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Attentional capture from looming alters perception

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ABSTRACT

Studies suggest looming motion represents a special class of attentional capture stimulus due to behavioural urgency: the need to act upon objects moving toward us in an environment. In particular, one theory suggests that faster reaction times to targets cued by looming relative to receding motion are driven by post-attentional, motor-priming processes beyond the attentional capture effects seen with other stimulus qualities such as colour pop-out. The present study tested this theory using a relative size judgment task where targets were pre-cued by looming and receding optic flow fields. Results show systematic increases in the perceived size of targets that were cued by looming flow fields, consistent with previous attentional capture studies using onset cues. These results challenge theories attributing behavioural changes from looming motion to motor-priming alone.

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Looming motion; attentional capture; behavioral urgency; relative size judgments; perceptual distortion

Looming movement patterns are thought to represent a specific class of stimulus that derives its salience due to being behaviourally urgent, or likely to require immediate action from an observer (Franconeri & Simons, 2003). This contrasts with other salient characteristics such as colour pop-out or rapid onsets/offsets that may also capture exogenous attention but do not necessarily indicate the need for immediate action. One recent theory suggests that observed behavioural effects (i.e., faster correct reaction times) due to cueing by looming motion result from post-attentional mediation by the motor system (Skarratt et al., 2009, 2014). Previous target discrimination studies that compared looming, receding and static pre-cues over multiple display sizes showed equivalent slopes across set size for looming and receding stimuli and much larger slopes for static stimuli, though looming targets had consistently faster reaction times (RT) overall compared to receding targets. These results were interpreted as showing that both looming and receding motion capture attention but looming stimuli represent a special class of exogenous cue that primes the motor system – leading to faster overall RTs across set size. However, the vast majority of studies to date that examine attentional capture from looming or receding stimuli use speeded discrimination tasks assessing RT and discrimination accuracy to measure the strength of an attentional capture effect (Abrams & Christ, 2003; Lewis & Neider, 2015; Lin et al., 2008; Moher et al., 2015; Rossini, 2014). These are limited by a reliance on speeded motor responses which do not isolate perceptual effects. Thus, more evidence is needed to determine whether a separate mechanism exists that primes motor responses for behaviourally urgent stimuli or if these stimuli simply take precedence over (or “outrank”) other stimuli competing for attentional priority.

While RT and accuracy are the most utilized measurements of attentional capture within the broader literature (Yantis & Jonides, 1984), rapid shifts in exogenous attention can systematically alter participants’ perception of target stimuli, including resolution, contrast, shape and location (Anton-Erxleben & Carrasco, 2013; Fortenbaugh et al., 2011; Pratt & Arnott, 2008). Previous studies have shown that attentional capture leads to transient increases in the perceived size of objects subsequently presented at the cued location (Anton-Erxleben & Carrasco, 2013; Fortenbaugh et al., 2019). While the impact of attentional capture from looming motion on RT is clear, testing this form of attentional capture using paradigms such as a relative size

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judgments task that minimizes reliance on motor response speed represents a novel focus that could help elucidate the basis of this process.

Looming patterns such as optic flow fields have traditionally been used to simulate movement toward a participant in studies looking at orientation, navigation, and wayfinding (Warren et al., 2001). Optic flow patterns have been shown to elicit robust attentional capture effects (Wang et al., 2012) and have also demonstrated the looming advantage when looming and receding flow fields are presented simultaneously (Rossini, 2014). However, to our knowledge, only experiment 4 of von Mühlenen and Lleras (2007) has assessed the impact of optic flow fields on size judgments of attentional capture. Squares presented within looming flow fields were perceived as larger than squares presented within equal regions of random motion, but experimenters suggested that the distortion was not large enough to drive RT results. Since dot motion patterns continued through target presentation, apparent size distortions were attributed to a context-related illusion similar to the Ponzo Illusion while the RT effects observed in the other experiments were driven by attentional orienting. However, the use of motion patterns throughout each trial did not allow the dissociation of context-driven distortions in perceived size from those driven by attentional orienting. It therefore remains unknown whether looming optic flow fields lead to perceptual changes in the perception of target shapes.

