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Fixation Not Required: Characterizing Oculomotor Attention Capture for Looming Stimuli

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Abstract A stimulus moving toward us, such as a ball being thrown in our direction or a vehicle braking suddenly in front of ours, often represents a stimulus that requires a rapid response. Using a visual search task in which target and distractor items were systematically associated with a looming object, we explored whether this sort of looming motion captures attention, the nature of such capture using eye movement measures (overt/covert), and the extent to which such capture effects are more closely tied to motion onset or the motion itself. We replicated previous findings indicating that looming motion induces response time benefits and costs during visual search Lin, Franconeri, & Enns(Psychological Science 19(7): 686–693, 2008). These differences in response times were independent of fixation, indicating that these capture effects did not necessitate overt attentional shifts to a looming object for search benefits or costs to occur. Interestingly, we found no differences in capture benefits and costs associated with differences in looming motion type. Combined, our results suggest that capture effects associated with looming motion are more likely subserved by covert attentional mechanisms rather than overt mechanisms, and attention capture for looming motion is likely related to motion itself rather than the onset of motion.

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On a typical day, we may be required to process rapidly and respond to environmental stimuli. For example, a sudden loud noise may indicate an alarm that requires us to evacuate from our office, or a vehicle quickly expanding in visual angle in front of us while driving might cue us to an impending collision that we must respond to in order to avoid. Stimulus properties that evoke these sorts of reflexive high-priority responses often are referred to as being capable of capturing attention. Given that moving objects in the real world often are behaviorally informative (particularly if the object is moving toward an observer), it is perhaps unsurprising that motion has been a focal point for study in the context of attentional capture effects (Folk et al., 1994; Franconeri & Simons, 2003; Hillstrom & Yantis, 1994; Ludwig, Ranson, & Gilchrist, 2008). For example, it has been found that object motion induces a search cost for invalid spatial cues when searching for a moving target (Folk et al., 1994). Additionally, looming motion associated with a target engenders faster RTs, but looming motion associated with a distractor object engenders slower RTs across differing set sizes (Lin, Franconeri, & Enns, 2008). Researchers also have demonstrated that capture does not necessarily occur uniformly for all motion (Franconeri & Simons, 2003; Lin et al., 2008). Interestingly, Franconeri and Simons (2003) have demonstrated that motion captures attention but that the effect depends on the *type* of motion (collision vs. noncollision trajectory). These findings are consistent with the importance that looming motion often plays in our daily lives. An item that is looming toward an individual is more likely to be something he might have to respond to, whereas an item moving away from an individual is less likely to require an immediate action.

Although ample evidence exists to support the assertion that object motion captures attention, some findings have suggested that this might not be a ubiquitous relationship. Failures to find evidence for motion-related capture effects have been attributed to overly simplistic motion instantiations (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999) or to experimental confounds, such as motion continuing during target search and onsets occurring simultaneously with mask offsets (Franconeri & Simons, 2003). However, it has been argued that the absence of motion-related capture in some cases is evidence that motion itself does not capture attention. Rather, motion *onset* is the critical factor that demands processing priority (Abrams & Christ, 2003, 2005; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988). Indeed, there is substantial evidence that stimulus onsets are "special" in their ability to capture attention (Jonides & Yantis, 1988; Theeuwes, Kramer, Hahn, & Irwin, 1998). Counter to these claims, Abrams and Christ (2006) provided evidence that motion could draw attention to an object independently of motion onset, despite the superior capture properties of an onset. The claim that motion onset substantially contributes to capture effects arises again in response to the use of apparent motion to evaluate these effects. In many previous experiments, motion was created by presenting multiple brief displays, above the perceptual threshold at 60 ms per display, to create apparent motion (Lin et al., 2008). As a result, capture may have been due to multiple stimulus onsets and not to perceived apparent motion. Supporting this possibility, recent findings have indicated that smooth motion sometimes fails to capture attention (Sunny & von Mühlenen, 2011).

While manual response measures, such as RT, can provide a broad indicator of the processing costs and benefits associated with motion-based attention capture effects, they do not provide an understanding of how such effects unfold over time. Analysis of eye movements, however, can enable finer-grained predictions regarding the nature of motion-associated attention capture. For example, attentional shifts can be described in terms of overt or covert shifts (Posner, 1980). On the one hand, overt attention shifts involve a coupling between attention and foveal fixation (Beck & Lavie, 2005). On the other hand, attention also can be divorced from fixation. In assessing visual performance differences during capture, researchers have found evidence that search and oculomotor behaviors change when attention capture occurs (Boot, Kramer, & Peterson, 2005; Ludwig et al., 2008). For example, Boot et al. (2005) found an increase in overt attentional shifts (i.e., first saccades towards the distractor) and increased saccadic latencies when onset-associated capture occurred during search. Furthermore, Ludwig and colleagues (2008) found that in a search and discrimination task, the presence of nonlooming motion and other dynamic distractors resulted in an increased number of saccades toward irrelevant distractors. Despite these findings characterizing oculomotor behavior in the context of capture for onsets, or with general motion, there is limited research evaluating how looming motion capture affects search and oculomotor behavior.

The world we live in is a dynamic one and our perceptual systems are not only tasked with managing motion information from the environment, but also with identifying motion that might be particularly important, such as when someone or something is moving toward us. In the current studies, we explored the extent to which looming motion acts to capture attentional processes (Hillstrom & Yantis, 1994). Specifically, we conducted four experiments in which participants searched for an oval target among distractor spheres—a paradigm that largely replicates previous studies by Lin and colleagues (2008). In some trials all objects were static, whereas in other trials either a target or a distractor loomed towards the observer. Additionally, we measured oculomotor behavior while manipulating the nature of the looming motion itself (apparent and smooth looming motion). Our goals were threefold. First, we sought to provide further evidence that looming object motion does in fact engender the attentional benefits and costs typically associated with attention capture. Although previous studies (Lin et al., 2008) have demonstrated RT differences between looming targets and distractors, these studies have not reported effects in relation to a control condition in which no motion occurred. Without this critical comparison, it is impossible to determine whether RT differences associated with looming motion represent an attentional benefit (when a target looms), cost (when a distractor looms), or both. In the current studies, the critical comparison was provided by comparing RTs when an object (target or distractor) loomed in a control condition in which no objects loomed. Second, we further characterized how attention capture arising from looming object motion unfolds over time. Previous findings have been somewhat unclear as to whether capture benefits/costs associated with looming motion result from facilitation/attenuation of covert attentional mechanisms, or whether RT differences result from an associated oculomotor shift. While there is evidence that capture associated with stimulus onsets often coincides with an eye movement (Boot et al., 2005), less is known about the oculomotor correlates of motion-related capture, particularly looming motion. Third, we attempted to extend existing theoretical frameworks describing the underlying causes of motion-related capture effects to stimuli that moved in a looming manner. Specifically, we were interested in testing the proposition that motion-based capture arises from stimulus onsets, as opposed to motion itself. We did so by comparing capture effects of apparent looming motion, which could be construed as a rapid series of onsets, to capture effects of smooth looming motion. If capture effects for looming motion are strongly tied to stimulus onsets, then we would expect to find larger capture effects in the apparent motion condition than in the smooth motion condition.

