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Metamorphism in Potential Function while Maintaining Upright Posture during Exposure to Blurred Images

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Abstract– We propose a new index, sparse density (SPD), of stationary stabilograms for detecting the metamorphism in the (temporally averaged) potential function of stochastic differential equations, which occurs when a human attempts to maintain an upright posture. It is known that a mathematical model of the body sway can be developed by a stochastic process. The authors have succeeded in finding the nonlinearity in the potential function. In this study, subjects in a standing position were stimulated by a movie scrolling from left to right on a liquid crystal display (LCD). We also measured the degree of determinism in the dynamics of the sway of the center of gravity of the subjects. The Double-Wayland algorithm was used as a novel method. As a result, the dynamics of the body sway in the presence of the stimulus as well as in its absence were considered to be stochastic. The metamorphism in the potential function during exposure to blurred images could be detected by using the SPD.

1. Introduction

The human standing posture is maintained by the body's balance function, which is an involuntary physiological adjustment mechanism [1]. Sensory signals such as visual inputs, auditory and vestibular inputs, and proprioceptive inputs from the skin, muscles, and joints are the inputs that are involved in the body's balance function [2]. Even when a young, healthy individual attempts to stand still, the centre of gravity of his/her body and the centre of pressure (COP) under his/her feet move relative to a global coordinate system [3], which is induced by the complex sensorimotor control system. A plot of time-varying coordinates of the COP is known as a stabilogram. The COP could be measured in accordance with stabilometry in which many of the earlier studies limited the analysis of the plots to summary statistics, i.e., calculation of the length of sway path, average radial area, etc. [3].

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 $\mathbf{E}^2 \ni (x, y)$

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

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

have been proposed as mathematical models that generate stationary stabilograms for z = x, y [3],[5]-[7]. 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 [7];

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

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 [7]. The variance in the stabilogram depends on the form of the potential function in the SDE.

Motion sickness brings about abnormality in the stabilograms. Stoffregen and Smart argued that motion sickness is not caused by sensory conflict, but by postural instability [8], although the most widely known theory of motion sickness is based on the concept of sensory conflict [9]. The blurred images on the LCDs sometimes induced "image sickness" in viewers, which is an unpleasant feeling that is similar to the motion sickness. Significant increases in the postural sway were observed during the image sickness induced by simulator [8]. On the other hand, optokinetic stimulation is known to trigger motion sickness [10]. In particular, anterior displacement of the COP remarkably increased during the body sway when random dots were rotated vertically at a speed of 40-60 deg/s as optokinetic stimulation to the subjects. The conventional LCD would aggravate symptom of the motion sickness. Furthermore, newly developed optically compensated bend display might suppress the symptom of the motion sickness. However, there has been no study to evaluate the LCDs viewed by subjects using the data obtained from stabilograms.

As mentioned above, most of previous investigations ignored the dynamic characteristics of stabilograms. Using our Double-Wayland algorithm [11], [12], we herein examine hypothesis that visually induced motion sickness was affected by the conventional LCD, and the postural control system might drastically change by the visually induced motion sickness.

2. Material and Method

We adjusted the temperature in the experiment room, which was kept dark, to 25°C.

The test subjects were six persons from 20 to 27 years of age with no history of equilibrium function problems. The subjects first stood with their eyes open for 1 min (resting state); they then viewed a moving map on a 32-inch display of the previous model with a contrast ratio of 600:1 for the next 1 min (testing state). Subsequently, they closed their eyes for 1 min in order to evaluate effect of moving map task on the body of sway after the visual stimulus.

2.1. Stabilometry

The subjects stood without moving on the detection stand of a stabilometer (G5500, Anima Co., Ltd.) in the Romberg posture [13] with their feet together for 1 min before the sway was recorded. A centre of pressure (COP) was measured as a projection of the centre of gravity on to a force plate. Each sway of the COP was then recorded with a sampling frequency of 20 Hz. With regard to each component of the stabilograms, translation errors E_{trans} [14] in the following states were estimated in m dimensional embedding space ($1 \leq m \leq 10$) by the Double-Wayland algorithm [11], [12]. In addition, we calculated indices for stabilograms such as "total locus length [13]" and "SPD [15]". Statistical comparison was employed by Wilcoxon matched-pair signed-rank test in which the level of significance was set to be 0.05.

2.2. Moving Map Task

The map of a fictitious city was scrolled from left to right (or right to left). The subjects had to read the name of a place from the moving map as a moving map task. The scroll speed of the moving map was 20 dots/s. The viewing distance was 1 m.

