Changes of Potential Functions While Maintaining Upright Postures After Exposure to Stereoscopic Video Clips

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Abstract. Asthenopia and visually induced motion sickness (VIMS) is a well-known phenomenon in viewing video, playing video games and others. In previous studies, we pointed out peripherally viewing as a pathogenesis of the VIMS whose evidence was also shown and described the anomalous sway by using mathematical models. Stochastic differential equations are known to be a mathematical model of the body sway. We herein discuss the metamorphism in the potential functions to control the standing posture during/after the exposure to stereoscopic video clips.

Keywords: Style · Visually induced motion sickness (VIMS) · Stabilometry · Stereoscopic image · Stochastic differential equation (SDE) · Temporally averaged potential function (TAPF)

1 Introduction

Current 3D display mechanisms include stereoscopy, integral photography, the differential binocular vision method, volumetric display [1], and holography [2]. With these rapid progresses in image processing and stereoscopic technologies, images are not only available on television but also in theaters, on game machines, and elsewhere. Unpleasant symptoms such as asthenopia, dizziness and nausea have been observed in subjects viewing three-dimensional (3D) films in some individuals [3]. While the symptoms of general motion sickness include dizziness and vomiting, the phenomenon of visually-induced motion sickness (VIMS) is not fully understood. Currently, there is not enough knowledge accumulated on the effects of stereoscopic images on the living body and basic research is thus important [4].

At present, VIMS is explained by the sensory conflict theory [5]. In humans, the standing posture is maintained by the body's balance function that is an involuntary

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physiological adjustment mechanism referred to as the "righting reflex". In order to maintain the standing posture in the absence of locomotion, the righting reflex is initiated in the following sensory system and processed in the cerebral cortex. Sensory receptors, such as visual inputs, auditory, and vestibular functions, and proprioceptive inputs from the skin, muscles, and joints, are referred to maintain the body's balance function [6]. According to the sensory conflict theory, motion sickness is a response to the conflict generated by a discrepancy between received and previously stored messages. Variations are thus expected that may arise from acquired experiences. Contradictory messages originating from different sensory systems, or the absence of a sensory message that is expected in a given situation, are thought to lead to the feeling of sickness. Spatial localization of self becomes unstable and produces discomfort. Researchers generally agree that there is a close relationship between the vestibular and autonomic nervous systems both anatomically and electrophysiologically. The motion sickness is considered to be caused by the excess signal from the vestibular to the hypothalamus. This view strongly indicates that the equilibrium system is associated with the symptoms of motion sickness [7] and provides a basis for the quantitative evaluation of motion sickness based on body sway, an output of the equilibrium system.

Stabilometry is a useful test of body equilibrium for investigating the overall equilibrium function. Stabilometry methods are presented in the standards of the Japanese Society for Equilibrium Research and in international standards [8]. Stabilometry is a simple test in which 60 s recording starts when body sway stabilizes [9]. Objective evaluation is possible by the computer analysis of the speed and direction of the sway, enabling diagnosis of a patient's condition [10].

In previous studies, subjective exacerbation and deterioration of equilibrium function were observed after peripheral viewing of 3D video clips [11]. This persistent influence has been observed while subjects view a poorly depicted background element peripherally, which generates depth perception that contradicts daily life. Moreover, it has been mentioned on whether the sway values depend on the viewing period [12]. In this mathematical analysis, we examined the 3D viewing effect on systems of the equilibrium function to determine whether it is dependent on the exposure time.

2 Mathematical Models of Body Sway

In stabilogram, variables x (lateral direction) and y (anterior/posterior direction) are regarded to be independent [13]. The linear stochastic differential equation (Brownian motion process) have been proposed as a mathematical model to describe body sway [14–16]. To describe the individual body sway, we especially show that it is necessary to extend the following nonlinear stochastic differential equations:

$$\frac{\partial x}{\partial t} = -\frac{\partial}{\partial x} U_x(x) + w_x(t) \tag{1}$$

$$\frac{\partial y}{\partial t} = -\frac{\partial}{\partial y} U_y(y) + w_x(t) \tag{2}$$

where $w_x(t)$ and $w_y(t)$ are pseudorandom numbers produced by white noise [17]. The following formula describes the relationship between the distribution in each direction; $G_x(x), G_y(y)$, and the temporal averaged potential constituting the stochastic differential equations (SDEs);

$$U_x(x) = -\frac{1}{2}\ln G_x(x) + const. \tag{3}$$

$$U_y(y) = -\frac{1}{2}\ln G_y(y) + const. \tag{4}$$

The variance of stabilograms generally depends on the temporal averaged potential function (TAPF) with several minimum values when it follows the Markov process without abnormal dispersion. SDEs can represent movements within local stability with a high-frequency component near the minimal potential surface, where a high density at the measurement point is expected.