Experiment 1

To evaluate the role of looming motion on attention capture in search, we designed our experiment based on previous methods by Lin et al. (2008). We presented an array of 6 spheres in which participants searched for an oval target onset. To better distinguish between capture benefits and costs we included a control condition in which objects were static.

Methods

Participants

Twenty-six participants from the University of Central Florida's undergraduate research pool participated in Experiment 1 (14 females, *M* age = 19.42, *SD* = 1.94). Sample sizes were generally based on several prior related studies (Abrams & Christ, 2003; Boot et al., 2005; Kramer, Cassavaugh, Irwin, Peterson, & Hahn, 2001). Participants were required to have normal or corrected to normal visual acuity (assessed with a Snellen chart) and normal color vision (assessed with Ishihara Plates). In exchange for 1 hour of participation, participants received course credit.

Instruments

An Eyelink 1000 eye tracker (SR Research) was used for tracking eye movements for the participant's right eye at 500 Hz. Participant movement was restricted using a headrest positioned at 60 cm from the display screen. Stimuli were presented on a SyncMaster 2233 LCD display (48 cm wide × 30 cm height; ~43° × 28°) with a screen resolution of 1680 × 1050 and refresh rate of 100 Hz. Responses were collected using a keyboard. The experiment was programmed and displayed using Experiment Builder (SR Research) and eye movements were quantified using the SR Research default algorithms.

Design and Stimuli

The experiment used a 2 (Motion type; between subjects) × 3 (Looming Condition; within subject) mixed factorial design. The looming conditions were: looming target, no looming (control), and looming distractor. Trial conditions were randomly interleaved within each block of trials and balanced within each block. The search target on all trials was an oval, either horizontally or vertically oriented.

The displays were comprised of six spheres that could appear in eight possible locations on two invisible rings, with three spheres on each ring on each trial. The inner ring diameter subtended 10.5° and the positions were top, right, bottom, and left; the outer ring diameter subtended 20° and the positions were top right, bottom right, bottom left, and top left (Fig. 1). Spheres were created using Blender 2.6 (http://www.blender.org/) and subtended 5° (unless they were the object in motion, in which case they spanned 1.2° to 5° throughout looming) of visual angle and were shaded to appear three-dimensional. Oval targets were created by distorting the original sphere by 17 % and then orienting the resulting oval shape either horizontally or vertically.

Experimental trials were comprised of multiple successive displays to induce the percept of motion for the participant for the corresponding conditions (Fig. 2). Looming apparent motion was created by having the designated sphere appear at three different sizes in rapid succession (1.2°, 3.2°, and 5°); this method of creating looming was a replication of previous work (Lin et al., 2008). Each display was presented for 60 ms with all nonlooming spheres at the standard size (5°). Smooth motion was created by presenting a series of 18 displays (Franconeri & Simons, 2003; Sunny & von Mühlenen, 2011) in which the visual angle of a sphere increased incrementally in size from 1.2° to 5°. Each frame of the looming motion was presented for 10 ms, providing a more cohesive pattern of motion relative to the apparent motion condition. The total duration of the motion displays was equivalent across the apparent and smooth motion conditions (180 ms).

Following the completion of motion, at which point all spheres were equal in size, a white screen was presented for 22 ms to minimize the onset effects of the change in shape of the oval target, followed by the final search display. The inclusion of this brief intervening white screen (which served as a sort of mask) caused all objects in the final search array to appear as an onset, which eliminated any target or distractor exclusive onset benefits. In the search display, one of the original spheres was replaced by the oval target. Search displays were presented until the participant responded or 4 s elapsed; if participants did not respond within 4 s the trial was considered an error. Participants responded using a game controller for the target direction; for horizontal targets the right trigger

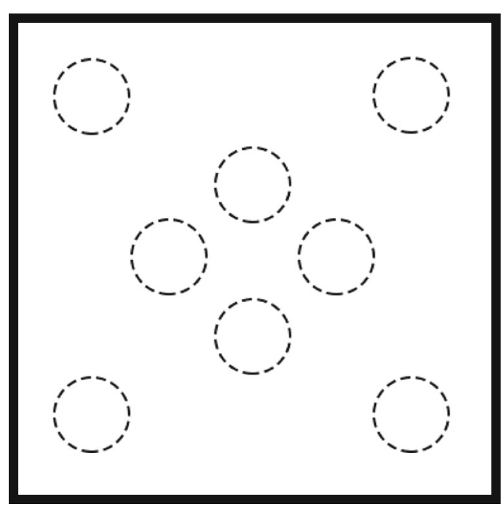

Fig. 1 Example placeholder layout for search array

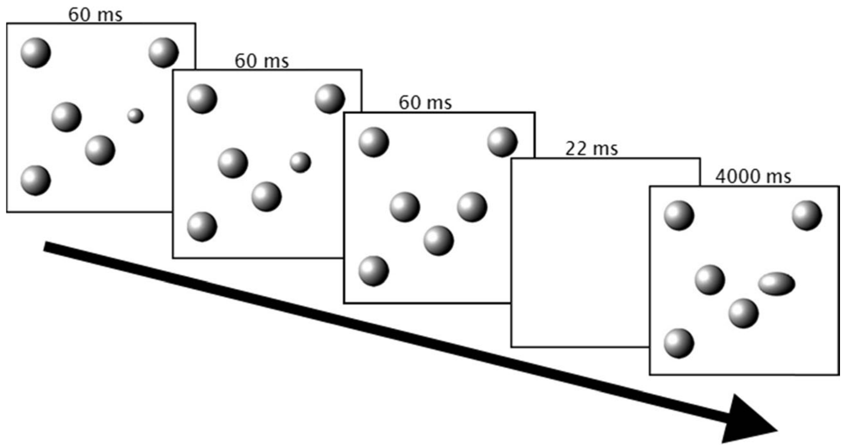

Fig. 2 Example of displays for to create apparent motion and target display onset

was used and for vertical targets the left trigger was used. Between trials participants were required to fixate a small circle at the center of the screen and then press the enter key to advance to the next trial. This fixation period between each trial served two purposes—to ensure each participant was fixating the center of the screen at the start of the trial and to correct the eye tracker calibration for drift error.

