A Temporal Analysis of Body Sway Caused by Self-Motion During Stereoscopic Viewing

Akihiro Sugiura[1,2(✉)], Kunihiko Tanaka[1], Hiroki Takada[3], Takehito Kojima[2], Tatsuya Yamakawa[2], and Masaru Miyao[2]

[1] Department of Radiology, Gifu University of Medical Sienese, Seki, Japan
{asugiura, ktanaka}@u-gifu-ms.ac.jp
[2] Graduate School of Information Sciense, Nagoya University, Nagoya, Japan
tkojima45@gmail.com, yamakawa.tatsuya@d.mbox.nagoya-u.ac.jp, mmiyao@is.nagoya-u.ac.jp
[3] Graduate School of Engineering, University of Fukui, Fukui, Japan
takada@u-fukui.ac.jp

Abstract. While continuously viewing objects in motion, humans may develop an illusionary sense of moving in the opposite direction as the objects, despite being quiescent. This phenomenon is termed as vection. In this study, we investigated the effect of long-duration viewing through binocular stereopsis on vection by measuring the body sway. Subjects watched a static movie for a minute, sinusoidal-motion movie at 0.3 Hz for 3 min, and the initial static movie for a minute, in sequence. We had three observations from the results of this study. First, the longer the viewing time, the higher the synchrony with direction of motion in the movie. Stoppage of the motion-movie and returning to viewing a static movie decreases the synchrony gradually. Second, synchrony is higher while viewing a 3D- than a 2D-movie. Third, the body sways in the anteroposterior direction in a cyclical manner by sensing self-motion in the horizontal direction.

Keywords: Self-motion · Vection · Stereoscopic movie · Sinusoid · Synchrony

1 Introduction

It is assumed that the mechanism of human posture control processes information about self-location, -posture, and -direction. This information is generated through integration of the visual system, vestibular-labyrinthine apparatus, and somatosensory system through a brain to whole body continuum. It has been reported that information from the visual system has the largest effect on human posture control with it constituting more than 50 % of the input [1, 2]. When continuously observing moving objects, humans may develop an illusionary sensation of moving in the opposite direction as the moving objects, which is a good example of posture control by the visual system. This phenomenon is termed as vection [3–6]. Vection is described as a sensation of self-motion in a person attributed to visual information despite the person being quiescent.

In previous studies on vection, three major approaches were followed. The first approach was to measure vection. Measurement methods can be classified as subjective and

M. Antona and C. Stephanidis (Eds.): UAHCI 2015, Part II, LNCS 9176, pp. 246–254, 2015.
DOI: 10.1007/978-3-319-20681-3_23

objective. The advantage of the subjective method is that it enables direct measurement of sensory phenomenon. In previous studies, orally answering questions about both the perceived direction of self-motion and its amplitude were mainstream. In particular, magnitude estimation, which is one of the methods in experimental psychology, has frequently been used in studies on vection. On the other hand, objective methods in vection studies evaluate bodily changes attributed to kinesthesis. In vection-measurement, correlation between bodily changes and the sense of self-motion is an important verification point. Previous studies, which included both oral-response and physiological measurements, indicate a correlation between body displacement, such as head movement, body sway or nystagmus, and answers on self-motion [1, 5, 7, 8]. Thus, objective methods in vection studies have been used extensively. Recent studies have utilized functional magnetic resonance imaging to identify active parts of the brain during vection [9].

The second approach was trend analysis for identifying human characteristics for easy perception of vection. Previous studies have reported that motion sickness is strongly linked to vection [10–12].

Third is the analysis of relationship between movie-characteristics and vection. Studies have investigated vection while viewing movies, which differ in the direction of optic flow in the foreground and background, or which change the velocity or acceleration of optic flow. In addition, the effects of interaction between central and peripheral vision and binocular stereopsis on vection have also been studied. These show that background motion, which is detected by the peripheral vision, wields influence over vection. Thus, spatial perception is important in vection. However, the longest viewing time utilized in previous studies was 1 min, which fails to describe the characteristics of vection in longer viewing durations. Therefore, in this study, we investigated the effect of long-duration viewing through binocular stereopsis on vection by measuring body sway.