3. Results

A typical stabilogram, which represents an example of the stabilometry results, is shown in Fig. 1. The figure shows the result when a subject viewed the conventional LCD. In this figure, the vertical axis shows the anterior and posterior movements of the COP, and the horizontal axis shows the right and left movement of the COP. The square (dashed line) in the figure indicates the range recorded in the resting state (RS). The amplitudes of the sway as well as the right-left movement tended to be larger when the subjects viewed the display than when they were in the RS.

Most E_{trans} values estimated by the Double-Wayland

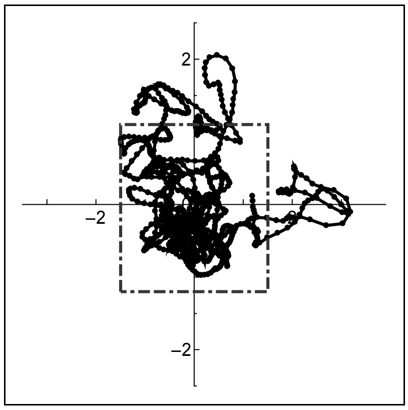

Fig.1 Typical examples of stabilograms extracted from a subject viewing the conventional LCD [18].

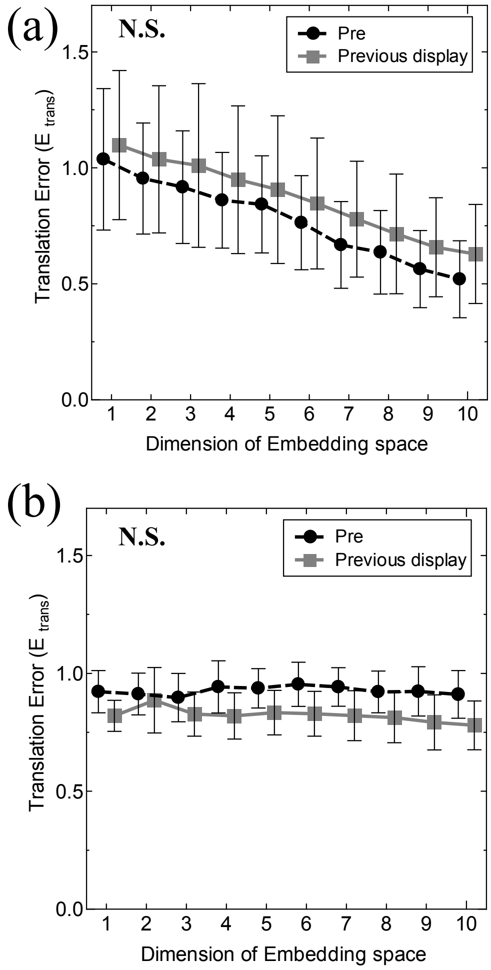

Fig. 2. Statistical comparisons of translation errors in the resting with testing states (Pre and Previous display, respectively). For all embedding spaces, no significant difference between these states was observed by the sign test in translation errors derived from (a) the time series data of the anterior /posterior direction and (b) the temporal differences of the time series. Similarly, there was no significant difference between these states in the other direction (See [16]).

algorithm [11], [12] were larger than 0.5 for each embedding space (Fig. 2). There appeared to be no differences between the E_{trans} values derived from the time series data of the lateral and anterior/posterior directions. $0.8 \leq E_{trans} \leq 1$ was obtained from the temporal differences of these time series.

4. Discussion

Information from the vision, vestibule, and somato-sensory regions is managed at the centriciput in order to prevent falling down. The most widely known theory of motion sickness is based on the concept of sensory conflict [9]. It was reported that the onset of motion sickness may be preceded by significant increases in postural sway [8]. Instability in the standing posture can also occur due to anomalous eyesight, which exhibits some patterns in stabilograms.

In order to evaluate display devices, a geostationary image and characters were generally used in previous studies [17]-[19]. We have proposed a new method for comparing the standing posture when a subject gazes at an LCD displaying a movie scrolling from the left to the right [20]. By using a stabilometer, a newly developed LCD was also compared with a conventional LCD. In the next step, we should quantitatively investigate effects of a background moving from the left to right without any utilization of a display on the body sway. However, the moving pictures were rotated horizontally at a speed of 25 deg/s or less, which was considered to be sufficiently small optokinetic stimulation. The speed was regarded as half of the maximum speed in order to follow smooth eye movements; therefore, the standing posture would be controlled by a mechanism regardless of whether or not the subjects viewed the moving pictures. This speculation was substantiated by the results in the translation errors.

In this study, we measured the degree of determinism in the dynamics of the sway of COP. The Double-Wayland algorithm was used as a novel method. $E_{trans} \geq 0.5$ 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 [21]. The threshold 0.5 is half of the translation error resulting from a random walk. We physiologically consider that the stochastic process to control standing posture originates in kinociliums leaning toward random direction in an otolithic organ.