Analyzing perceptual measures of attentional capture should yield important information because the motor priming interpretation of behavioural urgency is not easily reconciled with single cell recording studies that have shown changes in receptive field properties in extrastriate cortex following shifts of spatial attention (Connor et al., 1997; David et al., 2008; Womelsdorf et al., 2006). These electrophysiological studies suggest that attentional capture should alter not only the speed and accuracy of visual information processing (leading to motor priming), but also the representation of visual stimuli. This is consistent with perceptual changes in stimulus size, luminance, and resolution that have been previously observed (Anton-Erxleben & Carrasco, 2013; Fortenbaugh et al., 2011, 2019; Suzuki & Cavanagh, 1997). If the looming advantage is driven by attentional precedence over other exogenous cues rather than a unique motor priming mechanism, then similar perceptual changes should be observable even when looming motion patterns are competing with simultaneous receding motion patterns. The present study was therefore designed to test whether looming, "behaviorally urgent," optic flow fields lead to increases in the perceived size of subsequently presented squares relative to receding flow fields using a relative size judgment task.

Methods

Participants

Twenty naïve college undergraduates (15 females, mean age = 22.1 ± 1.84 years) participated in this experiment. Participants took the Freiburg Visual Acuity & Contrast Test (Bach, 1996) and passed for normal or corrected-to-normal acuity. This research was approved by the VA Boston Healthcare Internal Review Board and followed the tenets of the Declaration of Helsinki. All participants provided signed informed consent before the study began and were compensated $15/hr for their time.

Materials and Procedure

The experiment was conducted on a 15″ Macbook Pro (1440 × 900 screen resolution) with stimuli created using Matlab (Mathworks, Natick, MA) and the Psychtoolbox extensions (Brainard, 1997). Participants were seated at a viewing distance of 50 cm from the screen.

Figure 1 shows an example of a trial sequence. Trials began with a white fixation dot (0.30° diameter) at the centre of the screen against a black background for 1,000 ms. The flow field stimuli were then shown for 300 ms. These consisted of 1,000 white dots (0.05° width) presented within annulus apertures (outer diameter = 5.0°, inner diameter = 0.15°) centred 10° to the left and right of fixation. In the static condition, dots remained in their initial position throughout the 300 ms duration. During the coherent motion trials, the dots moved radially within the aperture to create expanding/looming or contracting/receding flow fields. Coherent motion trials included one expanding and one receding flow field on opposite sides of the display. Dot speed was 4 degrees/second with dots moving outside the aperture

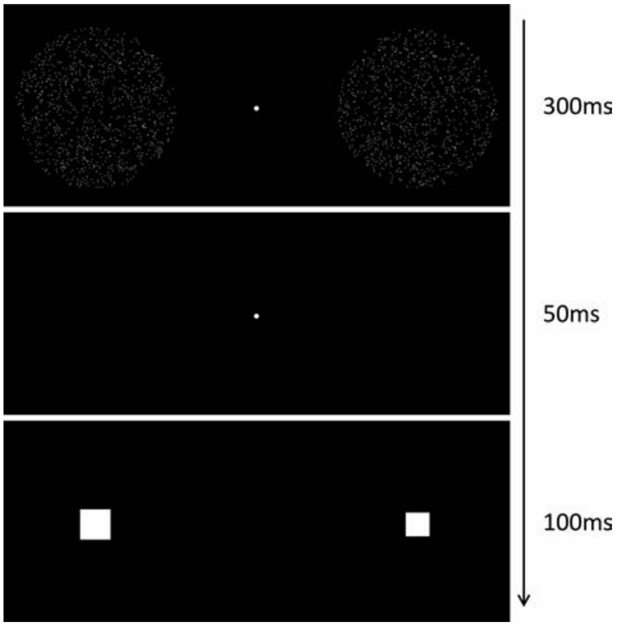

Figure 1. *Experimental trial displays and durations*. Dots expanded from or collapsed to the centre of the circle on coherent motion trials.

