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Looming motion and visual attention

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Abstract

Motion perception is essential to adapt behavior in a dynamic environment. Many studies have suggested that looming motion captures attention, whereas receding motion does not, highlighting the behavioral urgency of motion perception. The present study examined whether attentional resources can be attracted by a specific directed flow in the presence of multiple flows that are simultaneously displayed in the visual field. The results showed that when two flows of opposite direction (looming and receding) are displayed together, participants more efficiently discriminate the target inside the looming motion. When four flows are presented (one looming and three receding or three looming and one receding), the results showed that the target displayed inside the looming flow was more rapidly identified but also suggest that attention can be attracted by receding motion. This suggests that the process inside a looming flow is more efficient, but this effect could not be attributed to attentional focusing processes.
Keywords: visual attention, motion perception, flow fields, looming motion.

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Introduction

The ability to perceive motion is an important factor for immediate action and survival in the environment. Studies performed in the last 10 years have claimed that certain stimuli such as abrupt motion onset and direction can attract attention more efficiently than other characteristics (Billington, Wilkie, Field, & Wann, 2011; Shirai & Yamaguchi, 2010; Shirai, Kanazawa, & Yamaguchi, 2004b; Shirai et al., 2009; Tyll, Bonath, Schoenfeld, Heinze, Ohl, & Noesselt, 2012).

In an extensive series of experiments, Franconeri and Simons (2003, 2005) and Abrams and Christ (2003, 2005, 2006) highlighted the importance of motion direction (looming or receding) and motion onset to attract attention. Franconeri and Simons (2003) suggested that the abrupt onset of a stimulus in the visual field is not the only feature that attracts attention and emphasized that the visual process can be significantly influenced by motion direction, especially motion directions that elicit immediate adaptive behaviors (i.e., behavioral-urgency hypothesis). This interpretation is supported by a large number of studies that suggest special sensitivity in the visual system to looming motion compared with receding motion (Náñez, 1988; Takeuchi, 1997). In humans, this ability is also observed in infants during the first months of life and significantly contributes to the implementation of defensive responses (Náñez, 1988; Náñez & Yonas, 1994; Shirai, Kanazawa, & Yamaguchi, 2004a).

Recently, an interesting study was conducted by von Mühlenen and Lleras (2007) using optical flow to simulate looming or receding perception. In six experiments, the authors investigated the ability of many types of optical flows or randomly moving dots to allocate attention in the visual field. The trial began with the presentation of dots that moved randomly across the visual field. After a certain time interval, the dots from one hemifield gradually shifted to an oriented flow. The looming motion was simulated by oriented dots that moved away from the central point of expansion, whereas receding flow was generated by dots that moved in the opposite direction. The subjects were instructed to identify the target at the center of one of the two hemifields. The main idea in this procedure was to use optical flow as a spatial cue to attract attention to a specific area and improve target detection, as in the classical Posner task (Posner, Snyder, & Davidson, 1980). The results showed that when the coherent motion began abruptly, many types of motion attracted attention, but when the coherent motion became gradual, only looming motion attracted attention. These results support the behavioral-urgency hypothesis, with looming motion playing a critical role, and the notion that motion onset or the appearance of a new object in the visual field is an important factor to attract attention. More recently, Wang, Fukuchi, Koch, and Tsuchiya (2012) used optical flows in three-dimensional depth structure and found that expansive motion but not contractive motion attracted the attention resource.

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These results also support the hypothesis that a looming stimulus is processed by specialized mechanisms.

To investigate whether the looming motion advantage is mediated by attention resources or the motor system, Skarratt, Cole, and Gellatly (2009) compared the effects of objects in looming or receding motion in depth. Their experiments used arrays with binocular disparity to generate stereoscopic depth, thus creating the effects of looming and receding objects. The results showed that both looming and receding motion attracted attention and suggested that looming motion primes the motor system. In this way, looming motion improves response preparation outside the attentive stage. In a subsequent study, Skarratt, Gellatly, Cole, Pilling, and Hulleman (2014) examined the visuomotor priming to looming motion across five experiments and provided strong evidence that looming and receding motion equivalently attracts attention, but the looming motion advantage is motoric rather than perceptual.