2 Method

2.1 Creation of Movies

A screenshot of the movie used in this study is shown in Fig. 1. The movie was created using the computer graphics software 3dsMax 2015 (AUTODESK, USA). The movie shows a large number of balls at random position. We created four types of movies with the following features. Motion-direction in the movies followed two patterns: depth direction (Z-direction) and side direction (X-direction); and the kind of movies were 2-dimensional (2D) and 3-dimensional (3D), using horizontal image translation (H. I. T.) with binocular stereopsis. The motion in the movies was sinusoidal at 0.3 Hz in each direction generated by moving camera-simulated ocular globes (the balls did not move directly). Amplitude of the sinusoidal motion was same in all directions. The maximum dive distance and maximum pull distance from the ocular globes in the 3D movies were, respectively, 0.85 m (parallactic angle, 2.5 degree) and 2.961 (parallactic angle, 1.8 degree), when the viewing distance was 2 m.

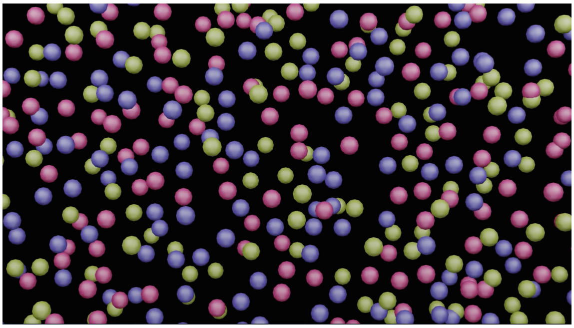

Fig. 1. Screenshot of the movie (2D image version). A large number of balls were placed at random positions in the movie space. Direction of motion in the movie followed two patterns: depth direction (Z-direction) and side direction (X-direction), and the movies were either 2-dimensional (2D) or 3-dimensional (3D) with binocular stereopsis. Sinusoidal motion at 0.3 Hz in each direction was generated by moving camera-simulated ocular globes (no direct motion of the balls).

Fig. 2. A scene of the study. The subject stands on a Wii Balance Board to measure body sway with a 2 m viewing distance to the screen. In 3D-movie viewing, subjects wear 3D-glasses.

2.2 Measurements

Nineteen students (12 male and 7 female, 21–24 years old) who did not have vision and equilibrium problems participated in this study which was approved by the Research Ethics Committee at Gifu University of Medical Science (approval number: 26-6). Written consent was obtained from participants after the purpose and significance of the study, and nature and risk of measurements were explained, both orally and in writing. Following this, the study was carried out in line with the Helsinki Declaration.

The setup utilized in the study is shown in Fig. 2. We performed measurements under a controlled environment (temperature: 29.5 degrees, illuminance: 13 lx), to avoid variations caused by visual stimuli. For presentation, the movie was projected on a white wall 2 m in front of the subject with a domestic version 3D projector (EH-TW5100, EPSON, Japan). Projected movie size was 155 cm × 274 cm, and the viewing distance was 2 m. Thus, the view angle was 68.8 degrees. In 3D movie viewing, subjects wore 3D-glasses (ELPGS03, EPSON, Japan) as a parallax barrier. In addition, to measure body sway during movie viewing, subjects stood on a Wii Balance Board (Nintendo, Japan) with a static erect position and toe opening at 18 degrees.

The following protocol was followed. First, subjects watched a non-moving movie (static movie: SM) for a min as pre-test. Next, subjects watched a sinusoidally-moving movie (motion movie: MM) for 3 min. Finally, the initial static movie was shown again for 1 min. During the entire duration, the body sway was recorded continuously. These 4-min tasks were treated as one trial, after which, four trials (2D-X-direction, 3D-X-direction, 2D-Z-direction, and 3D-Z-direction) were performed in random sequence to avoid the order effect. Trial-interval was set at more than 5 min.