edges replaced by a new dot at a randomly chosen location inside the aperture. After a 50 ms inter-stimulus interval, two white squares, centred 10° to the left and right of fixation were presented for 100 ms. The standard square had a fixed size of 1.5° × 1.5°. The comparison square was one of seven sizes: 0.70°, 1.0°, 1.3°, 1.5°, 1.7°, 1.9°, and 2.3°. On half of the trials the comparison square appeared on the left side of the display and on the other half it appeared on the right side of the display. A blank screen was then presented and participants were instructed to hit the left or right arrow key to indicate their response. In one block of trials participants indicated which rectangle appeared larger and in the other block of trials they indicated which rectangle appeared smaller. Both response types were included to control for any response biases that might occur in the case of uncertainty. Block order (larger/smaller) was alternated across participants. Across the 3 flow field types (expansion on left, expansion on right, static) × 2 comparison sides (left, right) × 7 comparison sizes, each of the 42 conditions was repeated 10 times within a block for a total of 420 trials/block. Across the two response conditions (larger/smaller) a total of 840 trials were completed. Two breaks were provided within each block. Prior to beginning each block, participants completed 10 practice trials to familiarize them with the task and response type. During practice, incorrect responses were followed by a 500 ms tone.

Results

Since response type was not of primary interest in the current study and preliminary analyses showed no main effect or interaction when response type was included as a factor, unselected targets for the "smaller" block were rescored as "larger" discriminations so averages could be calculated across blocks. Data were also coded to indicate the relative position of the flow field to the comparison rectangle side. This yielded three main flow field conditions for analyses: when the comparison square was preceded by the expanding flow field, a static flow field, or the contracting flow field for each of the 7 comparison sizes. The proportion of trials the comparison was judged to be larger was calculated across the 40 repeats in each of the 21 conditions (3 Flow Field × 7 Comparison Sizes). Cumulative Gaussian functions were fit to the data for each of the 3 flow field conditions as a function of comparison size to determine the point of subjective equality (PSE), or how large the comparison square needed to be in each condition to be perceived as equivalent to the size of the standard rectangle (Figure 2(a)).

A repeated measures ANOVA calculated on the PSE measurements showed a strong effect of Flow Field condition: $F(1.4,26.4) = 20.81$, $p < 0.001$, $\eta_p^2 = 0.523$, using Greenhouse-Geisler correction for violations of sphericity (Figure 2(b)). Bonferroni corrected post-hoc comparisons showed significant pairwise differences in PSEs across all levels ($p \leq 0.006$ for all). As seen in Figure 2, comparison rectangles had a smaller PSE when preceded by looming motion relative to both the static and receding flow field conditions. This is consistent with looming motion increasing the perceived size of the comparison square as increases in perceived size would lead to decreases in the physical size of the comparison square that was required to make it appear the same size as the standard square. Importantly the opposite pattern was observed when the comparison square was preceded by the receding flow field, with larger PSE values compared to the static condition, indicating a relative reduction in perceived size. Both the group-level cumulative Gaussian fits and the PSE measurements show monotonic shifts in the