The main objective of the present study was to investigate how attention is attracted by multiple oriented flows in the visual field. Based on the "cue effect" (Posner et al., 1980; von Mühlenen & Lleras, 2007), if attentional deployment is governed by urgency factors (behavioral-urgency hypothesis), then the looming flow would always have an advantage in attracting attentional focus compared with receding motion. On the other hand, if receding flow also mobilizes attentional focus, then this may indicate that a possible temporal processing advantage that is elicited by looming flow may occur in nonattentive stages.

EXPERIMENT 1

Experiment 1 investigated whether attention can be attracted by looming flow when two flows are simultaneously presented in the visual field. Under these conditions, the participants viewed two flows, side by side, in three possible arrays (looming/receding, looming/looming, and receding/receding).

Method

Participants

Fourteen subjects (nine females) aged 18-30 years participated in the experiment. All of the participants reported normal or corrected-to-normal visual acuity and were naive to the purpose of the study.

Apparatus and stimuli

The stimuli were presented on an LG Flatron W2253V monitor that ran at 60 Hz and was controlled by an Apple Mac Mini 2.26/ 2X 1G. The experiment was controlled by VPixx Visual Testing Software (April 2010). The background of the monitor was black (.05 cd/m²), and the optical flow and target were white (22 cd/m²). Each trial began with a red fixation dot (size 0.5º of visual angle) that was presented at the center of the display. Optical flows were composed of radial dots (.5 dots/cm² density) in linear expanded or contracted motion, thus simulating looming and receding motion, respectively. The dot consisted of a 3 × 3 white pixel that moved at a constant speed of 2 cm/s (looming) or -2 cm/s (receding). The flows were placed within an area of 28º × 14º of visual angle. The center of the expanded or contracted motion was placed at 7º to the left and right sides of the center of the display. The target was a white line (0.3º × 0.7º) that was horizontally or vertically oriented.

Procedure and design

The participants sat 57 cm away from the monitor in a dimly lit room. They were instructed to press the spacebar on the computer keyboard to initiate each trial. At the beginning of each trial, a red fixation dot was displayed at the center of the computer screen for 500 ms, followed by two directed flows that were simultaneously presented in each hemifield (flow onset). After 250 ms, the target was presented at the center of one flow and remained until a response was emitted by the participant. In half of the trial the target was shown in looming motion; in the other half the target was shown in receding motion. The task was to indicate the line orientation by pressing one of two keys on the keyboard (down arrow for a vertical target or right arrow for a horizontal target) as quickly and accurately as possible. The trial sequence is shown in Figure 1. After 10 practice trials, the participants performed 240 trials, with 30 trials per condition.

Results and discussion

Correct response times (RTs) were used to calculate the mean RT for each condition. Outliers were defined as RTs that were located more than two standard deviations above the mean condition for each participant. Response times below 100 ms were excluded from the analyses. Mean RTs are shown in Figure 2. These data were subjected to a 2 × 2 within-participant analysis of variance (ANOVA) for (1) target position: target inside single flows (looming/receding) or target inside multiple flows (looming/looming or receding/receding) and (2) motion: looming and receding. The analysis confirmed that the effect of the target position factor was not significant ($F_{1,13} = 0.22$, $p = .648$). The main motion effect was significant ($F_{1,13} = 4.9$, $p = .044$, $\eta_p^2 = .28$), with no significant interaction between factors ($F_{1,13} = 0.50$, $p = .490$). Newman-Keuls *post hoc* comparisons confirmed no differences in RTs when the target was displayed inside the single looming flow compared with the target displayed inside the single receding flow ($p = .35$). The single looming flow RT was 556 ms, and the single receding flow RT was 590 ms. Similarly, the responses did not differ when the target was displayed inside multiple looming flows compared with the target displayed inside multiple receding flows ($p = .48$). The multiple looming flows RT was 570 ms, and the multiple receding flows RT was 585 ms. The mean error rate did not exceed 3.75% in any condition, with no evidence of significant errors among conditions.

