The attentional influence of new objects and new motion

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Previous research on the attentional influence of new objects and new motion in the environment has focused on studying these two visual features in isolation. In the present study, we examined new objects and new motion when they co-occurred within one scene. In addition, we evaluated the extent to which low-level luminance changes can contribute to the attention-capturing properties of each of these dynamic events. Results suggest that new objects have a larger impact on the allocation of attention than new motion and, under certain circumstances, the appearance of new objects may suppress the attentional benefit typically afforded to new motion. Lastly, our findings indicate that low-level factors account for some, but not all, of the attentional effects observed for new objects and new motion.

Keywords: attention, motion, new objects, visual search

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Introduction

As we navigate through and interact with our environment, our visual systems are constantly faced with a vast and limitless stream of visual information. Unable to attend to all such input, we are forced to select particular aspects of the visual environment for further processing. The mechanism by which this selection and prioritization process occurs is called visual attention. Effective functioning in everyday life relies on our ability to proficiently shift and allocate visual attention as needed.

So how then do we choose which aspects of our visual environment to attend and process further? Most researchers would agree that the allocation of visual attention can be driven by both "top-down" processes related to our goals and expectations as well as "bottom-up" processes related to low-level characteristics of the stimuli (Yantis & Egeth, 1999). At any given moment, our attention may be influenced by one or both of these factors. For example, while driving on an unfamiliar stretch of highway, we may try to actively search our environment for a white speed limit sign (goal-directed attention) but be distracted by the flashing red and blue lights in the rearview mirror (stimulus-driven attention).

Previous research has shown that a number of different stimulus properties (e.g., color, line orientation) may be utilized to direct attention in a top-down fashion when such properties are task relevant and/or consistent with the person's current goals (Folk, Remington, & Wright, 1994; Yantis & Egeth, 1999). In contrast, other types of stimuli continue to influence attention independent of a person's intentions and as such may attract attention even when it is detrimental to the task at hand (e.g., Christ & Abrams, 2006a, 2006b; Neo & Chua, 2006). These latter stimuli seem able to capture attention in a truly bottom-up, stimulus-driven fashion.

One stimulus event which is believed to capture attention in a stimulus-driven manner and which has been the focus of extensive research in the past is the appearance of a new object (Yantis & Jonides, 1984, 1996). Past studies have found that, for a brief period of time following their appearance, new objects enjoy a perceptual advantage and are given attentional priority over pre-existing objects (e.g., Davoli, Suszko, & Abrams, 2007; Enns, Austen, Lollo, Rauschenberger, & Yantis, 2001; Oonk & Abrams, 1998). In addition, recent work by our research group and others (Christ & Abrams, 2006a; Neo & Chua, 2006) has shown that the capture of attention by a new object may be automatic in that a new object continues to influence one's attentional allocation even in the presence of strong motivation to maintain attention elsewhere in the display.

Recently, researchers have reported a new visual attribute that appears to also capture attention in a bottom-up fashion: new motion in a scene (Abrams & Christ, 2003; Franconeri & Simons, 2003).[1] Utilizing a visual search paradigm, we (Abrams & Christ, 2006)

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found that participants were faster to respond to a target that appeared in an item that recently had begun to move (new motion) as compared to items that were not moving (static), had been moving for some time (old motion), or recently had stopped moving (motion offset) despite the fact that the target was equally likely to appear in any one of these items. In addition, the new motion item appeared to be given attentional priority as evidenced by the fact that participants were equally fast to respond to a target in the new motion item regardless of the number of distracting items present in the display. Results from subsequent studies (Abrams & Christ, 2005; Christ & Abrams, 2006b) suggest that the attentional influence of new motion, like that of a new object, appears to be automatic and resistant to suppression.

The previous research on new objects and new motion has generally studied these phenomena and their influence on attention in isolation from one another. For example, Abrams and Christ (2003) compared targets that underwent various different types of motion using only displays in which no new objects appeared. On the other hand, Yantis and Jonides (1984) examined attentional capture by new objects in the absence of new motion. Given the dynamic nature of our day-to-day environment; however, it is unlikely that these visual events always occur in isolation in the real world. As such, studying the effects of new objects and new motion in the presence of the other, not just in isolation, may allow for greater ecological validity. The present study was designed to do precisely that and, as a result, to extend our understanding of stimulus-driven capture of attention to a more realistic, dynamic situation.