3 Materials and Methods

Sixteen healthy male subjects (mean age ± standard deviation: 22.4 ± 0.8 years) participated voluntarily in the study. We ensured that the body sway was not affected by environmental conditions. We used an air conditioner to adjust the temperature at 25 °C in the exercise room. The experiment was explained to all subjects and written informed consent was obtained in advance.

In this experiment, we conducted a stabilometry test with subjects peripherally viewing 2D and 3D images. The device used was a Wii Balance Board (Nintendo, Kyoto). The sampling frequency of the Wii Balance Board was 20 Hz. The subjects stood upright on the device in Romberg's posture. We conducted two types of measurements: (I) after resting for 30 s, the body sway of each subject was measured for one minute with opened eyes and for three minutes with closed eyes consecutively, and (II) after resting for 30 s, the body sway of each subject was measured for two minutes with opened eyes and three minutes with closed eyes consecutively. However, in the two-minute measurement test with opened eyes, we also collected data for a period of one minute after the test. Experiments were performed in a dark room to avoid irritation from sources other than the video. The 2D or 3D images were shown on a 3D KDL 40HX80R display (SONY, Tokyo) placed two meters away from the subject. In the image used in the experiment, spheres were fixed at the four corners, while another sphere moved around the screen. A comparison was then made with subjects who were asked to gaze simply at a point 2 m in front of them at eye level in the case where no image was displayed. The experiments were carried out in random order. Each experiment was carried out on a separate day.

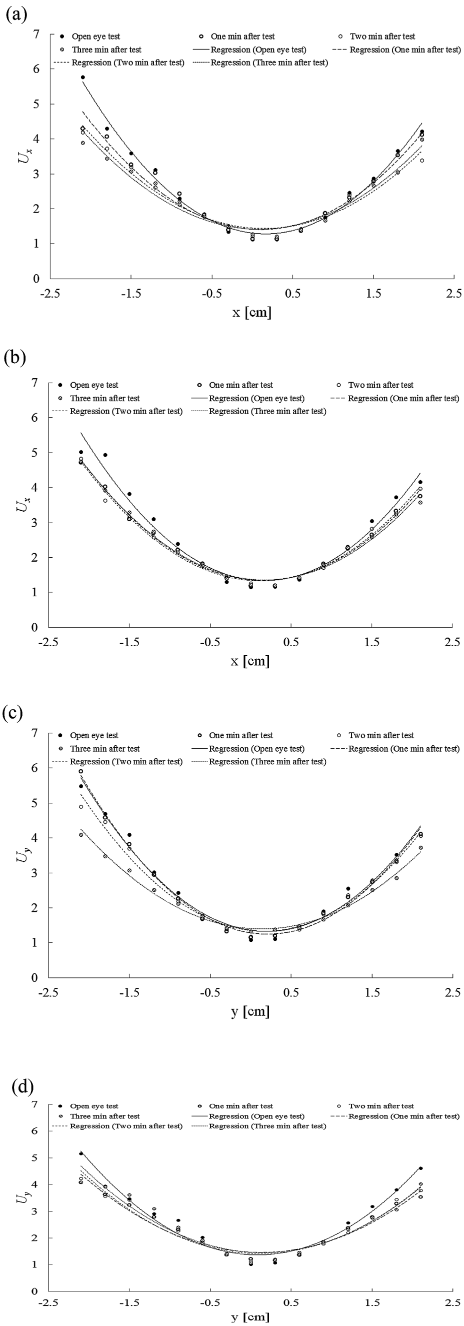

Fig. 1. Temporal averaged potential function derived from stabilograms during/after exposure to video clips; a 2D video clip (a), (c); a 3D video clip (b), (d). The TAPFs $U_x(x)$ in (a), (b) can be compared with $U_y(y)$ in (c), (d).

4 Results

The x-y coordinates were recorded for each sampled time point collected in the tests that were conducted with open and closed eyes, and the quantitative indices were calculated. The data were converted to time series and included the position of the center of gravity in the x (the right direction, designated as positive) and y (the anterior direction, designated as positive) directions in each of the open and closed eye tests.