Most studies that have investigated the attentional allocation of dynamic objects have suggested that motion

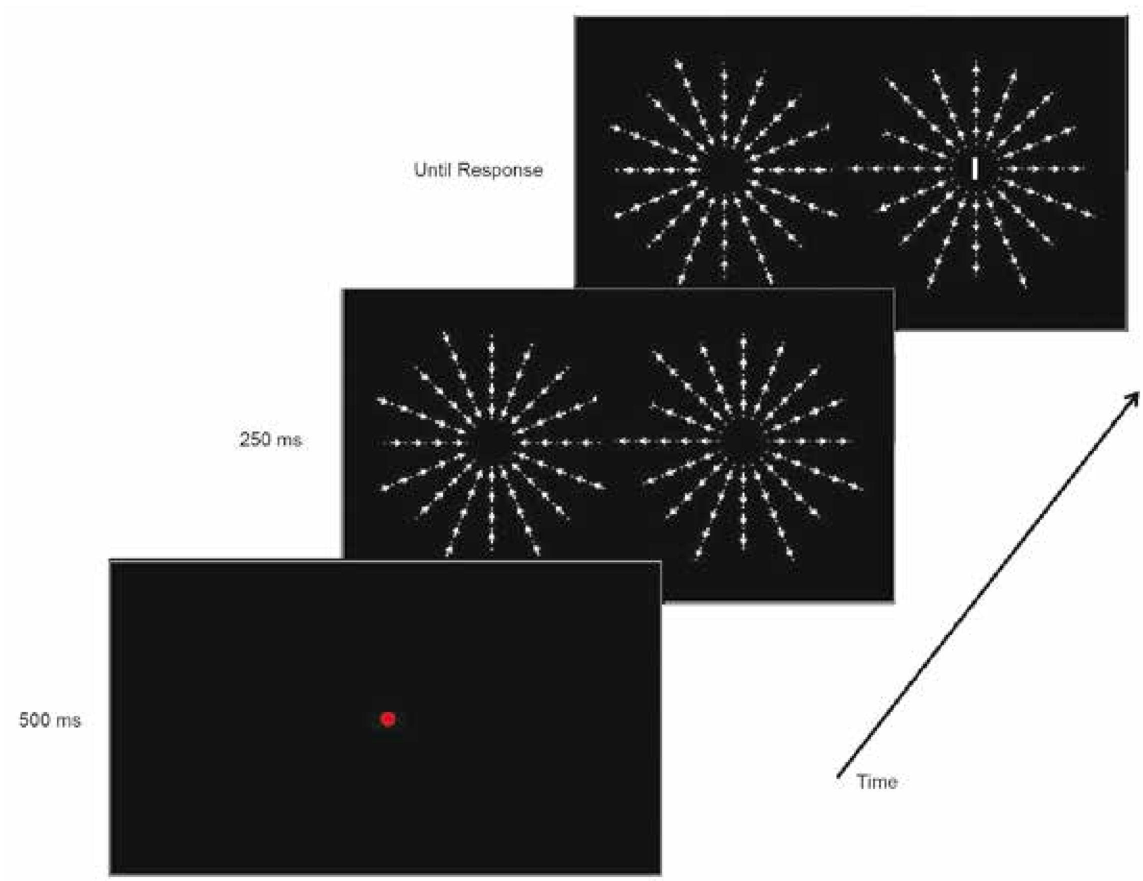

Figure 1. Sequence of events on a trial with looming and receding flows. Arrows represent the direction of motion.

