Effect of Display Size on Body Sway in Seated Posture While Viewing an Hour-Long Stereoscopic Film

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Abstract. Viewing stereoscopic films may have adverse effects, such as asthenopia and visually induced motion sickness (VIMS). The phenomenon of VIMS is not fully understood, so the aim of this study is to evaluate the effect of viewing a long stereoscopic film on the human body. We conducted stabilometric analysis on subjects in the Romberg posture, carried out flicker tests, and provided subjective questionnaires to detect fatigue and eye strain every 20 min. Symptoms of VIMS were detected during exposure to an hour-long stereoscopic film. The display size and the engagement were analyzed for their affect on the total locus length and the sway area, respectively. The severity of the motion sickness induced by viewing the 3D film was measured by stabilometry, and the analogous sway was not observed in participants after viewing the 2D film in this study. Based on these results, guidelines can be developed to ensure safety while viewing stereoscopic movies.

Keywords: Visually induced motion sickness, Stabilometry, Liquid crystal displays (LCDs), Hour-long stereoscopic film.

1 Introduction

The posture of humans in a standing position is maintained by the body's balance function, which is an involuntary physiological adjustment mechanism called the righting reflex [1]. The righting reflex, centered in the nucleus ruber, is essential to maintain a standing posture in the absence of locomotion. Sensory signals such as visual inputs, auditory and vestibular inputs, and proprioceptive inputs from the skin, muscles, and joints are involved in the body's balance function [2]. The evaluation of this function is indispensable in diagnosing equilibrium disturbances such as cerebellar degenerations, basal ganglia disorders, or Parkinson's disease [3]. Stabilometry has been employed to evaluate this equilibrium function both qualitatively and quantitatively. A subject's center of gravity is projected onto a detection stand and measured as an average of the center of pressure (COP) of both feet. The COP is traced for each time step, and a time series of the projections are traced on an x-y plane. A stabilogram is created by connecting the temporally vicinal points, as shown in Fig. 1. Several parameters, including the sway area (A), total

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locus length (L), and locus length per unit area (L/A) quantify the instability involved in the standing posture, and such parameters are widely used in clinical studies. In particular, the last parameter (L/A) depends on the fine variations involved in posture control [1]. This index is therefore regarded as a gauge to evaluate the function of 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 the equilibrium function by using the previous indices and measuring patterns in the stabilogram. Large differences among individuals render the results of such a comparison difficult to analyze.

The equilibrium function in humans deteriorates when viewing three-dimensional (3D) films [4]. One cause of visually induced motion sickness (VIMS) is sensory conflict, i.e., the disagreement between convergence and visual accommodation; sensory conflict occurs while viewing a 3D film [5]. As a result, stereoscopic images have been devised to reduce this disagreement [6]. VIMS can be measured using psychological and physiological methods. The simulator sickness questionnaire (SSQ) is a well-known psychological method used to measure the extent of motion sickness and was used in this study to verify the occurrence of VIMS [7]. For the physiological method, the following parameters of autonomic nervous activity are measured: heart-rate variability, blood pressure, galvanic skin reaction, and stabilograms [8]. We proposed a method to measure the effect of 3D images on the equilibrium function. The sparseness of COP density (Appendix) is a useful index in stabilometry to measure VIMS because a high COP density decreases during exposure to 3D films [4]. In this study, we examined the effect of an hour-long stereoscopic film on the equilibrium function.

2 Materials and Methods

Seven healthy subjects (age 22.3 ± 0.8 yr) participated voluntarily in the study. We ensured that body sway was not affected by environmental conditions. We used an air conditioner to adjust the temperature to 25 °C in the exercise room, which was kept dark.

The subjects were seated and positioned facing 23-in and 40-in liquid-crystal display (LCD) monitors, RDT233WX-3D (Mitsubishi Denki, Tokyo) and KDL40HX80R (Sony, Tokyo), respectively, on which a commercially available 3D film was presented. The distance between the wall and the subjects was set at three times the absolute display height (3H).