As a starting point, we focused on the co-occurrence of new objects and new motion as it relates to a previously unresolved discrepancy within the literature on motion and attention. Although recent findings (Abrams & Christ, 2003; Christ, Castel, & Abrams, in press; Franconeri & Simons, 2003) support the notion that new motion captures attention, a handful of earlier studies (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999) failed to find evidence of any such attentional benefit for motion.

One possible explanation for these mixed findings relates to the fact that, in those studies where motion was not found to attract attention (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999), motion was coupled with the appearance of a new object and the attentional advantage of motion was evaluated by comparing a newly appearing moving object to a newly appearing static object. In contrast, in the majority of studies were motion did attract attention (Abrams & Christ, 2003; Franconeri & Simons, 2003), motion was not coupled with a new object and its attentional advantage was evaluated by comparing pre-existing objects that were either static or newly moving. Preliminary support for this notion comes from a recently reported experiment (Abrams & Christ, 2006) in which we found that the attentional benefit for motion was substantially smaller when the onset of the motion coincided with the initial appearance of the search array elements (thus coinciding with the appearance of multiple new objects) as compared to when it occurred later.

In our first experiment, we sought to further examine whether co-occurrence with a new object does indeed dampen the attentional influence of new motion and therefore could explain otherwise discrepant past results in the literature. In the subsequent two experiments, we evaluate the role of low-level luminance transients, such as those that often accompany the appearance of new objects and new motion.

Experiment 1

In the present experiment, we utilized a visual search paradigm in which participants were asked to search for a target letter located among distracter letters. This type of visual search paradigm has been studied extensively, and we have used it successfully in the past to study a number of issues related to attentional capture (e.g., Abrams & Christ, 2003; Christ & Abrams, 2006a, 2006c).

The target letter was equally likely to appear in one of four items in the display: a pre-existing static item, a pre-existing item that had recently begun to move, a newly appearing static item, or a newly appearing item that was moving. The latency needed to correctly identity the target was measured for each of the item types. This served as a measure of the relative effectiveness with which each of these items (and their associated transient events) attracted attention.

Method

Subjects

Twelve naïve undergraduate students served as subjects in a single 45-minute session in exchange for course credit. All had normal or corrected-to-normal vision.

Apparatus and procedure

The apparatus and procedure were based upon those used previously (Abrams & Christ, 2003; Christ et al., in press) to study attentional capture by new motion. Participants were seated 34-in. from a CRT display in a dim, sound-attenuated room. The sequence of events on a trial is illustrated in Figure 1. Each trial began with a preview display that consisted of a central fixation point and two figure-eight placeholders. Each placeholder 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.

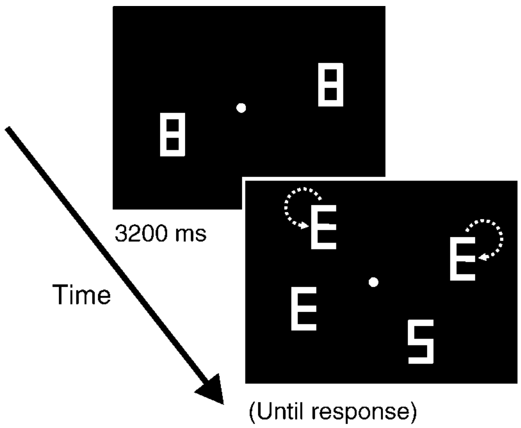

Figure 1. Sequence of events on a trial in Experiment 1. The arrow indicates motion of one of the elements, but the arrow did not appear in the display. Introduction of the new elements and motion was coincident with the appearance of the search array (i.e., the letters in the display).

When the display initially appeared, both of the placeholders were stationary.

Following a 3200-ms delay, several events occurred simultaneously: (1) Two line segments were removed from each placeholder to reveal letters. (2) One of the items began moving along a tight circular path (2° diameter measured from the center of the placeholder) while the other remained stationary. The motion was accomplished by displaying the item for 67 ms at each of 16 evenly spaced positions along its movement path. (3) A new static letter and a new moving letter appeared in previously unoccupied locations. (The locations met the criteria noted above, and the movement parameters were identical to those described for the newly moving old item).

