Analysis of the Body Sway While/After Viewing Visual Target Movement Synchronized with Background Motion

Nao Amano[1], Hiroki Takada[1](✉), Yusuke Jono[1], Toru Tanimura[1], Fumiya Kinoshita[2], Masaru Miyao[3], and Masumi Takada[4]

[1] 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
[2] Toyama Prefectural University, 5180 Kurokawa, Imizu-shi, Toyama 939-0398, Japan
[3] Nagoya Industrial Science Research Institute, 2-10-19 Sakae, Naka, Nagoya 460-0008, Japan
[4] Chubu Gakuin University, 2-1 Kirigaoka, Seki-shi, Gifu 501-3993, Japan

Abstract. Stereoscopic imaging techniques have also become used for not only amusement but also in the industrial, medical care, and educational fields, however, symptoms due to the stereopsis have been reported. In this study, we especially focus on the effect of background motions on the equilibrium function. The body sway was recorded while/after viewing a sphere as a visual target synchronized/unsynchronized with periodic motion of the view point. Statistical analysis was conducted for the stabilograms.

Keywords: Body sway · Total locus length · Area of sway
Total locus length per unit area · Sparse density · Stereopsis
Synchronized/unsynchronized motion

1 Introduction

In these days when developments in the graphical technology has produced an increase in the chance to view 3D video clips, visually induced motion sickness (VIMS) has been widely reported as a negative result from the developments. The onset of the VIMS is explained by some hypothesis; overstimulation theory and sensory conflict theory [1]. The overstimulation theory cannot explain the space motion sickness [2–7] and the simulator sickness with no vestibular stimulation. Along with the later [8–12], disagreement between the convergence and lens accommodation has been pointed out as a cause of visually induced motion sickness (VIMS) with stereopsis [13]. We conducted simultaneous measurements of lens accommodation and the convergence in a dark room >1 lx [14–18]. According to these researches, the time sequences have showed that the lens accommodation also follows the convergence in case of the stereoscopic vision. The lens accommodation is not fixed at the surface of objects/displays. 3D sickness might not be caused by the disagreement between the

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convergence and lens accommodation. Also, we investigated the effect of long-term exposure to 3D video clips on the visual function [19] and the body sway [20, 21].

However, the cause of the VIMS does not have been proved yet whereas dizziness and nausea are regarded as symptoms of the VIMS. Previous researches showed that the exposure to blurred/rotational images induces the motion sickness [22] which is also induced while viewing 3D video clips in dark environment on the head-mounted displays [23–26]. The body balance function is affected by the peripheral vision of a 3D video clip compared to a 2D video clip [27]. The authors investigated the effect of the blurred background, especially in the periodic motion, on the equilibrium function [28].

In prior work, background images with 3D images in the peripheral visual field are shown to affect the body's equilibrium system [29]. Furthermore, when viewing images with background instability, the equilibrium system is shown to be affected more when a visual target is present than when there is not [28]. However, the effect on the human body of the connection between visual target movement and background instability is an issue that remains unsolved at present. The objective of the present paper is to study how the body's equilibrium system is affected by background instability in video containing a visual target, that is periodic motion in the backgrounds. A comparative experiment was conducted to experimentally assess the impact on the equilibrium system of the following: video clips with/without a stationary visual target; and video clips that show a spherical visual target moving back and forth quasi-periodically between near and far-distance, while moving from side to side and up and down, showing the visual target movement synchronized with/without the periodic viewpoint changing from side to side (synchronized/unsynchronized movement).

One of the methods to assess motion sickness is stabilometry [30], which is an effective way for the quantitative assessment of the effect of 3D video viewing on the equilibrium system. The present paper therefore makes use of stabilometry.

