Contrast-dependent effects of smooth pursuit eye movement on the perceived direction of ambiguous retinal motion

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When an apparent motion stimulus with an ambiguous direction in the retinal image is presented during smooth pursuit eye movements, the dominant perceived direction is opposite to the direction of eye movement (Terao et al., 2009). Here we report that pursuit of a stimulus characterized either by continuous ambiguous motion or by discrete apparent motion facilitates retinal motion opposite to the direction of the pursuit. This finding suggests that pursuit enhances motion signals in the opposite direction of the pursuit relative to signals in the same direction. We then investigated how stimulus contrast affected motion perception during pursuit because a previous study reported that sensitivity to the contrast of luminance grating was reduced for signals moving in the opposite direction of the pursuit (Schütz et al., 2007). Our results demonstrated that the perceived direction was opposite to the pursuit direction when the grating contrast was high, whereas the perceived and pursuit directions were the same when the grating contrast was low. This result indicates that pursuit has different effects on motion signals depending on the level of stimulus contrast.

Key words: eye movement, visual motion

We recently found that extra-retinal signals during pursuit resolve ambiguity in apparent motion perception (Terao, Kato, Murakami, Yagi and Nishida, 2009). When displacement was retinally ambiguous, the perceived direction was opposite to the direction of pursuit.

Facilitating the perception of motion in the direction opposite to that of pursuit suggests that pursuit enhances motion signals in the anti-pursuit direction on the retina relative to those in the direction of pursuit. To examine this notion is valid, we determined whether this facilitation phenomenon was also observed for continuous ambiguous motion. Whereas our previous study used discrete ambiguous motion (Terao et al., 2009), the current study used a more natural counterphase grating stimulus.

**Experiment 1**

Methods

Observers in this study include two of the authors (M. T. and S. N.) and two volunteers who were unaware of the purpose of the experiments. A retinally counterphase sinusoidal grating was presented on a gray background, while the observer's eyes tracked a marker moving smoothly below the grating. The counterphase grating was the sum of two gratings that had the same spatiotemporal frequency but drifted in opposite directions. We manipulated the contrast ratio of the two gratings to control the balance of motion signals in the two directions. When the grating contrast ratio was 1, the opposing motion signals in the counterphase grating were balanced. When the contrast ratio of one component relative to the other was greater than 1, perception was more likely to be dominated by the stronger contrast direction.

Three conditions were tested: a rightward pursuit condition, a leftward pursuit condition, and a fixation condition. For the pursuit conditions, one component of the counterphase grating remained stationary on the display. During pursuit, this grating would drift on the retina at the speed same as the pursuit but in the opposite direction. The other component of the counterphase grating moved on the display in the direction of pursuit at twice the
speed of the pursuit target. During pursuit, this grating would drift on the retina in the pursuit direction at the speed same as the pursuit.

Results and Discussion

When continuous ambiguous motion was presented on the retina during pursuit, the observer usually perceived that the motion was in the opposite direction to that observed with discrete apparent motion. To eliminate this induction effect, the luminance contrast of the motion signal in the pursuit direction was increased by \( \sim 10\% \).

These results indicate that motion signals in the opposite direction were relatively enhanced during pursuit. A previous report, however, showed that sensitivity to the contrast of a luminance grating was reduced in the direction opposite of pursuit relative to that in the same direction (Schütz et al., 2007). This effect predicts that the perceived direction should be the same as the pursuit direction, because the motion energy is expected to be stronger in the same direction. This is inconsistent with our results.

This apparent inconsistency may result from the strong luminance contrast used in Experiment 1. In contrast, the previous study (Schütz et al., 2007) used weak contrast values to investigate motion detection thresholds. Thus, in the second experiment, we investigated how stimulus contrast affects the perceived direction of motion during pursuit.

Experiment 2

Methods

In Experiment 2, observers were asked to judge the direction of motion of a counterphase grating during pursuit. The protocol was similar to Experiment 1, except that we manipulated the overall contrast of the counterphase grating by balancing the contrast ratio of the two drifting components.

The other task in Experiment 2 was designed to measure the detection threshold of motion during pursuit. We presented a drifting grating that moved in either the same or opposite direction relative to the pursuit. We manipulated the grating contrast (not the contrast ratio) and changed the grating posi-

Figure 1. Representative results of Experiment 2.

tion randomly (top or bottom) from trial to trial. Observers were asked to judge the grating position, not the direction of motion.

Results and Discussion

Figure 1 shows the performance of an observer reporting the direction of motion and the detection threshold for motion during pursuit. At high contrast values, motion perception in the opposite direction relative to the pursuit was more likely. As the grating contrast decreased, however, the percentage of trials in which the observer reported perceiving the motion direction as opposite to that of the pursuit was reduced. In addition, the more likely perceived direction was reversed at low contrast values. Consistent with the change in direction, motion detection was worse in the low-contrast range when the stimulus moved opposite to the direction of pursuit rather than in the pursuit direction. This asymmetric sensitivity modulation was consistent with results from the previous study (Schütz et al., 2007).

These results suggest that the modulation of motion signals by pursuit depends on the level of stimulus contrast.

References