The visual analog scale (VAS) and the SSQ were completed prior to the stabilometry; the subjects stood on a detection stand, which was a Wii Balance Board (Nintendo, Kyoto), in the Romberg posture for 1 min before sway was recorded. The sway of the COP was then recorded at a sampling frequency of 20 Hz during the measurement; the subjects were instructed to maintain the Romberg posture with their eyes open for the first 60 s and with their eyes closed for the following 60 s. For the first 60 s, the subjects viewed a visual target (circle) with a diameter of 2 cm. The distance between the wall and the subjects was 2 m. These actions were conducted before

exposure to the stereoscopic film and 20, 40, and 60 min after exposure. An electrocardiogram was continuously measured in this experiment.

3 Results and Discussion

There was a significant difference between subjective items (VAS and SSQ subscores) completed 20 and 60 min after exposure to the 3D film. Symptoms of VIMS were detected during exposure to the hour-long 3D film.

We compared stabilograms measured before exposure to the stereoscopic film and 20, 40, and 60 min after exposure. Typical stabilograms are shown in Fig. 1, which is a collection of data observed 60 min after the exposure to 2D or 3D films. The size of the display during the exposure to the 2D film (Fig. 1a, 1c) did not affect the body sway of the participants. However, the body sway depends on the display size for participants viewing the 3D film (Fig. 1b, 1d). There was an overall increase in body sway observed for the 3D film data.

According to the two-way analysis of variance (ANOVA) with repeated measures, there was no interaction between two factors: the display size and the loading time (i.e., the engagement). The main effects on the display size and the loading time tended to be obtained via the statistical analysis of the sway area and the total locus length, respectively (Figs. 2–3). The sway values after the exposure to the 3D film were compared with those obtained before the exposure (pre) via the Wilcoxon signed

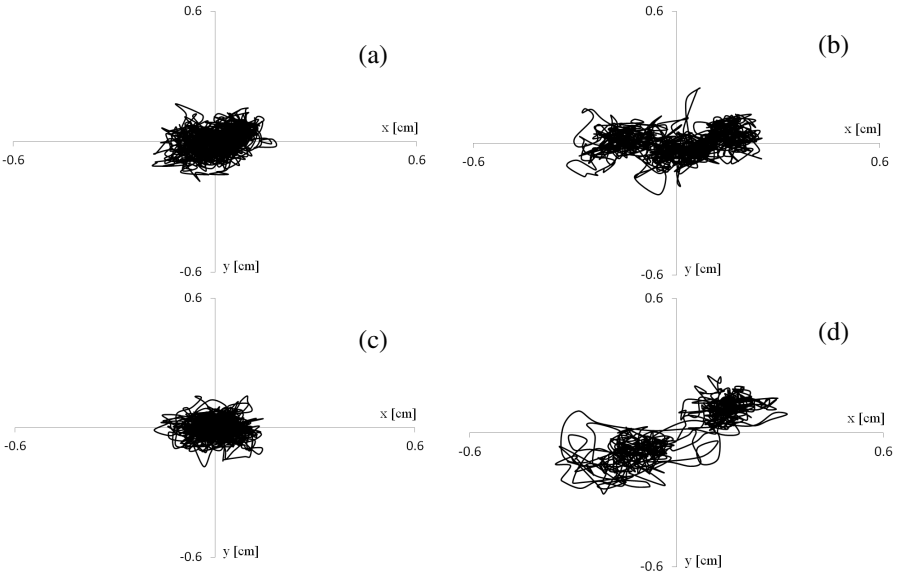

Fig. 1. Typical stabilograms

(a) 23-in display, viewing 2D images (b) 23-in display, viewing 3D images
(c) 40-in display, viewing 2D images (d) 40-in display, viewing 3D images

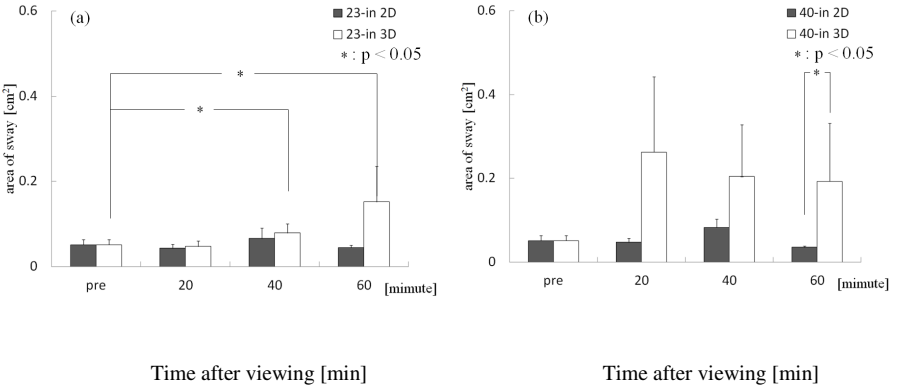

Fig. 2. Sway area before and after viewing 2D images and 3D films on (a) the 23-in display and on (b) the 40-in display

