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Comparison of Form in Potential Functions while Maintaining Upright Posture during Exposure to Stereoscopic Video Clips

Kenichiro KUTSUNA, Yasuyuki MATSUURA, Kazuhiro FUJIKAKE, Masaru MIYAO and Hiroki TAKADA, *Member, IEEE*

Abstract— **Visually induced motion sickness (VIMS) is caused by sensory conflict, the disagreement between vergence and visual accommodation while observing stereoscopic images. VIMS can be measured by psychological and physiological methods. We propose a mathematical methodology to measure the effect of three-dimensional (3D) images on the equilibrium function. In this study, body sway in the resting state is compared with that during exposure to 3D video clips on a liquid crystal display (LCD) and on a head mounted display (HMD). In addition, the Simulator Sickness Questionnaire (SSQ) was completed immediately afterward. Based on the statistical analysis of the SSQ subscores and each index for stabilograms, we succeeded in determining the quantity of the VIMS during exposure to the stereoscopic images. Moreover, we discuss the metamorphism in the potential functions to control the standing posture during the exposure to stereoscopic video clips.**

I. Introduction

The use of three-dimensional (3D) images has been spreading rapidly. Despite the increase in the number of 3D display products and numerous studies on stereoscopic vision, the influence of stereoscopic vision on the human body is not sufficiently understood. However, symptoms such as eye fatigue and 3D sickness have been noted when viewing 3D films for a prolonged period of time; therefore, it is important to consider the safety of viewing virtual 3D content.

The human standing posture is maintained by the body's balance function, which is an involuntary physiological adjustment mechanism termed the righting reflex [1]. The righting reflex, centered in the nucleus ruber, is essential for maintaining a standing posture in the absence if locomotion. Sensory signals ranging from visual inputs and auditory and vestibular inputs to proprioceptive inputs from the skin, muscles, and joints are involved in the body's balance function [2]. The evaluation of this function is indispensable for diagnosing equilibrium disturbances such as cerebellar degenerations, basal ganglia disorders, and Parkinson's disease in patients [3].

K. Kutsuna is with Faculty of Education, Shizuoka University, 836 Oya Suruga-ku Shizuoka, Shizuoka, 422-8529 Japan (e-mail: kutsuna@shobunka.com).

Y. Matsuura is with Center of Career Development and Support, University of Fukui, 3-9-1 Bunkyo Fukui, Fukui, 910-8507 Japan (corresponding author to provide phone: +81-776-27-8795; fax: +81-776-27-8420; e-mail: matuura@u-fukui.ac.jp)

K. Fujikake is with Systems Safety Research Group, The Institute for Science of Labour, 2-8-14 Sugao Miyamae-ku Kawasaki, Kanagawa, 216-8501 Japan (e-mail: fujikake@nagoya-u.jp).

M. Miyao is with Graduate School of Information Science, Nagoya University, Furo-cho Chikusa-ku Nagoya, Aichi, 464-8603 Japan (e-mail: mmiyao@is.nagoya-u.ac.jp).

H. Takada is with Graduate School of Engineering, University of Fukui, 3-9-1 Bunkyo Fukui, Fukui, 910-8507 Japan (e-mail: takada@u-fukui.ac.jp)

Stabilometry has been used to evaluate this equilibrium function qualitatively and quantitatively. A projection of a subject's center of gravity onto a detection stand is measured as an average of the center of pressure (COP) of both feet. The COP is traced for each time step, and the time series of the projections is traced on an x-y plane, where x and y express lateral and anterior/posterior components, respectively. By connecting the temporally vicinal points, a stabilogram is created. Several parameters such as the area of sway (A), total locus length (L), and locus length per unit area (L/A) have been proposed to quantify the instability involved in the standing posture, and such parameters are widely used in clinical studies. The last parameter, in particular, depends on the fine variations involved in posture control [1]. This index is then regarded as a gauge for evaluating the function of the proprioceptive control of standing in human beings. However, it is difficult to clinically diagnose disorders of the balance function and to identify the decline in equilibrium function by utilizing the abovementioned indices and measuring patterns in the stabilogram. Large interindividual differences make it difficult to understand the results of such a comparison.