2 Materials and Methods

The gravicoder was used to record the *x*-*y* coordinates for the centre of pressure (CoP) for all sampling times, namely while subjects watched the video clips for 1 min and while they stood with their eyes closed for 2 min in the Experiment 1; and for 1 min in the Experiment 2. CoP data were divided into those for *x* (right is positive) and *y* (forward is positive) directions, converted into time series and generated as stabilograms (Fig. 1). The indices; total locus length; area of sway; total *locus length per unit area*; and sparse density were assessed. Total locus length, area of sway and total *locus length per unit area* were used as analytical indices for stabilograms in previous studies, and they have been calculated based on the equations that were defined by the Japan Society for Equilibrium Research as well as in the present paper [31]. Sparse density is an index proposed by Takada *et al.* indicating the density of sampling points distributed in each division on the plane, and is considered to be linked to stability of the body's equilibrium system [32].

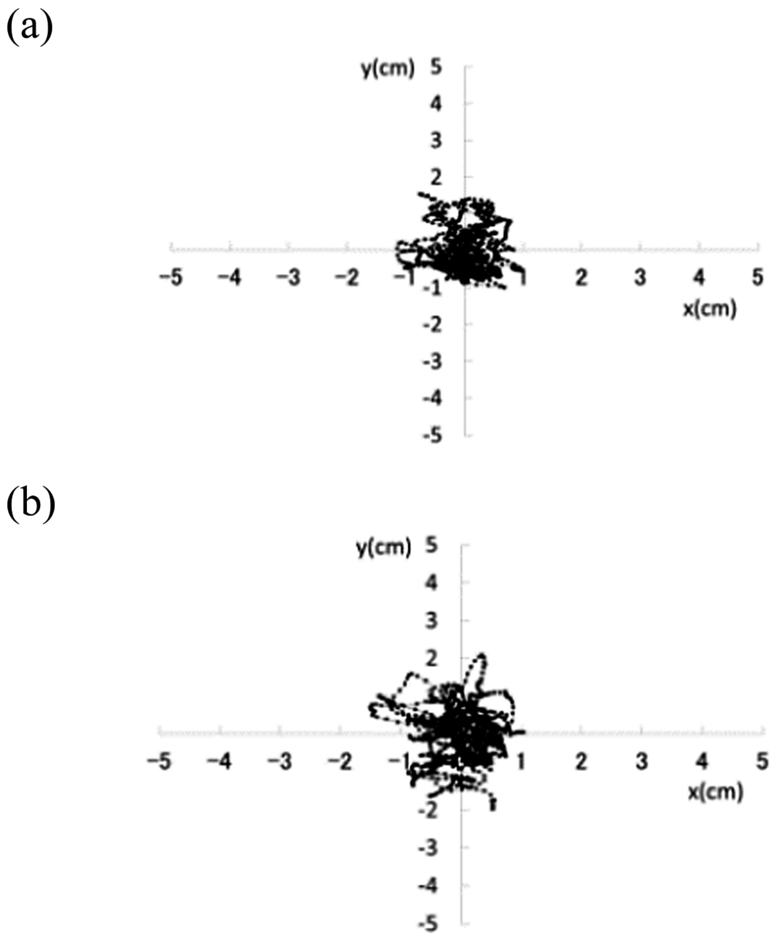

Fig. 1. Typical example of stabilograms.

2.1 Experiment 1

The experiment was conducted with nine healthy males aged 21–24 years. Consumption of alcohol and caffeine as well as smoking were prohibited for the two hours prior to the experiment, and written consent was obtained upon full explanation of the details of the experiment. Subjects were shown the following sequence with the periodic motion in the backgrounds: a 2D video clip (VC) without a visual target (VC-1); a 3D video clip without a visual target (VC-2); a 2D video clip with a fixed visual target in the centre (VC-3); a 3D video clip with a fixed visual target in the centre (VC-4); a 2D video clip with unsynchronized movement of the visual target (VC-5); a 3D video clip with unsynchronized movement of the visual target (VC-6); a 2D video clip with synchronized movement of the visual target (VC-7); a 3D video with synchronized movement of the visual target (VC-8). Additionally, subjects were shown a control image (Pre) showing a white dot against a gray background. The experiment is performed with subjects assuming the upright Romberg's posture, and the display used is the 40″ KDL-40HX80R 3D display (Sony, Tokyo). For the stabilometry, a *Gravicoder* GS-3000 (Anima, Tokyo) was used. Sampling rate was set at 20 Hz. Stabilometry was performed for a total of 3 min: 1 min while viewing the video, followed by 2 min of rest with eyes closed.