One of the four items was the letter "S" or "H," representing the target stimulus. All remaining items were distracter letters (either all "E"s or all "U"s). Participants were instructed to respond to the target's identity as quickly as possible by pressing one of two keys (i.e., "z" or "/" key) on the keyboard.

The search display remained visible until the subject responded or 3000 ms had elapsed. If the subject responded incorrectly, a brief tone followed by the message "Wrong Response" was presented. A tone and relevant message (i.e., "TOO EARLY" or "TOO SLOW") was presented if a subject responded less than 300 ms after display onset or failed to respond within 3000 ms, respectively.

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 items, the distracter 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 participants. Trial types were randomly mixed. At intervals of 48 trials, subjects were given the opportunity to take a break.

Results and discussion

Trials on which an error occurred were excluded from the RT analysis. Mean reaction times are shown in Figure 2. The data were analyzed using a 2 (pre-existing object or new object) × 2 (static or new motion) repeated measures ANOVA.

Consistent with previous research (e.g., Christ & Abrams, 2006c; Davoli et al., 2007; Yantis & Jonides, 1996), we found that participants were generally faster to respond when the target appeared in a new object as compared to a pre-existing object, $F(1, 11) = 68.72$, $p < .001$. Subsequent *t*-test comparisons confirmed that this was true regardless of whether the item had recently begun to move or not, $t(11) > 7.0$, $p < .001$ in both instances.

An overall main effect of motion state, $F(1, 11) = 34.68$, $p < .001$, and an interaction between object age and motion state, $F(1, 11) = 36.74$, $p < .001$, were also found. As can be seen in Figure 2, these latter two effects appear to be driven by the fact that participants were faster to respond when the target appeared in a pre-existing new motion item as compared to a pre-existing static item (mean RT for pre-existing object-static condition minus mean RT for pre-existing object-new motion condition = 76 ms), $t(11) = 8.10$, $p < .001$. Interestingly, a similar benefit was not observed for newly appearing moving items as compared to newly appearing static items (mean RT for new object-static condition minus mean RT for new object-new motion condition = 3 ms), $t(11) < 1$, $p > .7$.

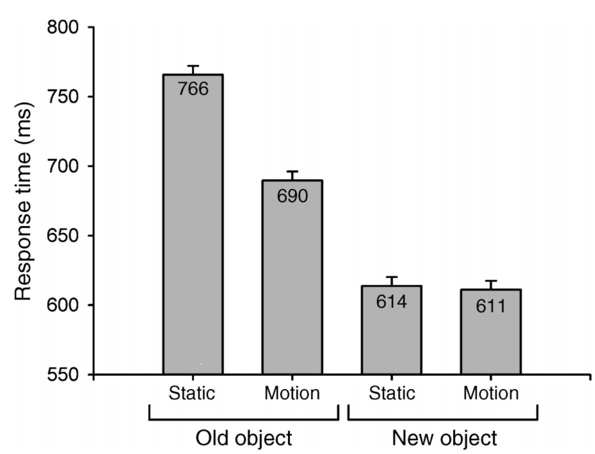

Figure 2. Mean reaction times for target identification in Experiment 1, shown separately for each object age (old or new) and each motion status (static or motion). Error bars represent 95% confidence intervals.

Error rate analysis

A 2 (pre-existing object or new object) × 2 (static or new motion) repeated measures ANOVA revealed a main effect of object age [$F(1, 11) = 18.38$, $p < .005$], but no evidence of a main effect of motion state [$F(1, 11) = 5.79$, $p = .402$] or an interaction between object age and motion state [$F(1, 11) = 2.64$, $p = .13$]. Participants made fewer errors in the new object condition (mean error rate = 2.1%) as compared to the old object condition (mean error rate = 4.1%).

