Are changes in semantic and structural information sufficient for oculomotor capture?

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The abrupt onset of objects often involuntarily captures attention (J. Jonides & S. Yantis, 1988) and the eyes (J. Theeuwes, A. F. Kramer, S. Hahn, & D. Irwin, 1998). The new-object hypothesis proposes that the appearance of something new (new semantic and structural information and/or spatiotemporal newness), not the accompanying low-level perceptual transients, causes an involuntary reorienting of attention (S. Yantis & A. P. Hillstrom, 1994). We investigated whether semantic and structural changes alone are sufficient to capture the eyes as strongly as abrupt onsets do. Observers moved their eyes to a target object while another object either onset or smoothly and quickly morphed. If semantic and structural changes are sufficient to capture the eyes, morphs should capture the eyes as strongly as onsets do. Results show that morphs were not fixated first as often as onsets. These findings indicate that new semantic and structural information alone is far less effective at capturing the eyes as onsets.

Keywords: visual attention, oculomotor capture, eye movements, objects

Citation: Wong, J. H., Peterson, M. S., & Hillstrom, A. P. (2007). Are changes in semantic and structural information sufficient for oculomotor capture? *Journal of Vision, 7*(12):3, 1–10, http://journalofvision.org/7/12/3/, doi:10.1167/7.12.3.

Introduction

We are constantly inundated by stimuli from the environment, yet attention enables us to remain focused on a task and to ignore irrelevant events. However, it is sometimes necessary to attend to an urgent stimulus in the environment even if it may not be relevant to the current goal. For example, if you are searching for an icon on your computer screen but a message window suddenly appears and distracts you, then your attention has been captured. If the irrelevant object causes you to make an involuntary eye movement, then oculomotor capture has also occurred. Despite the vast amount of research investigating attention and oculomotor capture, there is little agreement on the types of stimuli that will cause this reorientation.

The first research on involuntary orienting of the visual system examined covert attention capture. A prominent theory of attention capture, the new-object hypothesis, states that only the abrupt onset of a new visual stimulus will capture attention (Jonides & Yantis, 1988; Yantis & Jonides, 1996). This result was obtained by suddenly displaying a new object while the participant was searching for a letter target and by ensuring that the target was no more likely to be the onsetting object than any other element was. When the abrupt onset coincided with the target, reaction times were very fast and did not depend on the number of nontarget elements in the display (display size). The independence of detection speed from display size was taken as evidence that the abrupt onset target captured attention. In contrast, when the target letter was distinctive in terms of color or luminance but did not abruptly onset on the screen, detection continued to be dependent on display size and often was not faster than when the target was not distinctive.

Two classes of explanations for abrupt onsets capturing attention have been explored. The first is that distinctive stimulus transients may engage the magnocellular system, capturing attention because of perceptual distinctiveness. Early experiments suggested that object movement (Hillstrom & Yantis, 1994) or objects that increase in luminance (Yantis & Hillstrom, 1994) do not capture attention, which led to an initial rejection of this possibility. However, a number of experiments have subsequently investigated whether color changes (Cole, Kentridge, & Heywood, 2005; Lambert, Wells, & Kean, 2003; Lu, 2006; Snowden, 2002; Sumner, Adamjee, & Mollon, 2002; Theeuwes, 1995), luminance changes (Enns, Austen, Lollo, Rauschenberger, & Yantis, 2001; Rauschenberger, 2003; Theeuwes, 1995; Yantis & Egeth, 1999), and movement (Abrams & Christ, 2003; Chastain, Cheal, & Kuskova, 2002; Franconeri & Simons, 2003) can capture attention. These studies have had mixed results

doi: 10.1167/7.12.3 Received January 17, 2007; published September 17, 2007 ISSN 1534-7362 © ARVO

and have led many to conclude that transients have some ability to capture attention if they are distinctive enough.

The alternative explanation for why the abrupt onset of objects captures attention is that the newness of the object itself captures attention, not (or in addition to) the associated motion or the luminance transient. The theoretical basis for the new-object hypothesis lies in the necessity for the visual system to identify objects in the display. When a search display is first presented, individual objects are processed into an object file (Kahneman & Treisman, 1984). Existing object files are effortlessly reviewed across time and are constantly updated. If enough about the object has changed because the last review, then that file will be marked for reprocessing (Kahneman, Treisman, & Gibbs, 1992). When a new object appears as an abrupt onset, a new object file must be created and thus attracts attention, which is necessary for binding visual features into an object file (Yantis & Hillstrom, 1994; Yantis & Jonides, 1996).

