Backscroll illusion in far peripheral vision

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The backscroll illusion refers to the apparent motion perceived in the background of a movie image that presents a locomotive object such as a person, an animal, or a vehicle. Here, we report that the backscroll illusion can occur in far peripheral visual fields at retinal eccentricity of more than 30°. In psychological experiments, we presented a walking person in profile against an ambiguously moving background of vertical counterphase grating. This stimulus, which subtended 30° of visual angle in width and height, was projected onto a hemispheric screen and positioned at horizontal eccentricity between 0° and 50° at intervals of 10°. The eccentricity was changed randomly trial by trial, and stimulus duration was as short as 350 ms so that observers could not effectively move their eyes to the stimulus. Six observers viewed the stimulus either monocularly or binocularly and reported their perceptual impression for the grating in a three-alternative forced-choice procedure: drifting left, drifting right, or flickering. Results showed that the grating appeared to move in the opposite direction of walking at high probabilities even in the far periphery. Additional experiments confirmed that walking action could be recognized from the far peripheral stimulation. Our findings suggest that the visual system uses high-level object-centered motion signals to disambiguate retinal motion signals in the whole visual field.

Keywords: peripheral vision, apparent motion, biological movements


Introduction

The backscroll illusion refers to apparent motion seen in a pattern behind a locomotive object such as a person, an animal, or a vehicle. It is effectively demonstrated in a movie clip in which a person makes a treadmill step against a counterphase grating background (Fujimoto & Sato, 2006). Although the grating has physically ambiguous motion, it appears to drift in the opposite direction of the gait. This illusion indicates that the visual system evaluates retinal motion signals in relation to high-level representations of object motion. We have hypothesized that such object-centered motion perception plays a role in the stability of the visual world in everyday life, where retinal motion is inherently ambiguous due to the observer’s movements or the aperture problem (Fujimoto & Sato, 2006).

Here, we would like to raise a simple question. Can peripheral vision perceive the backscroll illusion? If so, what amount of eccentricity makes it possible? Moving objects regularly appear in the whole visual field in everyday life. An investigation of peripheral vision will therefore provide implications for the above hypothesis. In this study, we conducted psychological experiments in which human observers viewed a stimulus movie appearing at various locations, including far peripheral visual fields up to 50° of retinal eccentricity.

Thorpe, Gegenfurtner, Fabre-Thorpe, and Bülthoff (2001) reported that human observers could detect an animal in a photograph of a natural scene presented at a far peripheral visual field of more than 30° eccentricity. This suggests that far peripheral vision can perform complex figure–ground segregation. However, perhaps due to the brief presentation time of 28 ms employed in their study, the accuracy was relatively low and identification was impossible. Ikeda, Blake, and Watanabe (2005) reported that the recognition of the biological motion of human actions was poor even at a near peripheral field of less than 20° eccentricity.

The perception of relatively simple motion is also inaccurate in peripheral vision. For instance, Georgeson and Harris (1978) reported a foveofugal bias for an ambiguously moving pattern. They presented a counterphase grating at a parafoveal field of 5° eccentricity. Observers tended to perceive unidirectional motion away from the fovea. Such a foveofugal bias also has been found in the perception of unidirectional stimuli (Ball & Sekuler, 1980; Dumoulin, Baker, & Hess, 2001). Other studies, on the other hand, have recognized a centripetal bias (Mateeff & Hohnsbein, 1988; Raymond, 1994). Edwards and Badcock (1993) reported that anisotropy decreased with increasing eccentricity up to 24° of eccentricity. By contrast, Fahle and Wehrhahn (1991) found a foveofugal bias in far peripheral vision. Such discrepancies may come from differences of stimuli.
In addition to anisotropies, peripheral vision is poor at discriminating the direction and velocity of moving stimuli (Anderson & Hess, 1990; Orban, Van Calenbergh, De Bruyn, & Maes, 1985). However, this is mainly the result of undersampling at the early level of visual processing. Retinal cells and their projection to the primary visual cortex become sparse with increasing eccentricity (Curcio, Sloan, Kalina, & Hendrickson, 1990; Horton & Hoyt, 1991; Jonas, Schneider, & Naumann, 1992). Magnifying stimulus size is therefore predicted to compensate for such undersampling so that perceptual performance will improve (McKee & Nakayama, 1984; Virsu & Rovamo, 1979). It is likely that motion processing in peripheral vision is not essentially different from that in central vision.