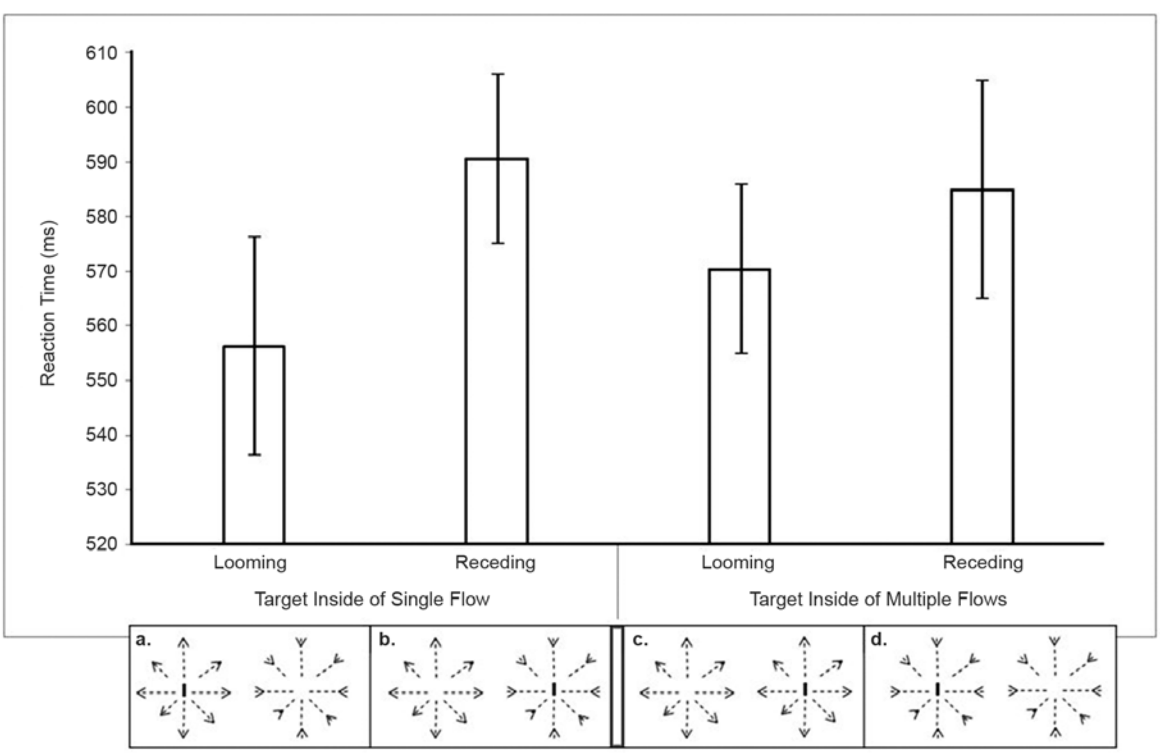

Figure 2. Mean reaction time to identify the target inside of optical flow. (a) looming/receding (target inside the looming motion). (b) looming/receding (target inside the receding motion). (c) looming/looming (target inside the looming motion). (d) receding/receding (target inside the receding motion). Error bars represent standard erros.

onset is fundamental to attract attention (Abrams & Christ, 2003, 2005; Christ & Abrams, 2006). However, there has been prolific debate about whether the movement direction itself is a feature that is able to attract attention. Thus, many authors have suggested an advantage for detecting objects in looming motions compared with static or receding motion (Franconeri & Simons, 2003; von Mühlenen & Lleras, 2007; Wang et al., 2012). The studies by Franconeri and Simons (2003) and von Mühlenen and Lleras (2007) used different methods to simulate looming and receding motion and concluded that objects in looming motion are prioritized in the environment. These results suggest that the visual system is especially efficient in processing stimuli that represent important aspects of the environment for rapid behavioral adaptation. Moreover, other results suggest that the temporal advantage associated with looming motion could reflect an improvement of information processing in nonattentive (pre- or postattentive) stages. In this sense, Skarratt et al. (2009) presented favorable evidence of a postattentive (motor) effect elicited by looming motion in a visual search task.

The results of Experiment 1 corroborate the interpretation that looming flow receives enhanced processing. The participants generally discriminated the target inside the looming motion faster than the target inside the receding motion. Notably, to separate the effects of the onset of looming and receding flows, a 250 ms interval was introduced between the onset of flows and target occurrence. However, these results do not allow inferring that they are attributable to a general alerting effect elicited by the looming motion because the RT did not differ in the single condition (with one looming flow and one receding flow) and when two looming flows or two receding flows were displayed together. Importantly, no significant difference was revealed by the Newman-Keuls *post hoc* test between single looming flow and single receding flow conditions. This may suggest that both the looming flow and the receding flow are similarly able to mobilize attention focus.

The objective of Experiment 2 in the present study was to extend the research on a possible cue effect in arrays with four flows, one looming and three receding or one receding and three looming, that simultaneously compete for attentional resources in the same array.

EXPERIMENT 2

Method

Participants

Twelve subjects (six female), including the author, aged 20-38 years, participated in the experiment. All of the participants reported normal or corrected-to-normal visual acuity. None of the participants in Experiment 2 participated in Experiment 1.

Apparatus and stimuli

The apparatus, target, and stimuli were similar to those used in Experiment 1, with the exception of the number, position, and density of the dots in the optical flows. The optical flows were composed of radial dots with a density of 2 dots/cm² in linear motion (looming or receding). The flows were simultaneously presented in four quadrants of the visual field (top and bottom, left and right). The centers of the optical flows were placed within a radius of 7º, diagonal to the center of the screen. The flow array is shown in Figure 3.

