PERGAMON

Vision Research 43 (2003) 745–749

Vision Research

www.elsevier.com/locate/visres

Rapid Communication

Sustained deviation of gaze direction can affect "inverted vection" induced by the foreground motion

Shinji Nakamura [a,*,1], Shinsuke Shimojo [b,c]

[a] Faculty of Social and Information Sciences, Nihon Fukushi University, 26-2 Higashihaemicho Handa, Aichi, 475-0012, Japan
[b] Computation and Neural Systems, Division of Biology, California Institute of Technology, 139-74 Pasadena, CA 91125, USA
[c] NTT Communication Science Laboratories, Morinosato, Atsugi, Kanagawa 243-0198, Japan

Received 29 January 2002; received in revised form 18 November 2002

Abstract

A slowly moving foreground with an orthogonally moving background can induce self-motion perception in the same direction as the foreground motion (inverted vection; [Vision Research 40 (2000) 2915]). In the present study, we investigate the effect of sustained gaze deviation on inverted vection. We hypothesized that gaze deviation affects eye-movement information registered in the perceptual system, which might be a primary factor for causing inverted vection. The experiment revealed that strength of inverted vection decreases with observer's gaze deviation in the same direction as the foreground motion, while it increases with the deviation in the opposite direction to the foreground. These results support our hypothesis and suggest that inverted vection is affected by eye-movement information.

Keywords: Vection; Self-motion; Foreground; Gaze deviation

1. Introduction

Visually induced self-motion perception, or vection, has been investigated as strong evidence for the effects of visual information on self-motion perception. Many researchers reported that background stimuli dominate vection, while foreground stimuli are irrelevant to self-motion perception (e.g., Brandt, Wist, & Dichgans, 1975; Ohmi, Howard, & Landolt, 1987). However, we found that the foreground stimulus plays an important role in perceiving self-motion, by showing that a foreground moving slowly in front of an orthogonally moving background can induce self-motion perception in the same direction as the foreground motion (inverted vection; Nakamura & Shimojo, 2000).

We proposed a hypothesis about the mechanism underlying inverted vection, in which we assumed that eye-movement information registered in the perceptual system is intrinsically related to this phenomenon. The foreground stimulus evokes optokinetic nystagmus (OKN) in the direction of its motion, but fixation of a stable visual target suppresses such eye movements. This situation is equivalent to the cancellation of OKN by the intention of pursuit in the opposite direction which is not actually executed. In such a situation, information which indicates that the eye has moved in the direction opposite to the foreground motion is supposed to be registered in the perceptual system according to the outflow information of the intention of the pursuit (e.g., Post, Shupert, & Leibowitz, 1984). The observer's self-motion may be evaluated with such information (Royden & Hildreth, 1996). The percept of self-motion is consequently shifted in the direction opposite to the registered eye movement, which is the same direction as the foreground motion. [2]

* Corresponding author. Fax: +81-569-20-0127.
E-mail address: shinji@n-fukushi.ac.jp (S. Nakamura).
[1] Future Project Division, Toyota Motor Corporation, 1200 Mishuku, Susono, Shizuoka, 410–1193 Japan.

[2] Uniform retinal image motion of visual pattern can be contributed as one of sources of eye-movement information (e.g., Nakamura, 1997), and thus the foreground motion would be able to affect eye-movement information directly, not by way of OKN suppression hypothesized in this article. However, in such a case, stability of the visual pattern in the external world must be hypothesized just like as background stimulus, and such an assumption is not the case with the foreground stimulus.

0042-6989/03/$ - see front matter © 2003 Published by Elsevier Science Ltd.
doi:10.1016/S0042-6989(03)00081-6

In this study, we examine this hypothesis by directly manipulating gaze direction. When observers deviate their gaze direction laterally and maintain it there, viscoelastic forces of the eye-movement muscles tend to return the eye to the primary position (Leibowitz, Shupert, Post, & Dichgans, 1983). Thus, voluntary effort to sustain gaze deviation should be needed in order to overcome the viscoelastic forces. The sustained effort of gaze deviation is equivalent to the intention of pursuit in the same direction as the deviation, and eye-movement information is registered in accordance with such a pursuit effort (Heckman, Post, & Deering, 1991). We assumed that eye-movement information caused by the voluntary gaze deviation and by the nystagmus suppression both affect the observer's self-motion perception in qualitatively the same way, thus inducing inverted vection. The mis-registered eye-movement information would be in the opposite direction to the foreground motion, and in the same direction as observer's gaze deviation. Therefore, we predict that gaze deviation in the same direction as foreground motion would reduce, and gaze deviation in the opposite direction would facilitate, the strength of inverted vection.