Experiments have aimed to remove transients from onsets in a number of ways to see whether new objects capture attention in the absence of the low-level stimulus transients that engage the magnocellular system. Yantis and Hillstrom (1994) made their objects equiluminant to the background, defining them by either texture patterns or motion of the pattern on the surface of the objects. They found that abrupt onsets still captured attention (but see Gellatly, Cole, & Burton, 1999).

Franconeri, Hollingworth, and Simons (2005) manipulated stimulus transients by introducing new objects either behind a shrinking occluder or in front of it. New objects introduced behind the occluder were revealed at the same time that the shrinking occluder revealed previously present objects. Therefore, the presentation of the new object was not unique in terms of luminance transients. When the new object was introduced in front of the shrinking occluder, a luminance transient accompanied the object. Results showed that the new object introduced behind the occluder did not capture attention, whereas the new object introduced in front of the occluder did. Although this experiment calls into question whether newness of objects captures attention in the absence of luminance transients, further research has shown that the shrinking annulus may have been a distraction and led to the lack of attention capture (Davoli, Suszko, & Abrams, 2007). It remains an open question whether new objects unaccompanied by stimulus transients may capture attention.

A recent series of experiments presented objects dynamically morphing over a short time and examined the effect of morphs on attention. Morphing changes the identity and structure of an object without introducing abrupt featural changes and without introducing spatiotemporal newness (i.e., something appearing where nothing had been before). The hypothesis was that these changes would necessitate the creation of a new object file rather than updating the existing one. Thus, a morphed object should be treated like a new object and should show evidence of attentional processing. In one critical set of experiments, a single object was presented and the object morphed into another some time before a target featural change occurred (Hillstrom, Chai, & Leeman, 2000). Morphs close in time to the appearance of the target resulted in low target detection accuracy. This phenomenon was akin to an attentional blink, leading to the conclusion that attention was obligatorily engaged by the morph.

In another set of unpublished experiments, observers responded to targets presented in one of two objects (Hillstrom, Wong, & Norris, 2007). A cue appeared in one of the objects, and a target appeared soon after in the same object or the opposite object as the cue. This paradigm typically produces a benefit for targets appearing in the same object as the cue compared to equidistant targets appearing in the other object (Egly, Driver, & Rafal, 1994). When a dynamic event was introduced between cue and target presentation, it disrupted this object-based attention effect when the event was a morph, but not when the event was a rotation or a translation of the object. This suggests that changing identity and/or structural description created a demand on attention for immediate processing. Taken as a whole, the behavioral measures of attentional processing have produced mixed results about what underlies attention capture by onsets, leaving open the possibility that both perceptual transients and newness of semantic and structural information have the ability to draw attention.

Recent research has highlighted the importance of examining oculomotor effects of attentional processing along with the behavioral effects. Abrupt onsets capture not only attention, but also the eyes (Theeuwes, Kramer, Hahn, & Irwin, 1998). When an irrelevant onset suddenly appeared in a display when participants were searching for a color target, the eyes often moved toward the onset first, stopped briefly, and then moved to the target. These oculomotor capture results have been replicated in many studies (Kramer, Hahn, Irwin, & Theeuwes, 1999; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999). This finding, combined with studies showing that covert attention precedes both voluntary (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995) and involuntary (Peterson, Kramer, & Irwin, 2004) eye movements, suggests that tracking the eyes also tracks the location of attention (Corbetta, 1998; Schall, 2004)—an object that has captured the eyes has also captured attention. Therefore, the paradigm of Theeuwes et al. (1998) is an excellent way to explore which component of abrupt onsets overtly captures attention.

The experiments presented here test whether a morph will produce oculomotor capture as an abrupt onset does. If the newness of the onsetting object's identity or structural description is what produces oculomotor capture, then morphs should produce oculomotor capture as well. But if the low-level transients or spatiotemporal newness are what produce oculomotor capture, then morphs should not produce the same capture. To summarize, the core question is whether identity change during spatiotemporal continuity represents a new object that will capture the eyes.

We investigated this hypothesis by smoothly morphing an already-present object in the display into another object while participants had to saccade to a target. This presented new semantic and structural information while minimizing low-level luminance changes. All objects in the display translated about a fixed location, which controlled for the motion of the morph animation. If new semantic and structural information is the cause of capture by abrupt onsets, rates of capture should be the same between displays that include a morphing object and those with an abrupt onset.

