Effect of Background Viewing on Equilibrium Systems

Hiroki Takada(✉), Yuki Mori, and Toshitake Miyakoshi

Department of Human and Artificial Intelligent Systems Graduate School of Engineering, University of Fukui, 3-9-1 Bunkyo, Fukui 910-8507, Japan
takada@u-fukui.ac.jp

Abstract. Our previous study indicated an increase in the sway values that were observed during peripheral viewing. Especially in the background, there are large differences between human binocular images and artificial stereoscopic images, to which our convergence corresponding to depth cues is not accommodated. This is why equilibrium functions are affected by peripheral viewing. In the present paper, we examine the effect of the exposure to stereoscopic video clips without the background on our equilibrium function. Fifteen healthy young males voluntarily participated and maintained the Romberg posture in stabilometry. Their stabilograms were recorded during monocular vision or binocular parallax vision using semipermeable smart glasses. We also measured the body sway with the subjects' eyes closed 0–3 min after the exposure to the video clips. A statistical comparison indicated that our equilibrium function is significantly affected by video clips with the background 0–2 min after the exposure to the video clips.

Keywords: Visually-induced motion sickness (VIMS) · Stabilometry · Stereoscopic video clips · Background

1 Introduction

When humans maintain an upright posture, the body always sways. The base supporting the body is a narrow area comprising the bilateral feet. To ensure a stable posture, it is necessary to control the feet along a spatial perpendicular line from the center of gravity within the narrow base of support [1]. Although the floor reaction to actually support the body is provided by the bilateral legs, since the center of gravity of the head, upper limbs, and trunk, accounting for 2/3 of the body weight, is present at 2/3 of the height from the floor surface, the center of gravity constantly sways in the space, and balance is maintained by controlling the relationship with the center of pressure, serving as a fulcrum to support the body, within the base of support [2, 3]. The reflex to return a swaying body to its original position is termed the righting reflex. Physiologically, it is a body equilibrium function controlled by an involuntary regulatory system [4]. Elucidation of the function is essential to diagnose symptoms accompanying equilibrium disorders, such as progressive cerebellar degeneration, basal ganglia disorder, and Parkinson's disease [5].

M. Antona and C. Stephanidis (Eds.): UAHCI 2015, Part II, LNCS 9176, pp. 255–263, 2015.
DOI: 10.1007/978-3-319-20681-3_24

A body equilibrium function test, stabilometry, is considered useful to comprehensively evaluate the equilibrium function. Stabilometry is generally performed on standing in Romberg's posture in which the feet are together and the eyes open and closed, and for 60 s each, sways of the center of pressure (COP) are measured, which is regarded as a projection of the center of gravity. To increase the diagnostic value of stabilometry, measurement methods and analytical indices of stabilograms have been proposed [6]. The analytical indices include the total length of body sway and locus length per unit area. The latter is considered to represent micro changes in postural control and serve as a scale of proprioceptive postural control. Romberg's posture is an upright posture with the feet placed together. It is an unstable standing posture because the base of support is narrow, and so body sway becomes marked, and a reduced equilibrium function is likely to appear in stabilograms.

Stabilograms measured by stabilometry represent the process accompanied by irregular swaying components, and time-course sways in lateral and front-back directions in stabilograms can be independently assessed [7]. Stochastic differential equations (SDEs)

$$\frac{\partial x}{\partial t} = -\frac{\partial}{\partial x} U_x(x) + w_x(t), \tag{1.1}$$

$$\frac{\partial y}{\partial t} = -\frac{\partial}{\partial y} U_y(y) + w_y(t), \tag{1.2}$$

are used as mathematical models to describe sways of the center of gravity [8]. The described time-courses are considered to be generated through the Markov process, and when there is no anomaly, there is a relationship between the distribution in the measured direction, G_z, and temporally averaged potential constituting the stochastic differential equation, U_z, as follows: ($z = x, y$)

$$U_z(z) = -\frac{1}{2} \ln G(z) + const. \tag{2}$$

The stochastic differential equation describes minimum stable movement local of the potential surface, and a high density at the measurement point, z, is expected to be around the minimal points.