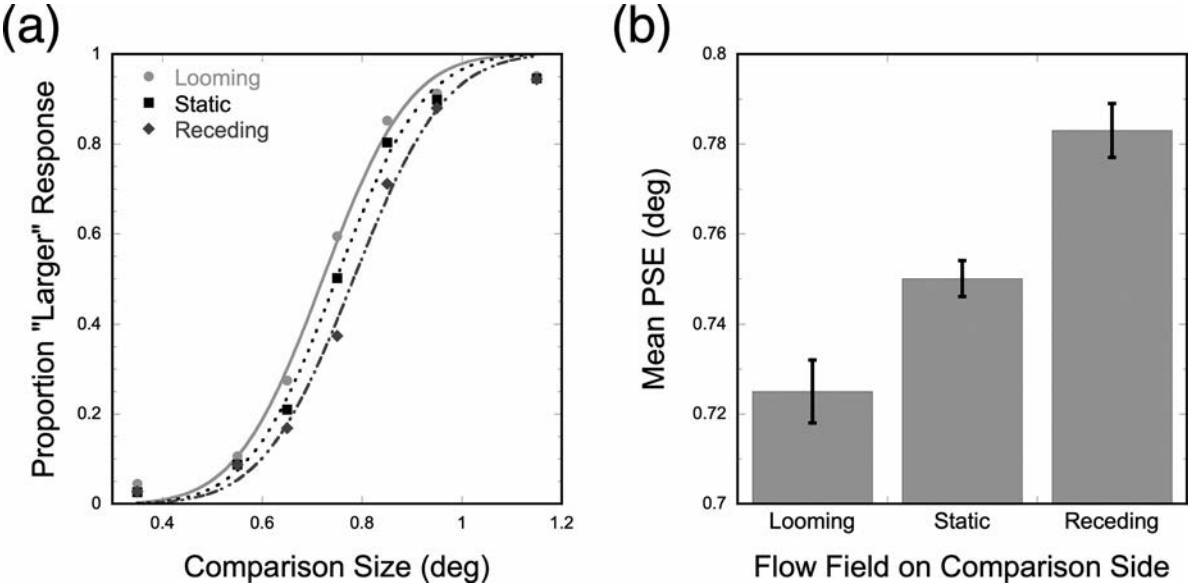

Figure 2. *Perceived size of target squares across flow field conditions*. (a) Mean proportion of time participants responded that the comparison square was larger than the standard square for the seven comparison sizes when it was preceded by looming, static, or receding flow fields. Group means are fit with a cumulative Gaussian function. (b) Bar graph showing the mean point of subjective equality (PSE) as a function of flow field condition. Error bars show ±1 SEM.

perceived size of comparison squares following looming, static, and receding flow fields. This indicates that looming optic flow fields led to systematic increases in the perceived size of the squares presented on the same side of the display relative to when the same size square was presented on the opposite side with the receding optic flow field.

Discussion

To date, questions have remained regarding potential perceptual consequences of attentional orienting due to looming stimuli. To control for the depth cues thought to drive the size distortion seen in experiment 4 of von Mühlenen and Lleras (2007), flow fields in this study were only presented prior to the onset of the target stimuli as perceptual distortions cease when the context is removed in size illusions such as the Ponzo and Ebbinghaus. Even when the flow fields are removed prior to target onset, comparison squares are seen as larger when they follow expanding flow fields relative to contracting flow fields. This supports an attentional capture preference toward looming motion relative to receding motion using a perceptual measure that indicates attentional mediation outside of the motor system.

Consistent with a growing body of literature that attentional orienting not only alters motor responses but perception as well (Anton-Erxleben & Carrasco, 2013; Fortenbaugh et al., 2011; Suzuki & Cavanagh, 1997), we view the size distortions not as independent but mechanistically linked to the motor priming response displayed by Skarratt et al. (2009, 2014). These results showed equivalent and relatively flat slopes as a function of set size for targets preceded by looming and receding placeholders. This was interpreted as evidence that both looming and receding capture attention (i.e., flat slopes) and against an attention-based explanation of the overall faster RTs for looming targets. We postulate that this RT pattern is due to how set size was manipulated. Specifically, using one looming and one receding placeholder along with a variable number of static placeholders could create an inherent attentional capture hierarchy across set size. If the only looming stimulus has the highest behavioural urgency, attention may be first biased toward the looming space by the time of target onset. As there was always one looming placeholder, the observed looming RT advantage may be a strong but otherwise typical attentional capture effect. As receding motion is not incoming but still presents higher behavioural urgency than a static stimulus, this would form a strong 1–2 hierarchy relative to the static placeholders. This behavioural urgency hierarchy becomes prevalent when set sizes grow as additional items will only consist of static placeholders. Since cue-induced perceptual distortions have been attributed to shifts in attentional focus towards cued locations (Fortenbaugh et al., 2019; Suzuki & Cavanagh, 1997), the theoretical framework in which attention is first directed preferentially toward looming stimuli when both looming and receding motions are in a given display is consistent with the observed bias in perceived size seen in the present study.