Procedure

Participants provided informed consent and were then screened for visual function. Following screening, participants were provided instructions on the experimental task, calibrated in the eye tracker (9-point calibration procedure) and then completed 36 practice trials. At the start of each trial, participants completed the drift correct sequence prior to display onset. The experimental display was presented for 180 ms, and then the search display was presented until a response was made or the display timed out. Throughout the experiment, participants wore active noise cancelling headphones. Each participant completed 504 experimental trials over 7 blocks (72 trials each) and was permitted to take breaks in-between blocks.

Results and Discussion

All analyses were mixed factorial ANOVA performed on correct trials, unless noted as otherwise. The between-subject factor was motion type (apparent, smooth) and the within-subject factor was looming condition (target, absent, distractor). All pairwise comparisons utilized Bonferonni corrections to control for family-wise error. All error bars represent standard error of the mean.

Accuracy

One participant was removed from all analyses due to having accuracies more than two standard deviations below the mean. Participants were highly accurate across looming conditions (greater than 96 %), regardless of whether items in the display loomed ($F(2, 46) = 1.05$, $p = 0.358$, *partial* $\eta^2 = 0.044$) or motion was apparent or smooth ($F(1, 23) = 0.045$, $p = 0.833$, *partial* $\eta^2 = 0.002$).

Response Times

RTs as a function of looming type and motion condition are shown in Fig. 3. ANOVA confirmed that RTs varied as a function of looming condition ($F(2, 46) = 130.23$, $p < 0.001$, *partial* $\eta^2 = 0.849$), but not motion type ($F(1, 23) = 0.17$, $p = 0.682$, *partial* $\eta^2 = 0.007$). When the target was looming, RTs were faster (M = 642.92 ms) than when no items loomed (control) (M = 769.50 ms) or a distractor loomed (M = 846.01 ms). There was a search benefit for looming targets compared to control (apparent 117.03 ms, $p < 0.001$; smooth 136.93 ms $p < 0.001$) and a cost of looming distractors compared with control (Apparent 68.16 ms, $p = 0.012$; Smooth 85.56 ms $p < 0.002$). This data pattern is consistent with previous findings characterizing the costs and benefits of looming motion on RT (Lin et al., 2008). The looming condition x motion type interaction was not significant ($F(2, 46) = 1.01$, $p = 0.371$, *partial* $\eta^2 = 0.044$), indicating that the RT costs and benefits associated with looming motion were comparable for both apparent and smooth motion conditions. Because apparent motion could be thought of as representing a series of rapid onsets that appear as motion, one might expect it to induce larger capture effects than motion that appears smooth. Our data appear to contradict this extrapolation, as search effects were the same across motion types.

Fixations to Looming Objects

The manual RT data clearly indicate that the instantiation of looming motion to either a search target or distractor engenders search benefits and costs, respectively, compared to a display in which motion of any type is absent. These data offer

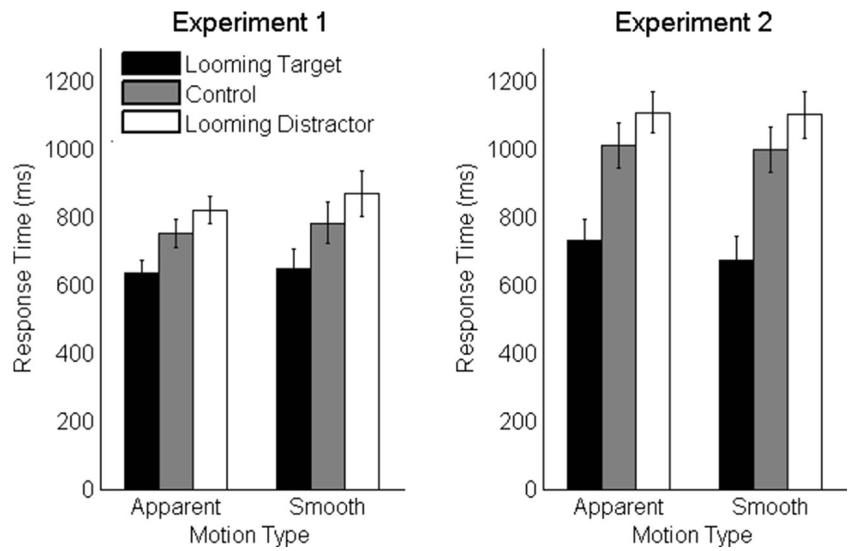

Fig. 3 Response times as a function of experimental conditions for target location and looming type for apparent and smooth motion for both Experiments 1 and 2

further confirmation that looming motion does in fact induce attention capture (Lin et al., 2008). However, it remains unclear whether those benefits and costs are directly associated with an eye movement toward the looming object (either target or distractor). Previous findings have suggested that a number of transient event types, including motion (and particularly motion onset), do attract oculomotor attention (Ludwig et al., 2008; Remington, Johnston, & Yantis, 1992). To determine whether looming motion induces a similar behavioral correlate, we calculated the proportion of trials in which fixations to a looming object occurred. Any fixation that occurred within 0.5° from the outer boundary of an object was considered a fixation on that object. If attentional capture from looming motion is strongly coupled with overt oculomotor processes, then we would expect participants to display a large proportion of looming object fixations across all trials in which looming motion was present.

Data were submitted to a 2 (looming target and looming distractor) × 2 (apparent motion and smooth motion) ANOVA and are displayed in Fig. 4; the control condition was omitted from the analysis, because no looming occurred in that condition. The proportion of trials in which a fixation was made to a looming object varied as a function of looming condition ($F(1, 23) = 79.12, p < 0.001, partial\ \eta^2 = 0.775$) ; participants fixated on looming targets in almost twice as many trials as looming distractors. The proportion of fixations to looming objects also differed as a function of motion type ($F(1, 23) = 13.17, p = 0.001, partial\ \eta^2 = 0.364$), and the motion type x

