Visual Pursuit of Two-Dimensional/Three-Dimensional Objects on Video Clips: Effects on the Human Body

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Abstract. With the recent rapid progress in image processing and three-dimensional (3D) technology, stereoscopic images are visible on television and in theaters and game machines, etc. However, 3D sickness symptoms, such as intoxication and eye fatigue, have been observed when viewing 3D films, depending on display and visual environment conditions. Further, the effect of stereoscopic vision on the human body has not been explored sufficiently. Therefore, to clarify its effects on the human body in society at large, it is important to consider the safety of viewing virtual 3D content. This present study aimed to examine the effects of peripheral viewing on the human body, specifically during exposure to two-dimensional (2D)/3D video clips. We compared stabilograms recorded during exposure to video clips with or without visual pursuit of a 3D object using two-way analysis of variance. Using statistical analysis, we found that our equilibrium is significantly affected by the background after exposure to the video clips.

Keywords: Visually induced motion sickness (VIMS) · Visual pursuit · Peripheral viewing · Stabilometry

1 Introduction

In recent times, the familiarity towards three-dimensional (3D) images has increased greatly because 3D movie contents providing binocular parallax are loaded onto different sources of amusement, such as cinema, home television, and game machines. Although the visual presence has been enhanced by the progress in 3D technology, which enables portrayal of movie scenes more realistically, each merit has its demerit. In this case, motion sickness is induced while viewing stereoscopic video clips [1].

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Watching 3D movies, though, can produce certain adverse effects such as asthenopia and motion sickness [2]. It has been considered that this visually induced motion sickness (VIMS) is caused by the sensory conflict that results from the disagreement between convergence and visual accommodation while viewing 3D images [3]. Thus, stereoscopic images have been devised to reduce this disagreement [4, 5]. In this paper, we also examine whether the VIMS is caused by this kind of the sensory conflict.

However, it is still unclear how long the duration of the impact of the mild symptoms induced by peripherally viewing of the 3D video clips are remained on our equilibrium systems. In order to approach the mechanism, we investigated the relationship among the body sway, visual function, and head posture while viewing stereoscopic video clips. Until recently, it has been believed that our convergence adjusts to virtual depth popped up from 3D TV screen, whereas human beings focus on the surface of the display during stereoscopic vision. It is generally explained that, "During the stereoscopic vision, accommodation and convergence are mismatched, and this is the main reason for the visual fatigue caused by viewing 3D video clips". According to the findings presented in our previous report [6], however, such explanations are incorrect. We developed a new device that can simultaneously measure accommodation and convergence. As a result, lens accommodation is considered to be consistent with convergence because the accommodation does not adjust to the surface of the display, but adjusts to the virtual depth during the stereoscopic vision [7].

The recent widespread use of stereoscopic vision facilitates provision of virtual reality and sensation; however, as discussed, since long, there has been concern over the symptoms caused by stereoscopic vision. Accordingly, in the present study, we have examined whether our visual and equilibrium systems are affected by an hour-long session of stereoscopic viewing [8, 9]. In an earlier study by Yoshikawa et al. [9], the sway values measured after visual pursuit of the stereoscopic sphere in a video clip tended to become smaller than those after (peripheral) viewing without purposeful pursuit of the object. In addition, when the subjects were not allowed to fix the point of gaze as they wished, they looked at the objects with different virtual depth. Especially in the background, there are large difference between human binocular image and artificial stereoscopic image to which our convergence corresponding to depth cues is not accommodated. Each time subjects change their point of gaze, interaction occurs between systems to control accommodation and convergence. A state of non-equilibrium in the control system for visual information processing imposes additional load on the human body. Further, the intermittent inconsistency between accommodation and convergence is considered to cause imbalance in our autonomic nervous system. That is why equilibrium function affect from peripheral viewing. In this paper, we examine effect of the exposure to stereoscopic video clips without the background on our equilibrium function.