2.2 Experiment 2

This experiment was conducted with 116 subjects, male and female, aged 15–89 years. Three groups were formed, of young, middle-aged and elderly subjects, and compared. They were shown a 3D video clip showing uncoordinated movement of the visual target and the viewpoint (VC-I), and a 3D video showing back and forth (coordinated) movement of the visual target and the viewpoint (VC-II). Additionally, subjects were shown a comparison-video (Pre) showing a white dot against a gray background. By changing the background periodically from side to side, subjects' viewpoint alone is altered without any input into the vestibular system, provoking sensory discordance and increasing the load when using peripheral vision. Specifically in video II, the visual target moving back and forth changes appearance with the changes in viewpoint, and appears to be displaying more complex motion.

The experiment is performed with subjects assuming the upright Romberg's posture, and the display used is the 50" 3D TH-P50VT5 display (Panasonic, Osaka). For the stabilometry, a *gravicoder* GS-3000 (Anima, Tokyo) was used. Sampling rate was set at 20 Hz. Stabilometry was performed for a total of 2 min: 1 min while viewing the video, followed by 1 min of rest with eyes closed.

3 Results

3.1 Experiment 1

Sway values were obtained from stabilograms while/after viewing video clips (Fig. 2, 3 and 4).

Comparing stabilograms with/without visual target while eyes were open, the value of the total locus length was significantly higher when viewing VC-1 and VC-2 than when viewing the static image (Pre) ($p < 0.05$), and the same statistical tendency was also seen in the sparse density ($p < 0.10$). For the 2 min with closed eyes, the value of the total locus length per unit area tended to be significantly lower when viewing VC-2 compared to the Pre ($p < 0.10$), and significantly lower when viewing VC-4 ($p < 0.05$).

A comparison of the static/dynamic visual target shows that, with their eyes closed for first 1 min, the value of the total locus length was significantly higher in VC-2 compared to VC-4 ($p < 0.05$). With their eyes open, the value of the total locus length was significantly higher while viewing VC-6 than that of the Pre ($p < 0.05$) and tended to be greater while viewing VC-3 and VC-5 ($p < 0.10$). However, no significant results were found when viewing VC-4. Moreover, with their eyes closed for first 1 min, more