Histograms of the stabilograms obtained from tests were prepared. Each stabilogram was processed by subtracting the series mean from each time-series to set the center of the stabilogram at the origin (0, 0). We compared histograms that were composed of all subjects' stabilograms and compared in the x and y directions, with eyes open and closed. The TAPFs in viewing 2D and 3D images were determined from the histograms using Eq. (3). The TAPFs were herein regressed by the following polynomial of degree 2 (Fig. 1).

$$\hat{U}_x(x) = a_x x^2 + b_x x + c \tag{5}$$

$$\hat{U}_y(y) = a_y y^2 + b_y y + c \tag{6}$$

5 Discussion

Constructing the nonlinear SDEs from the individual stabilograms in accordance with Eq. (2), their temporally averaged potential functions U_x, U_y have plural minimal points. However, a parabolic function is appropriate for the potential which is derived from all subjects' distribution (Fig. 1).

The following SDE could be obtained approximately as a mathematical model for the motion process with substituting an optimal regression polynomial (5), (6) to the first term of the right-hand side in Eqs. (3) and (4).

$$\frac{\partial x}{\partial t} = -(2a_x x + b_x) + w_x(t) \tag{7}$$

$$\frac{\partial y}{\partial t} = -(2a_y y + b_y) + w_x(t) \tag{8}$$

a_z and b_z are estimated as regression coefficients of the optimal polynomial of degree 2 by the least square method $(z = x, y)$. The second- order coefficient a_x in Eq. (5) decreased with eyes closed (Tables 1 and 2). Especially in the anterior/posterior direction y, the second-order co-efficient a_y in Eq. (6) decreased with eyes closed after the exposure to the 3D video clip (Table 2). Moreover, the coefficient of determination R^2 can be estimated to evaluate each regression. The value R^2 shows the suitability for the regression curve and the relative importance of correlations of different magnitudes [18]. The value 0.9 seems to be sufficiently large as a coefficient of determination R^2 because the correlation coefficient R attains to 0.95. In most cases, the coefficient of determination $R^2 > 0.9$ as shown in Tables 1 and 2. Fluctuations could be observed in the neighborhood of a minimal point. The variance in the stabilogram depends on the form of the potential function in the SDE; therefore, the SPD is regarded as an index for its measurement [19].

Table 1. Coefficients of TAPFs with eyes open for each component during/after the exposure to the 2D video clip for two minutes: the lateral direction x (a), the anterior/posterior direction (b).

(a)

component x

Two min 2D viewing	*a*	*b*	*c*	R^2
Open eye test	0.85	-0.28	1.30	0.92
One min after test	0.69	-0.15	1.41	0.97
Two min after test	0.58	-0.17	1.45	0.94
Three min after test	0.59	-0.10	1.42	0.98

(b)

component y

Two min 2D viewing	*a*	*b*	*c*	R^2
Open eye test	0.83	-0.33	1.36	0.90
One min after test	0.85	-0.35	1.28	0.89
Two min after test	0.76	-0.26	1.35	0.92
Three min after test	0.57	-0.15	1.41	0.95

We have examined whether the exposure to the 3D video clips affects the equilibrium function [12]. Conducting the stabilometry, we verified that 3D viewing the effect on our equilibrium function depends on exposure time. The SPD significantly increased after the exposure to the 3D video clip or the 2D video clip for two minutes. In these cases, sufficient loadings change the form of the TAPFs in the SDEs (1) and (2).

When viewing a 2D image, sway is increased depending on the viewing time [12]. Moreover, when viewing an image for two minutes, the area of sway and the total locus length were significantly smaller for the open eye test compared to the values elicited when the image had been viewed two minutes after the test. Therefore, we considered that after the image had been viewed, equilibrium function still remained. Moreover, regardless of the solidity images (2D/3D), the area of sway and the total locus length were significantly smaller in the open eye test compared to the values elicited in the case where these images were viewed three minutes after the test. The results of the control were the same as these. Accordingly, the reason for the sway increase in the case when the images were viewed three minutes after the test is not attributed to the effects of VIMS but to the effects of fatigue. Therefore, we considered that the change in viewing time affected the equilibrium function system, and that viewing a 3D image for two minutes affected the equilibrium function system for a period of two minutes after the images had been viewed.

Table 2. Coefficients of TAPFs with eyes open for each component during/after the exposure to the 3D video clip for two minutes: the lateral direction x (a), the anterior/posterior direction (b).

(a)

component x

Two min 3D viewing	*a*	*b*	*c*	R^2
Open eye test	0.82	-0.28	1.36	0.93
One min after test	0.68	-0.20	1.36	0.94
Two min after test	0.69	-0.17	1.34	0.96
Three min after test	0.66	-0.23	1.38	0.92

(b)

component y

Two min 3D viewing	*a*	*b*	*c*	R^2
Open eye test	0.81	-0.14	1.38	0.98
One min after test	0.59	-0.15	1.47	0.96
Two min after test	0.63	-0.14	1.42	0.97
Three min after test	0.64	-0.19	1.47	0.94

The sway value total locus length was increased after the exposure to these video clips, which might be caused by the diminution of the gradient in the bottom of the parabolic potential function (Fig. 1). We herein note that it is important to focus on the form of the potential function. We have succeeded in estimating the decrease in the gradient of the potential function by using the SPD. This tendency was enhanced by the exposure to the 3D video clip.