2.3 Analysis Procedure

Each change in the voltage of four strain gauge sensors at the corners of the Wii Balance Board were output to a biological signal acquisition system (DC-300H, NIHON KOHDEN, Japan). These voltage data were recorded at 200 Hz using the biological signal recording software Lab Chart 7 (AD Instrument, USA). Next, voltage data were transformed to gravity point data using a reduction formula. Finally, the gravity point data underwent downsampling at 20 Hz following low-pass filtering at 10 Hz, which is the norm in studies on body sway using a stabilometer.

The continuous data on temporal change in body sway were separated by each 1-min of viewing time. Each separated data unit underwent a frequency analysis by fast Fourier transform using the Hamming window.

3 Results

A typical stabilogram result from one of the subjects (24 years old, female) viewing the 3D-Z direction movie is shown in Fig. 3a–e. Comparison of SM (Fig. 3a) and MM viewing (Fig. 3b–d) showed that the continuous change in gravity point in the direction of motion was bigger while viewing the MM than while viewing the SM. Moreover, the change in gravity point increased with an increase in the viewing time. The large change in body sway in the motion-direction while viewing the MM from 120 to 180 s (Fig. 3d) was drastically reduced in the following motionless SM (Fig. 3e). Thus, there was a gradual return to the initial state by viewing the SM. This phenomenon was seen in the viewing of movies with motion in all directions, and was regardless of the Z-direction.

Frequency analysis for body sway of the 19 subjects while viewing the SM (pre-test) and 3D-MM (120 to 180 s) are shown in Fig. 4a (3D-X-direction) and 4b (3D-Z-direction). The graphs show average magnitude values calculated from the Fourier analysis as the ordinate, and frequency as the abscissa. Both graphs showed

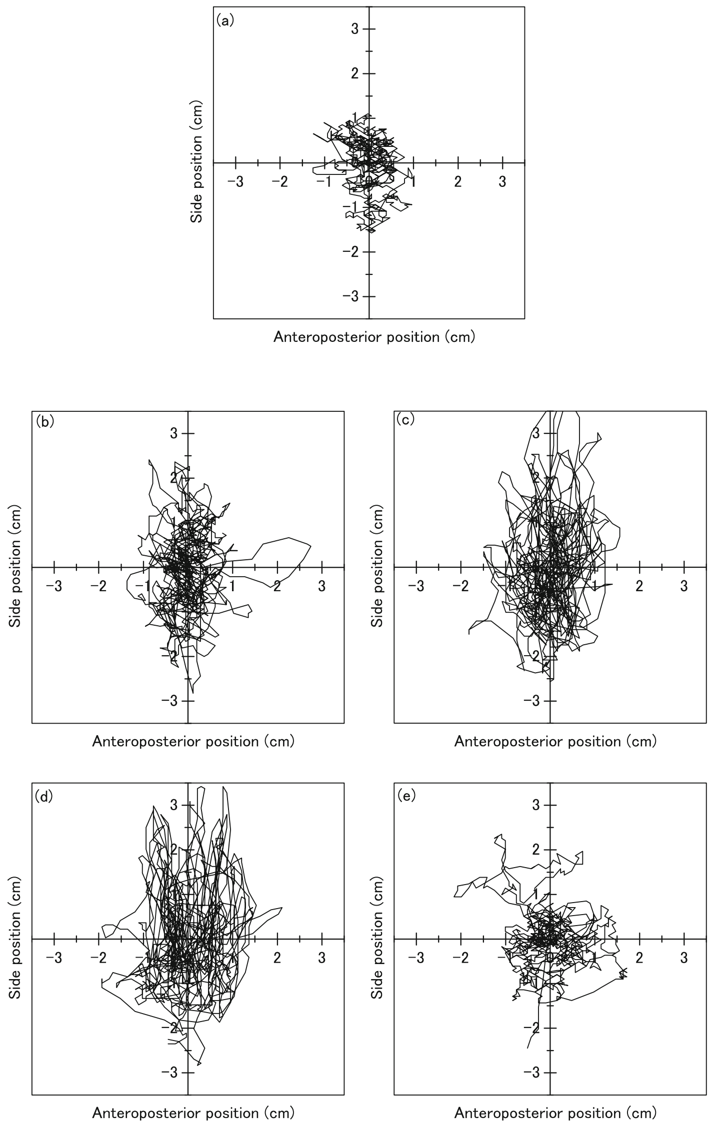

Fig. 3. Stabilogram of one subject (24 years old, female) viewing a 3D-Z direction movie. (a) Viewing the SM (pre-test), (b) viewing the MM for 0 to 60 s, (c) viewing the MM for 60 to 120 s, (d) viewing the MM for 120 to 180, and (e) viewing the SM (post-test).