Experiment 1

Before a study comparing the oculomotor capture rates of onsets and morphs can be conducted, it is important to ensure that morphs and onsets are equally detectable. Experiment 1 ascertains whether the morph and the onset stimuli to be used in Experiment 2 are similarly detectable to participants and that detection of each event type is uniformly fast. Participants were shown geometric shape stimuli that could morph into another shape or abruptly onset onto the screen. Responses were made based on whether an event was detected.

Method

Participants

A total of 10 George Mason University undergraduates participated (2 males, 8 females). The naive observers received partial class credit in exchange for their participation. The mean age of participants was 22.5 years, and all participants had normal or corrected-to-normal color vision.

Apparatus and stimuli

A Power Macintosh G4 (Dual 1 GHz) equipped with a 21-in. (20-in. viewable) ViewSonic P225fb operating at 85 Hz at a resolution of 1024 × 768 was used to display stimuli. The system ran custom software to present the stimuli, to control the timing of experimental events, and to record participants' response times. This computer was networked to a Dell Pentium 4 that collected eye-tracking data in conjunction with an Eyelink 2 eye tracker (SR Research, Ontario, Canada). The Eyelink 2 system samples at a rate of 250 Hz and has a 0.2° spatial resolution. The head was stabilized by means of a chin rest located 70 cm from the monitor.

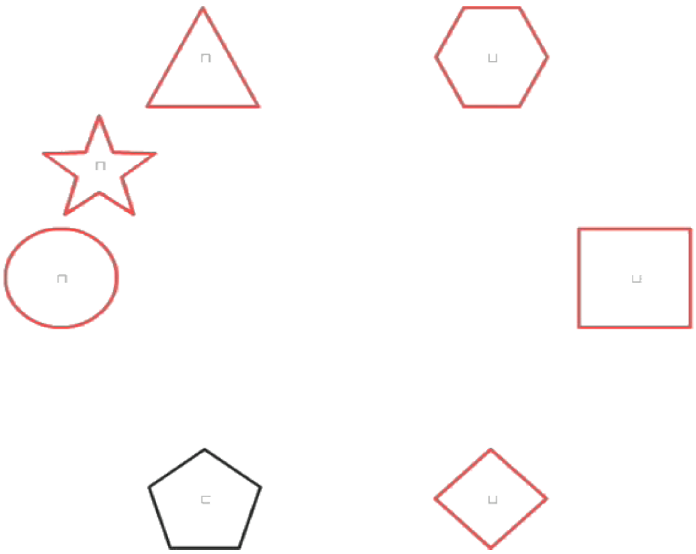
Seven different shapes (circle, diamond, hexagon, pentagon, square, five-pointed star, and triangle) were used and were 3.90° in diameter. The shapes were located 9.33° away from the center of the screen, arranged in a circular fashion, each positioned 60° apart on the circle, which itself was not visible. Shape morph animations were created using Macromedia Flash Professional 8 (Adobe Systems, San Jose, CA). Each frame of the animation was saved as a separate image.

At the center of each outlining shape was a 0.03° × 0.03° gray figure-eight mask. At the time of event presentation (morph or onset), all shapes in the display changed color from red to black. Lines within the figure eights were removed to reveal blocks Cs, all facing up or down. The Cs and preceding figure eights were present because they were used in Experiment 2. They had no role in the detection task of Experiment 1.

Design and procedure

Experiment 1 varied within subject whether the displayed event was an onset, a morph, or neither. Participants' task was to use the "z" and "/" keys of the computer keyboard to respond. One key was used to indicate detection of a morph or an onset, and the other key was used to indicate that neither of those events occurred (keys were counterbalanced across participants). The instructions emphasized speed over accuracy, encouraging participants to respond quickly. Thus, participants simply had to detect whether an event occurred.

Participants fixated on a central cross and pressed the space bar to start each trial. If the participant fixated within 2° of the cross, a drift correction occurred, after which the trial proceeded. If the participant did not fixate within 2° of the cross, nothing occurred, indicating to the participant to attempt the drift correction again. Once the trial began, six shapes were then presented in an imaginary circle around the screen, each containing a block figure-eight mask. See Movie 1 for an approximation of the display. As soon as they appeared, the shapes began to oscillate approximately 0.05° from its starting position for 750 ms plus a random 200- to 300-ms interval. This oscillation was included to be as similar as possible to Experiment 2, where oscillation of shapes was used to control for morph motion in the display. Each shape then changed from black to red and the masks within each shape were changed into up-facing or down-facing Cs and the response timer began. At the same time, one of three events could occur with an equal probability across 324 trials: one of the objects morphed into another shape that was not already present on the screen, a new object and internal C abruptly onset between the existing shapes, or neither occurred. In the morph event, all six shapes were equally likely to morph. In the onset event, all six gaps between shapes were equally likely to be the position of the onset. Each event occurred 108 times