We focus on instability in the mathematical model of the body sway. In order to discuss metamorphism of the potential function U_z in the SDEs, it is important for us to take nonlinearity of the function into consideration. The degeneration in the function U_z would be lifted due to the perturbation actualized by the experimental load for our balance system. For instance, the alcoholic intake represses function of the cerebrum, and motor disturbance can be seen in the clinical observation.

To begin with, upright postures is considered to be instable. When humans maintain an upright posture, the body always sways. To ensure the posture, it is necessary to control the feet along a spatial perpendicular line from the center of gravity within the narrow base of support [1]. In the Romberg posture, the base supporting the body is the narrowest. The posture could become more instable on a tilting table [9].

Stereoscopic videos utilizing binocular stereoscopic vision often cause unpleasant symptoms of asthenopia, such as headache and vomiting, depending on the audiovisual condition [10]. Ataxia in simulator-induced sickness has been reported. The influence of visual induced motion sickness on the body has been measured employing subjective scales, such as the Simulator Sickness Questionnaire (SSQ) [11], and by quantitatively investigating the relationship between external factors and internal conditions using physiological indices [12–15], such as respiratory function, electro - cardiogram, skin electrical activity, electrogastrogram, and the body sway.

Although mechanism of the symptoms does not have been elucidated and been unclear, our previous study showed increase in sway values that were obsereved during peripheral viewing [16, 17]. Especially in the background, there are large difference between human binocular image and artificial stereoscopic image to which our convergence corresponding to depth cues is not accommodated. That is why equilibrium function affect from peripheral viewing. In this study, we examine effect of the exposure to stereoscopic video clips without the background on our equilibrium function.

2 Materials and Methods

Fifteen healthy young males (age, 21–24 years), who may have had any otorhinolaryngologic or neurological diseases in the past, voluntarry participated in this study. The experiment was sufficiently explained to the subjects, following which written consent was obtained from them.

In this experiment, the body sway was measured while viewing 2D/3D video clips with use of semipermeable smart glasses that displayed content in the Sky Crystal (Olympus Memory Works Ltd. Co., Tokyo), which was modified with permission from the company, and was used as the visual stimulus in this experiment. The stimulus includes spheres fixed in four corners, which supplies perspective. A sphere complexly ambulated in a video clip. The subjects stood on the detection stand of a stabilometer GS3000 (Anima Co. Ltd., Tokyo), without moving, with their feet together in the Romberg posture, for 30 s before the sway was recorded. Each sway of the COP was then recorded at a sampling frequency of 20 Hz. The subjects were instructed to maintain the Romberg posture during the trials. For the first 60 s, the subjects were asked to do the following:

I. Gaze at a static circle with a diameter of 3 cm (Control).
II. Peripherally viewing video clips without pursuing the ambulated sphere (Fig. 1a).
III. Peripherally viewing video clips as same in II without the backgrounds (Fig. 1b)

We also measured body sway with eyes closed 0–3 min after the exposure to them, and the Post-stabilogram were composed every 1 min. We calculated sway values that were obtained from stabilograms during/after exposure to video clips with/without the background (i.e. clouds in the sky/plain gray background).

The circle (I) was placed before the subjects, 2 m away, at their eye level. Stereoscopic video clips (II)/(III) and their monocular (2D) vision were shown to subjects on the binocular parallax 3D display. We measured the body sway and the subjective

