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DYNAMIC GAZE CUEING ALTERS THE PERCEIVED DIRECTION OF APPARENT MOTION

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Visual attention automatically shifts in the direction of another person's gaze shift. However, this gaze cueing effect has been tested only in static situations. In the present study, we examined whether dynamic gaze cueing, triggered by the dynamic gaze shift of another person, could alter the perceived direction of apparent motion. In Experiment 1, we presented a drifting or counterphased flickering sinusoidal grating in the upper visual field and a pictorial face stimulus with its eyes smoothly moved towards the left or right side of the grating in the lower visual field. Observers were asked to report the perceived motion direction in the grating; consequently, it was biased in the direction of the gaze shift. In Experiment 2, we ruled out the possibility of motion capture due to the motion signals in the eyes as a source of bias in the previous experiment. From these results, we concluded that dynamic gaze cueing altered perceived motion direction, and we proposed the usefulness of our approach in exploring gaze perception in dynamic environments.

Key words: gaze perception; motion perception; attention shift

The human visual system is sensitive to the gaze direction of other people. For example, in a visual search task, a straight gaze direction among averted gaze directions is detected faster and with fewer errors than is an averted gaze among straight gaze directions (von Grünau & Anston, 1995). Until now, numerous studies have investigated how observers know where another person is looking (e.g., Anstis, Mayhew, & Morley, 1969; Cline, 1967; Gibson & Pick, 1963; Symons, Lee, Cedrone, & Nishimura, 2004; Todorović, 2006) and have demonstrated that observers discriminate the gaze direction of another person with high accuracy. Moreover, perceived gaze direction has been determined based on the interaction between the actual gaze direction and the locations of the objects at which the gaze is directed (Lobmaier, Fischer, & Schwaninger, 2006).

It is well known that another person's gaze shift produces a shift of an observer's visual attention in the gazed direction (e.g., Downing, Dodds, & Bray, 2004; Driver, Davis, Ricciardelli, Kidd, Maxwell, & Baron-Cohen, 1999; Frischen, Smilek, Eastwood, & Tipper, 2007; Frischen & Tipper, 2006; Langton & Bruce, 1999). Specifically, observers tend to respond to targets at which the gaze is directed more quickly and accurately than to those at which the gaze is not directed. This kind of cueing effect of attention by another person's gaze direction is often called "gaze cueing". A number of studies have shown that the gaze shift in a schematic face, drawn in a line drawing format is enough to cause gaze cueing (e.g., Friesen & Kingstone, 1998; 2003; Friesen, Moore, &

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Kingstone, 2005). Moreover, Bavelier, Schneider, and Monacelli (2002) demonstrated that gaze cueing influenced the perception of illusory line motion, in which a static line appears to gradually unfold from a cued location (Hikosaka, Miyauchi, & Shimojo, 1993), supporting the rapid and strong effects of gaze direction on attentional shifts.

In these previous studies, the gaze cueing effect was examined mainly with static gaze stimuli and static targets. However, the situations in which we judge another person's gaze direction in daily life are dynamic, and needless to say, so are the eyes. Therefore, the lack of evidence on the gaze cueing effect in a dynamic situation seems to be a logical hole in the discussion of gaze perception.

In this study, we examined whether the smooth gaze shift of another person modulated the perception of an ambiguous apparent motion. Specifically, we investigated whether perceived motion direction was biased in the direction of the dynamic gaze shift, which caused gaze cueing along the direction. We call the tendency for a smoothly moving gaze cue to trigger observers' attention shift "dynamic gaze cueing". It is well known that multistable motion is biased in the direction of attention shift (e.g., Cavanagh, 1992; Julesz, 1971; Lu & Sperling, 1995; Shim & Cavanagh, 2004; Shioiri, Cavanagh, Miyamoto, & Yaguchi, 2000). If the smooth gaze shift was related to dynamic gaze cueing, the perception of the ambiguous apparent motion stimulus would be biased in the direction of dynamic gaze cueing. In Experiment 1, we tested the bias in the perceived motion direction, which was caused by dynamic gaze cueing. In order to explain the bias in the first experiment, in Experiment 2, we ruled out the contribution of motion capture by the motion signal in the eyes to the biased motion perception. As a result, we corroborated dynamic gaze cueing based on the smooth gaze shift. Moreover, we proposed that our approach to testing dynamic gaze cueing with an ambiguous motion display is a useful tool for exploring the gaze cueing effect in dynamic situations.

EXPERIMENT 1

METHODS

Observers

Six observers including one of the authors (YY) participated in this experiment; however, one of the observers was excluded from the further analysis because he/she judged the motion direction of the grating to be leftward in most trials of the experiment. All, except for YY, were unaware of the purpose of the experiment and all had normal or corrected-to-normal visual acuity.