Movie 1. Trial schematics of the two conditions in Experiment 2. (a) Onset condition. Six shapes were presented, all containing figure-eight masks. After a random interval lasting between 950 and 1050 ms, a new shape would abruptly onset onto the screen on 80% of the trials. Nontarget shapes would change color to red, leaving one remaining black shape as the target. Participants moved their eyes (represented by the mouse pointer) to the remaining black shape and then made a response based on whether there was a left- or right-facing C inside of the shape. (b) Morph condition. After a random interval lasting between 950 and 1050 ms, a shape already present on the screen would begin to morph on 81.8% of the trials. Between 0 and 140 ms after the start of the morph animation, the target would be presented. The target and response were identical to the onset condition.

throughout the experiment. Eighteen events occurred at each possible position. The morph took place over five frames, each lasting 35 ms, for a total of 175 ms.

Results

Across the three conditions, an average of 4.35% of all trials were discarded because participants did not remain fixated on the center cross throughout the entire trial. Remaining fixated at the center was a requirement because the ability to detect events in the periphery was being examined.

Detection sensitivity. Due to the nature of the detection task, sensitivity to detecting a morph or an onset was examined. The d' for morphs and onsets was calculated for each participant, and a two-tailed t test showed no difference in sensitivity for detecting a morph or an onset (M = 3.83, SE = 0.19 for morphs, M = 3.82, SE = 0.13 for onsets, $t(9) = 1.0$, $p = .93$).

Reaction times. Figure 1 summarizes reaction times for participants' detection of morphs and onsets. A 1 × 3 ANOVA revealed a significant difference in reaction times for the different events, $F(2, 18) = 62.73$, $p < .001$. Nonevents were responded to more slowly than morph or onset events, as shown by a linear contrast between morph (M = 520.29 ms, SE = 21.30) and onset (M = 511.32 ms, SE = 23.68) versus nonevents (M = 664.12 ms, SE = 18.81), $F(1, 9) = 125.13$, $p < .001$. This is likely because correctly detecting the absence of an event was qualitatively different than detecting a present (morph or onset) event. Linear contrasts, however, found that morphs were detected no more slowly than onsets, $F(1, 9) = 0.34$, $p = .57$.

Discussion

Seven geometric shapes were designed for this experiment, with the goal of using these stimuli in Experiment 2. Overall, detectability of morphs and onsets was similar. Morphs were detected as easily and as quickly as onsets. However, it would still be prudent in Experiment 2 to allow the morph to be displayed for some time before presenting the target. This should provide a head start so the visual system to give it a chance to detect the morph before target presentation.

Experiment 2

In this experiment, the stimuli of Experiment 1 were used. During each trial, all but one of the shapes changed color to red, and the target of the task was defined as the one black shape. Participants were to fixate on or near the remaining black shape target and to make a button press

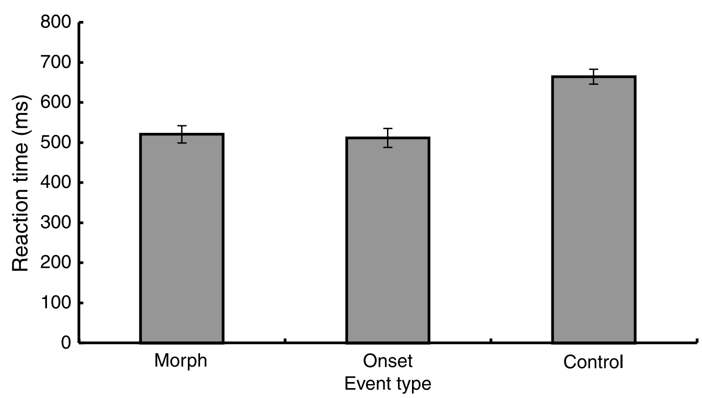


Figure 1. Reaction time to detect a morph, an onset, or a control event in Experiment 1. Control trials took significantly longer to be responded to than when a morph or an onset occurred. Critically, there was no difference time to detect a morph or an onset. All errors bars represent the standard error of the mean.

response to the orientation of the C inside the shape. Two distractor events were introduced to determine if they captured eye movements. In the morph condition, one of the nontarget objects morphed into another identity, whereas in the onset condition, a new object abruptly onset onto the screen. The goal of the experiment was to determine if the morph would capture the eyes at the same rate as the onset.