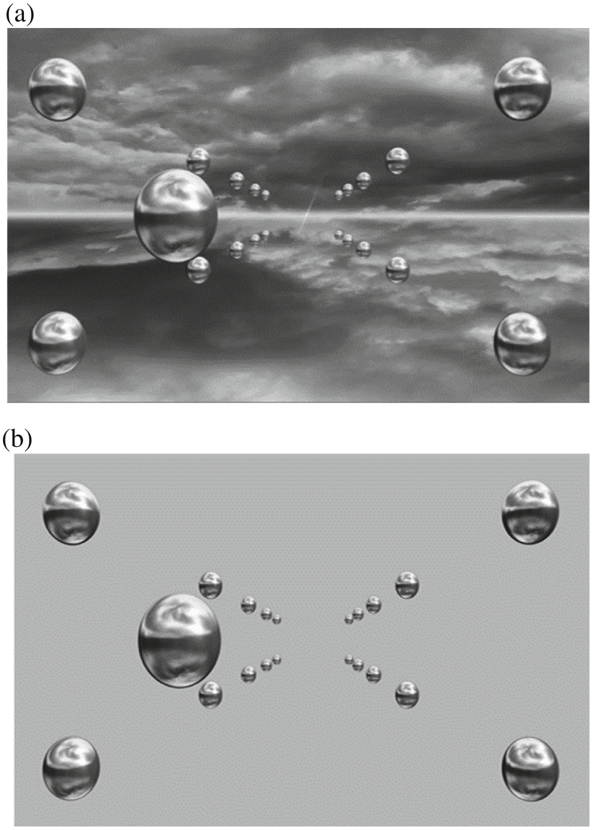

Fig. 1. One cut of the video clips with backgrounds (a) and without background (b)

evaluation for each vision (I) Control, (II)-2D, (II)-3D, (III)-2D, and (III)-3D situation randomly, according to the abovementioned protocol.

We conducted the stabilometry with eyes open/closed. The experimental periods with eyes open and closed was designed in our experimental protocol to evaluate the severity of the VIMS during and after viewing the video clips. In stabilometry, the COP on an x-y plane was recorded at each time step where x and y directions were defined as the right and the anterior planes on their faces, respectively. Stabilograms were obtained each experimental period from the time series of their COP. Finally, we calculated the new index sparse density (SPD) (See Appendix), and the previously stated sway values such as area of sway, total locus length, total locus length per unit area, defined in Suzuki *et al.* [6].

The aforementioned indices were calculated from each stabilogram recorded with the eyes open/closed. Any two of the following were assumed to be potentially important influencing factors: the solidity of the subjects' vision (2D/3D), existence of the backgrounds in the video clips, and persistency of the visual stimulus. A two-way analysis of variance (ANOVA) was conducted 15 times on these factors. In addition, the influence of the exposure to the video clips on our equilibrium system was investigated in comparison with the control data (I). The sway values during and after the viewing of the (I), (II)-2D, (II)-3D, (III)-2D, and (III)-3D stimuli were compared using Wilcoxon signed-rank tests for multiple comparisons.

3 Results and Discussion

Most stabilograms observed 0–2 min after viewing a 3D video clip with the background (II)-3D were dispersed compared with the control stabilograms. In contrast, no persistent tendency was observed in the stabilograms measured 2–3 min after the cutoff of the visual stimulus. However, most stabilograms observed 0–2 min after exposure to video clips without the background (III)-2D/3D were not dispersed compared with the control stabilograms. The stabilograms were dispersed three minutes after the cutoff of the visual stimulus.

The two-way ANOVA on the sway values did not reveal an interaction between any pair of two factors. According to the two-way ANOVA whose factors were set as the solidity and the persistency, the former primary effect was observed from the total locus length per unit area during/after viewing the video clips with the background. Furthermore, the main effect of the background presence was observed from the total locus length per unit area during/after exposure to a 2D video clip in accordance with two-way ANOVA, whose factors were set to be the presence of the background and the persistency of the visual stimulus. We also found the same main effect while calculating the SPD S_3 during/after exposure to a 3D video clip, in accordance with two-way ANOVA.

Post hoc tests of the total locus length indicated a significant difference between the control and (II)-3D stabilograms 1–2 min after viewing a 3D video clip with the background as shown in Post 1–2 in Fig. 2a. The latter was significantly greater than the control total locus length. One to two minutes after viewing the video clips, the total locus length for a stereoscopic video clip with the background (II)-3D was significantly greater than that for a 2D video (II)-2D (Figs. 2a, 3a).