peaks at 0.01 Hz and 0.3 Hz for MM viewing but the 0.3 Hz peak was missing for SM. Thus, only 0.3 Hz sway increased while viewing the MM. Frequency at 120 to 180 s while viewing the MM was analyzed (Fig. 4). The 0.3 Hz component was also detected in other Sects. (0 to 60 s or 60 to 120 s). In addition, while viewing the 2D-MM, a similar tendency was found.

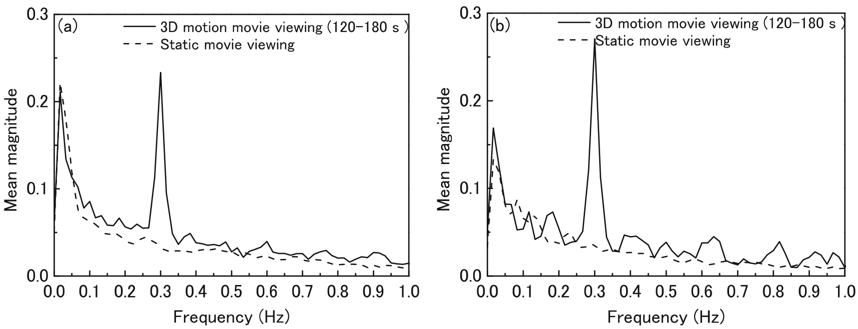

Fig. 4. Frequency analysis for body sway of 19 subjects while viewing the SM (pre-test) and viewing 3D-MM for 120 to 180 s. The both (a) and (b) show average magnitude value calculated from the Fourier analysis as the ordinate and frequency as the abscissa. (a) Shows data from viewing of 3D-X-direction MM, and (b) from viewing of 3D-Z-direction MM.

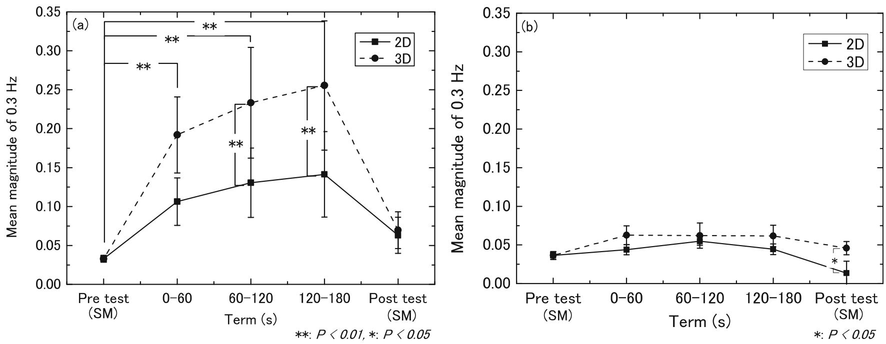

Fig. 5. Temporal change in the 0.3 Hz component in SM and Z-direction MM viewing. (a) Analysis result of sway in same direction as movie motion (Z-direction), and (b) analysis result of sway in the vertical direction relative to movie motion (X-direction).

Temporal change in the 0.3 Hz component while MM viewing was analyzed (Fig. 5, 6). Figures 5a, b show results from viewing of the Z-direction MM, and Fig. 6a, b, X-direction MM. (a) and (b) in each figure are analysis direction of the body sway: (a) is the same direction as the motion direction in the movie, and (b), the relative vertical direction.