Method

Participants

A total of 20 George Mason University undergraduates participated (7 males, 13 females). The naive observers received partial class credit in exchange for their participation. The average age of participants was 19.6 years, and all participants had normal or corrected-to-normal color vision. No participants in this experiment had participated in Experiment 1.

Apparatus and stimuli

The computer and the eye-tracking equipment used in Experiment 2 were identical to the equipment used in Experiment 1.

The shapes were identical in size and in placement to those used in Experiment 1.[1] The only difference in stimuli from Experiment 1 was in the target, which remained black once the nontarget shapes had turned red. The block figure eights inside the shapes turned into block Cs when the color change occurred. Within any red nontarget shape, the block C faced up or down. Within the target shape, it faced left or right.

Design and procedure

In this experiment, distractor-event type (onset or morph) was varied between participants, with 10 participants assigned to each type. Whether the distractor event was present or absent was varied within participant. For the morph condition, the time between the start of the morph and the presentation of the target was also manipulated within participant.

Movie 1 shows the sequence of displays for both conditions. For both conditions, participants fixated on a central cross and pressed the space bar to start each trial. If the participant fixated within 2° of the cross, a drift correction occurred, after which the trial proceeded and began with the preview period.

During the preview period, six shapes arranged in a ring around the center cross were presented, each shape surrounding a figure-eight mask. Each shape immediately began oscillating. Shapes moved no more than 0.05° to the left or to the right of the center of the circle. This oscillation was included so that all shapes would show some kind of movement, not just the shape that morphed. Participants were told to keep their eyes at the center cross until the target appeared. If participants moved their eyes more than 3.12° away from the center cross while waiting for the target, they received a warning and the trial ended early. The center cross was removed after 750 ms, and a random period of time between 200 and 300 ms elapsed.

After this delay, the singleton event began (if it was presented), and five of the six shapes changed color from black to red, leaving one remaining black shape as the target, and the response timer began. In the onset condition, target presentation coincided with the onset, whereas in the morph condition, it began either at the same time or a short while later. Coinciding with target presentation, the masks within each shape were changed into Cs. Nontarget (red) shapes contained an up- or down-facing C, and the target shape enclosed a left- or right-facing C. The participants' task was to move their eyes from the center of the display to the C within the target shape and press "z" or "/" depending on whether the C was facing to the right or to the left. Responses were not accepted until the eyes were fixated no further than 4.68° from the center of the shape that enclosed the target letter. Response keys were counterbalanced across participants.

The singleton that morphed or onset was never the target; therefore, the morph or the onset was antipredictive and participants had no reason to fixate it. Each condition began with six practice trials. Neither condition took longer than 1 hr to complete.

Onset condition. Movie 1a shows the sequence of events for the onset condition. After the preview period (750 ms) and the random delay (200–300 ms), on 80% of trials a new shape containing an up- or down-facing C abruptly onsetted onto the screen in between two already-present shapes at the same time that the target-defining color change occurred. On 20% of trials, nothing onset when the target-defining color changed occurred.

This condition consisted of 270 trials, and of these, 216 (80%) trials contained an abrupt onset. The number of trials and the ratio of onset-present to onset-absent trials were selected to be as similar as possible to the morph condition. The target was located equally often at each of the six positions in the display (36 trials per target position), and an onset took place equally often in any of the six positions halfway between the six original shape positions.

Morph condition. Movie 1b shows the sequence of events for the morph condition. After the preview period (750 ms) and the random delay (200–300 ms), on 81.8% of the trials, the morph animation began with one already-present shape smoothly morphing into a new shape over 175 ms.

The target was presented at three possible times (stimulus onset asynchronies, SOAs): 70 ms after the start of the morph animation, 140 ms after, or coincident with the start (0 ms). Although the results of Experiment 1 indicated that morphs were as detectable as onsets, it is still prudent to give morphs a 70- or a 140-ms head start before the target appears to give the morph a strong detection advantage.

The morph condition consisted of 330 trials, with 270 trials (81.8%) including a morphing object. This high ratio of morph-present to morph-absent trials was chosen to keep to a manageable level the number of trials in the experiment. Trials containing a morph were evenly split between the three SOAs (90 trials per SOA). The target appeared equally often in the six display positions (15 trials per position), and morphs were presented equally often in the five remaining positions.