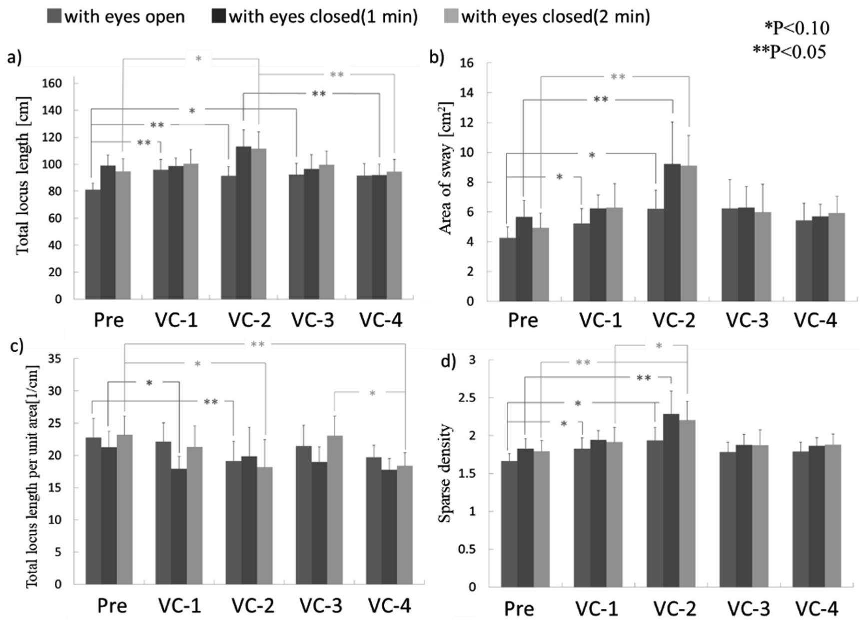

Fig. 2. Sway values while/after viewing a/no visual target with the periodic motion in the backgrounds

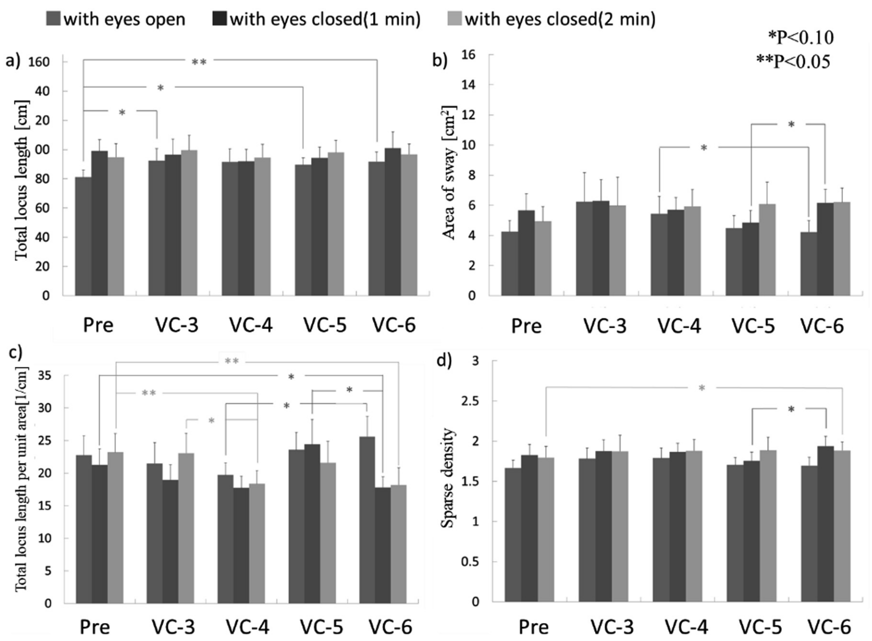

Fig. 3. Sway values while/after viewing a static/dynamic visual target.

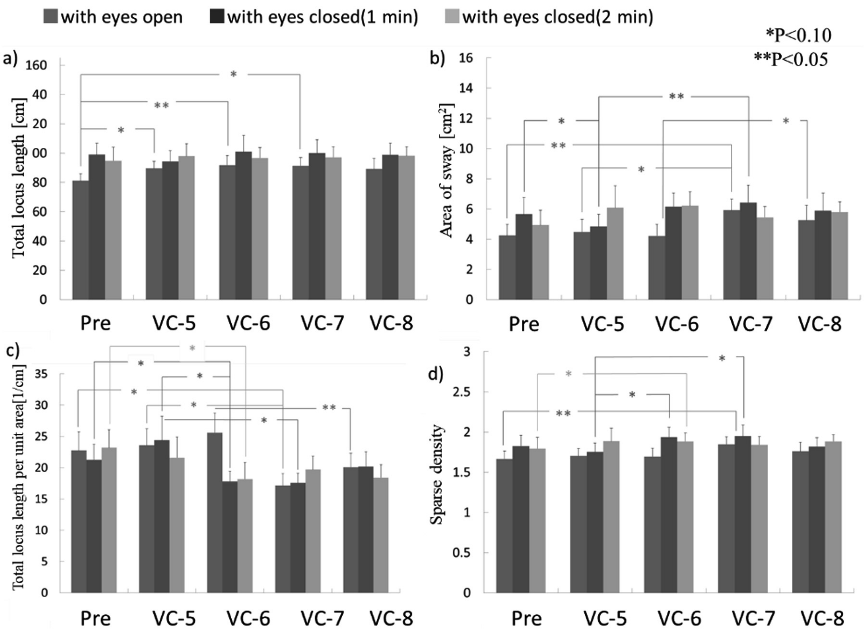

Fig. 4. Sway values while/after viewing visual target movement synchronized with/without a periodic motion of the view point