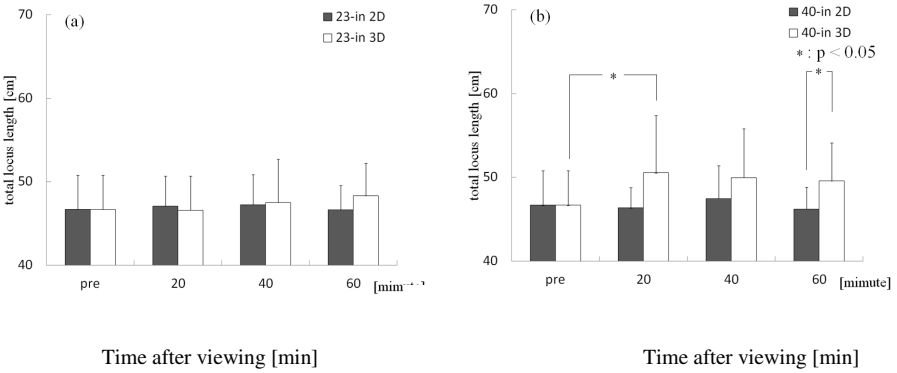

Fig. 3. Total locus length before and after viewing 2D images and 3D films on (a) the 23-in display and on (b) the 40-in display

rank test. The total locus length significantly increased 20 min after viewing the 3D film on the 40-in display ($p < 0.05$). For the 23-in display, the sway area significantly increased for measurements 40 and 60 min after viewing the 3D film ($p < 0.05$).

4 Conclusion

In this study, we have examined whether the severity of VIMS depends on the display size of the film. The body sway tended to increase while viewing the 3D film in comparison with the minimal effects of the 2D film. According to our statistical analysis

of stabilograms, the display size and the engagement affect the total locus length and the sway area, respectively. The severity of motion sickness induced by viewing the 3D film was measured by stabilometry, and the analogous sway was not observed in participants after viewing the 2D film in this study.

3D television sets are available in the market and are increasingly popular among consumers. However, viewing 3D films may have adverse effects, including asthenopia and VIMS, which is a phenomenon that is not yet fully understood. One cause of VIMS is a sensory conflict induced while viewing a stereoscopic film. VIMS can be analyzed in both subjective and physiological terms. The aim of this study was to evaluate the effect of viewing a long stereoscopic film on the human body. We conducted stabilometric analyses for subjects in the Romberg posture and asked the subject to fill out subjective questionnaires to detect fatigue and eye strain every 20 min. Statistical significance was observed for the averages of the subjective test results obtained prior to film exposure and 20 min after the initiation of the measurement ($p < 0.05$). Symptoms of VIMS were detected during exposure to the hour-long 3D film. Based on these results, guidelines can be developed to ensure safety while viewing 3D movies.

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Appendix Sparseness of COP Density

Here, we describe the new quantification indices, sparseness of COP density (SpD) [9].

The SpD is defined by an average of the ratio $G_j(1)/G_j(k)$ for $j = 3, 4, \ldots, 20$, where $G_j(k)$ is the number of divisions having more than k measured points. A stabilogram is divided into quadrants whose latus is j times longer than the resolution. If the center of gravity is stationary, the SpD value is 1. If there are variations in the stabilograms, the SpD value is greater than 1. Thus, the SpD depends on the characteristics of the stabilogram and the minimal structure of the temporally averaged potential function.

For the data analysis, the anterior-posterior direction was considered to be independent of the lateral direction [10]. Stochastic differential equations (SDEs) were proposed as mathematical models to generate the stabilograms [11]-[13]. The variance in the stabilogram depends on the form of the temporally averaged potential function in the SDE, which generally has plural 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 on the stabilogram [13]; SpD is regarded as an index for this measurement.

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