Results

Approximately 6.87% of trials were discarded because participants did not remain fixated on the center cross before the target or transient singleton was presented. This includes uncontrolled saccades and eye blinks made before target presentation. Task accuracy was 95.73%. Because all eye movements were executed before a response could be made, trials on which inaccurate responses were made were not excluded from the eye movement analyses.

Initial fixations. Figure 2 summarizes the percentage of first fixations that landed on the target, the singleton, or another nontarget object as a function of the type of singleton that was present in the display: an onset or a morph with one of three SOAs. A fixation was determined to be on an object if the eyes were no more than 4.68° from the center of the object, which was 3.90° in diameter.

A 1 × 3 repeated measures ANOVA across the three different SOAs (0, 70, and 140 ms) showed a difference between the rates at which the morph was fixated first, $F(2, 18) = 5.00$, $p < .05$. Additional analyses show that the shape morph was fixated more often when it was given a head start before target presentation, as shown by a contrast that indicated a significant difference between 0 ms versus 70 and 140 ms SOA conditions, $F(1, 9) = 7.96$, $p < .05$. The length of the head start did not affect the rate of first fixations past 70 ms, as shown by the insignificant difference between 70 and 140 ms conditions, $F(1, 9) = 2.64$, $p = .12$. Because SOA had a significant effect on fixations on the morph, all analyses were conducted for each SOA condition.

To examine whether morphs were fixated first as often as onsets, we compared the difference between the first fixation rate of onsets to the first fixation rate of morphs at each individual SOA. Three Bonferroni-corrected independent-samples t tests ($\alpha = .0167$) showed that onsets were fixated first more often than morphs at each SOA ($M = 49.63\%$, $SE = 3.73$ for onsets; $M = 1.94\%$, $SE = 0.67$ for morphs with 0 ms SOA; $M = 5.66\%$, $SE = 1.78$ for morphs with 70 ms SOA; and $M = 10.48\%$, $SE = 3.50$ for morphs with 140 ms SOA), $t(18) = 12.6$, 10.65, and 7.66, respectively, $p < .001$ for all. These analyses show that when an onset appeared at the same time as the target, the eyes would first fixate on the onset about 50% of the time. However, when the morph was the only unique event in the display before target presentation, the eyes were not as likely to fixate the morph as often as the abrupt onset.

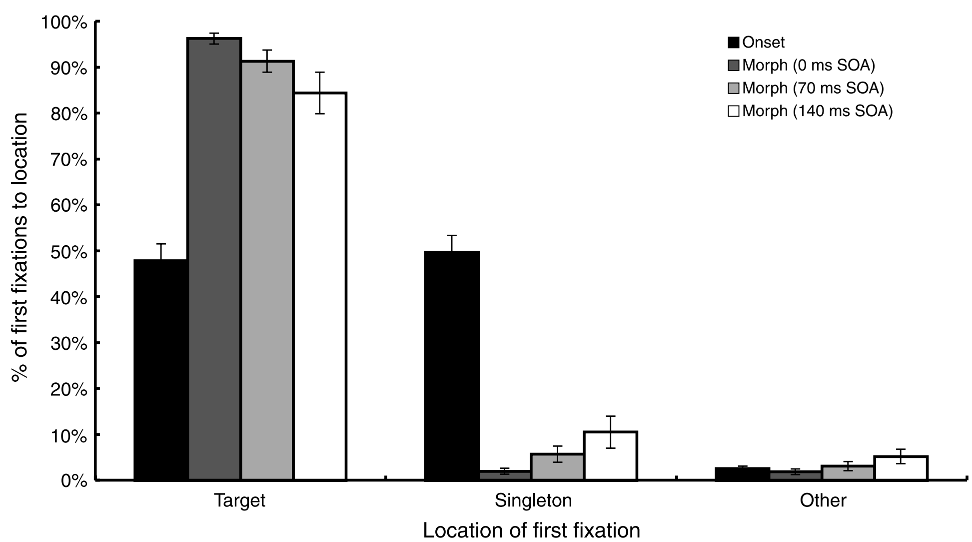


Figure 2. The percentage of trials where the first fixation landed on the target, the singleton, or another nontarget object in the display in Experiment 2. Because the length of SOA affected morph capture rates, the data with respect to the morph condition were broken down across SOAs. There were significantly more fixations that landed on the onset versus fixations that landed on the morph across all morph SOAs. All errors bars represent the standard error of the mean.