2. Experiment 1

2.1. Methods

2.1.1. Stimulus and apparatus

Visual stimuli consisted of two overlapping random-dot patterns; the foreground and background patterns. The foreground stimulus had a crossed binocular disparity of 36 arc min specifying that it was 15 cm nearer than the screen. The background stimulus had an uncrossed disparity of 27 arc min specifying that it was 15 cm farther than the screen. The foreground stimulus moved horizontally at a constant speed of 5 deg/s and the background stimulus moved upward at 25 deg/s. Our previous experiments confirmed that this stimulus-speed combination is optimal for inducing inverted vection. Each dot in the pattern had a luminance of 14.8 cd/m^2 and a diameter of 3.2 deg. Dot density was 0.02 dots/deg^2. A fixation cross, whose size was 1×1 deg, and whose luminance was 14.8 cd/m^2, was presented with zero-disparity and located at one of three positions; the center of the screen, 10 deg left or 10 deg right from the screen center. The stimuli were generated by a graphics workstation (SiliconGraphics IRIS320VGX) and projected to the 115×200 cm screen by a 3D video projection system (Sony Tektronix 4190).

2.1.2. Procedure

Subjects were three adult males and one adult female, ages ranged from 24 to 33 with corrected-to-normal vision. All of the subjects had previous experience in vection experiments, but were naive to the aim of this experiment. In a darkened room, subjects sat in the upright position in front of the screen and observed the stimulus with their eyes fixed on the fixation cross at a viewing distance of 100 cm. The subject's head position was fixed by a chin and forehead rest, and directed toward the center of the screen. Subjects wore goggles with polarized filters for the stereoscopic observations. The subject's visual field was restricted by the edges of the goggle (90 deg horizontally, 60 deg vertically), and they could not see anything except the visual stimulus.

Before all experimental sessions, subjects underwent 10 training trials using the standard stimulus in order to establish a standard for magnitude estimation. The standard stimulus consisted of a single random-dot pattern which was presented on the plane of the screen and moved rightward at a speed of 50 deg/s. In experimental sessions, subjects were instructed to attend only to horizontal self-motion which was parallel to the foreground motion. As indices of the strength of inverted vection, duration and estimated strength were obtained in each trial. At the end of the stimulus presentation, which was lasted for 120 s, subjects estimated strength of inverted vection by using a scale from 0 (no horizontal self-motion was perceived) to 100 (horizontal self-motion component was as strong as in the training trials), or beyond (see Nakamura & Shimojo, 2000 for the method measuring inverted vection).

2.1.3. Stimulus condition

There were three gaze directions. In the condition of central fixation, the observer fixated the fixation cross which was located straight ahead of the observer's head. In the left and right fixation condition, observer fixated at 10 deg left or right from straight ahead. Motion direction of the foreground stimulus was leftward or rightward. Thus, the conditions included gaze deviation in the same or in the opposite direction to the foreground motion, and gaze toward straight-ahead. Trials for each condition were repeated six times in a randomized order.

2.2. Results and discussion

Durations and estimated magnitudes of inverted vection were averaged across the subjects, because there were no noticeable inter-subject differences. Fig. 1 shows averaged durations and strength estimates of inverted vection under different stimulus conditions. In the conditions where the observer's gaze was opposite to the foreground motion, inverted vection became stronger than in the condition of gaze toward straight-ahead. The strength of inverted vection decreased when the gaze deviation was in the direction of the foreground motion. There were no differences between the two foreground-motion directions. A two-way analysis of variance in-

