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Research Report

I'll Walk This Way

Eyes Reveal the Direction of Locomotion and Make Passersby Look and Go the Other Way

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ABSTRACT—*This study shows that humans (a) infer other people's movement trajectories from their gaze direction and (b) use this information to guide their own visual scanning of the environment and plan their own movement. In two eye-tracking experiments, participants viewed an animated character walking directly toward them on a street. The character looked constantly to the left or to the right (Experiment 1) or suddenly shifted his gaze from direct to the left or to the right (Experiment 2). Participants had to decide on which side they would skirt the character. They shifted their gaze toward the direction in which the character was not gazing, that is, away from his gaze, and chose to skirt him on that side. Gaze following is not always an obligatory social reflex; social-cognitive evaluations of gaze direction can lead to reversed gaze-following behavior.*

In everyday sidewalk encounters, it is not uncommon for one person to move in the same direction as an oncoming pedestrian. To prevent collision, both persons might make a corrective move in the same direction, which might be followed by even another joint corrective move to the opposite direction. However, people usually avoid such embarrassing encounters by relying on various cues of each other's direction of movement. In this report, we show how humans flexibly make use of other people's gaze direction for guiding their own visual attention and selecting collision-free walking paths during simulated locomotion.

Humans possess remarkable social-attention skills related to perception of others' gaze (Emery, 2000; Langton, Watt, & Bruce, 2000): People are accurate in judging gaze direction (Gamer & Hecht, 2007) and readily infer others' intentions and preferences from the eyes (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Castiello, 2003; Pierno, Mari, Glover, Georgiou, & Castiello, 2006). Others' gaze direction is also a powerful cue that guides the deployment of covert (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999) and overt (Deaner & Platt, 2003; Kuhn & Kingstone, 2009; Mansfield, Farroni, & Johnson, 2003) attention during simple cuing tasks, as well as perception of real-world scenes (Castelhano, Wieth, & Henderson, 2007; Langton, O'Donnell, Riby, & Ballantyne, 2006; Smith & Henderson, 2008). Automatic gaze following is thought to occur because it is often beneficial; sharing the locus of attention with an interlocutor enables co-operation for pursuing a shared goal (Emery, 2000).

However, there are also occasions on which it is equally beneficial not to have a shared attentional focus—for example, when walking past another pedestrian on a sidewalk. Humans' gaze direction during locomotion is highly indicative of their heading (Hollands, Patla, & Vickers, 2002); hence, judging other pedestrians' gaze direction could allow one to decide how to steer clear of them. Accordingly, to ensure that one's own motion path is clear of obstacles, one should inspect the side of the sidewalk that an oncoming pedestrian is not looking toward. This scenario suggests that effective sampling of scenes cannot always rely on the simplistic "social reflex" of imitating other individuals' gaze direction.

In the study reported here, we used a simulated version of the sidewalk encounter described in the previous paragraph to study control of eye movement by gaze-direction cues. We investigated whether—and in which way—the gaze direction of a person walking toward an observer on a colliding course influences the observer's eye movements and choice of a motion path. We presented participants with animations depicting a street with a pedestrian walking directly toward them. The pedestrian could gaze left or right, and, after hearing an auditory signal, participants had to indicate the side on which they would skirt the person. Eye movements were recorded during the task. We show that in this kind of situation, humans use the oncoming pedestrian's gaze direction for inferring his or her direction of locomotion and orient their own attention away from the perceived gaze direction.

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EXPERIMENT 1

Experiment 1 had two aims: (a) to test whether humans spontaneously use others' gaze information for avoiding collisions during locomotion and (b) to assess how viewers' own gaze direction is influenced by the gaze behavior of the person to be skirted.

Method

Twenty students (14 women and 6 men; mean age = 23 years) from the University of Turku participated in the experiment. All gave informed consent. The stimuli (see Fig. 1) were two 6,750-ms full-screen (640 × 480 pixels) animations created with Poser 5 (Curious Labs Inc., Santa Cruz, CA). The animations portrayed a male figure walking directly toward the camera and looking constantly either to the participant's left or to the participant's right. The viewpoint was aligned at the eye level of the figure and the participant's field of vision, and the scene moved constantly forward, giving participants the impression that they were moving. Each video was presented both in the original orientation and in the mirror-image orientation. Stimuli were presented on a 20-in. ViewSonic monitor (150-Hz refresh rate, resolution of 640 × 480 pixels) with a 2-GHz Pentium IV computer. Eye movements were recorded with an EyeLink II eye tracker (SR Research, Mississauga, Ontario, Canada) connected to a 2-GHz Pentium IV computer. The sampling rate of the eye tracker was 500 Hz, and the spatial accuracy was better than 0.5°. Manual responses were gathered with an EyeLink II response pad.