In this study, we observed the VIMS by conducting the stabilometry. The sway values were evaluated during/after peripherally viewing video clips. On the contrast, it is known that there are two different cortial streams (vental and dorsal). This division of visual information is traditionally separated into an object and spatial vision [20] or color/form and motion vision [21]. The later proceeds in an unconscious state, which may be corresponding to the 3D sickness induced by peripherally viewing. We will examine whether the exposure to sufficient loadings of 3D video clips affects the brain activity in the dorsal stream in the next step.

Previously, we evaluated body sway by conducting stabilometry studies with simply used of the analytical indices for stabilograms [12]. In this study, we furthermore obtained TAPFs in the SDEs as mathematical models of the body sway. We also examined whether there is remarkable metamorphism in the potential functions to control the standing posture during/after the exposure to stereoscopic video clips. As a result, we verified that 3D viewing effects on our equilibrium function depends on exposure time.

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References

1. Suyama, S., Date, M., Takada, H.: Three dimensional display system with dual frequency liquid crystal varifocal lens. Jpn. J. Appl. Phys. **39, Part 1**(2A), 480–484 (2000)
2. Gabor, D.: A new microscopic principle. Nature **161**, 777–779 (1948)
3. International standard organization: IWA3: 2005 image safety-reducing determinism in a time series. Phys. Rev. Lett. **70**, 530–582 (1993)
4. Sumio, Y., Shinji, I.: Visual comfort and fatigue based on accommodation response for stereoscopic image. Inst. Image Inf. Telev. Eng. **55**(5), 711–717 (2001)
5. Reason, J.T., Brand, J.J.: Motion Sickness. Academic Press, London (1975)
6. Okawa, T., Tokita, T., Shibata, Y., Ogawa, T., Miyata, H.: Stabilometry: significance of locus length per unit area (L/A) in patients with equilibrium disturbances. Equilib. Res. **55** (3), 283–293 (1995)
7. Barmack, N.H.: Central vestibular system: vestibular nuclei and posterior cerebellum. Brain Res. Bull. **60**, 511–541 (2003)
8. Japan Society for Equilibrium Research: Standard of stabilometry. Equilib. Res. **42**, 367–369 (1983)
9. Kaptyen, T.S., Bles, W., Njiokiktjien, C.J., Kodde, L., Massen, C.H., Mol, J.M.: Standarization in platform stabilometry being a part of posturography. Agreessologie **24**, 321–326 (1983)
10. Hase, M., Ohta, Y.: Meaning of barycentric position and measurement method. J. Environ. Eng. **8**, 220–221 (2006)
11. 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. **20**, 79–89 (2015)
12. Yoshikawa, K., Kinoshita, F., Miyashita, K., Sugiura, A., Kojima, T., Takada, H., Miyao, M.: Effects of two-minute stereoscopic viewing on human balance function. In: Antona, M., Stephanidis, C. (eds.) UAHCI 2015. LNCS, vol. 9176, pp. 297–304. Springer, Heidelberg (2015)
13. 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)
14. Emmerrik, R.E.A., Van Sprague, R.L., Newell, K.M.: Assessment of sway dynamics in tardive dyskinesia and developmental disability: sway profile orientation and stereotypy. Moving Dis. **8**, 305–314 (1993)
15. 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)
16. 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)
17. Takada, H., Kitaoka, Y., Shimizu, Y.: mathematical index and model in stabilometry. Forma **16**, 17–46 (2001)
18. Sokal, R.R., Rohlf, F.J.: Introduction to Biostatistics. W.H. Freeman and Company, San Francisco (1973)
19. Takada, H., Kitaoka, Y., Ichikawa, M., Miyao, M.: Physical meaning on geometrical index for stabilometry. Equilib. Res. **62**, 168–180 (2003)
20. Ungerleider, L.G., Mishkin, M.: Two cortical visual systems. In: Ingle, D.J., Mansfield, R.J. W., Goodale, M.A. (eds.) The Analysis of Visual Behavior, pp. 549–586. MIT Press, Cambridge (1982)
21. Van Essen, D.C., Maunsell, J.H.R.: Hierarchical organization and functional streams in the visual cortex. Trends in Neurosci. **6**, 370–375 (1983)