Taken together, the present results suggest that the appearance of a new object has a greater impact on the allocation of attention than new motion alone. Although participants were faster to respond to a pre-existing object that began to move as compared to a pre-existing static object (thus replicating the past findings on attentional capture for new motion in pre-existing objects; Abrams & Christ, 2003), the attentional benefit observed for new motion was still less than that associated with the appearance of a new object. This finding is in line with previous studies (Enns et al., 2001; Rauschenberger, 2003; Mühlenen, Rempel, & Enns, 2005) showing that new objects play a very important role in the allocation of attention.[2]

In addition, when these two events co-occurred within the same item (i.e., a moving new object), the motion did not afford any benefit above and beyond that related to the appearance of the object. [This, in turn, replicates past findings of no attentional benefit for newly appearing moving object as compared to a newly appearing static object (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999).]

Experiment 2

In Experiment 1, we found evidence that both new objects and new motion attract attention, with the former having the greater impact. It is important to note, however, that the visual objects in Experiment 1 were defined by differences in luminance relative to the background, and the appearance of the new objects was coupled with a luminance transient. As a result, it is possible that some of the attentional benefit that accrued to new objects there was due to the low-level transients rather than the "newness" of the object (Franconeri, Hollingworth, & Simons, 2005; but see Davoli et al., 2007). Similarly, the introduction of motion to an item is also coupled with low-level luminance transients of its own (e.g., initiation of movement on the retina along a luminance edge). It remains unclear what role (if any) such transients play in attentional capture by new motion.

To control for the influence of these low-level perceptual factors, we replicated Experiment 1 with one modification: A 200-ms energy mask was inserted just prior to the appearance of the target display and the introduction of the new objects and new motion. The insertion of the mask insured that luminance transients were equivalent across all items (new and old) and any observed attentional effects would not be contaminated by such factors.

Method

Subjects

Eighteen naïve undergraduates who had not served previously were selected from the same population as that in Experiment 1. Each served in one 45-minute session in exchange for course credit. Two potential participants were replaced due to an excessive error rate (>10%).

Apparatus, procedure, and design

This experiment was very similar to Experiment 1, with differences noted here. The sequence of events on a trial is illustrated in the left panel of Figure 3. As in Experiment 1, the initial display was comprised of two placeholders and a fixation point. A 200-ms energy mask, however, was inserted just prior to the appearance of the target display and the introduction of the new objects and motion onset.

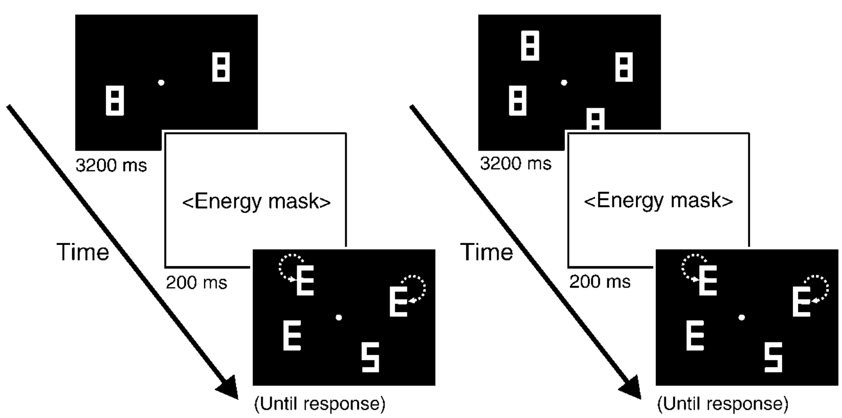

Figure 3. Sequence of events on a trial in Experiment 2 (left panel) and Experiment 3 (right panel).

The energy mask was generated by changing all pixels on the screen to the same color and luminance level as that used to define the contours of the objects in the display.

Following 24 practice trials, the subjects served in 288 experimental trials. Trial types were randomly mixed.

Results and discussion

Trials on which an error occurred were excluded from the RT analysis. Mean reaction times are shown in Figure 4. The data were analyzed using a 2 (pre-existing object or new object) $\times$ 2 (static or new motion) repeated measures ANOVA.