When they arrived at the laboratory, participants were given instructions on how to perform the experimental trials. The eye tracker was calibrated to ensure that average error was less than 0.5°. After 4 practice trials, the 20 experimental trials (10 with leftward and 10 with rightward gaze) were presented in random order. Each trial began with a drift correction: The participant had to focus his or her gaze at a circle presented at the center of the screen. When the participant's eyes were fixated on the circle, the experimenter initiated the trial. After a period of 100 to 500 ms (duration was pseudorandomly determined), the animation started. After 5 s, a 200-ms beep (the imperative signal) indicated that the participant should respond by pressing the left or the right response-pad button to indicate the side on which he or she would skirt the pedestrian. The animation was followed by a 1,000-ms blank screen.

The percentage of left and right skirting responses was computed for the left- and right-gaze conditions. For the eye movement data analysis, we selected four fixations: the fixations occurring prior to and during the imperative signal and the two subsequent fixations (labeled as −1, 0, 1, and 2, respectively). Fixations −1 and 0 thus represent the baseline gaze position. The fixations' mean *x*-coordinates (in degrees, with negative numbers representing the left visual field and positive numbers representing the right visual field) were used to index the participants' horizontal gaze position.

Results and Discussion

The results are summarized in Figure 2. The manual skirting responses were analyzed by comparing the frequency of the