Procedure and design

The participants were subjected to a single block of 480 trials (10 replicates per condition). Each trial was composed of (1) one flow with looming motion and three flows with receding motion or (2) three flows with looming motion and one flow with receding motion. Thus, each trial displayed a single direction flow (looming or receding) with three flows in the opposite direction. The single direction flow was randomly presented in one of the four quadrants in the visual field (12º × 12º). The target appeared with equal probability in a single direction flow (looming or receding) or in one of the three opposite flows. The task and instructions were the same as in Experiment 1. At the beginning of the block, the participant responded to 96 practice trials that were excluded from the analysis.

Results

The RT data were analyzed using two-factor repeated-measures ANOVA for (1) target position: target inside the single flow and target inside multiple flows and (2) motion: looming and receding. A main effect of target position was observed ($F_{1,11} = 19.70$, $p < .001$, $\eta_p^2 = .64$) for the target displayed inside the single direction flow (looming and receding flow; $M = 549$ ms, $SE = 18$) and target displayed inside multiple direction flows (three looming and three receding flows; $M = 570$ ms, $SE = 22$). The main effect of motion was also significant ($F_{1,11} = 6.61$, $p = .02$, $\eta_p^2 = .37$). The interaction was not significant ($F_{1,11} = 0.02$, $p = .87$). Newman-Keuls *post hoc* comparisons confirmed no differences in RTs when the target was displayed inside the single looming flow compared with the target displayed inside the single receding flow ($p = .09$). Similarly, the responses did not differ when the target was displayed inside multiple looming flows compared with the target displayed inside multiple receding flows ($p = .14$). The mean error rates were low and did not exceed 3%. Mean RTs are shown in Figure 4.

General discussion

In two experiments, the results suggested that looming motion is an important factor for improving visual processes. Neurophysiological studies showed that the visual system is particularly sensitive to looming motion (Duffy, 1998; Field & Wann, 2005; Laurent & Gabbiani, 1998; Sun & Frost, 1998), and many other behavioral experiments with human infants supported the view that motion perception is fundamental for normal development and survival (Náñez & Yonas,