Apparatus

A PC (Sony VAIO) was used to control the stimuli presentation and collect the data. Stimuli were displayed on a 19-inch CRT monitor (Nanao, FlexScan T761) with a resolution of 1024 × 768 pixels. The vertical refresh rate was 75 Hz. Using the gamma-correction software of the computer and a luminance meter (Minolta, LS-100), we linearized the luminance value emitted from the CRT display.

Stimuli

Each stimulus consisted of a fixation symbol, a pictorial face, and a luminance sinusoidal grating. The fixation symbol, which was located at the center of the display, was composed of four concentric circles, each with a diameter of 1.1, 0.8, 0.5, and 0.3 deg, respectively, of visual angle. The pictorial face was presented

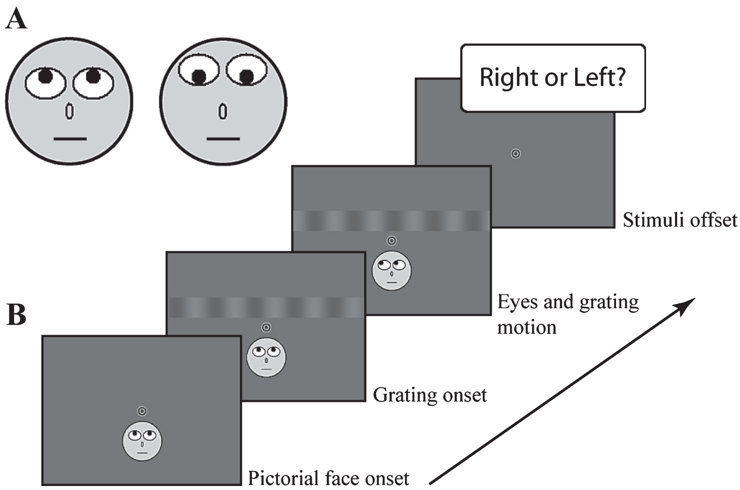

Fig. 1. (A) Examples of the pictorial face stimuli used in Experiment 1 (left) and Experiment 2 (right). (B) Schematic representation of the time course of a trial in the leftward condition in Experiment 1. The procedure of Experiment 2 was the same as that of Experiment 1 other than the position of the white ellipses in the face stimulus.

below the fixation symbol, with its center located at an eccentricity of 3.2 deg. The radius of the circle marking the face's contour was 2.1 deg. Thus, the top and bottom parts of the face contour were positioned at eccentricities of 1.1 and 5.3 deg, respectively. The eyes consisted of white ellipses with black circles. The long and short axes of the ellipse had lengths of 1.4 and 1.0 deg, respectively, and the black circles had a diameter of 0.46 deg. Initially, the eyes were presented such that the top edges of the black circles were touching the top of the inner edge of the ellipse (Fig. 1A).

A luminance sinusoidal grating with 0.24 cpd (cycles per degree) of spatial frequency was used as a probe. The width and height of the grating were 33.3 and 2.1 deg of visual angle, respectively, and the center of the grating was positioned at an eccentricity of 2.1 deg. The luminance contrast of the grating was set at 78%. The initial phase of the grating was randomized in a given trial. Every 167 ms, the phase was shifted by 150°, 160°, 170°, 180°, 190°, 200°, or 210°, respectively, where shifts smaller and greater than 180° represented leftward and rightward drifts, respectively. At 180°, the motion signal in the grating was bi-directional; and thus, perception of motion direction was assumed to be inherently bistable.

Procedure

Fig. 1B describes the time course of the stimulus presentation. The experiment was conducted in a dark room, where the observers sat at a distance of 60 cm from the CRT display. A chin/head rest was used to stabilize their visual field. Observers initiated each trial by pressing the space key on the computer keyboard; following which, the pictorial face without gaze shifts was presented for 750 ms. Then, a static grating was presented, and the onset of drifting was delayed by 500 ms. The drift of the grating and the gaze shift occurred simultaneously and lasted for 833 ms. The observers were instructed to monitor the drift of the grating while maintaining fixation on the central symbol. In the leftward and rightward conditions, the gaze shift was a smooth translation of the black circles toward the right or left by 0.033 deg in each 83 ms. On the other hand, in the no shift condition, the black circles did not move. No mask stimuli were used after the disappearances of the grating and the pictorial face. After the stimuli disappeared, the observers were required to report the perceived motion direction of the grating—right or left—by pressing the assigned keys. They were also told that neither the pictorial faces nor the gaze shifts in the face were relevant to the task and could therefore be ignored. Each observer performed a total of 210 trials involving 3 (gaze shifts: rightward, leftward, or no shift) × 7 (phase shift) × 10 repetitions.