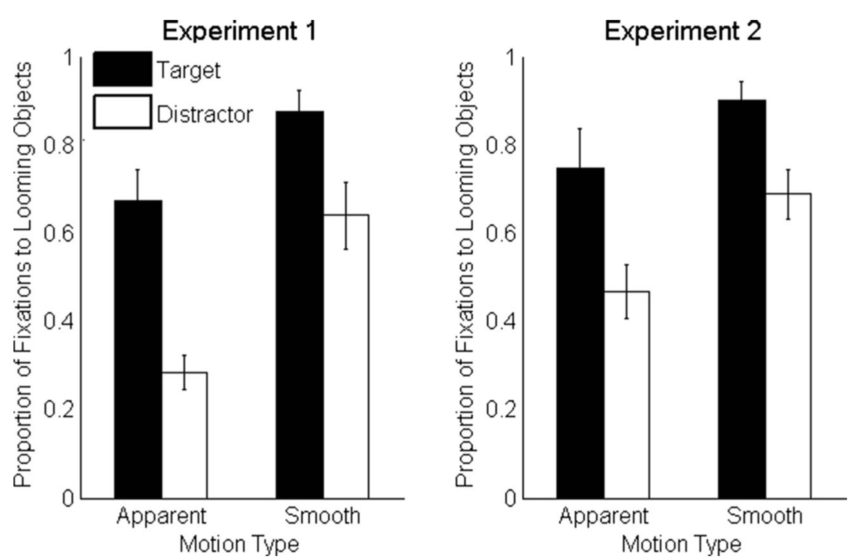

Fig. 4 Looming object fixation proportions as a function of experimental conditions for hard target location and looming type for apparent and smooth motion for Experiments 1 and 2

looming condition interaction was significant ($F(1, 23) = 4.89$, $p = 0.037$, *partial* $\eta^2 = 0.175$); looming items were fixated more often when motion was smooth (targets ~87 %, distractors ~68 %) compared with when it was apparent (targets ~64 %, distractors ~28 %), and the difference between target and distractor looming object fixations was larger for apparent motion compared with smooth motion. This pattern of data seems to argue against an explanation of motion-related oculomotor capture in which capture is closely tied to stimulus, or motion onsets (Abrams & Christ, 2003, 2005, 2006). If oculomotor capture for moving objects was a result of motion onset rather than motion itself, then we would have expected fixations to looming items to occur most often in the apparent motion condition, which is a series of onsets, as opposed to in the smooth motion condition.

Response Times as a Function of Fixation

Although our analysis of object fixations might suggest that oculomotor capture effects associated with motion are divorced from motion onset, object fixations alone do not tell us *when* RT benefits or costs occurred. That is, participants may have made fixations to looming targets or distractors, but these fixations may have been orthogonal to the RT data. Ultimately, the question that must be answered is whether attention capture effects for looming motion, as defined in terms of RT benefits and costs, are directly related to oculomotor mechanisms, or are covert in nature. Even if motion onset does not capture the eyes, it might still capture attention. If oculomotor mechanisms were closely associated with the RT differences in our study, then we would expect to find benefits and costs only in trials where an eye movement to a looming object occurred. Alternatively, if RT benefits and costs occurred independently of eye movements toward a given looming object, then it would suggest that capture is associated with covert attentional mechanisms. To decouple these competing possibilities, we analyzed RT as a function of whether or not an object fixation occurred on a given trial.

RTs as a function of motion type, looming condition, and fixation are show in Fig. 5. RTs varied as a function of fixation ($F(1, 23) = 23.00$, $p < 0.001$, *partial* $\eta^2 = 0.500$) and looming condition ($F(1, 23) = 97.86$, $p < 0.001$, *partial* $\eta^2 = 0.810$). There was no main effect of motion type ($F(1, 23) = .01$, $p = 0.942$, *partial* $\eta^2 = 0.000$); apparent motion was no more or less likely to engender attention capture effects than smooth motion, regardless of whether or not the looming object was fixated. The interaction between fixation and looming condition did not reach significance, $F(1, 23) = 0.40$, $p = 0.531$, *partial* $\eta^2 = 0.017$, but the interaction between motion and fixation was marginally significant ($F(1, 23) = 4.28$, $p = 0.050$, *partial* $\eta^2 = 0.157$). There are three main points that should be taken from these data. First, the pattern of RT data in relation to eye movements, which was broadly consistent with those observed in our analysis of RT alone, also demonstrated that the RT pattern occurred independently of whether or not the looming item was fixated. Second, when a looming item was fixated, the effect on RT was generally additive in nature. That is, the effect of a looming item fixation was primarily an increase in overall RT but not a change in the pattern of differences in looming conditions. Critically, there was no interaction between the fixation and looming conditions, which indicates that the present benefit and costs occur independently of an overt shift of attention (although there was some trend toward significance, it seems reasonable that any differential change in RT would be quite small). Finally, RT benefits and costs were similar for both apparent and smooth motion. Combined, these data suggest that (1) attention capture effects associated with looming motion are largely covert in nature and (2) that attention capture effects associated with looming motion are likely related to motion itself and not the onset of motion.[1]

Experiment 2

Participants in Experiment 1 located the target most quickly when the target item loomed and most slowly when a distractor item loomed, relative to a control condition in which all items were static. Critically, this pattern of data was consistent regardless of whether or not a looming display item was fixated and whether item motion was apparent or smooth. This finding was somewhat surprising given that a number of studies have suggested that stimulus onsets might retain a sort of processing prioritization in the context of eye movements (Boot et al., 2005; Wu & Remington, 2003; but see Ludwig et al., 2008 for an alternative account). These findings provide converging evidence with similar work conducted by Lin and colleagues indicating that looming objects capture attention (Lin et al., 2008). Furthermore, our analyses of eye movements suggest that oculomotor capture and attention capture (as characterized by RT differences) are mutually exclusive of each other in the case of looming motion. Interestingly, to the extent that apparent

[1] To further evaluate whether these effects were related to looming object motion or properties of the search array we also conducted an identical analysis for trials where the looming item was not fixated compared to trials where it was fixated within the first 250 ms of the trial (motion occurred during the first 180 ms of a trial), with nearly identical results. Participants took longer to respond when distractors loomed compared to when targets loomed ($F(1, 20) = 23.92$, $p < .001$, *partial* $\eta^2 = 0.545$), and there was no interaction between looming item type (target/distractor) and fixation (whether the critical sphere was fixated in the first 250 ms of the trial) ($F(1, 20) = .61$, $p = .162$, *partial* $\eta 2 = 0.096$), indicating that the effect of looming motion occurred independently of whether the looming item was fixated.