statistical tendency was observed in VC-6 compared to VC-5, for the area of sway, the total locus length per unit area and sparse density ($p < 0.10$).

Comparing total locus length while viewing 3D video clips with synchronized/unsynchronized movement of the visual target, the value in VC-6 was significantly higher than that in Pre but no significant difference was seen in VC-8 ($p < 0.05$). Furthermore, with their eyes open, the value of the total locus length per unit area while viewing VC-8 was significantly lower compared to VC-6 ($p < 0.05$). With their eyes closed, the value of the total locus length per unit area tended to be lower for VC-7 compared to for VC-5 ($p < 0.10$).

3.2 Experiment 2

Subjects were divided into a young, middle-aged and an elderly group, and the analytical indices were calculated from the stabilograms recorded when subjects viewed the videos (Figs. 5, 6 and 7). Results showed that for all age groups, sway values were significantly higher when watching the videos than for the Pre.

In the young group, the value of the total locus length with their eyes open was significantly higher while viewing VC-II than in the Pre ($p < 0.05$), and it tended to be statistically higher while viewing VC-I ($p < 0.10$). With their eyes closed, the value of the area of sway was larger after viewing VC-I than in the Pre ($p < 0.05$), and the value

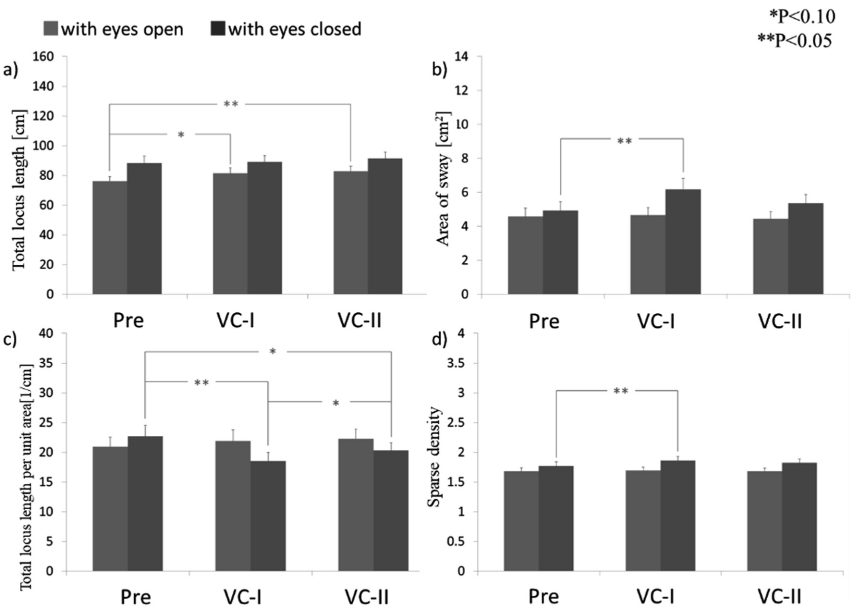

Fig. 5. Sway values for the young.