The translation errors obtained from the subjects viewing the displays were similar to those of subjects in the RS (Fig.2). Moreover, the body sway has been described previously by a stochastic process [3], [6]-[8], which was shown with the Double-Wayland algorithm [11]. $0.8 \leq E_{trans} \leq 1$ obtained from the temporal differences of these time series exceeded the translation errors estimated by the Wayland algorithm. However, it was similar to the latter, except for the RS, which agreed with the abovementioned dynamics to control a standing posture [12]. Knowing that the degree of deter-minism is unchanged, the postural control system can be regarded as a stationary process. Based on this result, we can obtain an assurance of the premise in the time series analysis for stabilograms.

We statistically compared the RS among the testing states using the values of the indices that were used to evaluate the stabilograms (Fig. 3). It was found that the values of indices were significantly larger when the subjects viewed the display of the previous model than when they were in the RS ($p < 0.05$). These statistical results indicated that visually induced motion sickness was affected by the display of the previous model.

The moving map task would not change it into a deterministic one. Mechanical variations were not observed in the lateral locomotion of the COP. The moving map task was thus regarded as an appropriate stimulus to evaluate the displays. By using several indices for the form of stabilograms [13], [15], some LCDs could be ranked hierarchically [20]. The indices might reflect the coefficients in stochastic processes although the translation error did not exhibit a significant difference between the RS and the conventional LCD (Fig.2). The total locus length during exposure to blurred images was significantly greater than that in the RS (Fig. 3a). We considered that

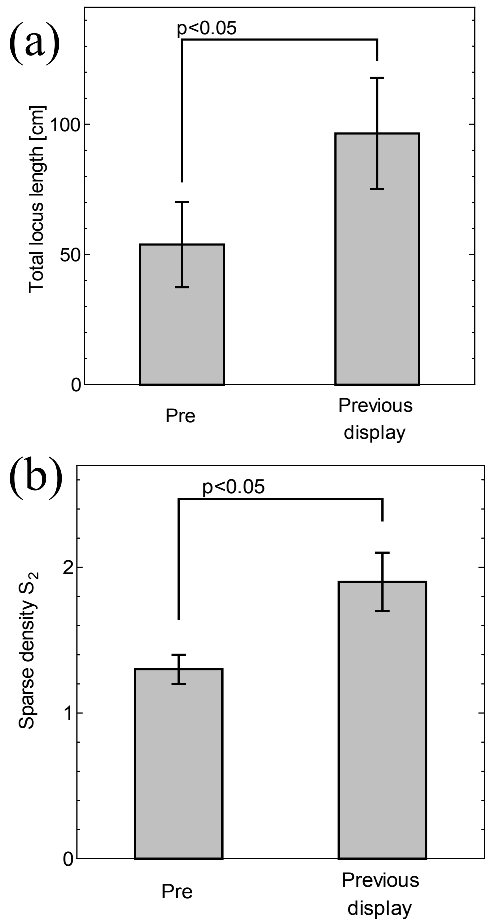

Fig. 3. We statistically compared the RS with the testing states using the values of the indices that evaluated the stabilograms: (a) total locus length and (b) SPD S_2.

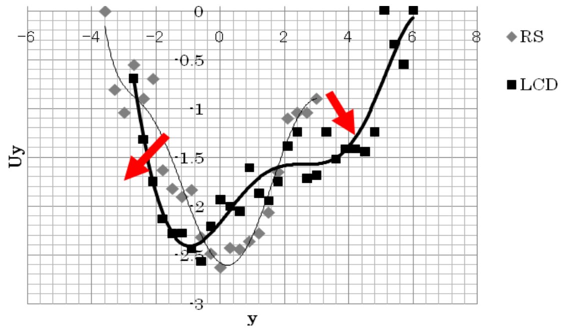

Fig. 4. Typical examples of temporally averaged potential functions constructed from stabilograms in accordance with Eq.(3). The graph of a polynomial was fit to that of the potential function by the minimum square method. The higher degree coefficient of the polynomial when a subject viewed the conventional LCD (■) was lower than that in the RS (◆).

the blurred images on the conventional LCD decrease the gradient of the potential function (Fig. 4). Moreover, we concluded that the metamorphism in the potential function during exposure to the blurred images could be detected by using the SPD (Fig. 3b).

The moving map task was thus regarded as an appropriate stimulus to evaluate the displays. Some indices for the form of stabilograms are useful for evaluating the LCD displaying the movie. We conclude that our method, where a subject views an LCD displaying a scrolling movie, was effective in evaluating the characteristics of movies being displayed on LCDs.

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