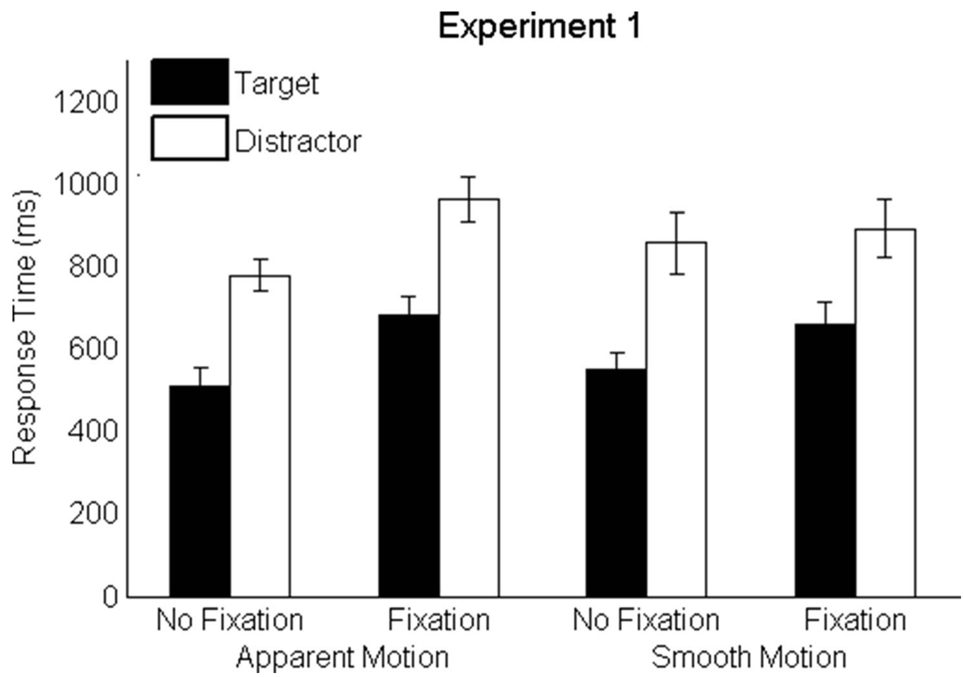

Fig. 5 Response times as a function of object fixation and looming conditions for easy targets for apparent and smooth motion for Experiment 1

motion might be operationalized as a series of successive onsets, we found little to no support for the notion that attention capture for looming motion is related to the onset of motion, as opposed to motion itself (Abrams & Christ, 2003, 2005).

There is some reason for caution, however, when interpreting the data from Experiment 1. Though participants displayed similar RT differences regardless of whether or not they fixated a looming item, it is worth considering the possibility that this data pattern may have been associated with the nature of our experimental task, as opposed to attention capture itself. More specifically, the discrimination task that participants were asked to perform in Experiment 1 was rather easy. Close inspection of Fig. 4 indicates that while participants did make eye movements to looming items, the proportion of eye movements to looming items was somewhat low overall, particularly in the case of looming distractors (~28 % of trials for apparent motion and ~64 % of trials for smooth motion). Although participants made more eye movements to looming targets, many of those eye movements were likely associated with target verification processes and not a result of oculomotor capture; during search observers typically fixate the target before pressing the button to confirm their choice.[2] In fact, it is somewhat surprising that participants did not fixate the looming target *more* often than they did, particularly in the apparent motion trials where looming targets were only fixated on ~67 % of trials. Combined, these data suggest that participants may have been able to resolve the search items in our task in a peripheral manner, making eye movements to the looming or static targets unnecessary. Although this possibility does not necessarily invalidate the general findings that looming motion induces RT benefits and costs consistent with the classical literature on attention capture, it does call into question our eye movement-related findings in Experiment 1, and by extension, our assertion that attention capture for looming motion is associated with covert attentional processes, but not overt attentional processes. To rule out the possibility that the data in Experiment 1 were confounded with the possibility that participants may have been able to complete the search task using peripheral vision only, in Experiment 2 we had participants complete an identical search task, with the caveat that the target discrimination task was made more difficult. If the findings in Experiment 2 are consistent with those from Experiment 1, then it would provide converging evidence that attention capture effects for looming motion are not predicated on eye movements to the looming items themselves.

Methods

Participants

Twenty-five participants from the University of Central Florida's undergraduate research pool participated in Experiment 2 (16 females, M age = 20.32, SD = 3.30).

[2] An analysis isolating eye movements most likely to be associated with looming motion (within the first 250 ms of each trial) supported this interpretation. Specifically, participants were equally likely to fixate a looming target or distractor on saccades made within the first 250 ms of each trial ($F(1, 23) = 2.87$, $p = .104$, *partial* $\eta^2 = 0.111$). Thus, the overall difference between looming target and distractor fixations was likely driven by search-related processes.

Participants were required to have normal or corrected normal visual acuity and full-color vision. In exchange for 1 hour of participation, they received course credit.

Design and Procedure

The design and procedure in Experiment 2 were identical to Experiment 1, with one exception. In order to create a more difficult search task, the target sphere was deformed by only 8 % to produce an oval in Experiment 2, as opposed to 17 % in Experiment 1. The result of this attenuated deformation was an oval target that was more similar to the sphere distractors compared with oval targets in Experiment 1.

Results and Discussion

Accuracy

Accuracy was generally high. Three participants were removed from the subsequent analyses due to accuracies greater than two standard deviations below the mean (M = 96.78, SD = 2.21). No differences were found for accuracy across the looming conditions ($F(2, 40) = 1.55$, $p = 0.225$, *partial* $\eta^2 = 0.072$) or as a function of motion type ($F(1, 20) = 2.50$, $p = 0.130$, *partial* $\eta^2 = 0.111$).

Response Times

RTs for Experiment 2 are displayed in Fig. 3. ANOVA indicated a significant main effect of looming type ($F(2, 40) = 294.99$, $p < 0.001$, *partial* $\eta^2 = 0.937$) but no significant effect for motion type ($F(1, 20) = 0.01$, $p = 0.918$, *partial* $\eta^2 = 0.015$) or the interaction of looming and motion type ($F(2, 40) = 2.44$, $p = 0.100$, *partial* $\eta^2 = 0.109$). Consistent with Experiment 1, there was an RT benefit for looming targets compared to the static control (apparent 270.23 ms, $p < 0.001$; smooth 327.62 ms $p < 0.001$), as well as a cost for looming distractors (apparent 89.20 ms $p = 0.003$; smooth 102.9 ms, $p < 0.001$). Overall, these data patterns are consistent with those observed in Experiment 1, even with the implementation of a more difficult discrimination task.

Fixations to Looming Objects

The proportion of trials in which a looming object was fixated in Experiment 2 is shown in Fig. 4. Similar to Experiment 1, we found a significant main effect of looming type ($F(1, 20) = 73.29$, $p < 0.001$, *partial* $\eta^2 = 0.786$), reflecting the fact that participants fixated looming targets more often than looming distractors. There also was a main effect of motion type ($F(1, 20) = 4.90$, $p < 0.05$, *partial* $\eta^2 = 0.197$), reflecting the fact that participants were more likely to fixate a looming object when motion was smooth compared with when it was apparent. There was no interaction between looming type and motion type ($F(1, 20) = 1.43$, $p = 0.246$, *partial* $\eta^2 = 0.067$).