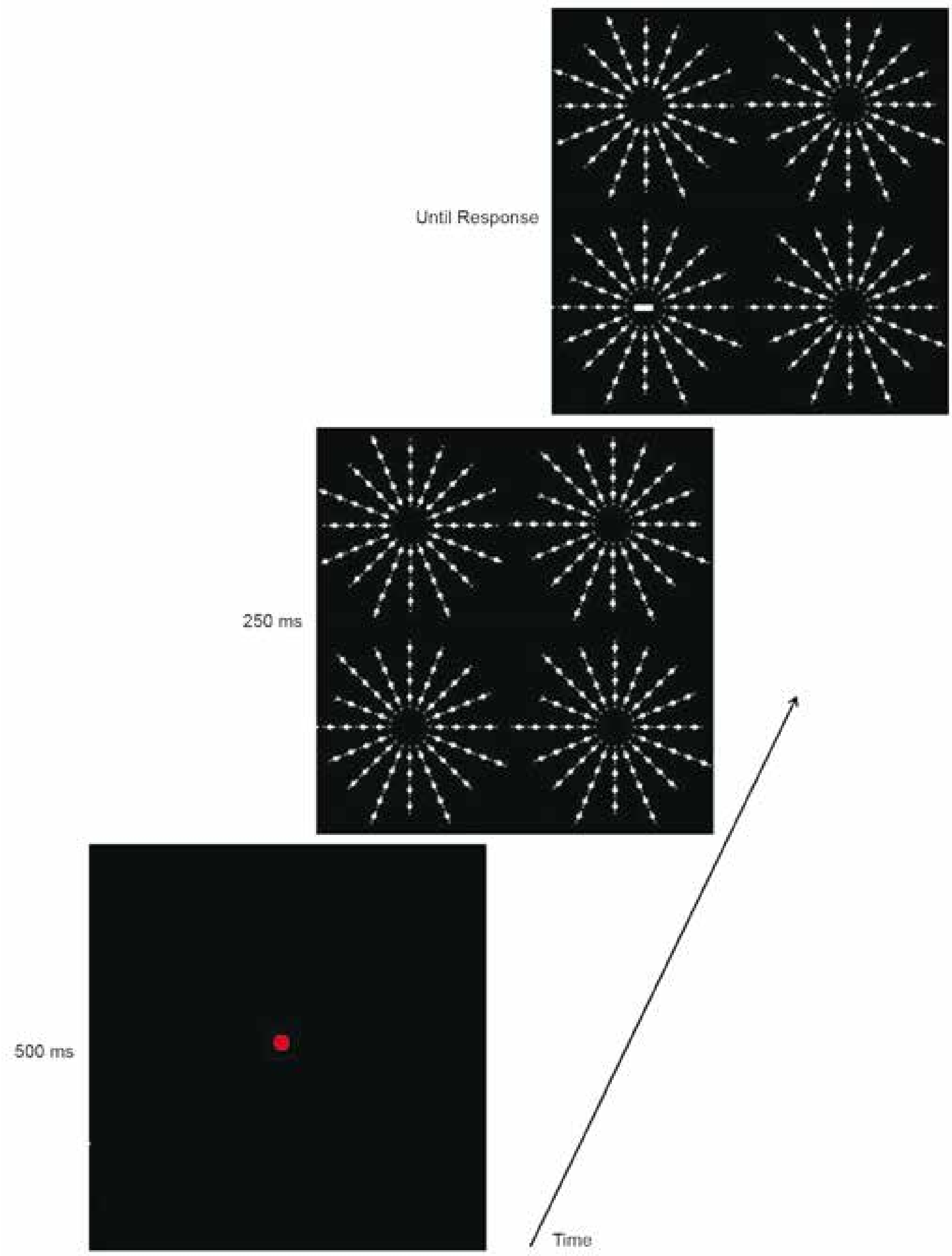

Figure 3. Sequence of events on a trial with four flows (three looming and one receding). Arrows represent the direction of motion.

1994; Shirai & Yamaguchi, 2010; Shirai et al., 2004b; Shirai et al., 2009; Wann, Poulter, & Purcell, 2011).

In general, the present study suggests that looming motion *per se* is an effective feature to enhance visual processes. Many studies have suggested that motion *direction* does not attract attention, but motion *onset* does (Abrams & Christ, 2003; Christ & Abrams, 2006). Studies have also suggested that certain motion features such as looming are able to attract attention (Franconeri & Simons, 2003; von Grünau, Matthews, & Cavallet, 2010; von Mühlenen & Lleras, 2007; Wang et al., 2012), with special emphasis on looming motion as a relevant behavioral alert (e.g., sign of danger) or associated with a postattentional motor priming process (Skarratt et al., 2009, 2014).

The specific objective of the present study was to investigate the attentional orientation of multiple optical flows with coherent motion (looming or receding) that were simultaneously presented as spatial cues 250 ms before the target onset. Because the flows were simultaneously presented and matched in all characteristics except for direction and position, a temporal advantage of identifying the target displayed inside the flow with specific direction would support the interpretation that certain aspects of motion are important for attentional orientation and selection.

The results of Experiment 1 in the present study showed that the looming flow condition generally had an advantage for target discrimination compared with target identification inside the receding flow