Analysis of body sway in the motion direction of the movie (a) showed an increase of the 0.3 Hz component in the viewing of all direction motion MM, compared to the SM (pre-test). In addition, as viewing time increased, so did the 0.3 Hz component. However, we found an appreciable reduction of this component in SM viewing (post-test). Between 2D-MM and 3D-MM viewing, the magnitude at 0.3 Hz was higher in all time segments. To test for significance, two-way repeated measures ANOVA with viewing time and kind of movie (2D or 3D) as factors was performed. Significant differences were found in both the kind of movie and viewing time ($P < 0.01$) without two-factor interaction, and regardless of the motion direction. Moreover, when we used

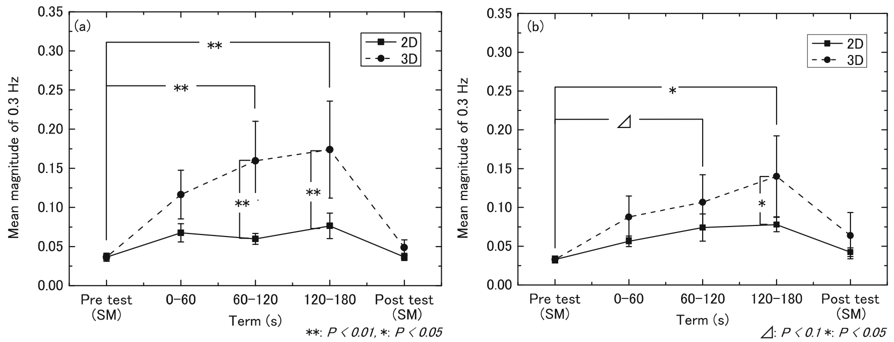

Fig. 6 Temporal change in 0.3 Hz components in SM and the X-direction MM viewing. (a) Analysis result of sway in same direction as movie motion (X-direction), and (b) analysis result of sway in vertical direction to movie motion (Z-direction).

the Tukey-Kramer method for multiple comparisons simultaneously, significant differences were found, as shown in Fig. 5a and 6a. Therefore, these results indicate that viewing of the MM significantly increases magnitude at 0.3 Hz in motion direction. In addition, magnitude at 0.3 Hz in viewing of the 3D-MM is significantly higher than that in 2D-MM.

Next, we analyzed sway in the vertical direction relative to motion in the movie (b). No significant changes were seen in sway in X-direction while viewing of the Z-direction MM, regardless of the kind of movie. By contrast, in viewing of the X-direction movie, an increase in magnitude at 0.3 Hz was seen during MM viewing. Additionally, between 3D-MM and 2D-MM viewing, the magnitude was higher in 3D-MM. Statistically significant differences were found in both the kind of movie and viewing time ($P < 0.01$) without two-factor interaction. Using the Tukey-Kramer method, significant differences were found (Fig. 6b).

4 General Discussion

In this study, we continuously measured body sway to investigate the effects of long-duration viewing on vection through binocular stereopsis. Using stabilograms, we found that changes in gravity point were in the same direction as that in the viewed movie (Fig. 3). Additionally, frequency analysis revealed a significant increase in the magnitude of 0.3 Hz sway component (Fig. 4). We inferred this specific change in body sway to be influenced by 0.3 Hz motion component in the MM. Vection is generally develop by continuous optic flow in one direction [13, 14]. However, similar to the findings of Ojima et al., we found that vection also occurs by viewing movies containing sinusoidal motion [15].

In frequency analysis, the component at 0.3 Hz in body sway increased with increase of viewing time, and decreased with the discontinuation of MM viewing (Fig. 5, 6). An increase of the 0.3 Hz component indicates an improvement in synchronization accuracy. There is a proportional relation between viewing time and synchronization accuracy of body sway in response to motion in the movie. Hence, The measurement of body sway might be effective in objectively evaluating the sensation of vection.

The 0.3 Hz component during 3D-MM viewing was significantly higher than while viewing the 2D-MM (Fig. 5, 6). This tendency was detected in each directional MM. Stereoscopic view by binocular parallax is a technique that provides humans with pseudo-depth perception. Additionally, vection is a phenomenon attributed to spatial movements. Thus, results in this study match those of previous studies and the theoretical mechanism for vection. However, during viewing of the X-direction MM, we noticed a significant cyclical swing at 0.3 Hz in the Z-direction. This swing could relate to the sole shape of humans. Postural maintenance is easier to disrupt in the horizontal than in the anteroposterior direction because feet are vertically positioned. The margin of change in gravity point in response to excessive moving in the anteroposterior direction is bigger than that in horizontal direction. Therefore, we conclude that the force of change in sway due to the sense of self-motion in the horizontal direction (X-direction) converts into an anteroposterior direction (Z-direction) to prevent a fall.