In order to examine this hypothesis, we measured the severity of the influence of peripheral viewing, which is expected to cause uncomfortable symptoms of motion sickness, and compare it with the influence of the visual pursuit of a virtual object on the equilibrium function.

2 Materials and Methods

Eight men (mean ± standard deviation, 22.6 ± 0.7 yrs.), who may have had any otorhinolaryngologic or neurological diseases in the past, participated in this study. The experiment was sufficiently explained to the subjects, following which written consent was obtained from them. The research was approved by the Ethics Committee in Graduate School of Information Science, Nagoya University.

In this experiment, the body sway was measured while viewing 2D/3D video clips. The subjects stood on the detection stand of a stabilometer GS3000 (Anima Co. Ltd., Tokyo), without moving, with their feet together in the Romberg posture, for 30 s before the sway was recorded. Each sway of the COP was then recorded at a sampling frequency of 20 Hz. The subjects were instructed to maintain the Romberg posture during the trials. For the first 60 s, the subjects were asked to do the following:

I. Gaze at a static circle with a diameter of 3 cm (Control).
II. Follow a sphere which complexly ambulated in a video clip (Fig. 1).
III. Peripherally view the same video clip as shown in (II) without pursuing the sphere on the 40-inch display KDL 40HX80R (Sony, Tokyo).

That is, we categorized the visual sighting method as pursuit (II) and peripheral viewing (III). Subjects gazed at a point of fixation (I) or video clips (II)/(III) with their eyes open for the first 60 s, after which they closed their eyes for 60 s.

The circle (I) was placed before the subjects, 2 m away, at their eye level. Stereoscopic video clips (II)/(III) and their monocular (2D) vision were shown to subjects on the binocular parallax 3D display. The content in the "SkyCrystal" (Olympus Memory Works Ltd. Co., Tokyo) was modified, with permission from the company, and used as the visual stimulus in this experiment. The stimulus includes spheres fixed in four corners, which supplies perspective. We measured the body sway and the subjective evaluation for each vision (I) Control, (II)-2D, (II)-3D, (III)-2D, and (III)-3D situation randomly, according to the abovementioned protocol.

We conducted the stabilometry with eyes open/closed. The experimental periods with eyes open and closed was designed in our experimental protocol to evaluate the

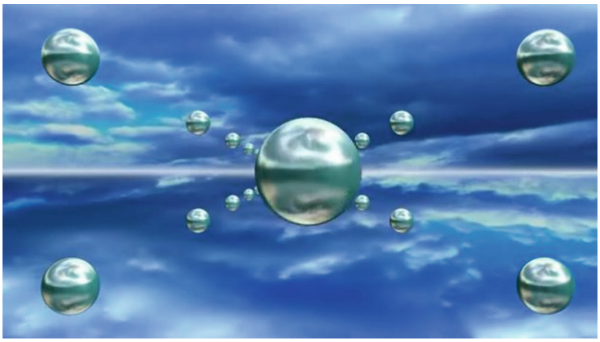

Fig. 1. One cut of the video clips [10]

severity of the VIMS during and after viewing the video clips. In stabilometry, the COP on an x-y plane was recorded at each time step where x and y directions were defined as the right and the anterior planes on their faces, respectively. Stabilograms were obtained each experimental period from the time series of their COP. Finally, we calculated the new index SPD, and the previously stated sway values such as area of sway, total locus length, total locus length per unit area, defined in Suzuki et al. [11].

The abovementioned indices were calculated from each stabilogram recorded with the eyes open and closed. Two-way analysis of variance (ANOVA) was conducted for 8 repeated values and used to determine solidity of the subjects' vision (2D/3D) and their vision method (visual pursuit versus peripheral viewing), which were assumed to be important influencing factors. In addition, the influence of exposure to video clips on our equilibrium system was investigated and compared with the control data (I). The sway values during and after viewing the (I), (II)-2D, (II)-3D, (III)-2D, and (III)-3D stimuli were compared using Wilcoxon signed-rank tests for multiple comparisons.