As a result of post hoc tests of the SPD, the control equilibrium system was regarded to exhibit higher stability than that experienced after 0–1 min of exposure to a 3D video clip with the background (Fig. 2b). Moreover, the control equilibrium system was regarded to be more stable than that after 2–3 min of exposure to a 2D video clip without the background (Fig. 3b).

The other sway values, 0–2 min after the cutoff of the visual stimulus, also revealed that our equilibrium system was affected by the video clips with the background. The sway values 2–3 min after the cutoff of the visual stimulus suggested that our equilibrium system was affected by the video clips with/without the background (Fig. 3b). The persistency of the upright posture might deteriorate in our equilibrium function. Conversely, the effect of the exposure to the video clips on our equilibrium function can be continued for 0–2 min. In contrast, the sway values 0–2 min after the cutoff of

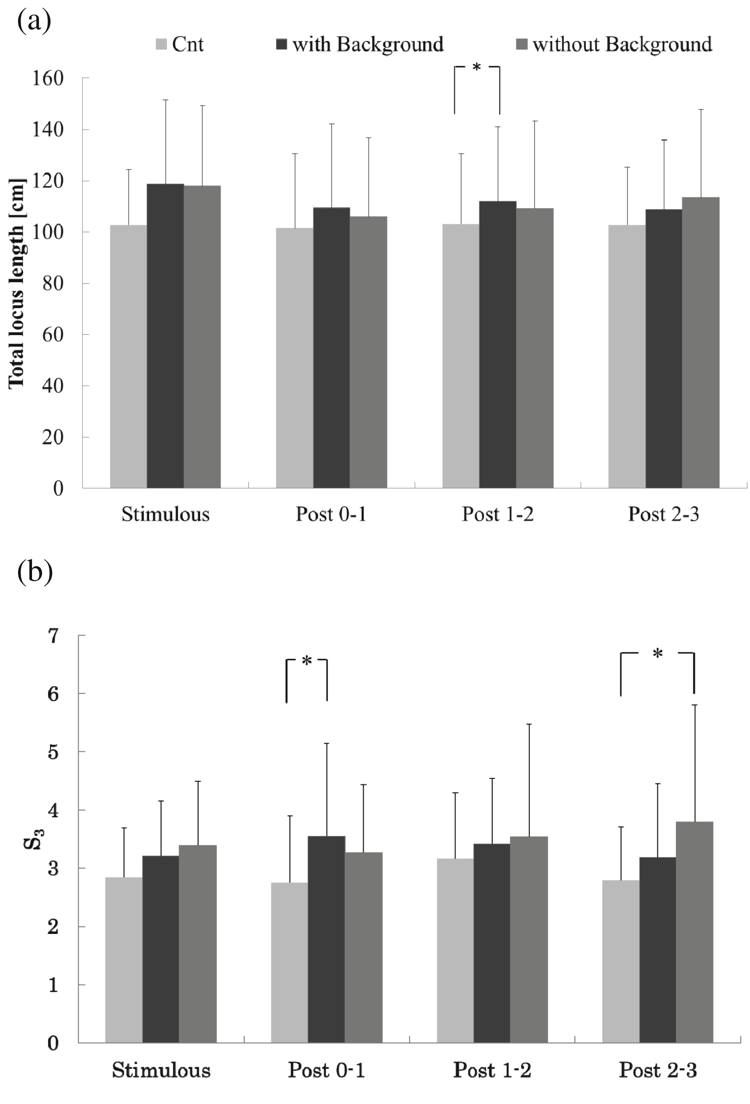

Fig. 2. Typical sway values during/after a 3D video clip: total locus length (a), SPD S_3 (b)

the visual stimulus suggested that our equilibrium system was not affected by the video clips without the background. Subjects tracked the sphere in the video clips owing to the absence of a background, and the VIMS did not occur by visual pursuit. Peripheral viewing could induce motion sickness, as our previous studies suggested. In future, we will discuss the metamorphism of the potential function (2) induced by this kind of VIMS.