Our current study used large stimulus displays to minimize influences from inhomogeneities. Their large sizes were also natural in comparison with retinal images in everyday viewing conditions.

**Methods**

**Observers**

Six adults (22–35 years old) voluntarily participated in the experiment. Five saw stimuli with their naked eyes, whereas the remaining one wore soft contact lenses. The visual acuity of all participants was 1.0 or better.

**Apparatus**

We used an Elumens VisionStation system (Figure 1) consisting of a hemispheric screen and an LCD projector (EPSON LMP-710). The hemispheric screen covered 160° of the horizontal visual field, and its physical dimensions were as follows: 1.7 m in width, 1.4 m in height, and 0.84 m in radius. The radius was the viewing distance, which was fixed by a head and chin rest. The LCD projector was placed on a desk in front of the screen and about 0.5 m below the observer’s eyes. A fish-eye lens was mounted on the projector through which images were projected onto the hemispheric screen.1,2 The projector had a resolution of 1,024 × 768 pixels and a refresh rate of 60 Hz controlled by a personal computer (Apple Power Mac G4).

**Stimulus**

The stimuli were movie clips that presented a walker in profile against a background of vertical sinusoidal counterphasing grating. This was a magnified version of the previously reported one (Fujimoto & Sato, 2006) in terms of physical and retinal size, although it kept the same pixel resolution. The walker subtended 6° in width and 11.6–14.0° in height, corresponding to everyday retinal sizes produced when one looks at a person of 1.5–1.8 m in height from a distance of about 7.3 m. The step length was 5.8°, defined by the distance between the arches of the feet when both legs were the most outstretched. One step lasted 500 ms, if completed, and apparent walking velocity was 11.6°/s. The grating subtended 30° in both width and height, with contrast modulation by a Gaussian window of 6° SD. The spatial frequency and temporal frequency were 0.5 cycles/deg and 4.0 Hz, respectively, which produced velocity components at 8°/s.

**Procedure**

Observers initiated each trial at their own pace by pressing a key after being signaled by a warning tone and the appearance of the fixation point. The stimulus was presented after a 500-ms interval during which only the fixation point was presented. The stimulus presentation lasted 350 ms. Observers responded by pressing one of three designated keys when the stimulus disappeared.

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There were 11 conditions of eccentricity, ranging between 0° and 50° at intervals of 10° in the left and right visual fields. These values pointed to the center of the stimulus. The order of the conditions was randomized. Observers were asked not to move their eyes voluntarily, and eye movements were monitored with an electrooculogram (EOG). All trials with more than 5° of eye movement were excluded from the data analysis. This occurred in less than 0.5% of the trials.

The observers’ task was to report their perceptual impression for the grating in a three-alternative forced-choice procedure. The alternatives were flickering, drifting left, and drifting right. In the data analysis, the directional responses were classified as the opposite response or the same response in relation to the walking direction. Response percentages were collected from a total of 16 trials (8 human models × 2 facing directions) if no trial was excluded due to excessive eye movement as described above.

To evaluate the statistical significance of the difference between the directional responses, as in our previous study (Fujimoto & Sato, 2006), we calculated the Directional Index (DI) using the following equation: DI = (% opposite − % same)/(% opposite + % same). DI ranged between −1 and 1. Positive values indicated dominance of the opposite response, whereas negative values indicated dominance of the same response. Statistical significance was evaluated by a single-sampled $t$ test for the mean DI versus 0. When the denominator was zero due to no directional responses, DI was designated as 0.

In addition to the movie clip stimuli consisting of an animated walker and a counterphase grating, we presented two other types of movie stimuli. One consisted of a static walker and a counterphase grating, and the other consisted of a counterphase grating alone. For each of these three movie conditions, 176 trials of stimuli were presented. The order of the conditions was randomized across observers.