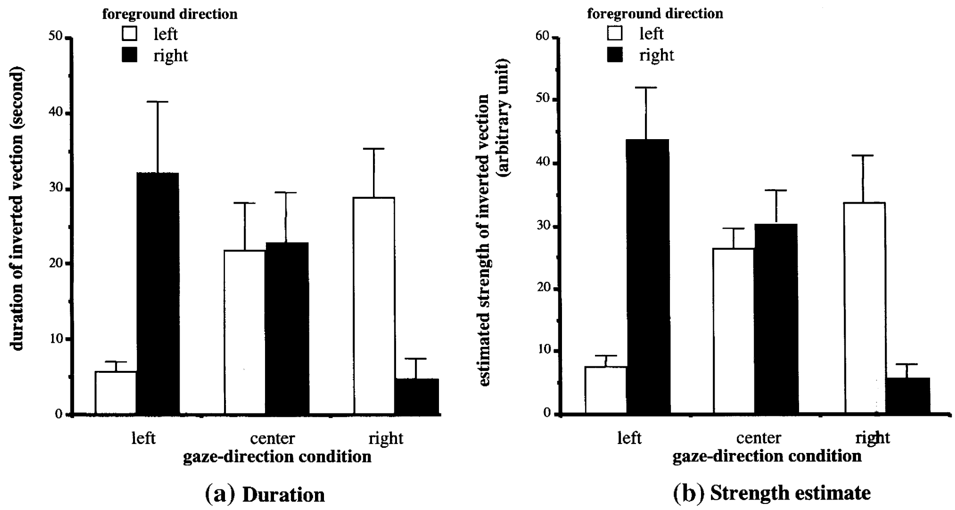

Fig. 1. Averaged duration (a) and estimated strength (b) of horizontal self-motion in the same direction as foreground motion (inverted vection) under each gaze-direction and foreground-motion condition (Experiment 1). Vertical bars indicate standard deviations.

dicated a significant main effect of gaze condition (i.e., same or opposite direction relative to the foreground motion) both for the duration and strength estimates ($F[2,6] = 31.91$ $p < 0.01$, $F[2,6] = 24.04$ $p < 0.01$, respectively). Neither a significant main effect of the direction of the foreground motion (duration; $F < 1$, estimation; $F[1,3] = 1.08$ n.s.), nor an interaction between these two effects (duration; $F < 1$, estimation; $F[1,3] = 1.96$ n.s.), was obtained.

The results of the Experiment 1 are consistent with the hypothesis that information about eye movements from the two sources, gaze deviation and OKN suppression, are added, and inverted vection occurs in accordance with the sum. However, the manipulation of the gaze direction used in this experiment also caused a change in the retinal locations of visual stimulus. Therefore, we cannot distinguish the effect of extra-retinal information from that of retinal signals. The next experiment was carried out to address this point.

3. Experiment 2

3.1. Methods

Subjects were four naive adult volunteers who did not participate in Experiment 1. The visual stimulus employed in this experiment was almost the same as Experiment 1. The fixation cross was always located at the center of the screen and the foreground stimulus moved rightward. The subjects observed the stimulus with their eyes fixated on the fixation cross, and their heads directed in one of three positions, the center of the screen, or 10 deg left or right from the screen center. The manipulation of head direction was accomplished by a chin and forehead rest. By manipulating the subject's head orientation while their fixation remained toward the center of the screen, we created the situation where the subject's eyes rotated in their orbits in the opposite direction to the head turn, but the retinal images of the visual stimulus were identical between the conditions. [3] In the condition of rightward head turn, the eye position in the orbit became in the opposite direction to the rightward moving foreground, and vice versa in the leftward head turn. Thus in short, we duplicated Experiment 1 without potential contamination of effect due to retinal image changes. Duration was measured as an index of inverted vection with the same procedure as Experiment 1.

3.2. Results and discussion

Fig. 2 indicates averaged duration obtained in each condition. The duration of the inverted vection became longest in the condition of rightward head turn (i.e., in the same direction as the foreground motion), and shortest in the leftward head turn (opposite to the foreground). Analysis of variance indicated significant effect of head turn condition ($F[2,6] = 17.54$ $p < 0.01$). The results of this experiment replicated those of Experiment 1. Therefore, it can be concluded that the result of Experiment 1 indicating that observer's gaze-direction affects the strength of inverted vection is not due to the

[3] Disparities both for the foreground and the background stimuli were calculated based on virtual cyclopean eye. Thus, in a reality, there are some differences between resulted depth perception in different head-turn conditions, because three dimensional positions of left and right eyes were not identical. However, the deviation of eye-position was about 1 cm between left and right head-turn conditions, as compared 100 cm of viewing distance, and thus negligible.