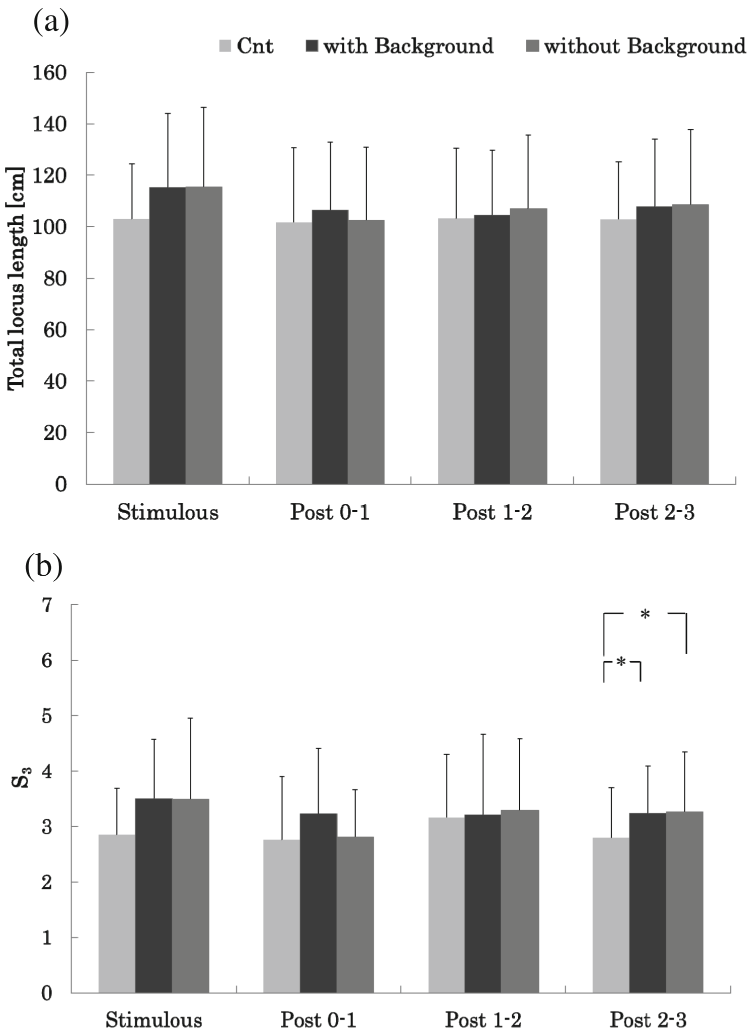

Fig. 3. Typical sway values during/after a 2D video clip: total locus length (a), SPD S_3 (b)

Acknowledgements. This work was supported in part by the Ministry of Education, Culture, Sports, Science and Technology, through a Grant-in-Aid for Scientific Research (C) (Number 26350004).

Appendix: Sparse Density

Herein, we describe the new quantification indices, sparse density (SPD) [18]. The SpD is defined as the average of the ratio $G_j(1)/G_j(k)$ for j = 3, 4, …, 20, where $G_j(k)$ is the number of divisions with more than k measured points. A stabilogram is divided into quadrants whose length of a side is j times longer than the resolution. If the center of gravity is stationary, the SPD value is unity. If there are variations in the stabilograms, the SPD value is greater than unity. Thus, the SPD depends on the characteristics of the stabilogram and form around minimal points of the temporally averaged potential function in the stochastic differential equations.

For the data analysis, the anterior-posterior direction was considered to be independent of the lateral direction [7]. Stochastic differential equations (SDEs) were proposed as mathematical models to generate the stabilograms [8, 19, 20]. The variance in the stabilogram depends on the form of the temporally averaged potential function in the SDE, which generally has multiple minimal points. In the vicinity of these points, local stable movement with a high-frequency component was generated as a numerical solution to the SDE. We can therefore expect a high-density of observed COP in this area of the stabilogram [18]. Therefore, SPD is regarded as an index for this measurement.