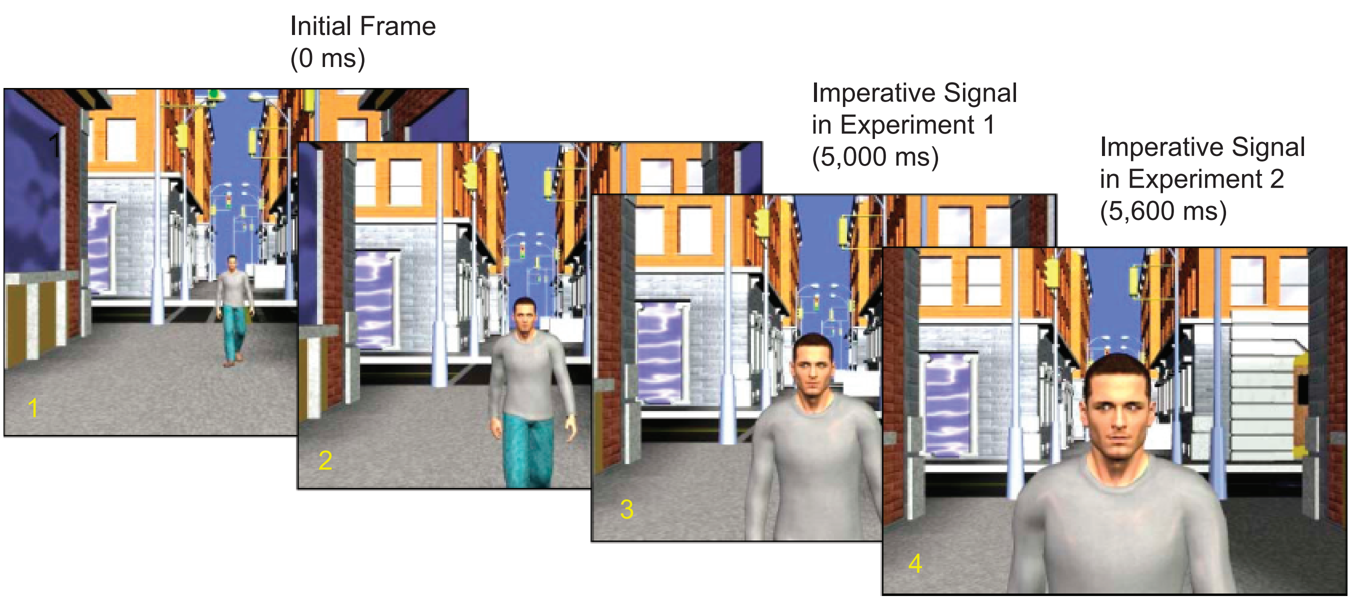

Fig. 1. Illustration of the video stimuli used in Experiments 1 and 2. In Experiment 1, the gaze direction was held constant (left or right) throughout the trial, whereas in Experiment 2, the character first walked toward the observer looking straight ahead and then suddenly shifted gaze direction from direct to the left or to the right. Frame 1 shows the start of the movie, Frame 3 shows the character's position at the time when the imperative signal was played in Experiment 1, and Frame 4 shows the character's position at the time when the imperative signal was played in Experiment 2. Note that the video frames are cropped slightly in this illustration.

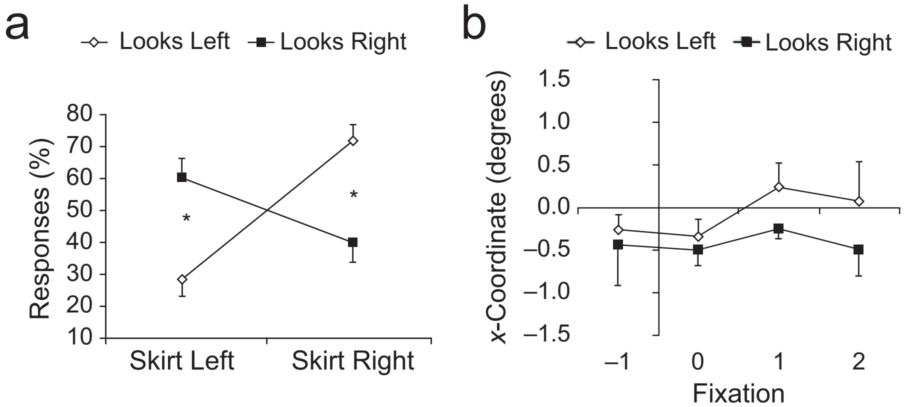

Fig. 2. Results from Experiment 1: (a) mean frequency of skirting on the left and on the right and (b) mean *x*-coordinates of the fixations made before (−1), during (0), and after (1 and 2) the imperative signal, as a function of the pedestrian's gaze direction. Negative coordinates indicate leftward gaze, and positive coordinates indicate rightward gaze. Error bars represent standard errors. Asterisks denote statistically significant ($p < .05$) contrasts between the gaze conditions.

"skirt left" and "skirt right" responses in the two gaze conditions (pedestrian gazed to the left vs. pedestrian gazed to the right). The frequency of skirting on the left was higher when the oncoming pedestrian looked to the right rather than to the left, $t(19) = 3.38$, $p_{rep} = .97$; conversely, the frequency of skirting on the right was higher when the oncoming pedestrian looked to the left rather than to the right, $t(19) = 3.30$, $p_{rep} = .97$. The eye movement data were analyzed with a 2 (pedestrian's gaze direction: left, right) × 4 (fixation: −1, 0, 1, 2) repeated measures analysis of variance (ANOVA). This analysis revealed a main effect of pedestrian's gaze direction, $F(1, 19) = 5.24$, $p_{rep} = .94$, $\eta_p^2 = .22$; on average, participants looked away from the direction in which the character gazed.

Experiment 1 showed that people use an individual's gaze direction for inferring his or her intended movement path. This "mind reading" from the eyes was reflected both in manual responses and in gaze position. Participants chose to skirt the stimulus character on the side that he was not looking toward. As predicted, participants' gaze direction did not mirror the pedestrian's gaze direction: Instead, participants tended to fixate the regions of the scene that the character walking toward them was not looking at. Accordingly, humans do not follow others' gaze direction in a deterministic manner. To the contrary, social-cognitive evaluations of the pedestrian's expected actions (i.e., walking path) governed the deployment of visual attention to the side of the street where he was not expected to walk.