With respect to the body sway, the anterior-posterior direction y was considered to be independent of the mediallateral direction x [4]. Stochastic differential equations (SDEs) forced by white noise w_z on the Euclid space $\mathbf{E}^2 \ni (x, y)$

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

$$\frac{\partial y}{\partial t} = -\frac{\partial}{\partial y}U_y + w_y(t) \quad (2)$$

have been proposed as mathematical models that generate stationary stabilograms for z = x, y [5-8]. Based on the Stratonovich's rule, a correspondence has been obtained between their temporally averaged potential functions U_z and distributions of the time series G(z) as follows [8];

$$U_z = -\frac{1}{2}\ln G(z) + const. \quad (3)$$

Due to the nonlinear SDEs constructed from the stabilograms, the potential functions Ux, Uy have plural minimal points, and fluctuations could be observed in the neighborhood of the minimal points [8]. The variance in the stabilogram depends on the form of the potential function in the SDE.

The analysis of stabilograms is useful not only for medical diagnosis but also for achieving control of upright standing by two-legged robots and for preventing elderly people from falling [9]. Recent studies suggest that maintaining postural stability is a major goal of animals [10] and that they experience sickness symptoms in circumstances where they have not acquired strategies for maintaining their balance [11].

The equilibrium function in humans deteriorates when viewing 3D video clips [12]. This visually induced motion sickness (VIMS) has been considered to be caused by a disagreement between vergence and visual accommodation while viewing 3D video clips. Thus, stereoscopic video clips have been devised to reduce this disagreement [13].

VIMS can be measured by psychological and physiological methods, and the Simulator Sickness Questionnaire (SSQ) is a well-known psychological method for measuring the extent of motion sickness [14]. The SSQ is used herein for verifying the occurrence of VIMS.

By using the SSQ and stabilometry, in this study, we examined whether the VIMS was induced by a stereoscopic video clip. We wondered if noise terms vanished from the mathematical model (SDEs) of the body sway. Using our Double-Wayland algorithm [15], we evaluated the degree of visible determinism for the dynamics of the sway.

We herein evaluate the effect of 3D video clips on the equilibrium function. In our previous study, we found that the high density of observed COP decreases during exposure to stereoscopic video clips [12]. Sparse density (SPD) would be a useful index in stabilometry to measure VIMS. In this study, body sway in the resting state is compared with that during exposure to 3D video clips on a liquid crystal display (LCD) and on a head mounted display (HMD).

II. MATERIALS AND METHODS

The subjects were 14 healthy people aged between 19 and 39 years. A sufficient explanation of the experiment was provided to all the subjects, and a written consent was obtained from them. They provided informed consent prior to participation. The following subjects were excluded from the study: subjects working the night shift, those dependent on alcohol, those who consumed alcohol and caffeine-containing beverages after waking up and less than 2 h after meals, those taking prescription drugs, and those who may have had any past otorhinolaryngologic or neurological diseases (except for conductive hearing impairment, which is commonly found in the elderly). In addition, the subjects must have experienced motion sickness at some time during their lives.

We ensured that the body sway was not affected by environmental conditions. The subjects stood without moving on the detection stand of a stabilometer (G5500; Anima Co. Ltd.) with their feet together. Three types of stimuli were presented in random order: (I) a static circle with a diameter of 3 cm (resting state); (II) a conventional 3D video clip that showed a sphere approaching and moving away from the subjects, irregularly (Olympus Visual Communications Co. Ltd.); and (III) the same 3D video clip as shown in (II). Stimuli (I) and (II) were presented on an LCD monitor (S1911- SABK, NANAO Co., Ltd.). The distance between the LCD and the subjects was 57 cm. During exposure to the last video clip (III), the subjects wore an HMD (iWear AV920; Vuzix Co. Ltd.). This wearable display is equivalent to a 62-inch screen viewed at a distance of 2.7 m.

The subjects stood without moving on the detection stand of a stabilometer (G5500; Anima Co. Ltd.) in the Romberg posture with their feet together for 1 min before the sway was recorded. Each sway of the COP was then recorded at a sampling frequency of 20 Hz during the measurement; subjects were instructed to maintain the Romberg posture for the 60 s. The subjects viewed one of the video clips, i.e., (I), (II), or (III) from the beginning until the end. The SSQ was filled before and after stabilometry.

We calculated several indices that are commonly used in the clinical field [16] for stabilograms, such as "area of sway," "total locus length," and "total locus length per unit area." In addition, new quantification indices that were termed "SPD," [17] and the translation error were also estimated. The translation error (E_{trans}) is calculated in order to evaluate the degree of determinism for dynamics that generate a time series. E_{trans} represents the smoothness of flow in an attractor, which is assumed to generate the time series data. Moreover, the time-averaged potential function is estimated by using the equation (3) in the distribution of each component of the stabilogram.