5 Conclusions

In this study, we investigated the effect of long-duration viewing by binocular stereopsis on vection using a continuous measurement of body sway. The following were demonstrated.

1. Longer the viewing time, higher is the synchrony with direction of motion in the MM. Stopping MM viewing decreases the synchrony in a gradual manner. The measurement of body sway might be effective as an objective evaluation tool for vection.
2. A 0.3-Hz component generated while viewing of the 3D-MM was significantly higher than that of 2D-MM because vection is attributed to spatial movement. Results in this study match the previous studies on theoretical mechanism behind vection.
3. By sensing self-motion in the horizontal direction, the body-sway significantly moves in a cyclical manner to the anteroposterior direction. This could be caused by conversion of the force of change in sway (due to vection) in the horizontal direction to the anteroposterior direction since center of gravity in humans is harder to disrupt in the anteroposterior direction.

References

1. Kawakita, T., Kuno, S., Miyake, Y., Watanabe, S.: Body sway induced by depth linear vection in reference to central and peripheral visual field. Jpn. J. Physiol. **50**, 315–321 (2000)
2. Edwards, A.S.: Body sway and vision. J. Exp. Psychol. **36**, 526–535 (1946)

3. Held, R., Dichigans, J., Bauer, J.: Characteristics of moving visual scenes influencing spatial orientation. Vision. Res. **15**, 357–365 (1975)
4. Schor, C.M., Lakshminarayanan, V., Narayan, V.: Optokinetic and vection responses to apparent motion in man. Vision. Res. **24**, 1181–1187 (1984)
5. Brandt, T., Dichgans, J., Koenig, E.: Differential effects of central verses peripheral vision on egocentric and exocentric motion perception. Exp. Brain Res. **16**, 476–491 (1973)
6. Zacharias, G.L., Young, L.R.: Influence of combined visual and vestibular cues on human perception and control of horizontal rotation. Exp. Brain Res. **41**, 159–171 (1981)
7. Allison, R.S., Howard, I.P., Zacher, J.E.: Effect of field size, head motion, and rotational velocity on roll vection and illusory self-tilt in a tumbling room. Perception **28**, 299–306 (1999)
8. Guerraz, M., Bronstein, A.M.: Mechanisms underlying visually induced body sway. Neurosci. Lett. **443**, 12–16 (2008)
9. Cardin, V., Smith, A.T.: Sensitivity of human visual cortical area V6 to stereoscopic depth gradients associated with self-motion. J. Neurophysiol. **106**, 1240–1249 (2011)
10. Stern, R.M., Hu, S., Anderson, R.B., Leibowitz, H.W., Koch, K.L.: The effects of fixation and restricted visual field on vection-induced motion sickness. Aviat. Space. Environ. Med. **61**, 712–715 (1990)
11. Smart, L.J., Stoffregen, T.A., Bardy, B.G.: Visually induced motion sickness predicted by postural instability. Hum. Factors **44**, 451–465 (2002)
12. Kiryu, T., Nomura, E., Bando, T., Kobayashi, N.: Time–frequency structure of image motion vectors around cybersickness intervals determined with biosignals. Displays **29**, 176–183 (2008)
13. Telford, L., Frost, B.J.: Factors affecting the onset and magnitude of linear vection. Percept. Psychophys. **53**, 682–692 (1993)
14. Andersen, G.J., Braunstein, M.L.: Induced self-motion in central vision. J. Exp. Psychol. Hum. Percept. Perform. **11**, 122–132 (1985)
15. Ojima, S., Yano, S.: Effect of depth sensation to body sway on binocular vision. IEICE Trans. Fundam. (J. Ed.) **J79–A**, 354–362 (1996)