3 Results

With the eyes open, most stabilograms observed during peripheral viewing of the 2D/3D video clips were widely scattered on the plane, compared with the control stabilograms. In contrast, there was no consistent tendency in the stabilograms taken when the subjects' eyes were closed. Moreover, most stabilograms taken during and after exposure to the video clips were dispersed in comparison to the control stabilograms. The sway values when the subjects' eyes were open were calculated from the stabilograms. Except for the total locus length per unit area, the control sway values were smaller than those obtained from stabilograms recorded during exposure to the 2D/3D video clips (Fig. 2).

The two-way ANOVA on sway values did not reveal any interaction between the two factors: solidity of the subjects' vision (2D/3D) and their vision method (visual pursuit/peripheral viewing), except for the total locus length per unit area. Therefore, the total locus length per unit area was excluded as an analytical index for stabilogram. No main effect resulted from stabilometry with the eyes open. However, the main effect of solidity of the subjects' vision was obtained from the SPD S_3, S_5 ($p < 0.1$) and the area of sway ($p < 0.05$) in stabilograms taken with the eyes closed.

The sway values during the exposure to the video clips (II)-2D, (II)-3D, (III)-2D, and (III)-3D were compared with the control (I) using the Wilcoxon signed-rank test. With the eyes open (Fig. 2a, b), the area of sway, total locus length, and SPD for the control were significantly smaller than those obtained from stabilograms during exposure to the video clips ($p < 0.05$). Further, there were no significant differences between any values for stabilograms taken during the exposure to the 2D and 3D video clips.

With the eyes closed (Fig. 3a, b), the abovementioned sway values obtained from stabilograms recorded during peripheral viewing of the stereoscopic video clip (III)-3D were also significantly greater than those obtained from the other conditions (I) and

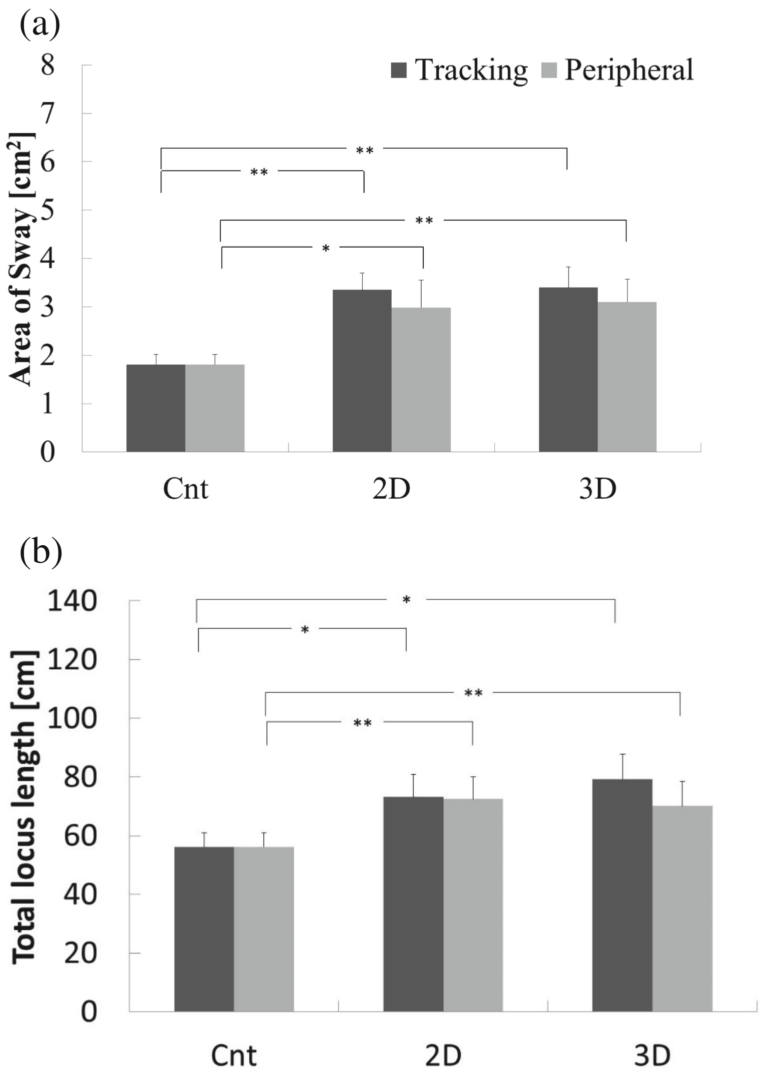

Fig. 2. Typical sway values with the eyes open: Area of sway (a), Total locus length (b)