To confirm that observers could recognize walking action, we performed an additional experiment. The stimuli were those used in the animated walker condition and their reverse sequences. These reverse animations looked like a person walking backward. The observers’ task was to judge the walking direction with a two-alternative forced choice: left or right. A correct response to a backward walker required the integration of the gait direction and the body facing direction, whereas a forward walker could be recognized from the facing direction alone. Thus, performance for the backward walker more adequately indicated the extent to which observers correctly recognized walking action.

Observers viewed the stimuli either binocularly or monocularly. In the monocular condition, observers used the dominant eye determined by the hole-in-card method. An eye patch covered the other eye. The sessions for each viewing condition ran on separate days.

## Results

### Binocular viewing

The data were classified by relating the facing direction of a person to the fovea to evaluate perceptual bias from the counterphase grating per se. We labeled the peripheral fields as foveopetal and foveofugal. Foveopetal refers to a condition in which a person faced the fovea, whereas foveofugal refers to a condition in which a person faced away from the fovea. The foveopetal and foveofugal conditions are represented as negative and positive eccentricities, respectively, on the abscissas of the graphs shown in Figure 2.

As shown in Figure 2a, an animated walker induced the opposite response at probabilities of 74.0–97.9%. These rates were all significantly higher than the same response rates based on the directional indexes, $0.84 < DI$ values ≤ 1.00, $t$ values(5) > 8.37, $p$ values < .001. The probabilities were highest at 10–30° eccentricities of the foveopetal conditions. A one-way ANOVA revealed a marginally significant effect, $F(10, 50) = 1.79, p < .10$.

Figure 2b illustrates the response probabilities for the static walker condition. The opposite responses occurred 53.1–77.1%, rates that were also significantly higher than the same response rates, $0.40 < DI$ values < 0.94, $t$ values (5) > 2.70, $p$ values < .05. Although the probabilities were highest at 10° eccentricity of the foveofugal condition, a one-way ANOVA showed no significant effect, $F < 1$.

Under both walker conditions, an opposite response also means a specific directional perception of the grating. That is, foveofugal perception occurred at negative eccentricities, whereas foveopetal perception occurred at positive eccentricities. The probabilities of corresponding responses occurring in the condition in which only the counterphase grating was presented are illustrated in Figure 2c. There was no fugal–petal bias, $F < 1$.

Figure 2d illustrates the recognition performance of walking action. For the normal forward walk, correct response rates were quite high and significantly above the chance level of 50%, $t$ values(5) > 4.07, $p$ values < .001. The backward walk also was correctly recognized, $t$ values (5) > 4.69, $p$ values < .01, except for the +50° eccentricity condition, $t(5) = 1.68, ns$.

### Monocular viewing

The data were classified according to nasal–temporal retinal fields to investigate constraints from the input levels of the visual system. On the abscissas of the graphs shown in Figure 3, temporal and nasal fields are represented as negative and positive eccentricities, respectively.
As shown in Figure 3a, an animated walker induced the opposite response at probabilities of 59.4–92.7%. These were significantly higher than the same response rates, 0.72 < DI values ≤ 1.00, t values(5) > 6.68, p values < .01. There was a drop at 50° eccentricity in the temporal field. A one-way ANOVA revealed a significant effect, F(10, 50) = 2.89, p < .01. Tukey’s HSD tests indicated significant differences between −50° and −40°, −30°, +20°, +30°, and +40° eccentricities (p < .05).

Figure 3b illustrates the response probabilities for the static walker condition. The opposite responses occurred 40.6–68.8%, which were significantly higher than the same response rates, 0.33 < DI values < 0.94, t values(5) > 2.69, p values < .05. There is a small drop at the temporal...
50° eccentricity. A one-way ANOVA indicated a marginally significant effect, $F(10, 50) = 1.85, p < .10$.

Figure 3d illustrates the recognition performance of walking action. For the normal forward walk, correct response rates were quite high and significantly above the chance level of 50%, $t$ values(5) > 4.02, $p$ values < .05. The backward walk also was correctly recognized, $t$ values (5) > 3.72, $p$ values < .05.

Discussion

The present results demonstrated that peripheral vision can perceive the backscroll illusion. The probabilities observed in the far periphery were as high as those in the center. Monocular viewing lowered the probability in the far temporal retina. This result can be explained by the constraints of input level. That is, the density of retinal cells in the temporal field is smaller than that in the nasal field (Curcio et al., 1990; Jonas et al., 1992). Recognition of walk was also poor in the far temporal retina. However, the current data were not strongly correlated with eccentricity. This could be due to the ceiling effect caused by the large stimulus displays. The involvement of higher level processing was also probable.