Using looming and receding lateralized flow fields, Rossini (2014) also found faster target discrimination within looming flow fields than receding flow fields as well as the capacity for receding flows to capture attention. While these results are consistent with the RT effects from Skarratt et al. (2014), Rossini (2014) also acknowledged that by only assessing RTs in this study, it is not possible to determine if the observed looming advantage was due to perceptual processes or motor priming.

The motor effects observed in these previous studies, in conjunction with the perceptual distortions in the present study, are consistent with cueing effects that have been found in the broader attentional capture literature (Fortenbaugh et al., 2019; Pratt & Arnott, 2008; Suzuki & Cavanagh, 1997). However, post-attentional motor-priming alone cannot account for both the RT and perceptual effects that have been measured. The current results support that looming does more than just prime the motor system – it can temporarily alter the perceived structure of objects.

The relationship between perceptual and motor responses is evolutionarily important for survival, as coordination between a behaviourally urgent sensory stimulus and motor priming can be the difference between readiness and helplessness in a life-threatening event such as seeing and avoiding a dangerous, looming projectile. If the mechanism of attentional capture bridges perceptual and motor processes, there should not be an "either/or" question between whether an attentional capture is motor or perceptual in nature because it is both. This contrasts with some models of attention including signal enhancement and/or noise reduction (Dosher & Lu, 2000) that could increase the efficiency of visual information processing, leading to benefits in response speed and accuracy on discrimination tasks without necessarily altering perceptual qualities of target stimulus representations. However, studies have documented systematic changes in perceptual representations as a function of attentional state (Anton-Erxleben & Carrasco, 2013), and single-cell recording studies have demonstrated not only tuning mechanisms among neurons in the extrastriate cortex (Desimone et al., 1989) but systematic shifts in receptive field centres and alterations in receptive field shapes toward the locations of attentional focus (Anton-Erxleben & Carrasco, 2013; Connor et al., 1997). This mechanism could plausibly underlie both motor priming and size distortions by effectively increasing the sampling of space around the focus of attention.

One limitation of note is that flow field presentations always included both patterns simultaneously – thus providing information about relative attentional capture strength. Characterizing the impact of looming/receding flow fields individually or against control conditions is therefore needed. For example, if receding motion alone captures attention it would be predicted that when paired with static or random motion fields, target squares following receding motion fields should appear larger than the standard. Additionally, while one study showed little impact of precue size on the magnitude of perceptual distortions in the attentional repulsion paradigm (Kosovicheva et al., 2010), other work suggests that altering the distribution of attention in exogenous cueing systematically impacts the magnitude of object size distortions (Kirsch et al., 2018). Thus, additional work varying the properties of flow field displays is needed to determine how attentional gradients relate to flow field properties and the extent to which this relationship aligns with previous studies of attentional capture on perception.

The present study shows that behaviourally urgent stimuli impact more than just response behaviour, they cue the attentional system at large including interconnected perceptual functions. This contrasts with theories that attribute the motor priming effects observed with looming versus receding motion to post-attentional processes. While behavioural urgency does have important motor-priming implications, the full effect it has on an observer is not entirely motor. These results increase the breadth and sensitivity of the attentional capture literature and offer a multidimensional look at an attentional mechanism that appears to detect, prioritize and magnify objects and events in terms of what is most likely to require immediate action.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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