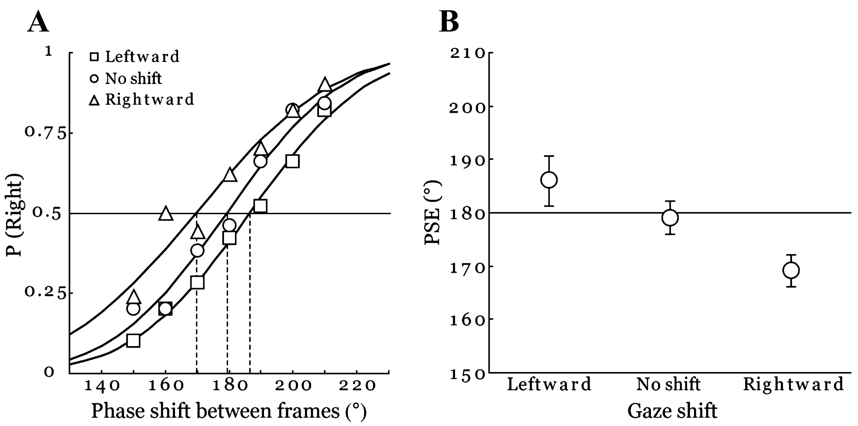

Fig. 2. (A) Averaged responses across all observers (n = 5) as a function of the seven predetermined phase shifts of the grating in Experiment 1. The abscissa depicts the phase shift with 180°, representing ambiguous motion signals. The ordinate depicts the rate of observers' rightward responses. (B) Estimated PSE averaged across observers for each condition in Experiment 1. Error bars denote standard errors of the mean.

RESULTS AND DISCUSSION

The data from each observer was fitted with a cumulative normal curve, using probit analysis (Finney, 1971). For each of the three conditions, we fitted the cumulative normal curve to the averaged proportions of reported rightward motion, shown in Fig. 2A, as a function of the phase shift in the grating. Using this individually fitted curve, we determined the point of subjective equality (PSE) of the bistable motion for each observer. Fig. 2B presents the PSE averaged across observers for each gaze shift. A one-way analysis of variance (ANOVA) of the PSE with gaze shift (leftward, rightward, and no shift) as a factor revealed a significant main effect, $F(2, 8) = 43.64$, MSE = 360.01, $p < .001$. Posthoc comparisons using Ryan's method (Ryan, 1960) revealed that the PSE was significantly larger in the leftward condition than in the no shift, $t(8) = 8.39$, $p < .005$, and rightward conditions, $t(8) = 9.30$, $p < .001$. In addition, the PSE in the no shift condition was larger than that in the rightward condition, $t(8) = 5.46$, $p < .001$. Moreover, one-sample t-tests revealed that the PSE in the rightward condition was significantly different from 180°, $p < .03$, while the PSE in the other conditions was not, $p > .05$.

We interpret these results in terms of the attentional modulation of perceived motion direction yielded by dynamic gaze cueing. The perceived motion direction was consistent with the direction of the dynamic gaze shift in the pictorial face. Notably, the comparisons between the PSE of each gaze condition and 180° showed a significant bias only in the rightward condition. This means that motion processing was more susceptible to rightward gaze shifts than to leftward ones. A similar rightward bias was reported in the previous study: The rightward gaze shift induced illusory line motion more effectively than did the leftward gaze shift (Bavelier et al., 2002). Consistent with Bavelier et al., the superiority of the rightward gaze in dynamic gaze cueing may underlie our results.

However, it is improvident to conclude that the results in Experiment 1 stemmed purely from dynamic gaze cueing. There was a possibility that the motion signals in the eyes resulted in the motion capture of the grating (e.g., Ramachandran & Anstis, 1983; Ramachandran & Inada, 1985; Ramachandran & Cavanagh, 1987). Motion capture is a phenomenon whereby stimuli without a unique motion direction are perceived to move in the direction of nearby motion. This phenomenon is believed to stem from co-operative interaction between ambiguous and unambiguous signals (Kim & Wilson, 1993). In this experiment, the motion signals in the eyes might have captured the ambiguous motion signal in the grating. The next experiment addressed this issue.

EXPERIMENT 2

Experiment 2 was conducted to rule out the possibility that motion capture influenced the results of Experiment 1: Ambiguous motion in the grating might have been captured by motion signals in the eyes in the pictorial face. In this experiment, we changed only the vertical position of the white ellipse of the eyes in the pictorial face stimuli upward. By doing this, the pictorial face looked downward while the grating was presented in the upper visual field. That is, the eyes of the face stimulus did not look at the grating. Under this stimulus condition, attention was not expected to shift towards the grating while motion capture was expected to occur due to the motion signal in the eyes. If motion capture was a source of the biased motion perception, the similar tendency as in Experiment 1 would be observed. On the other hand, if dynamic gaze cueing was a unitary source of the biased motion perception, no effect of direction in dynamic gaze shift on motion perception would be observed.