EXPERIMENT 2

Prior studies (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999) showing attentional shifts toward stimulus faces' gaze direction have relied on measuring response latencies to peripheral targets presented shortly after gaze-direction cues. Accordingly, one could question how the results of Experiment 1, in which the imperative signal was presented 5 s after the onset of the gaze stimulus, could be reconciled with results of studies using much shorter stimulus onset asynchronies. To make a more direct comparison possible, in Experiment 2, we used videos in which the approaching pedestrian first walked toward the observer gazing directly ahead and then abruptly changed gaze direction. If gaze following is indeed an automatic social reflex, such a condition should evoke saccades toward the gazed-at direction. However, if gaze perception involves social-cognitive analysis of other individuals' intentions, such a condition should trigger saccades away from the gazed-at direction, as observed in Experiment 1.

Method

Fifteen students (12 women and 3 men; mean age = 24 years) from the University of Turku participated in the experiment. All gave informed consent. The apparatus, stimuli, and design were identical to those in Experiment 1, with the exception that the stimulus figure walked gazing straight ahead for 5,600 ms and then abruptly shifted his gaze to the left or to the right. A beep played simultaneously with the gaze shift notified the participant to make a response. There were 15 trials with leftward and 15 trials with rightward gaze shifts, presented in random order.

Results and Discussion

Data were analyzed as in Experiment 1, and the results (see Fig. 3) were essentially the same. Again, the frequency of skirting on the left was higher when the stimulus character looked to the right rather than to the left, $t(14) = 2.16$, $p_{rep} = .92$, and the frequency of skirting on the right was higher when the stimulus character looked to the left rather than to the right, $t(14) = 2.11$, $p_{rep} = .92$. Analysis of the eye movement data revealed a main effect of the pedestrian's gaze direction, $F(1, 14) = 4.67$, $p_{rep} = .93$, $\eta_p^2 = .27$; on average, participants looked away from the

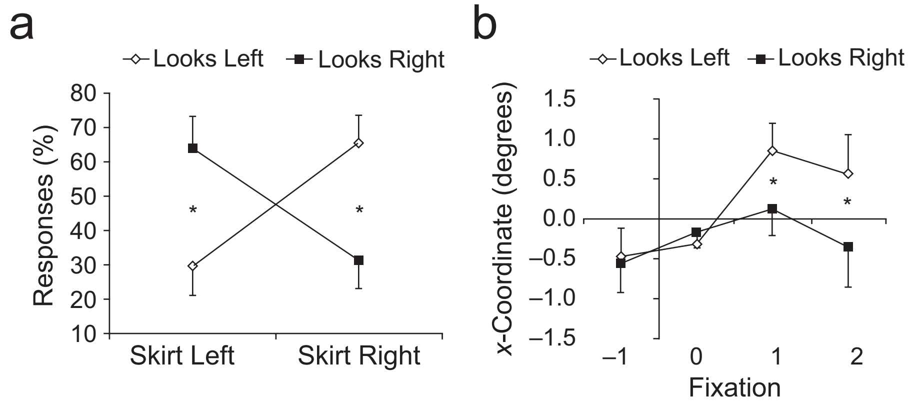

Fig. 3. Results from Experiment 2: (a) mean frequency of skirting on the left and on the right and (b) mean x-coordinates of the fixations made before (−1), during (0), and after (1 and 2) the imperative signal, as a function of stimulus gaze direction in Experiment 2. Negative coordinates indicate leftward gaze, and positive coordinates indicate rightward gaze. Error bars represent standard errors. Asterisks denote statistically significant ($p < .05$) contrasts between the gaze conditions.

direction in which the pedestrian gazed. However, the Fixation × Pedestrian's Gaze Direction interaction was also significant, $F(2, 28) = 4.45$, $p_{\text{rep}} = .98$, $\eta_p^2 = .24$. Contrast tests revealed that Fixation 1, $F(1, 14) = 4.59$, $p_{\text{rep}} = .92$, $\eta_p^2 = .25$, and Fixation 2, $F(1, 14) = 5.00$, $p_{\text{rep}} = .93$, $\eta_p^2 = .26$, deviated away from the direction in which the pedestrian was gazing, whereas such a difference was not observed prior to or during the imperative signal (Fs < 1).