(III)-2D. The sway values for visual pursuit of the 2D/3D sphere did not differ from those of the control, whereas a significant influence was seen when stabilometry was conducted with the subject's eyes open (Fig. 2a, b). The subjects' equilibrium after peripheral viewing of the 3D video clip was significantly less stable than that after peripheral viewing of the 2D clip. The control equilibrium system was more stable than that during peripheral viewing of the stereoscopic video clip.

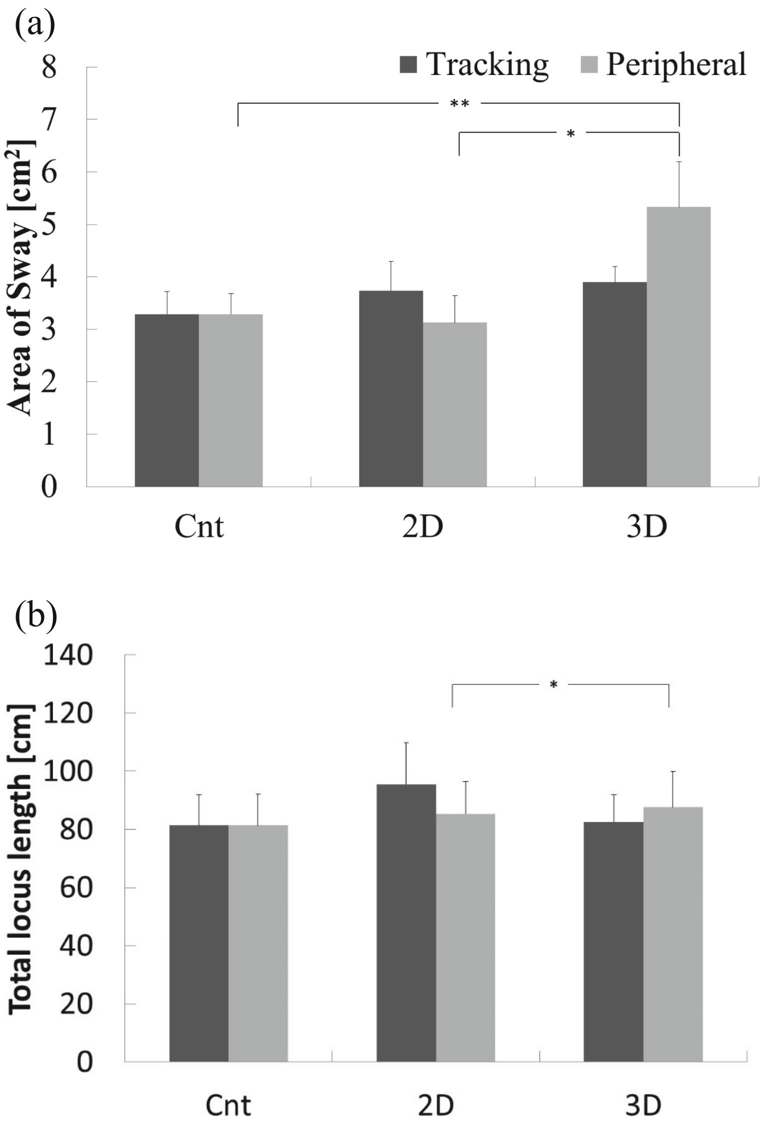

Fig. 3. Typical sway values with the eyes closed: Area of sway (a), Total locus length (b)