As in Experiment 1, participants responded more quickly when the target was in a new object as compared to a pre-existing object, $F(1, 17) = 9.73$, $p < .01$. Unlike Experiment 1, however, there was no evidence of a main effect of motion state, $F(1, 17) < 1$, $p > .9$, or interaction between object age (i.e., new vs. old) and motion state, $F(1, 17) < 1$, $p > .6$. Participants were equally slow to respond to pre-existing objects, regardless of whether they were static (M = 677 ms) or newly moving (M = 675 ms), $t(18) < 1$, $p > .7$. Error rates were relatively low (Overall mean = 2.6 %) and did not depend on condition, $p > .05$ in all instances.

The present results suggest that, despite elimination of the unique luminance transients that accompanied their appearance in Experiment 1, new objects continued to influence attention. This replicates recent findings of Davoli et al. (2007). It is worth noting, however, that the response time benefit for new objects was noticeable smaller in the current experiment (overall mean RT for old objects minus overall mean RT for static new objects = 15 ms) than that observed in Experiment 1 (overall mean RT for old objects minus overall mean RT for static new objects = 116 ms). This is consistent with the notion that

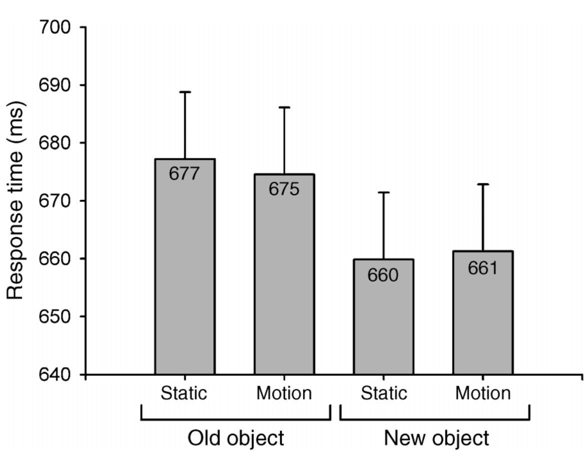

Figure 4. Mean reaction times for target identification in Experiment 2, shown separately for each object age (old or new) and each motion status (static or motion). Error bars represent 95% confidence intervals.

both the appearance of a new object and its accompanying luminance transient contributed to the response time benefit observed in Experiment 1 whereas only the former was responsible for the effect seen in the present experiment.

Most importantly, in contrast to the results from Experiment 1, new motion appeared to no longer influence attention in the absence of a unique transient at the time of its initiation. Inclusion of the energy mask resulted in the elimination of the previously observed benefit for new motion in a pre-existing object as compared to a static pre-existing object.[3]

Experiment 3

The results from Experiment 2 raise the possibility that the attentional influence of new motion is attributable solely to the low-level transients that accompany its initiation. To investigate this issue further, we conducted an additional experiment that again included an energy mask (thus equating all luminance transients at the time of target presentation) but did not include the appearance of new objects within the display.

Method

Subjects

Twelve naïve undergraduates who had not served previously were selected from the same population as that in Experiments 1 and 2. Each served in one 45-minute session in exchange for course credit.

Apparatus, procedure, and design

This experiment was very similar to Experiment 2, with differences noted here. The sequence of events on a trial is illustrated in the right panel of Figure 3. The initial preview display contained four figure-eight placeholders. After a 3200-ms delay, two segments were removed from each placeholder to reveal the search display, and two of the items began to move. (No new items appeared.) The target letter was equally likely to appear in one of the newly moving items or one of the remaining static items.

Following 24 practice trials, the subjects served in 288 experimental trials. Trial types were randomly mixed.

Results and discussion

Trials on which an error occurred were excluded from the RT analysis. Mean reaction times are shown in Figure 5. Participants responded more quickly when the target appeared in a pre-existing object that had begun to move (mean RT = 629 ms) as compared to a pre-existing