References

1. Winter, D.A., Patla, A.E., Prince, F., Ishac, M.: Stiffness control of balance in quiet standing. J. Neurophysiol. **80**, 1211–1221 (1998)
2. Gatev, P., Thomas, S., Kepple, T., Hallett, M.: Feedforward ankle strategy of balance in quiet stance in adults. J. Physiol. **514**, 915–928 (1999)
3. Loram, D., Kelly, S.M., Laike, M.: Human balancing of an inverted pendulum: is sway size controlled by ankle impedance? J. Physiol. **523**, 879–891 (2001)
4. Kaga, K.: Structure of Vertigo. Kanehara & Co., Ltd., Tokyo, 23–26, 95–100 (1992)
5. Okawa, T., Tokita, T., Shibata, Y., Ogawa, T., Miyata, H.: Stabilometry: significance of locus length per unit area (L/A). Equilib. Res. **54**, 283–293 (1995)
6. Suzuki, J., Matsunaga, T., Tokumatsu, K., Taguchi, K., Watanabe, I.: Q & A and a manual in stabilometry. Equilib. Res. **55**, 64–77 (1996). (in Japanese)
7. Goldie, P.A., Bach, T.M., Evans, O.M.: Force platform measures for evaluating postural control: reliability and validity. Arch. Phys. Med. Rehabil. **70**, 510–517 (1986)
8. Takada, H., Kitaoka, Y., Shimizu, Y.: Mathematicha index and model in stabilometry. Forma **16**, 17–46 (2001)
9. Fukui, Y., Mori, Y., Kinoshita, F., Takada, H.: A study of body sway on slopes with tilt angles of 10° and 20°. IEICE Technical report 114 (361), 7–10 (2014)
10. Ukai, K., Howarth, P.A.: Visual fatigue caused by viewing stereoscopic motion images. Displays **29**, 106–116 (2008)
11. Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G.: Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int. J. Aviat. Psychol. **3**, 203–220 (1993)
12. Holomes, S.R., Griffin, M.J.: Correlation between heart rate and the severity of motion sickness caused by optokinetic stimulation. J. Psychophysiol. **15**, 35–42 (2001)
13. Himi, N., Koga, T., Nakamura, E., Kobashi, M., Yamane, M., Tsujioka, K.: Differences in autonomic responses between subjects with and without nausea while watching an irregularly oscillating video. Auton. Neurosci. Basic Clin. **116**, 46–53 (2004)
14. Yokota, Y., Aoki, M., Mizuta, K.: Motion sickness susceptibility associated with visually induced postural instability and cardiac autonomic responses in healthy subjects. Acta Otolaryngol. **125**, 280–285 (2005)

15. Scibora, L. M., Villard, S., Bardy, B., Stoffregen, T. A.: Wider stance reduces body sway and motion sickness. In: Proceedings of VIMS, pp. 18–23 (2007)
16. Takada, M., Fukui, Y., Matsuura, Y., Sato, M., Takada, H.: Peripheral viewing during exposure to a 2D/3D video clip: effects on the human body. Environ. Health Prev. Med. (2014). doi:10.1007/s12199-014-0424-4
17. Takada, M., Miyao, M., Takada, H.: Subjective evaluation of peripheral viewing during exposure to a 2D/3D video clip. In: Proceedings of IEEE VR (2015) (to appear)
18. Takada, H., Kitaoka, Y., Ichikawa, M., Miyao, M.: Physical meaning on geometrical index for stabilometry. Equilib. Res. **62**, 168–180 (2003)
19. Newell, K.M., Slobounov, S.M., Slobounova, E.S., Molenaar, P.C.: Stochastic processes in postural center of pressure profiles. Exp. Brain Res. **113**, 158–164 (1997)
20. Collins, J.J., De Luca, C.J.: Open-loop and closed-loop control of posture: a random-walk analysis of center of pressure trajectories. Exp. Brain Res. **95**, 308–318 (1993)