in the 100-Hz condition replicate the pattern found by von Mühlenen et al.

(2005) with display size three (829, 833, 738 vs. 618, 615, 576 ms, for static, moving, onset targets, respectively), showing no evidence for capture by motion onset. This represents, in our view, the key finding of Experiment 1 because it invalidates Abrams and Christ's (2003) account, according to which motion onset should always capture attention including smooth motion. This absence of capture denies motion onset a special role in attention capture leaving motion onset on par with any other feature change. However, this absence can easily be explained within the theoretical framework provided by von Mühlenen et al.'s (2005) unique-event account, according to which motion onset should not capture attention when it occurs simultaneously with display transition (i.e., when it is not temporally unique).

On the other hand, the RTs in the 17-Hz condition for static, moving, and onset targets replicate Christ and Abrams (2008) RTs (872, 800, 756 vs. 766, 690, 614 ms, respectively).[3] It is also in line with other similar findings by Abrams and colleagues (Abrams & Christ, 2003; Christ et al., 2008), where they used 15 Hz motion.[4] Whereas Abrams and Christ interpreted their finding as evidence for capture by motion onset, the current study suggests that this effect was induced by motion jerkiness. One possible effect of motion jerkiness could be that the relatively large displacement of the moving stimulus produces a kind of transient flicker that captures attention (e.g., see Ludwig, Ranson, & Gilchrist, 2008; Spalek, Kawahara, & Di Lollo, 2009). This and other explanations will be taken up again in the general discussion. To sum up, the current study reconciles these apparently conflicting

[3] Our participants were somewhat slower and made more errors than theirs, but this is most likely due to differences in the homogeneity of the distractors (i.e., in a given trial we used different distractor letters, whereas they used identical letters).

[4] In one of their studies (Abrams and Christ, 2005) they used smooth 60 Hz motion in a cueing paradigm. They showed that only the onset of irrelevant motion reduced the inhibition of return effect. They interpreted this finding as further evidence for their motion-onset account. However, since the motion onset occurred around 400 ms before the target appeared, this finding is also in line with the unique-event account

results by showing that the RT benefit for motion onset targets depends on motion refresh rate.

Figure 2 might suggest that the interaction between target type and motion refresh rate is driven by an RT increase in the static condition (68 ms) rather than by a decrease in the motion condition (-26 ms), as would be expected if motion onset captures attention. However, this could be due to an overall main effect of motion refresh rate that is superimposed on the interaction (e.g., due to the increased perceptual noise/flicker at lower refresh rates). An indication of such an overlay effect comes from the fact that RTs in the onset condition show a similar increase (53 ms) as RTs in the static condition (this is also true for Experiment 2). Moreover, this main effect is mostly due to the 8-Hz condition (overall 30 ms slower RTs compared to the other three conditions), where motion jerkiness might have been particularly disruptive.

Experiment 2

In Experiment 2 motion onset was replaced with continuous motion, where the stimulus starts moving at the beginning of the trial and continues to move throughout the trial (see Figure 3). The aim was to test whether motion refresh rate had the same attentional effect when the motion onset signal was absent. Finding the same kind of interaction as in Experiment 1 would indicate that attention is altered by jerky motion per se, whereas the absence of such an interaction would indicate that attention is altered by jerky motion only in combination with motion onset. In other words, Experiment 2 tests whether jerky motion affects the perception of motion per se (e.g., by adding noise) or whether it affects the onset of motion (e.g., by boosting or delaying the perceived onset of motion).

Method

Participants. Twelve students from the University of Warwick (3 male, mean age, 18.5 years) participated in return for £5. All reported normal or corrected to normal vision and were naïve to the purpose of the experiment. None had participated in Experiment 1.

Apparatus, Stimuli, Procedure, and Design. The apparatus, stimuli, procedure and design were the same as in Experiment 1, except that the motion started at the beginning of the placeholder display (see Figure 3).

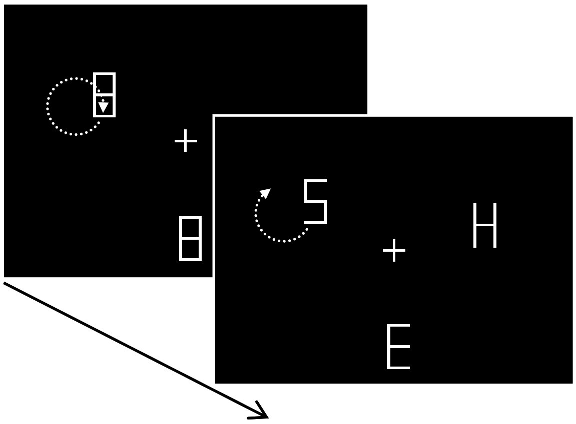

Figure 3. Example display in Experiment 2 with continuous motion.