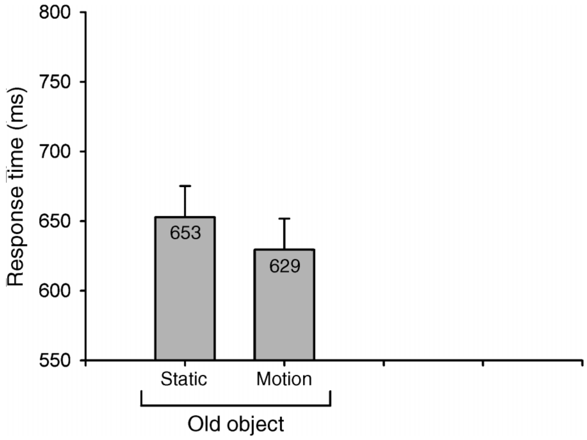

Figure 5. Mean reaction times for target identification in Experiment 3, shown separately for each motion status (static or motion). [All items in the display were pre-existing objects.] Error bars represent 95% confidence intervals.

static object (mean RT = 653), $t(11) = 2.31$, $p < .05$. Error rates were low (overall mean = 3.3%) and did not depend on condition, $t(11) < 1$, $p > .7$.

The present findings show that new motion can continue to influence attention even after eliminating any unique low-level luminance transients that would otherwise signal its initiation. Further support for this conclusion comes from related work by Franconeri and Simons (2005), which also found evidence of attentional capture by motion in the absence of unique luminance transients. In their experiment, presentation of the search array (which contained a moving item) coincided with the participants looking away from the computer screen. As such, participants did not witness the initiation of the movement and when they returned their gaze to the display, all elements had equivalent luminance transients.[4]

Of note, the present results differ in a key way from those of Experiment 2. In Experiment 2, there was no attentional benefit associated with new motion of pre-existing objects, whereas there was a substantial benefit in the present experiment. One obvious difference between the two experiments is that new motion in Experiment 2 was accompanied by the appearance of new objects elsewhere in the display, whereas there were no new-object onsets in the present experiment. It thus seems possible that the appearance of a new object somehow suppressed or interfered with the attention capturing effects of the onset of motion. While speculative, this possibility is discussed in more detail in the general discussion.

General discussion

In the present paper, we studied the conditions under which new objects and new motion can influence attention. We were particularly interested in displays in which both sorts of changes might take place simultaneously because such conditions are more similar to events that occur in natural scenes. Taken together, our results suggest that new objects have a stronger impact on the allocation of attention than new motion does. This conclusion is based on the following findings: (1) a greater attentional advantage was observed for the appearance of a new object as compared to the introduction of motion to a pre-existing object, (2) the coupling of a new object and new motion within the same item did not afford any attentional benefit above and beyond that observed for a new object alone, and (3) the co-occurrence of new objects and new motion within the same visual display (not necessarily the same item) appeared to completely suppress attentional influence by new motion (in the absence of unique luminance transients associated with the motion).

Despite the evidence just noted for the dominance of new objects over new motion, we did also replicate earlier findings that indicate that new motion does have strong attentional effects in its own right (e.g., Abrams & Christ, 2003). In particular, in Experiment 3, with no new objects appearing in the display, and even in the absence of transients to signal the motion, new motion was found to influence attention.

The notion that new objects dominate new motion is consistent with a recent study by von Mühlenen et al. (2005) that compared the attentional influence (as reflected in search slopes) for several dynamic events (i.e., new objects, new motion, and color changes), each studied in isolation. They found that, whereas the attentional effects of all three events were weakened when they coincided with a display transition (as compared to occurring at a time of "temporal calmness"), new objects were the least affected.[5]

The present results also bear on our understanding of the mechanisms underlying attentional capture by new objects and new motion. We propose that our findings may be best conceptualized within a theoretical framework which represents an integration of previous theories of attention and which allows for two potential components of stimulus-driven attentional capture: (1) a low-level component related to the observer's perception of the luminance transients typically associated with the appearance of a new object or the initiation of motion (Franconeri et al., 2005), and (2) a higher-level component associated with creating and updating of our internal representation of an object (i.e., "object file"), respectively (Kahneman, Treisman, & Gibbs, 1992; Yantis & Hillstrom, 1994; Yantis & Jonides, 1996).