Response Times as a Function of Fixation

RTs as a function of looming condition, motion type and fixation are displayed in Fig. 6 and varied as a function of fixation ($F(1, 20) = 11.85$, $p < 0.005$, *partial* $\eta^2 = 0.372$) and looming condition ($F(1, 20) = 183.25$, $p < 0.001$, *partial* $\eta^2 = 0.902$). All pairwise comparisons between looming conditions were significant ($ps < 0.001$), indicating that RTs were faster for looming targets compared with looming distractors in all cases. The interaction of fixation and looming condition also was significant ($F(1, 20) = 5.36$, $p < 0.05$). Fixations to looming items induced a general increase in RTs (~170 ms) and, not surprisingly, this increase was larger when distractors were fixated compared with targets. There was no main effect of motion type ($F(1, 20) = 0.39$, $p = 0.846$, *partial* $\eta^2 = 0.002$), no significant interaction between looming and motion ($F(1, 20) = .346$, $p = 0.563$, *partial* $\eta^2 = 0.017$), and no interaction for fixation, looming, and motion ($F(1, 20) = 3.64$, $p = 0.071$, *partial* $\eta^2 = 0.154$), but there was a significant interaction between motion type and fixation ($F(1, 20) = 4.88$, $p < 0.05$, *partial* $\eta^2 = 0.196$). Critically, and consistent with Experiment 1, we found strong evidence that RT benefits and costs associated with looming motion occur regardless of whether or not a looming display item was fixated.

Experiment 3

In Experiments 1 and 2, we maintained a balanced number of trials between the three looming conditions so that we could evaluate search differences against a no movement control condition. However, to characterize attention capture accurately a given target must be no more likely to be associated with a given display characteristic (in this case, looming motion) than any other item in a display. To address the possibility that trial balance may have influenced the results of our first two experiments, in Experiment 3 we replicated Experiment 2; however, in this case the target only loomed on 1/6 of the trials.

Methods

Participants

Fourteen participants from the University of Central Florida's undergraduate research pool participated in Experiment 3 (9 females, M age = 19.21, SD = 1.58). Participants were required to have normal or corrected normal visual acuity and full-color vision. In exchange for 1 hour of participation, they received course credit.

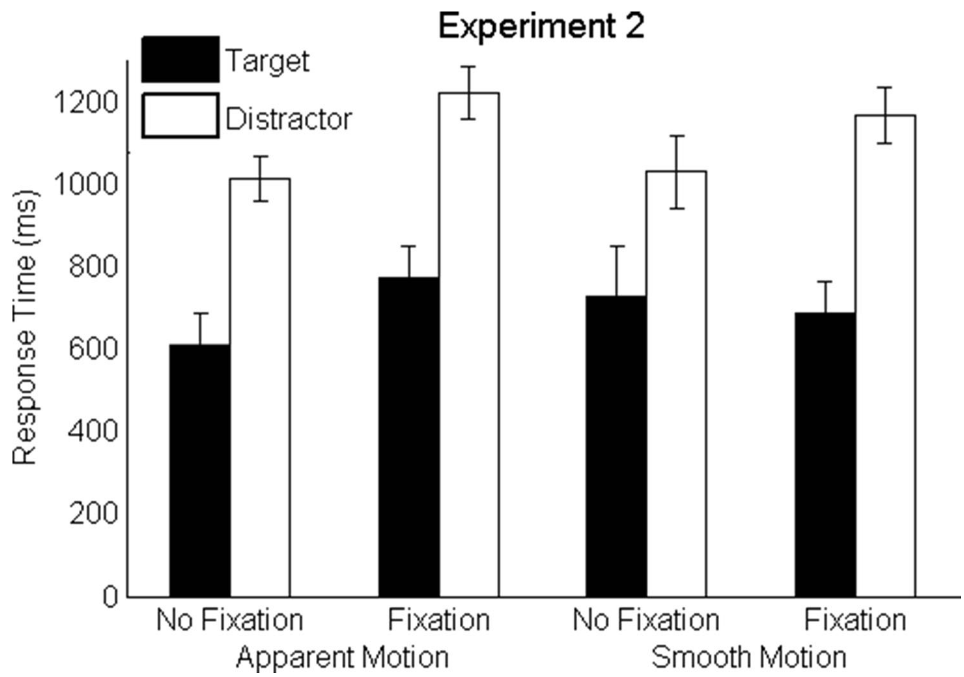

Fig. 6 Response times as a function of object fixation and looming conditions for difficult targets for apparent and smooth motion for Experiment 2

Design and Procedure

The design and procedure in Experiment 3 were similar to Experiment 2, except that the target only occurred in the same location as the looming object on 16.67 % (chance level based on 6 objects). Additionally, given the general absence of motion type effects (apparent vs. smooth) on RTs in Experiments 1 and 2, only apparent motion was used for Experiment 3. Each participant completed 455 experimental trials over 7 blocks (65 trials each); experimental conditions were balanced within each block.

Results and Discussion

Accuracy

Accuracy was generally high ($M = 92.61$, $SD = 12.21$). One participant, who responded at roughly change level, was removed from the subsequent analyses due to accuracies greater than two standard deviations below the mean. No differences were found for accuracy across the looming conditions ($F(2, 24) = 0.12$, $p = 0.792$, *partial* $\eta^2 = 0.010$).

Response Times

RTs for Experiment 3 are displayed in Fig. 7. ANOVA indicated a significant main effect of looming type ($F(2, 24) = 53.22$, $p < 0.001$, *partial* $\eta^2 = 0.861$). Similar to Experiments 1 and 2, there was an RT benefit for looming targets compared to the static control (143.19 ms, $p < 0.001$), as well as a cost for looming distractors (41.48 ms, $p = 0.001$). We replicated the search costs and benefits while minimizing the relationship between motion and target location.