Following the approach in cuing studies, we analyzed the latencies of the manual responses and first saccades made after the imperative signal with a 2 (congruency: toward vs. away from the pedestrian's gaze) × 2 (response type: manual vs. saccadic) ANOVA. This analysis yielded main effects of congruency, $F(1, 12) = 3.74$, $p_{\text{rep}} = .90$, $\eta_p^2 = .24$, and response type, $F(1, 12) = 40.92$, $p_{\text{rep}} = .99$, $\eta_p^2 = .77$. Latencies were faster for incongruent than for congruent responses (a difference of 37 ms) and were also faster for manual ($M = 321$ ms) than for saccadic ($M = 760$ ms) responses. This "anti–gaze cuing" effect suggests that observing an averted gaze prepared participants both to skirt the pedestrian and to look away from his gaze direction. Because response times were faster for manual than for saccadic responses, we conclude that the initial encoding of another individual's goal from his or her gaze direction is followed by modification of one's own movement goal and subsequently by changes in one's overt direction of attention. This finding suggests that during locomotion, one first decides the goal for movement and subsequently directs one's eyes toward that movement goal.

GENERAL DISCUSSION

A core question in oculomotor research is the degree to which eye movements are guided by physical and semantic features of the environment, as well as by top-down control. Models of eye movement control during scene perception assume that the distribution of fixations during scene inspection is initially determined by the visual conspicuity of the regions in the scene (Itti & Koch, 2001) and later influenced by top-down control and task demands (Torralba, Castelhano, Henderson, & Oliva, 2006). Our results confirm that the direction of other people's social attention is also an important determinant in guiding observers' movement and sampling of visual scenes (see Castelhano et al., 2007; Langton et al., 2006; Smith & Henderson, 2008). However, instead of simply imitating the oncoming pedestrian's gaze direction, our participants tended to skirt him on the side that he was not looking toward, and also tended to look in the direction where they would skirt him. This suggests that participants reasoned that the oncoming pedestrian's gaze direction signaled an intention to walk toward that direction; participants then decided to skirt him on the opposite side and tended to fixate in that direction (i.e., in the direction of their own upcoming movement).

These results contrast with those obtained when faces with an averted gaze are used as a cue in the Posner cuing paradigm. In such experiments, observers initiate rapid covert-attention shifts (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999) and saccades (Deaner & Platt, 2003; Kuhn & Kingstone, 2009; Mansfield et al., 2003) toward the direction in which the cue face is gazing, whereas in this study, both saccadic responses and manual skirting responses were faster when they were directed away from the stimulus person's gaze. This anti–gaze cuing shows that in dynamic social settings, eye movement guidance by other people's gaze is not always passive and stimulus driven (see also Itier, Villate, & Ryan, 2007). Social-cognitive inferences about other people's actions based on their gaze direction also influence which scene regions will be sampled, and this influence can sometimes override the gaze-following reflex and result in gaze aversion.

The present data and those from gaze-cuing studies can be reconciled by the notion that two parallel mechanisms guide gaze following (Mundy, Card, & Fox, 2000): a rapid, stimulus-driven mechanism that simply reacts to the perceived asymmetry of the gaze stimulus (cf. cuing studies) and another, slower, social-cognitive mechanism that guides the eyes on the basis of intentions and mental states inferred to underlie the gaze direction, as well as one's own goals (cf. this study). This dual-system model is supported by studies on individuals with autism spectrum disorders. These individuals are able to discriminate other people's gaze direction and have intact reflexive gaze cuing (for a review, see Nation & Penny, 2008), but also exhibit impaired joint attention and difficulties in inferring other people's mental states and intentions from their gaze (Baron-Cohen et al., 1995; Pierno et al., 2006). Rudimentary gaze following may thus be accomplished via a mechanism that is not contingent on mental-state attribution and is not sufficient for accommodating to complex social encounters.

People constantly move their eyes to update the representation of the visual environment according to their goals (Hayhoe & Ballard, 2005). Our results show that people are also aware of how and why others update their visual representations and use this information flexibly for their own movement planning and visual sampling of the environment. During locomotion, the gaze direction of an oncoming pedestrian is perceived as an intention to move toward the gazed-at direction, and people tend to move and gaze toward the *opposite* direction to prevent collision. Accordingly, looking toward your movement goal and occasionally observing other pedestrians' gaze direction not only prevents you from walking into other people, but also prevents other people from walking into *you*.

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