The low-level component may reflect the same mechanism that underlies previous findings of attentional capture by luminance changes in the absence of other dynamic events (e.g., the appearance of new objects or changes in existing objects) (e.g., Enns et al., 2001; Posner & Cohen, 1984). Such low-level effects can be eliminated through the use of an energy mask or similar methodological approaches (e.g., pattern mask: Davoli et al., 2007; looking away from the display: Franconeri & Simons, 2005), which aim to equate luminance transients across display elements at the time of new object appearance and/or new motion initiation. In the present study, controlling for such effects resulted in a substantial reduction in the attentional influence associated with new objects and new motion (as reflected in a comparison between the results for Experiments 1 and 2)—thus suggesting that a low-level component does indeed play a major role in attentional capture by new objects and new motion.

Present evidence for the existence of a higher-level component related to attentional capture by new objects comes from Experiment 2. While it remains impossible to entirely rule out all possible low-level explanations, the current experimental design represented our best efforts to control for such factors, most notably luminance transients. Within this context, new objects continued to influence the allocation of attention despite controlling for low-level factors. Similarly, the finding of an attentional advantage for new motion in Experiment 3 suggests that a higher-level component contributes to attentional capture by new motion as well (see also Abrams & Christ, 2006).

By comparing across the present conditions and experiments, we may also gain insight into the interplay among these higher-level components when new objects and new motion occur in a single scene. For example, in Experiment 1, we failed to find an additional benefit for new moving objects as compared to new static objects. This suggests that if a new object is moving at the time that its object file is created, its motion status may be automatically encoded along with other salient attributes (e.g., color, shape) of the object and therefore additional attentional resources may not be summoned to process the motion. In contrast, when motion is introduced to a pre-existing object, it requires updating of an existing object file and attracts attention (Abrams & Christ, 2006).

Although new motion captured attention in isolation in Experiment 3, it did not influence attention in Experiment 2 when studied alongside new objects. This suggests that the appearance of a new object within the same display (not necessarily the same item) may suppress the attentional effect of new motion. (Interestingly, co-occurrence within the same display, however, does not suppress the low-level component as evidenced by the attentional advantage observed for new motion in a pre-existing object in Experiment 1.)

The present study represents an early step in the study of attentional effects of multiple visual events within the same environment. Research such as this is important as we attempt to bridge the gap between typical laboratory experiments and the dynamic visual environments in which we find ourselves on a day-to-day basis. Although the aforementioned theoretical framework can account for the present data, it remains speculative at best, and further research is necessary to more fully understand the low-level and high-level components of attention and how they interact within a dynamic visual environment.

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Footnotes

[1]In some of our earlier papers on this topic, we used the term "motion onset" to describe the introduction of motion to a previously static item. That term, however, may imply that observes actually see the onset of motion when it occurs. We instead prefer the more general term "new motion," which refers to a situation in which there is a newly introduced change in the perceived location of an object–whether the stimuli permitted observation of the actual motion onset or not, and whether the object was previously present in the display or not (Abrams & Christ, 2006; Franconeri & Simons, 2005).

[2]Results of the present experiment are consistent with the notion that new objects and new motion attract attention thus leading to enhanced target identification. It is worth noting, however, that future studies involving manipulation of set size and/or event salience may provide additional evidence as to the extent to which co-occurrence of these two phenomena satisfies other tests of attentional capture (e.g., load-insensitivity criterion and intentionality criterion, Yantis & Jonides, 1990) as well.

[3]It could be argued that transients continuously occur during motion and that the present manipulation thus did not mask the transients in those conditions. Several previous studies, however, have shown that ongoing transients that accompany continuous (or "old") motion do not capture attention (Abrams & Christ, 2003, 2005; Yantis & Egeth, 1999).

[4]Because of some details of their method, it is unclear whether the objects employed in Franconeri and Simons' (2005) experiment were treated as old or new objects by the observers at the time that they returned their gaze to the display (for extensive discussion, see Abrams & Christ, 2006).

[5]In contrast to the present findings as well as those of several past studies by us and others (Abrams & Christ, 2003; Franconeri & Simons, 2003), von Mühlenen et al. failed to find evidence of attentional capture by new motion in a pre-existing item when introduction of the motion coincided with presentation of the target display. This

discrepancy may be due to the greater saliency of our motion relative to that employed by von Mühlenen et al. The present motion encompassed a larger portion of the display (diameter of movement path = 2° and 0.57°, respectively).

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