Fixations to Looming Objects

The proportion of trials in which a looming object was fixated in Experiment 3 is shown in Fig. 8. Similar to Experiments 1

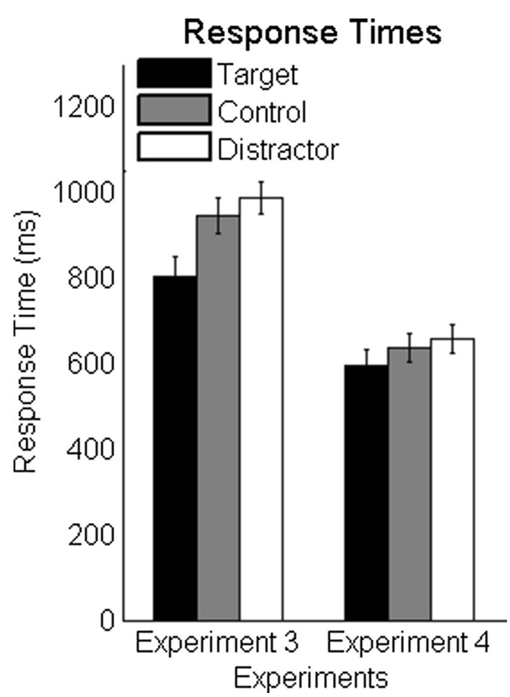

Fig. 7 Response times as a function of experimental conditions for both Experiments 3 and 4

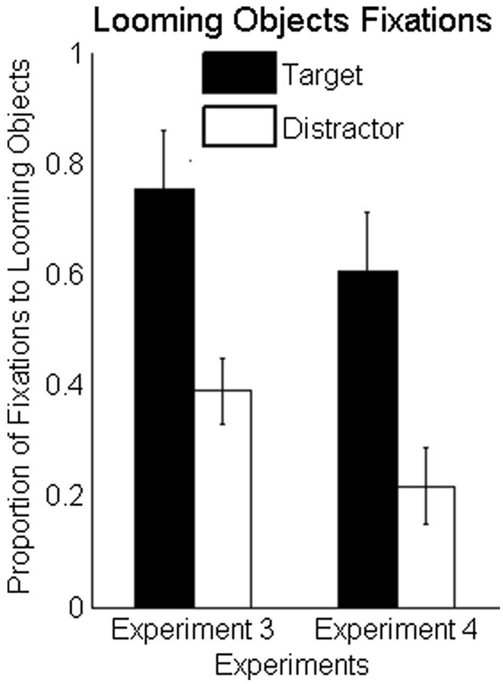

Fig. 8 Looming object fixations as a function of looming experimental conditions for Experiments 3 and 4

and 2, we found a significant main effect of looming type ($F(1, 12) = 37.09$, $p < 0.001$, *partial* $\eta^2 = 0.756$) reflecting the fact that participants fixated looming targets more often than looming distractors.

Response Times as a Function of Fixation

Four participants who always fixated the looming target were omitted from this analysis. RTs as a function of looming condition and fixation are displayed in Fig. 9 and varied as a function of fixation ($F(1, 8) = 8.41$, $p = 0.020$, *partial* $\eta^2 = 0.512$) and looming condition ($F(1, 8) = 28.96$, $p = 0.001$, *partial* $\eta^2 = 0.784$). The interaction of fixation and looming condition was marginally significant ($F(1, 8) = 4.99$, $p = 0.056$, *partial* $\eta^2 = 0.384$). Looming item fixations induced an increase in RTs (~186 ms) and this cost was larger when distractors were fixated compared to targets.

Experiment 4

Reducing the likelihood that a target item would appear at a looming object location in Experiment 3 to chance levels produced a pattern of data that was consistent with those observed in Experiments 1 and 2, providing further the assertion that looming motion induces attention capture. However, it remains possible that participants in our task were not responding to motion per say but to the fact that motion in our task represented a sort of featural singleton. In Experiment 4, we addressed this possibility by having participants search for a red oriented oval (amongst grayscale distractor ovals) in every trial. Thus, participants were able to prioritize a "red singleton" over a "motion singleton." Under these conditions, data consistent with our previous findings would provide strong support for the notion that looming motion does indeed capture attention, even when a participant's attentional set can be restricted to color information.

Methods

Participants

Thirteen participants from the University of Central Florida's undergraduate research pool participated in Experiment 4 (7 females, *M* age = 19.53, *SD* = 2.62). Participants were required to have normal or corrected normal visual acuity and full-color vision. In exchange for 1 hour of participation, they received course credit.

Design and Procedure

The design and procedure in Experiment 4 were similar to Experiment 3, except that the target sphere in every trial was colored red (RGB 255,0,0). Participants still responded to the orientation of the target sphere. Nontarget spheres were identical to those from the previous experiments.

Results and Discussion

Accuracy

One participant was removed from the subsequent analyses due to accuracies greater than two standard deviations below the mean. Overall, accuracies were high ($M = 94.43$, $SD = 4.20$) with no differences across the looming conditions ($F(2, 22) = 0.02$, $p = 0.985$, *partial* $\eta^2 = 0.001$).

Response Times

RTs for Experiment 4 are displayed in Fig. 7. ANOVA indicated a significant main effect of looming type ($F(2, 22) = 34.38$, $p < 0.001$, *partial* $\eta^2 = 0.758$). As seen in the previous experiments, there was an RT benefit for looming targets compared to the static control (42.22 ms, $p = 0.002$), as well as a cost for looming distractors (19.73 ms, $p = 0.025$). Overall, the pattern of data was consistent with those from the previous studies, despite the fact that participants were able to restrict their search to the red item.

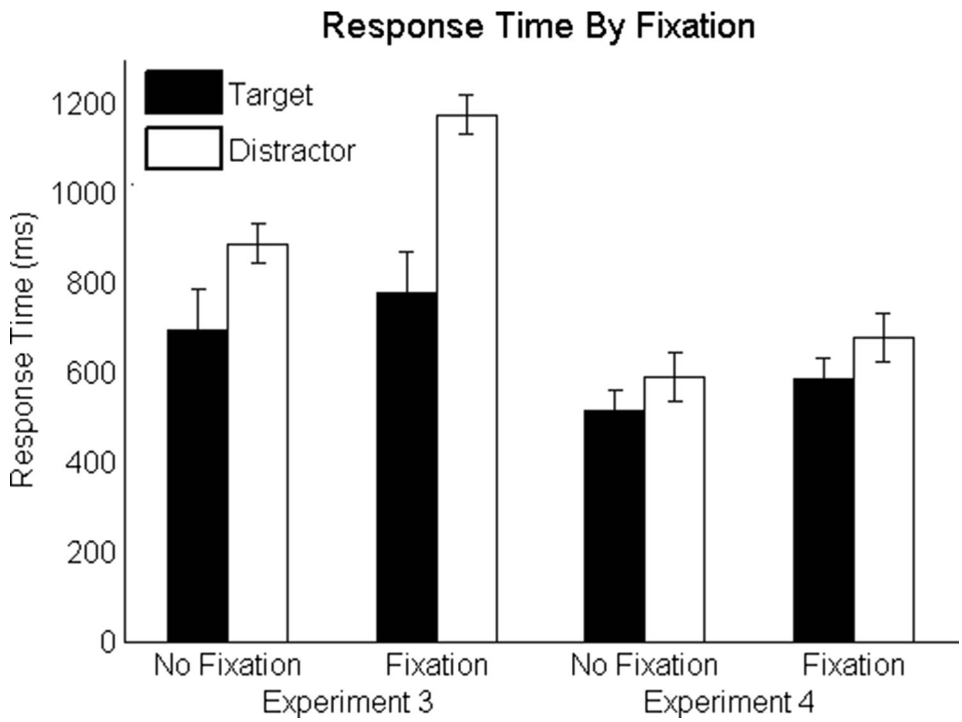

Fig. 9 Response times as a function of object fixation and looming conditions for both Experiment 3 and Experiment 4

Fixations to Looming Objects

The proportion of trials in which a looming object was fixated in Experiment 4 is shown in Fig. 8. We found a significant main effect of looming type ($F(1, 11) = 222.395$, $p < 0.001$, *partial* $\eta^2 = 0.953$); as seen in all previous experiments, participants fixated looming targets more often than looming distractors.