III. RESULTS

After the exposure to a 3D video clip (II), scores for SSQ-N (nausea), SSQ-OD (eyestrain), SSQ-D (disorientation), and SSQ-TS (total score) were 10.2 ± 3.4, 13.5 ± 3.3, 16.9 ± 6.6, and 15.2 ± 4.1, respectively. After the exposure to a 3D video clip (III), these scores were 8.2 ± 2.6, 13.2 ± 3.2, 16.9 ± 6.3, and 14.4 ± 3.7, respectively. Sickness symptoms seemed to appear with the exposure to the stereoscopic video clips, although there were large individual differences. However, increases were seen in the scores for SSQ-N and SSQ-D after exposure to the 3D video clips (II) and (III).

Whether subjects were exposed to the 3D video clips or not, E_{trans} derived from the temporal differences of those time series x, y was approximately 1. These translation errors in each embedding space were not significantly different from the translation errors derived from the time series x, y, although E_{trans} derived from the time series y is less than 1 for any embedding space without exposure to any of the stereoscopic video clips.

According to the Friedman's test, the main effects were seen in the indices for stabilograms, except for the chain ($p < 0.01$). Nemenyi tests were employed as a post-hoc procedure after the Friedman's test (Fig. 1). Except for the total locus length of the chain, indices of stabilograms were enhanced significantly by exposure to any video clips ($p < 0.05$). All indices obtained from stabilograms during exposure to the 3D video clip on an HMD (III) were greater than those obtained when using an LCD (II).

TABLE I. COEFFICIENT OF DETERMINATION

Degree of regression polynomial (x)	2	4	6
(I)	0.9381	0.9972	0.9997
(II)	0.9559	0.9824	0.9949
(III)	0.9528	0.9855	0.9924

Degree of regression polynomial (y)	2	4	6
(I)	0.9894	0.9911	0.9935
(II)	0.9146	0.9578	0.9726
(III)	0.9353	0.9893	0.9908

The time-averaged potential function was estimated by using the equation (3) in the distribution of each component of the stabilogram. Parabolic functions were appropriate for the potentials that were derived from the distributions of all subjects (coefficient of determination $R^2 > 0.9$ as shown in TABLE I). Diminution of the gradient was observed in the bottom of the parabolic potential function (Fig. 2). This tendency was enhanced by the exposure to the 3D video clip on an HMD (III).

IV. DISCUSSION

The total locus length during exposure to the 3D video clips (II) and (III) were significantly greater than that during exposure to the control image (I). Hence, we noted postural instability with the exposure to the stereoscopic video clips (II) and (III) by using these indicators associated with the stabilogram (Fig. 1). Furthermore, there was no difference between effects of 3D video clips (II) and (III) by using these indices.

In this study, we mathematically measured the degree of determinism in the dynamics of the sway of COP. The Wayland algorithm was used as a novel method. $E_{trans} > 0.5$ was obtained by the Wayland algorithm, which implies that the time series could be generated by a stochastic process in accordance with a previous standard [18]. The threshold 0.5 is half of the translation error resulting from a random walk. The body sway has been described previously by stochastic processes [5-7], which was shown with the Double-Wayland algorithm [19]. The exposure to 3D video clips would not change it into a deterministic one. Deterministic variations were not observed in the locomotion of the COP. We assumed that the COP was controlled by a stationary process, and the sway during exposure to the static control video clip (I) could be compared with that when the subject viewed 3D video clips. Indices for stabilograms might reflect the coefficients in stochastic processes, although the translation error did not exhibit a significant difference among the stabilograms measured during exposure to the static control video clip (I), the 3D video clip (II), and (III).

A theory has been proposed to obtain SDEs as a mathematical model of the body sway on the basis of the stabilogram. Fluctuations could be observed in the neighborhood of the minimal point [8]. 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. Multiple comparisons indicated that the SPD S_2 during exposure to the stereoscopic video clip was significantly larger than that during exposure to the static control video clip (I) when subjects stood in the Romberg