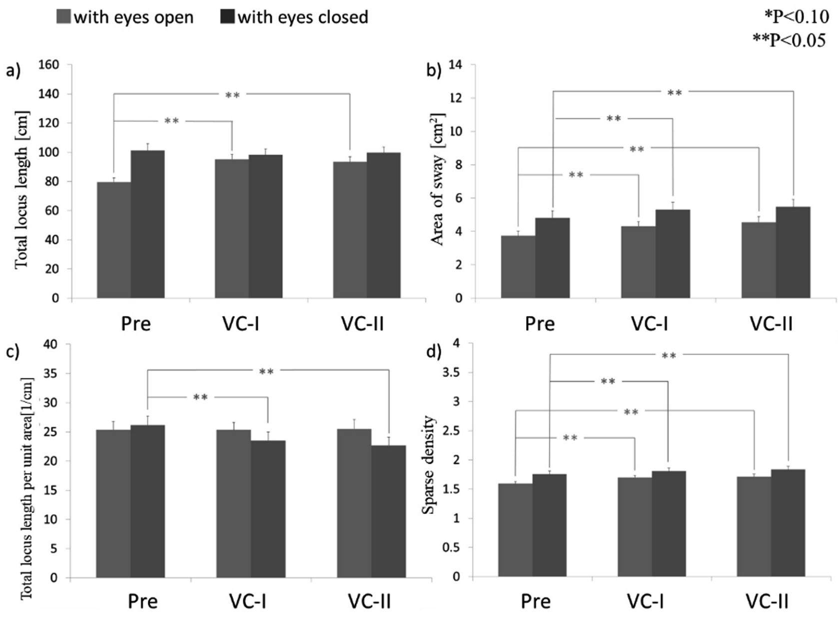

Fig. 6. Sway values for the middle-aged.

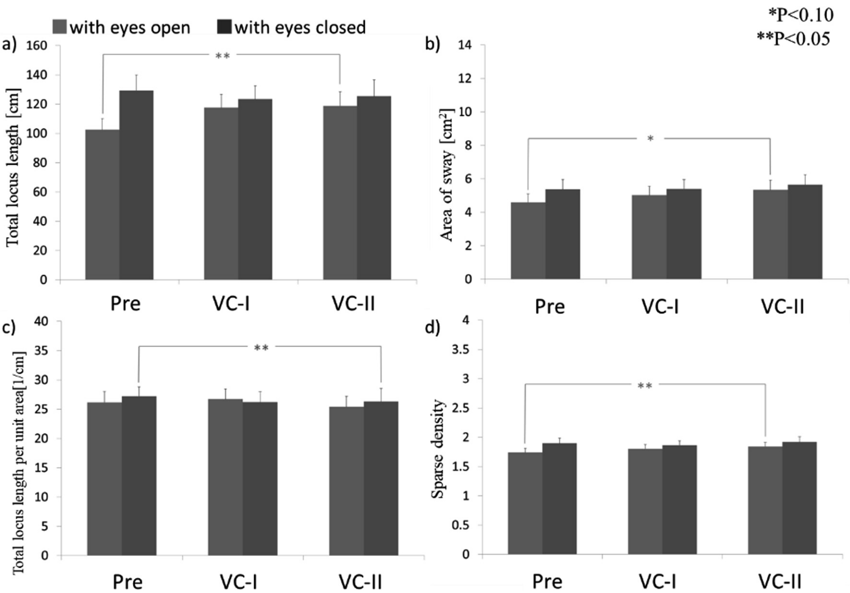

Fig. 7. Sway values for the elderly.

of the total locus length per unit area was significantly lower ($p < 0.05$). After viewing VC-II, total locus length per unit area tended to be lower compared to Pre ($p < 0.10$). Moreover, the value of the total locus length per unit area tended to be statistically higher after viewing VC-II than that for VC-I ($p < 0.10$).

In the middle-aged group, with their eyes open, the values of the total locus length, the area of sway, the *total locus length per unit area*, and the sparse density were significantly higher while viewing VC-I and VC-II compared to the Pre ($p < 0.05$). With their eyes closed, the values of the area of sway and the sparse density were significantly higher after viewing VC-I and VC-II compared to the Pre ($p < 0.05$). Moreover, results for the total locus length per unit area were significantly lower after viewing VC-I and VC-II than that of the Pre ($p < 0.05$).