4 Discussion

In this paper, we examined whether exposure to stereoscopic video clips could induce motion sickness and could worsen according to the vision method. Solidity of the subjects' vision (2D/3D) and their vision method (visual pursuit/peripheral viewing) were assumed to be influencing factors for the equilibrium function and were examined using two-way ANOVA for the body sway. When eyes were kept open, these factors showed no main effects for any sway values, although most sway values were greater than those obtained for the control condition during viewing of 2D/3D video clips. We also recorded stabilograms with eyes closed, immediately after the exposure to the video clips. We found that sway area and sparse density of a high degree was consistent with the main effect of solidity. Further, after peripheral viewing of the 3D video clip, a remarkable change in sway values was noted, thus explaining the instability in the subjects' equilibrium.

This change in subjective evaluations after peripherally viewing the video clips was also confirmed statistically [12, 13]. According to the analysis of the SSQ sub-score N, OD, TS, and VAS, we found an increase in the severity of symptoms such as discomfort and eye strain that were induced by the VIMS.

When the eyes open, the total locus length significantly increased with visual pursuit of the stereoscopic sphere, which was not seen in the sway value immediately after the exposure to the video clip (II)-3D (Figs. 2b and 3b). Therefore, this effect is considered temporary. However, with the eyes closed, a significant increase was not only seen in most of the sway values, including the previous indices for stabilograms, but also in the subjective evaluations, including the eye strain component. This is regarded as a persistent effect that might be caused by peripheral viewing in an unclear background element where depth perception differs from that in daily life. This indicates that a labored style of visual performance could be induced by binocular parallax because the stereoscopic images were constructed without consideration of our finite convergence. From this point of view, technology to compose stereoscopic images has been developed as a countermeasure [14], and is already being used in accommodation training. This technology is expected to be widely accepted. We used this technology in an accommodation training study on preventive medicine to improve pseudo-myopia by relaxing the contracted focus-adjustment muscles around the eyeball, such as the ciliary and extraocular muscles [15]. We verified the short-term effects of the apparatus on the eyesight of visual inspection workers (22 women) with eye fatigue. The workers were trained for 3 days. We found that visual acuity of the subjects improved in a statistically significant manner after continuous accommodation training, which promoted a ciliary muscle-stretching effect.

In a previous study, we also compared fixation distances between accommodation and convergence in young and middle-aged subjects, while they followed a sphere on 2D/3D video clips used in the present study [16]. Both groups of subjects showed roughly similar results. Fixation distances among accommodation, convergence, and depth map (theoretical distance of the surfaces of objects) were compared while the subjects tracked on the sphere in the video clip (II)-3D on LCD, and measurements were repeated. There were no differences between visual accommodation and convergence for the first 60 s of continuously viewing 3D images. However, an inconsistency was gradually observed, and we found delay in accommodation variations of the middle-aged subjects, indicating that subjects' accommodation and convergence when viewing 3D images changed the diopter value, which is synchronous with the movement of the 3D images. However, lens accommodation was not consistent with convergence in the middle-aged subjects after gazing at the 3D video clips for 90 s, although subjects in this study did not follow the stereoscopic sphere for more than 90 s. The abovementioned inconsistency was not considerable, indicating that this inconsistency between the lens accommodation and convergence may not be the cause of 3D sickness.

In this study, the influence of the vision method, i.e., visual pursuit and peripheral viewing, on our equilibrium systems during and after viewing 2D/3D video clips was examined. We found that regardless of the vision method followed by the subject, sway values were greater during viewing of 2D/3D video clips than those during viewing in the controls. Systems that help control upright posture tended to become unstable during exposure to the video clips. In addition to deterioration in equilibrium, subjectively increased exacerbation of uncomfortableness was observed after peripheral viewing of the video clips compared with to that after viewing clips involving visual pursuit of the sphere. This is regarded as persistent influence that might be caused by peripheral viewing in an unclear background elements due to their depth perception that differ from those observed in daily life. VIMS might be caused by an overload of visual information.

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