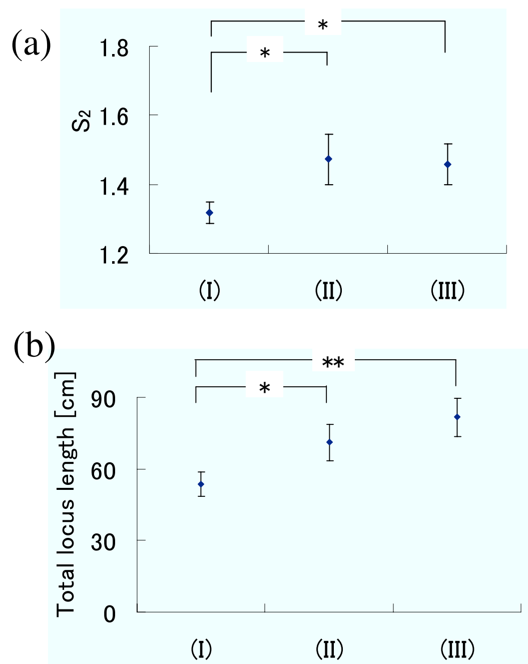

Figure 1. Typical results of Nemenyi tests for the following indicators: total locus length (a) and SPD (b) (*p < 0.05, **p < 0.01).

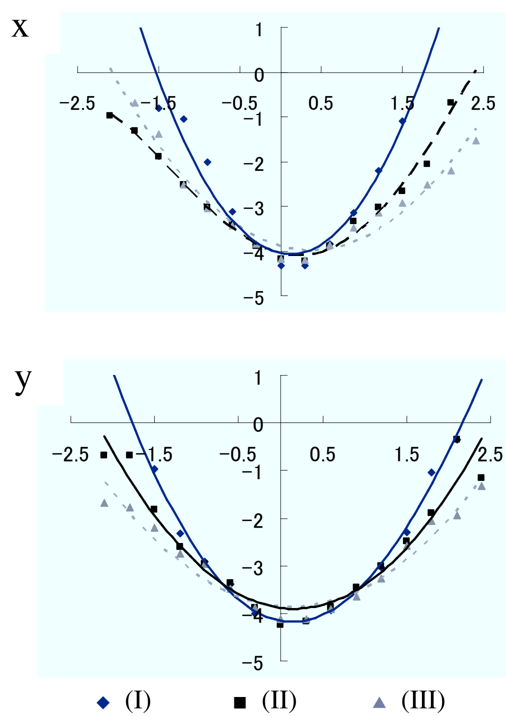

Figure 2. Metamorphism of the potential function. A clear change in the form of the potential function (1) occurs when viewing 3D viedo clips.

posture. The standing posture would become unstable because of the effects of the stereoscopic video clip. As mentioned above, metamorphism occurs in the time-averaged potential function (3) with exposure to stereoscopic video clips, which are assumed to reflect the sway in the COP.

The total locus length was increased during the exposure to the 3D video clips, which might be caused by the diminution of the gradient in the bottom of the parabolic potential function (Fig. 2). We 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 on an HMD (III).

Human beings perceive 3D objects by the simultaneous convergence and lens accommodation in natural binocular vision. They also perceive virtual video clips by the same mechanism. It has been commonly explained that lens accommodation makes us focus on the surface of a display, although the visual lines are crossed at the virtual video clip while viewing stereoscopic video clips. That is, there is discrepancy between convergence and accommodative focus. According to previous textbooks on 3D imaging, visually induced motion sickness and asthenopia are caused by this discrepancy. However, it seems to be the wrong explanation. As we discussed in a previous study [20], focus is not always fixed on the surface of a display while viewing stereoscopic video clips. We should more carefully investigate the effect of stereoscopic video clips on the visual functions. In the next step, we are going to use the simultaneous observation of convergence and lens accommodation.

A general stereoscopic view is obtained by using the binocular parallax. The images are composed of photographs taken by two cameras or formed using computer graphics (CG). Camera axes are fixed and crossed at the point of the virtual image at which the creator expects viewers to gaze. That is, viewers would suffer from finding the anomalous vergence if they looked at the other elements in a stereoscopic frame. Thus, a new technology to construct stereoscopic video clips (POWER3D) has been proposed by Nishihara & Tahara (2003) [21] that sets each camera axis as well as tracking muscle in human beings that change the vergence angle corresponding to the visual distance of subjects for photography. Viewers might not feel a sense of incongruity if they gazed at any elements in the frame. Hence, the new 3D video clip would reduce the body sway. The reduction could be evaluated by the SPD during exposure to the video clips on an LCD screen.

V. Conclusion

We quantitatively measured the body sway before and during exposure to 3D video clips. For the SSQ subscores and each index for stabilograms, we employed the Friedman's test with the display factors. Moreover, we discussed the metamorphism existing in the potential functions that could be used in the control of the standing posture at the time of exposure to stereoscopic video clips. As a result, the system to control the standing posture during exposure to the stereoscopic video clip on an HMD (III) was more unstable than that on an LCD (II). Further studies are planned with an increasing number of cases.

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