Results

RTs. Mean correct RTs excluding outliers (1.3%) are presented in Figure 4. A 3x4 ANOVA with the factors target type (static, onset, moving), and motion refresh rate (100, 33, 17, 8 Hz) found a significant effect for target type, $F(2,22) = 52.76$, $p < .001$: LSD tests revealed that moving targets were found 75 ms slower than static targets, which in turn were found 103 ms slower than onset targets (all $p < .001$). There was also a significant main effect of motion refresh rate, $F(3,33) = 25.99$, $p < .001$: LSD tests revealed that the 8Hz condition was 35 ms slower than the 17Hz condition, which in turn was on average 25 ms slower than the 33Hz and 100Hz conditions (all $p < .05$, except the difference between the 33Hz and 100Hz condition, $p = .61$). Critically, the two-way interaction was not significant, $F(6,66) < 1$.

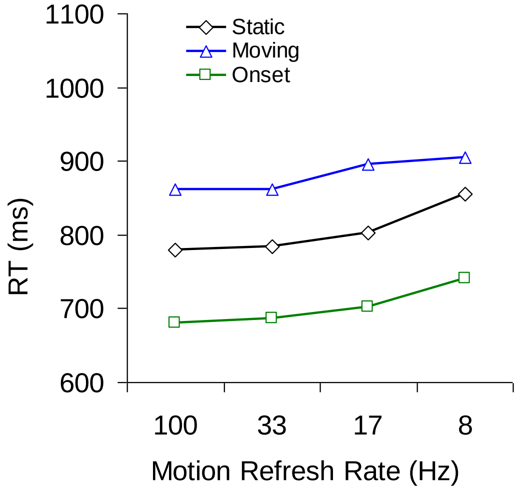

Figure 4. Mean correct RTs as a function of motion refresh rate in Experiment 2, with separate lines for each target type.

Errors. Mean percentage errors are presented in Table 1. A 3x4 ANOVA with the factors target type and motion refresh rate revealed no significant effects (all $p>.1$), indicating that RT results are not confounded by speed-accuracy tradeoffs.

Discussion

Experiment 2 did not show an RT benefit for continuously moving targets, with either smooth or jerky motion. That is, task-irrelevant continuous motion can easily be ignored, irrespective of whether the motion is jerky or not. This result is also consistent with previous findings (Abrams & Christ, 2003; Hillstrom & Yantis, 1994; von Mühlenen et al., 2005) and suggests that jerkiness interferes only with the onset of motion (Experiment 1), not with motion per se (Experiment 2).

Finding a target that was continuously moving actually took longer than finding a stationary target. This somewhat unexpected RT cost is consistent with previous findings. For example, Abrams and Christ (2003) found a similar disadvantage of around 20 ms, which was, however, statistically not significant. Likewise, von Mühlenen et al. (2005) reported a pilot experiment where search efficiency was impaired when the target was continuously moving. This could be explained by visual degradation of the continuously moving stimulus, either because the visual quality is reduced (e.g., retinal smearing, reduced luminance contrast), or because the cross-referencing of shape features becomes less reliable (for a similar account see von Mühlenen & Müller, 2000).

General Discussion

The results from the current study can be summarized as follows: When motion is smooth, neither the onset of motion nor continuous motion capture attention. However, when motion is jerky, the onset of motion (but not continuous motion) appears to capture attention. We have argued that the first finding fits with von Muhlenen et al's unique event account but not with Abrams and Christ's motion onset account. The second finding still needs further explanation. In the discussion of Experiment 1 we suggested that the transient flicker that accompanies jerky motion might capture attention. However, Experiment 2 rules out this possibility, by showing that jerkiness did not capture attention when motion was continuous. This suggests that jerkiness affects only the onset of motion. Maybe the temporal delay between two frames turns the moving stimulus into a new object (see Gibson & Yantis, 1994). However our moving stimulus – despite its jerkiness – always had an inter-stimulus interval of 0 ms, producing a strong impression of 2nd-order motion (i.e., of a single object moving from location A to B). Another explanation could be that jerkiness boosts the motion onset signal, making it strong enough to capture attention, or it delays the perceived onset of motion, turning it into a temporally unique event that captures attention. A possible reason for the perceived delay could be that the very first displacement of the moving stimulus goes unnoticed because of interference from the other changes co-occurring in the display (i.e., the onset and segment removals). Therefore, only the second displacement is noticed and becomes the perceived onset of motion. More empirical work is required to better understand the nature of this interaction between motion onset and jerkiness.

According to Abrams and Christ (2006), attention capture is not caused by lower-level changes in luminance defined contours, but instead by higher-level changes in the perceived location of the object. The current study clearly demonstrates that such a change in the perceived location is not sufficient for attention capture, as capture did not occur with smooth motion despite the evident change in the perceived location of the object. Thus, the current study allows a new interpretation of Abrams and Christ's (2003) findings, where lower-level changes play an important role in attentional prioritization. This is also is in line with the broader view that attention capture has a strong bottom-up component that is primarily saliency-driven (e.g., Theeuwes, 2010). It remains an open question, whether the temporal uniqueness of an event, as described by von Mühlenen et al's account, leads to an increase in the saliency of that event or whether it leads to an increase in the priority of that event at a later processing stage. Nevertheless, the unique-event account provides a useful framework that can account for a wide range of findings.

Author Note

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