METHOD

Observers

Five observers, including one of the authors (YY), participated in this experiment. All, except for YY, were unaware of the purpose of the experiment and all had normal or corrected-to-normal visual acuity.

Apparatus, Stimuli, and Procedure

These were identical to Experiment 1 except for the following: the white ellipses in the pictorial face were displaced vertically by 0.47 deg upward from their position in Experiment 1 (Fig. 1A). The pictorial face used in Experiment 2 appeared to look downward.

RESULTS AND DISCUSSION

For each of the three conditions, the cumulative normal curve was fitted to the averaged proportions of reported rightward motion, shown in Fig. 3A, as a function of the phase shift in the grating. As in Experiment 1, we determined the PSE of the bistable motion for each observer (Fig. 3B). A one-way ANOVA of the PSE with gaze shift

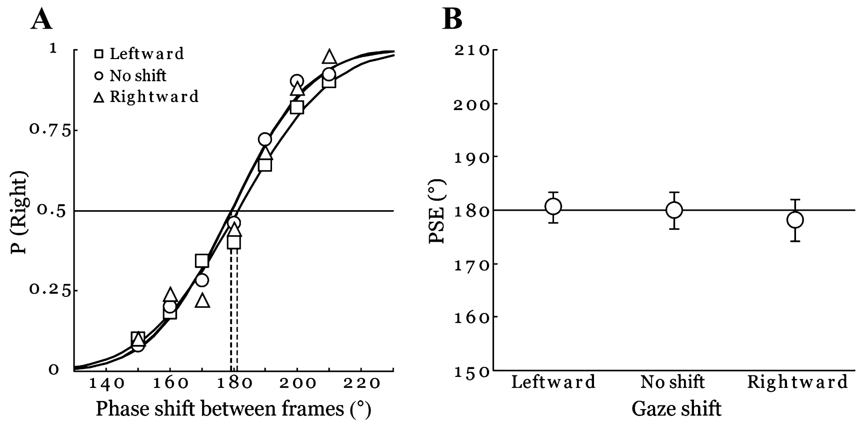

Fig. 3. (A) Averaged responses across all observers (n = 5) as a function of the seven predetermined phase shifts of the grating in Experiment 2. (B) Estimated PSE averaged across observers for each condition in Experiment 2. Error bars denote standard errors of the mean.

direction as a factor did not reveal a significant main effect [$F(2, 8) < 1$].

In this experiment, biased judgments for the motion direction of the grating were not observed. These results effectively ruled out the possibility that motion capture contributed to the results in Experiment 1. Since motion signals in Experiments 1 and 2 were equivalent, biased motion perception should have been observed if motion capture is a source of the results in Experiment 1. Instead, it is suggested that dynamic gaze cueing due to the dynamic gaze shift underlies the biased perception of motion direction of the grating.

General Discussion

We investigated gaze cueing in a dynamic situation by measuring the perceived motion direction in a grating with a given phase shift which varied from trial-to-trial. The results of the two experiments indicated that the perceived direction of the grating was biased in the direction of the dynamic gaze shift only when the pictorial face appeared to look toward the grating.

There is a concern that a simple response bias in favor of selecting the direction of the gaze shift led to the results of Experiment 1. It is possible that although the gaze shift was not practically related to the observers' task, when the motion percept was uncertain (particularly around the 180° phase shift), they might have given their response corresponding to the horizontal cued direction with a high degree of confidence; as a result, biased decisions were made. However, this seems unreasonable. In Experiment 2, even though the horizontal direction of the gaze cue was not changed from Experiment 1, observers did not made biased judgments. Therefore, the results in Experiment 1 appear to be free from response bias.

The approach in the present study serves as a new tool for exploring gaze perception in a dynamic situation. In this study, another person's gaze shift affected the appearance of motion stimuli. In addition to the previously used approaches of measuring reaction time for detecting static targets (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999), or accuracy for discriminating static gaze direction (Ando, 2002; Jenkins, Beaver, & Calder, 2006; Ricciardelli, Baylis, & Driver, 2000; Seyama & Nagayama, 2006; Sinha, 2000; Todorović, 2006), our approach offers a new index for the assessment of the dynamic state of attention by measuring the modulation of perceived motion direction by the dynamic gaze shift. In Bavelier et al. (2002), although the researchers demonstrated that another person's gaze shift induced motion perception against a static horizontal line, it differs from our experiment in that they used the static gaze direction to examine the effect of gaze cueing on motion perception. Thus, the present study benefits the further exploration of gaze perception in a dynamic situation. Comparisons between static and dynamic gaze cueing as well as between gaze cueing in static/dynamic environments will be required in the future.

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