A logical follow-up analysis is to examine whether morphs were fixated more often than other nontargets in the display. To explore this question, the first fixation rates on nontargets other than the morphing object were divided by four (the number of nontargets that did not morph). This was separately done for all three SOAs. Three Bonferroni-corrected paired-samples t tests (α = .0167) showed no significant difference between rates of first fixations on the morph versus another nontarget at any SOA (0 ms SOA: M = 1.94%, SE = 0.67 for morphs, M = 1.83%, SE = 0.60 for nontargets; 70 ms SOA: M = 5.66%, SE = 1.78 for morphs, M = 3.05%, SE = 1.00 for nontargets; 140 ms SOA: M = 10.48%, SE = 3.50 for morphs, M = 5.16%, SE = 1.59 for nontargets), $t(18)$ = 0.23, 1.61, and 1.74, respectively, p = .82, .14, and .12, respectively. Although these comparisons failed to reach significance, there was a trend toward significance as the SOAs increased, suggesting that with sufficiently increased power, first fixations may have landed on morphs more than other nontargets.

Initial saccade latencies. It is possible that covert attention was captured by the morph in the absence of overt attention, so saccadic latencies made to the target in the presence of a morph were analyzed. If morphs captured attention covertly, saccades should be delayed by the time required for attention to move to the morph, disengage from it, and move to the target. The most straightforward test of whether covert attention was captured by the morph is to explore whether saccades to the target were slower when a morph was present versus when it was absent. Although there was a difference between saccadic latencies to the target when a morph was present or absent (M = 485.06 ms, SE = 107.15 for morph-absent trials, M = 455.95 ms, SE = 96.52 for morph present trials, $t(9)$ = 3.91, p < .01), the result is opposite of the hypothesized effect. Saccades were faster when a morph occurred and were slower when no morph occurred.

Discussion

The rates at which onsets and morphs captured the eyes were examined by determining the landing position of the first saccade. If attention were under voluntary control, participants would directly saccade to the target and then make a response. However, if the eyes fixated on the task-irrelevant singleton first, then it can be concluded that the eyes were involuntarily captured by this event. When comparing first fixations on onsets to first fixations on morphs, onsets drew the eyes far more than morphs drew the eyes.

Some morphs were given a 70- or a 140-ms head start before the target appeared. This head start affected how often the eyes went to the morphs, but it did not have enough of an effect to cause morphs to capture the eyes as much as onsets did. At the longest SOA condition, the results showed that the first fixations went to onsets on 49.6% of the trials that contained an onset, but first fixations went to morphs on only 10.5% of the trials. Therefore, it appears that onsets were far more effective at capturing the eyes than the morphs.

To further elaborate the effect of morphs on the eyes, a comparison was made between first fixations on morphs versus first fixations on other nontargets. Although no significant difference was found, the trend suggested that increased power might result in evidence that morphs draw the eyes a bit, albeit weakly and far less than onsets do.

Along with oculomotor capture, the capture of covert attention was examined. If saccades were made more slowly to the target when a morph was present versus when it was absent, then it is likely that covert attention was captured by the morph. The hypothesized relationship was not found and in fact was in the opposite direction (slower responses when the morph was absent than when it was present), and this suggests that morphs did not capture attention.

One might argue that the slower responses to morph-absent trials were due to their relative rarity (80% of trials had events and 20% had no events). Experiments often find slower reaction times to low-frequency events than to higher frequency events (e.g., Miller & Anbar, 1981). This could have offset any RT benefit produced by covert attentional capture. However, what was less frequent in this experiment was the absence of a morph rather than the presence of something, and it is unclear whether that would have the same frequency effect. Nevertheless, strong conclusions about whether morphs draw covert attention should be left to future experiments.

General discussion

We tested a hypothesis that the abrupt onset of a new object captures the eyes effectively not because of any low-level luminance or motion transients and not because of spatiotemporal newness, but because of the new semantic and structural information that is at the core of an abrupt onset event. Previous studies have shown that low-level changes to existing objects often do not capture attention (Hillstrom & Yantis, 1994; Yantis & Hillstrom, 1994). The current study examined whether morphs of objects, which present new high-level information and minimize low-level transients, would capture the eyes. No matter how much time morphs were given as the unique event in the display, morphs were never first fixated as often as onsets. Therefore, new semantic and structural information alone had a far weaker effect on oculomotor capture than abrupt onsets.