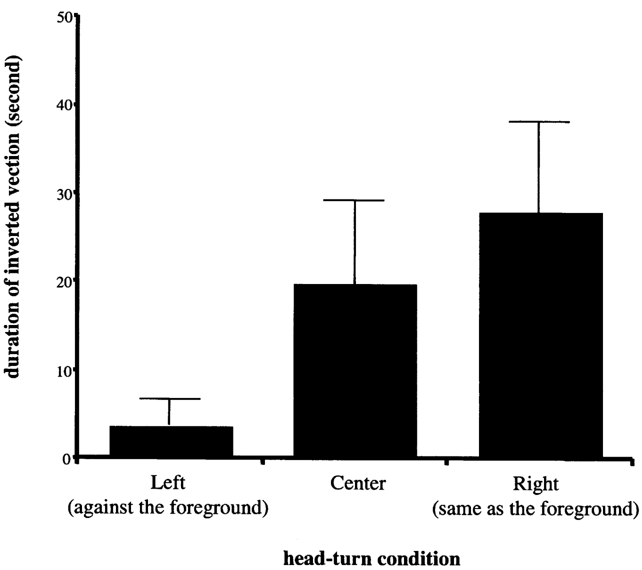

Fig. 2. Averaged duration of inverted vection under each head-direction condition (Experiment 2). Vertical bars indicate standard deviations.

artifacts of the retinal signal, but to the effect of the extra-retinal eye-movement information.

4. General discussion

The present experiments revealed that the strength of inverted vection increased when observers deviated their gaze in the opposite direction from the foreground motion, while it decreased with gaze deviation in the same direction as the foreground motion. These results are consistent with our hypothesis in that voluntary deviation of gaze direction can affect eye-movement information and inverted vection. Our preliminary observation indicated that standard vection induced by background motion alone is not affected by the sustained gaze-deviation. Therefore, the mechanism underlying inverted vection should be different from that of standard vection with regard to the eye-movement information. This does not, however, mean that the gaze deviation is the "cause" of the inverted vection. Note that eccentric gaze alone cannot induce inverted vection without a slowly moving foreground, even in the conditions where observer's fixation was set more eccentric than the one used in this study, that is 20 or 30 deg from the center. Heckman et al. (1991) also suggested that gaze deviation affects eye-movement information, but cannot cause illusory motion. Together these observations all suggest that sustained gaze-deviation is only a modulating factor, and thus cannot induce self-motion perception by itself, while the suppression of OKN by the foreground motion is the primary cause of the inverted vection.

The result in the straight ahead condition provided the baseline strength of the inverted vection caused by the OKN suppression alone, and the discrepancies between the straight ahead condition and eccentric gaze conditions indicated the magnitudes of additional modulation of the gaze deviation. The decrement of the inverted vection in the condition of the gaze deviation in the same direction as the foreground motion is much greater than the increment in the opposite-gaze condition. This might be due to difficulty in evaluating self-motion perception with eccentric fixation, which was often reported by the subjects. The difficulty might reduce evaluated strength of inverted vection, and apparently accentuate the decrement, but inhibit the increment.

Our previous experiments indicated that an orthogonally moving background is necessary in inducing inverted vection. Presentation of the stable background behind the moving foreground inhibited self-motion perception strongly. Especially with slower foreground motion, observers reported that there was no vection at all (Nakamura & Shimojo, 1999). A stable background inhibited vection so strongly that observers could perceive any self-motion, perhaps because the background motion is a primary factor in self-motion perception (e.g., Ohmi et al., 1987). Thus, inverted vection occurs only under conditions in which the orientation of the self is unstabilized by the motion of the background *and* eye-movement is grossly mis-registered by suppression of OKN.

Acknowledgements

The authors would like to thank two anonymous reviewers for many helpful suggestions. We also thank Dr. Mark Changizi of California Institute of Technology for editing of the final version of the draft.

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