The results of the binocular condition suggested some anisotropy. The probabilities of the backscroll illusion increased when a person appeared to walk away from the fovea. However, the results of the backward walk
conditions implied that a foveofugally facing person had deteriorated recognition of walking action. This result is paradoxical if the recognition of object locomotion determines the backscroll illusion. However, this finding of poorer recognition in the backward walk conditions can be explained by the interference caused by the facing direction of the person walking, which can determine the direction of locomotion in everyday life because a back-
ward gait is rare. It was possible, therefore, that shape information dominated motion information in walk recognition. This argument is also supported by the occurrence of illusion from the static figures in the current and previous experiments (Fujimoto & Sato, 2006). In addition, a foveofugal walker might require attention, for instance, to prepare tracking eye movements; otherwise, he or she will gradually fade away from the visual field in everyday situations. We therefore suggest that there are high-level factors that affect the backscroll illusion in peripheral vision.

Further investigations are required to more fully understand the backscroll illusion in peripheral vision. One possible idea for future studies is the use of a smaller display, which should worsen the recognition of walking and alter the appearance of the illusion. A smaller display would also allow us to formulate a magnification factor and make comparisons with other types of perceptual phenomena in peripheral vision.

Although neural mechanisms underlying the backscroll illusion are unclear, the most likely candidate is networks among motion-specific areas in the occipital–temporal cortex of the brain. Several studies have consistently reported that human bodily movements activated areas around the superior temporal sulcus (for review, see Puce & Perrett, 2003). On the other hand, motion components of a counterphase grating are extracted in the primary visual (V1) area and integrated in the middle temporal (MT+, the human homologue to MT/MST in macaque monkeys) area (Heeger, Boynton, Demb, Seidemann, & Newsome, 1999). Thus, neural connections among those areas probably have a relation to the backscroll illusion. A recent study using monkeys as subjects showed that different parts of MT receive inputs from different brain areas according to representation of the visual field (Palmer & Rosa, 2006). Central and near-peripheral representations receive inputs from various visual areas, whereas far periphery receives inputs exclusively from V1, MST, and the retrosplenial cortex, which probably plays a role in visual information processing for rapid reactions such as orienting or postural actions. The current results were slightly linked to such a neural organization. If further investigations find that the backscroll illusion is differently perceived between far and other visual fields, it may provide clues to the understanding of neural mechanisms.

This study is the first to confirm that far peripheral vision can recognize complex human motion quite robustly, to the extent that it induces apparent motion in its background image. Ikeda et al. (2005) reported that peripheral vision is poor at recognizing biological motion. However, this may be attributed to their use of artificial stimulus settings, in which a fragmented point-light figure was embedded in dynamic point-light noise. By contrast, in this study, we used realistic animations. Moreover, the largeness of our stimuli was likely advantageous to recognition. There is no doubt that peripheral vision is inferior to central vision in various aspects. However, this inferiority is relative. Our data indicate that peripheral vision has the ability to see a moving person at an ordinary distance. It is therefore important to make considerations for the actual viewing conditions of everyday life when investigating the recognition of natural objects or events.

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Footnotes

1There was a mismatch between the curvatures of the fish-eye lens and the hemispheric screen, such that pixel size enlarged gradually from the center to the edges of the screen. The size at 50° eccentricity was about 1.4 times as large as that at 0° eccentricity. No compensation was applied to maintain the resolution of the stimulus images. Such enlargement was trivial in comparison with the more than 14 times enlargement produced by cortical magnification factors (Horton & Hoyt, 1991; Rousselet, Husk, Bennett, & Sekuler, 2005; Rovamo & Virsu, 1979). For convenience, this article describes stimulus parameters in the central visual field.

Luminance decreased from the center to the periphery. No compensation was applied because the reduction was small at the mean luminance level, which ranged from 20 cd/m² at 0° eccentricity to 14 cd/m² at 50° eccentricity.

We confirmed few eye movements from further analyses of EOG data.
References