We tested morphs because an object that morphs changes conceptual identity and structure without abrupt low-level transients and without spatiotemporal newness, whereas onsets include all of these. If morphs had drawn the eyes, we could have concluded that conceptual identity and structure change was sufficient to produce oculomotor capture. Because we did not find strong oculomotor capture for morphs but did for onsets, the possible conclusions are that either (1) abrupt low-level transients play an important role in oculomotor capture or (2) spatiotemporal newness plays an important role in oculomotor capture. This study cannot distinguish between these possibilities. It is possible, though, to say that conceptually new objects do not capture the eyes strongly unless they also exhibit low-level transients or spatiotemporal newness.

Assuming the former interpretation, these results are in theoretical agreement with results showing oculomotor capture by luminance or color change (Irwin, Colcombe, Kramer, & Hahn, 2000). Transients appear to be able to draw the eyes, and new objects without transients (such as object morphs) rarely do. Along with the behavioral results from this study supporting the role of low-level transients in oculomotor capture, there is physiological evidence as well. When new semantic and structural information appears, the high-level information must travel from the eyes to occipital cortex for processing by many visual areas. Only after this lengthy process is complete will the morph be processed fully (Ungerleider & Mishkin, 1982). However, if the new object is accompanied by unique luminance change or motion, then the magnocellular pathway of the visual system that receives input from the rods (which are sensitive to transients) can directly influence the superior colliculus, an area responsible for oculomotor orienting. Fibers from the superior colliculus then feed to posterior parietal cortex, which is responsible for spatial orienting of attention (Theeuwes, Olivers, & Chizk, 2005).

Therefore, if a new object is coupled with luminance or motion transients, that information may cause a reorienting of the visual system to the location of the transient, and both oculomotor and attentional capture will have occurred. Because luminance and motion are able to skip high-level processing and can cause involuntary reorienting of the visual system, a sudden transient must accompany the onset of a new object to elicit oculomotor capture (Boot, Kramer, & Peterson, 2005). Although new semantic and structural information might necessitate a new object file, a sudden transient seems to alert the visual system that such processing is needed, which causes a rapid saccade to the object.

Returning to the alternative interpretation that spatiotemporal newness captures attention, morphs in that case represent not new objects but objects updated with changed conceptual and structural information. This requires us to reconsider as yet unpublished experiments that show that morphing an object rapidly and smoothly produces an involuntary attentional blink (Hillstrom et al., 2007; see also Raymond, 2003) and disrupts object-based attention effects in cuing experiments (Hillstrom et al., 2007). We have interpreted these results as showing that attention is captured by conceptually and structurally new objects that are spatiotemporally old and have no salient low-level transients. To reconcile the old and the new conclusions about the effect of morphs, note that one obvious difference in the paradigms used is that in the current study, morphs were in the periphery and irrelevant to the task, whereas in the earlier studies, morphs were task relevant and often attended before undergoing a morph. The current results suggest that although changes to conceptual identity and structure may affect attention, conceptual identity and structure likely play less of a role in the representation of unattended objects than that in the representation of attended objects. Although this is not a dramatically new idea (e.g., Wolfe & Bennett, 1997), it provides a sensible reason why eyes would rarely be drawn to morphing, peripherally presented objects, whereas attentive processing of objects would be disrupted through a smooth morph.

Conclusion

In summary, new objects are important to the visual system, as they often signify the introduction of crucial information to the environment. Past research has convincingly shown that the abrupt onset of a new object will often elicit an involuntary saccade. However, the results described here show that a morphed object, which we interpret as being conceptually and structurally new without being spatiotemporally new or having undergone any low-level transients, will not cause as many involuntary saccades as onsets can cause. Morphs may have a weak general effect on the visual system, but it is certainly not as strong as the effect of onsets. The morph must be processed to a high level before it is detected, whereas low-level luminance and motion may have a faster track into the visual system to cause a reflexive saccade to the abrupt onset.

Acknowledgments

Anne Hillstrom is now at Department of Psychology, University of Portsmouth. This work was supported by grant BCS0424919 from the National Science Foundation to APH. We would like to thank Ian Wiscovitch for his assistance and Miroslava Vomela for her insights.

Commercial relationships: none.
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Footnote

[1]We have run another version of this study using stimuli that are more complex and semantically rich than the stimuli used in Experiment 2. Morphs of these computer-generated real-world objects failed to capture the eyes, but object onsets did capture the eyes. These results were presented at the 2006 Vision Sciences Society conference (Wong, Hillstrom, & Peterson, 2006). This experiment is not included in the primary text because a detection experiment similar to Experiment 1 showed significant differences in detecting object morphs and object onsets.

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