In the elderly group, with their eyes open, values of the total locus length and the sparse density were significantly higher while viewing VC-II compared to the Pre ($p < 0.05$), and the value of the area of sway tended to be statistically higher ($p < 0.10$), With their eyes closed, the value of the total locus length per unit area tended to be statistically lower after viewing VC-II compared to the Pre ($p < 0.10$).

4 Discussion

4.1 Experiment 1

Since body sway was higher when viewing 3D video clips than when viewing 2D video clips, regardless of a visual target being present in the video or not, it is believed that background instability when viewing 3D video videos impacted more on the equilibrium system. Results were obtained showing that sway values when viewing video clips without a visual target was significantly increased compared to viewing Pre, regardless of solidity of the video clip (2D or 3D) with their eyes open/closed. However, when viewing video with visual targets, no significant differences were seen regardless of the solidity, and thus it is believed that when viewing video with a visual target, the effect due to background instability on the equilibrium system is reduced. We surmise that this may be due to stationary visual targets assisting in balance control in the upright posture. Total locus length when viewing 3D video is shown to be significantly lower after viewing video clip for 2 min with a visual target compared to viewing video without a visual target. Based on this, it can be concluded that, the 3D video clip without a visual target impacts more on the equilibrium than video with a visual target. We surmise that this may be because, since the video clip is in 3D, the visual target is felt to be nearer, thus assisting in balance control in the upright posture.

For viewing the 3D video clip except for the abovementioned comparison, the total locus length results are believed to be more perturbed due to the exposure to the video clips with a visual target. However, since opposite results are found for the area of sway and the total locus length per unit area, we can conclude that although there is an increase in slight sway variation, the range within which the centre of gravity changes has narrowed. It is surmised that this is because controlling one's CoP does not involve an attempt to stay in one spot, but rather it is controlled by swaying within a constant range while matching the movement of the visual target.

Compared to video clips with synchronized movement of the visual target, viewing video with unsynchronized movement of the visual target results in significantly higher total locus length than when viewing Pre. However, based on the results for the area of sway and the total locus length per unit area, statistically increased sway tended to be seen for the exposure to the video clip with synchronized movement of the visual target compared to that with unsynchronized movement. This leads us to conclude that although there is an increase in micro-sway, the range of motion of the CoP has narrowed for the exposure to the video clip with unsynchronized movement. It is believed that this is because, although the total locus length is increased when viewing the unsynchronized movement by swaying the body to match the movement of the visual target, the effect of the exposure to the video clip on the equilibrium system is increased when viewing video clip with the synchronized movement of the visual target.

Compared to video with a static visual target, video clips without a visual target affected the equilibrium system more. Additionally, we can say that the connection between the background and visual target when there is a visual target that functions as an aid to balance control changes the effect on the equilibrium system. This is based on the following: video clips with a moving visual target affected the equilibrium system more than video clips with a static visual target, and it is believed that the impact on the equilibrium system of a moving visual target was severer when viewing video with the synchronized movement of the visual target. Furthermore, in relation to the video clips used in the present paper, motion sickness was more likely to be induced when viewing the visual target movement synchronized with the background motion.

4.2 Experiment 2

Hardly any significant differences were seen between the video clips throughout the age groups. However, regarding the total locus length in the young group, for subjects showing statistical trends when viewing VC-I compared to the Pre, significant differences were seen for VC-II, and for the elderly group no differences were found for viewing VC-I compared to Pre, although significant differences were found in the case of viewing VC-II. Therefore, it is possible that viewing VC-II strongly affects the equilibrium. Since only the young group showed statistical trends between the video clips (Fig. 5c), it is possible that the young group is considered to have sensitive balance function for the VIMS.

In measurements of the middle-aged group, we could find a number of significant differences or statistical tendencies and lack of these in measurements of the elderly group. Deterioration in the stereopsis due to the aging also affect the statistical results in this study.

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