Response Times as a Function of Fixation

Because some participants always fixated on the looming target, five were removed from this analysis due to missing values. RTs as a function of looming condition and fixation are displayed in Fig. 9. There was a main effect of fixation ($F(1, 6) = 5.99$, $p = 0.050$, *partial* $\eta^2 = 0.500$) and looming condition ($F(1, 6) = 8.77$, $p = 0.025$, *partial* $\eta^2 = 0.594$). There was no interaction of fixation and looming condition ($F(1, 5) = 0.66$, $p = 0.663$, *partial* $\eta^2 = 0.034$).

General Discussion

Our goals in the current study were (1) to further elaborate on the claim that looming motion captures attention, (2) to assess whether attention capture associated with looming motion was closely coupled with oculomotor attention shifts, and (3) to further investigate whether previous motion-based attention capture arises from motion itself or the onset of motion. Overall, we replicated the findings of Lin and colleagues (2008), suggesting that looming motion elicits processing priority; when distractors appeared as looming toward the observer there were RT costs and when targets appeared as looming toward the observer there were RT benefits compared with trials with no looming motion. These RT patterns were preserved when we controlled for target-looming stimulus mapping contingencies (Experiment 3) and when the target was associated with a unique color (Experiment 4). These patterns are consistent with a number of studies demonstrating attention capture effects for various types of stimulus properties (Schreij, Theeuwes, & Olivers, 2010; Theeuwes et al., 1998).

Additionally, while we expected to find evidence for a close coupling between overt attentional mechanisms (i.e., eye movements) and attention capture effects given prior research (Boot, Kramer, & Peterson, 2005; Ludwig et al., 2008; Theeuwes et al., 1998), our data, somewhat surprisingly, did not support this expectation. Instead, we observed RT benefits and costs regardless of whether or not a looming item was fixated during a given trial or within the first 250 ms of trial. Importantly, this effect remained consistent when the target discrimination task was made more difficult, making it unlikely that the data pattern was an artifact of easily discriminable search items that could be resolved peripherally without the need for fixation. Although participants did fixate looming items more frequently when the target was harder to discriminate (Fig. 4), RT differences were still observed regardless of whether or not such fixations occurred (Fig. 5). Overall, our data suggest that attention capture effects associated with looming motion are more closely tied to covert attention mechanisms rather than overt attention mechanisms.

Our third goal was to investigate whether attention capture for looming motion was associated with the motion itself or the onset used to create motion (Abrams & Christ, 2003; Hillstrom & Yantis, 1994). To do so, we manipulated motion type (apparent and smooth) in Experiments 1 and 2. Given that apparent motion might be perceived more so as a series of onsets compared to smooth motion, we expected that if motion onset was the primary factor underlying looming motion attention capture effects, RT benefits and costs of looming motion would be largest in that condition compared to when motion was smooth. However, we found no evidence consistent with this prediction. RT costs and benefits were generally comparable across motion types. We note that our assertions in this regard should be considered somewhat speculatively, as a distinction could be drawn between a motion onset and the types of stimulus changes that occur during apparent motion. Interestingly, it has been previously proposed that attention capture effects associated with motion might have an ecological basis. The Behavioral Urgency Hypothesis (Franconeri & Simons, 2003; Lin et al., 2008) suggests that as motion stimulus properties become more realistic they demand higher processing priority, because they might be perceived as a stronger cue toward a potential threat. In our study, this hypothesis would predict that RT benefits and costs might actually be more robust when motion was smooth compared with when it was apparent, because smooth motion is more consistent with what is encountered in the real world. Again, our RT data did not support this account. However, it is worth noting that participants did fixate looming items more frequently when motion was smooth compared with when it was apparent, but these increased fixations did not induce a corresponding increase in RT benefits and costs. Further research characterizing motion-based attention capture effects in the context of different types of motion might produce some interesting findings.

Broadly, our findings are consistent with recent investigations of attentional orienting showing the humans are sensitive to looming stimuli. Evidence for such responses has been reported in the context of both traditional laboratory tasks involving simple stimuli (Lin, Franconerri, & Enns, 2008) and those involving natural environments and more complex action plans, such as when orienting to fellow pedestrians on looming trajectories while walking (Jovancevic-Misic & Hayhoe, 2009). In the latter, responses often were associated with a fixation directly to the looming pedestrians. We showed that although looming stimuli might often be fixated in real-world contexts, *attentional* orienting toward such stimuli is not necessarily dependent on *oculomotor* orienting, at least when the breadth of the visual field is limited, as is the case when viewing stimuli on a computer screen. These findings are not irreconcilable with the trove of behavioral data indicating that covert and overt attentional orienting mechanisms are tightly coupled (Deubel & Schneider, 1996; Henderson, Pollatsek, & Rayner, 1989; Irwin & Gordon, 1998; Rayner, McConkie, & Ehrlich, 1978) and perhaps even subserved by highly overlapping neuronal populations and circuitry (de Haan, Morgan, & Rorden, 2008; see Corbetta, 1998, for a review). Rather, we provide complimentary evidence that despite this strong linkage, covert and overt mechanisms can in fact be decoupled in the context of attention capture. This is consistent with other findings in the attention capture literature indicating that while covert attention is often highly sensitive to exogenous cues (Yantis & Jonides, 1984), involuntary eye movements toward such cues are less ubiquitous (Irwin, Colcombe, Kramer, & Hahn, 2000; Kramer et al., 2001). This raises the question of whether eye movements made toward looming stimuli in real-world contexts, such as orienting toward other pedestrians on a collision course while walking, is reflective of attention capture associated with looming motion, or instead is associated with normal resampling of visual information across a large visual field for reasons unrelated to attention capture. Future research will explore this possibility.

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