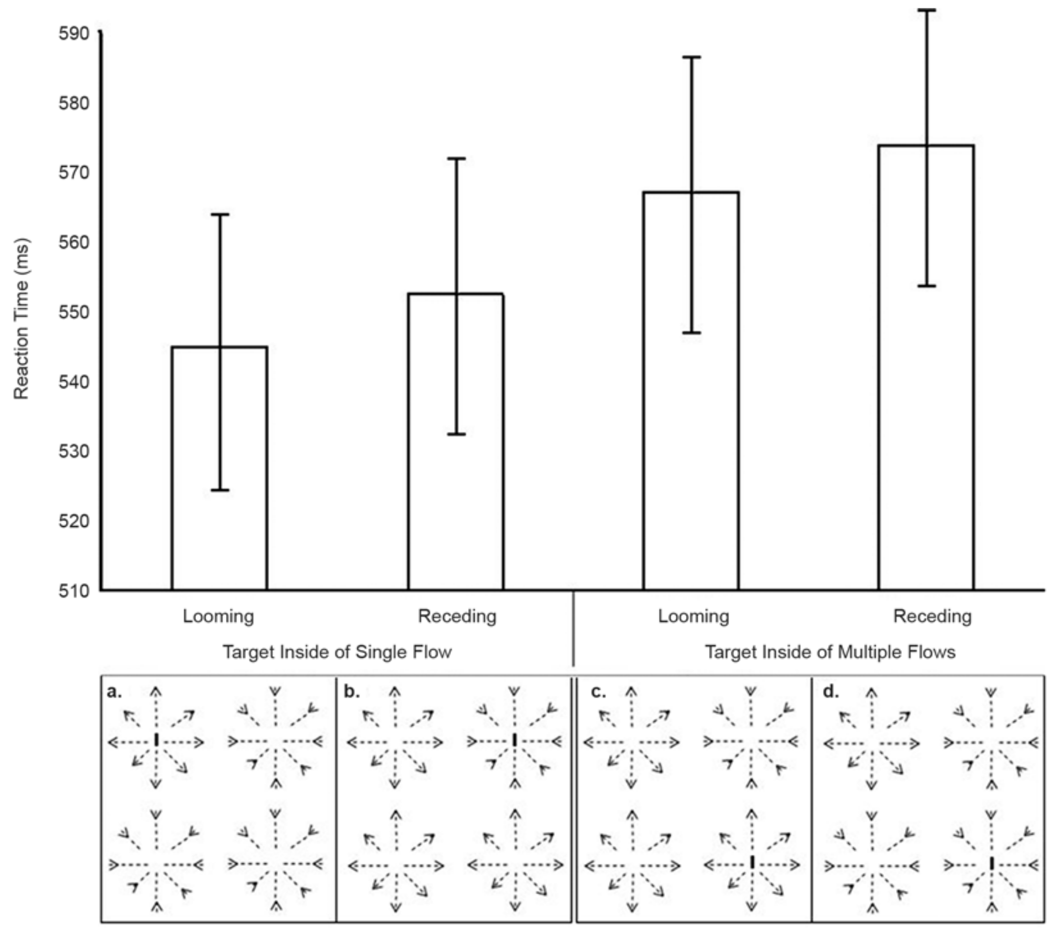

Figure 4. Results of Experiment 2. (a) one looming and three receding flows (target inside of looming). (b) one receding and three looming flows (target inside of receding). (c) three looming flows (target inside of receding).

(regardless of the number of flows presented). In previous studies, Franconeri and Simons (2003; who used increased or decreased stimuli to simulate looming or receding motions) and von Mühlenen and Lleras (2007; who used point flows in looming or receding simulated motion) suggested that looming motion plays an important role in attracting attention. However, in their experiments, looming and receding motion were not directly compared within the same array. This aspect was investigated by Skarratt et al. (2009, 2014) using stereoscopic depth arrays to simulate stimuli in looming or receding motion. One of the conclusions of this study is that both movements attract attention.

In an attempt to extend this line of investigation, Experiment 1 was designed to investigate possible competition between looming and receding motion for attentional priority using optical flows as simulated looming or receding visual stimuli. The results confirmed the advantage of looming flow to improve target discrimination, supporting the hypothesis that ecological factors constrain visual selection (Franconeri & Simons, 2003; von Grünau & Dubé, 1994; von Mühlenen & Lleras, 2007; Skarratt et al., 2009; Skarratt et al., 2014; Wang et al., 2012). However, the results showed no significant difference in RTs for discriminating the target presented within a single looming or receding flow. This fact suggests that both motions are capable of attracting attention, but the looming flow can elicit faster responses because of pre- or postattentional processes.

Similarly, Experiment 2 showed no differences between looming and receding flows when the target was presented inside the single direction flow or multiple direction flow. This evidence does not support the hypothesis that looming flow preferentially attracts attentional resources.

Generally, the results of both experiments suggest that both the looming and receding flows are able to attract the focus of attention, but there is a general temporal advantage in the processing of information that is presented within the looming flow. This advantage might occur outside the attentional stage. The temporal advantage elicited by looming motion could be attributed to postattentional mechanisms as suggested by Skarratt et al. (2009, 2014), and looming motion may prime the motor system to improve motor response programming. This interpretation is also supported by functional magnetic resonance imaging findings showing that activity in several motor areas of the brain are associated with looming motion processes (Field & Wann, 2005).

Conclusion

The results of the present study are consistent with the hypothesis that certain motion features such as looming are processed with priority by the visual system. In two experiments in which optical flows were used as concurrent spatial cues in the same array, the looming flow proved to have a temporal advantage in discriminating a target. The flows were presented at the same time and 250 ms before target onset, and this temporal advantage cannot be attributed to motion onset. The results also showed that looming and receding flows are capable of attracting attention, but looming motion produced globally shorter RTs. In this regard, the experimental design used in the present study is limited and does not allow drawing conclusions about whether this effect is perceptual or motor. Further studies that analyze looming and receding motion and its role in selective attention should be performed.

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