The Frequency Response Characteristics of Semicircular Canals on Visually Induced Motion Sickness

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ABSTRACT

This study focuses on the relationship between the oscillation frequency components and visually induced motion sickness when the motion simulated that observer goes straight with oscillation on an ordinary mountain road.

1 INTRODUCTION

Recently, the head mount display (HMD) has become usable even in the common households by the development of image production technology and image presentation technology, and the virtual reality (VR) has become common. In VR contents, it is important to obtain a high sense of presence and immersion in order to make the viewer feel that the space produced is closer to the reality, and the sense of movement in VR space seems to contribute to the sense of presence and immersion. In many VR contents, only visual stimuli are presented to HMD. Self-motion perception induced by visual motion alone is a well-known phenomenon was named vection by Fisher and Kommüler (1930).

On the other hand, viewing VR content may cause discomfort similar to car sickness [1, 2]. This is called visually induced motion sickness (VIMS), and eyestrain, headache and vertigo, nausea are mentioned as a concrete symptom. These symptoms are similar to carsickness and seasickness and are considered to be one of motion sickness. The mechanism of the occurrence of VIMS has not been clarified in detail, but the theory of sensory discrepancy has been proposed as the cause [3]. Sensory conflict theory is a theory that motion information input to vision and other senses is different from the prediction, causing conflict and inducing motion sickness.

Bos et al. (2008) showed that VIMS was induced when the rotation axis of the visuomotor stimulus and the gravity axis viewed from the observer were discordant [4]. Chen et al. (2016) also showed that the severity of VIMS varied with the frequency of vibration in the observer's anteroposterior axis [5]. Based on the results of these two studies, the directional component of motion and the frequency component of vibration included in the image can be considered as the factors that induce VIMS.

The vestibular sensory organ, which is involved in the reception of own acceleration information, consists of otolith, which receives linear acceleration and gravitational acceleration, and semicircular canal, which receives angular acceleration. From this fact, it was considered that the input from the visual system and the input from the otolith were discordant, when the rotational direction of the visual motion stimulation was discordant with the gravity axis of the observer, and that the image sickness was induced. The otolith and semicircular canals have different frequency response characteristics [6, 7]. From this fact, it was considered that the contradiction occurred in the input from visual system and input from vestibular sense organ, when the frequency of the vibration was the frequency in which the response of vestibular sense organ was good, and that the VIMS was induced. In this study, in order to clarify whether the frequency characteristics of the vestibular sensory system contribute to VIMS, the effect of the direction and frequency of vibration on VIMS was examined when the periodic vibration around the rotation axis of the observer's head was added to the visual stimulation which linearly moved forward. In this study, experiments were carried out under three conditions: Experiment 1, a pitch condition which rotationally oscillates around the horizontal axis of the observer, Experiment 2, a roll condition which rotationally oscillates around the anteroposterior axis of the observer. Experiment 3, a yaw condition which rotationally oscillates around the vertical axis of the observer.

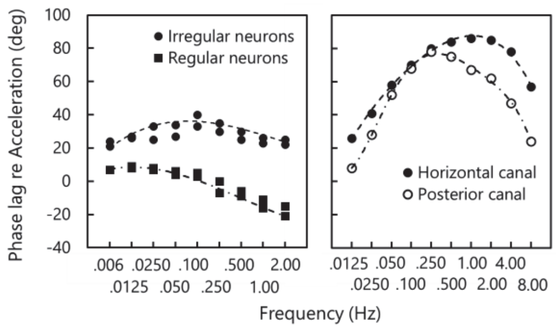

Fig. 1 The dynamic characteristic of the otolith organs (left) and the semicircular canals (right). (Revised Fernandez and Goldberg, 1971, 1976)

2 EXPERIMENT1

2.1 Apparatus

We used an head mounted display (HMD)(HTC Vive, HTC) to project a visual stimulus placed inside the semi-dark room (1.1 × 1.4 × 1.8 m (width × depth × height)). We installed a chair at the center of the semi-dark room so that an observer sitting upright had her/his feet touching the floor. We measured the observer's postural movements was measured by a force platform system (Wii Balance Board, Nintendo), which recorded center of foot pressure (COP) data for four different points on the platform at 90 Hz using strain gauges.

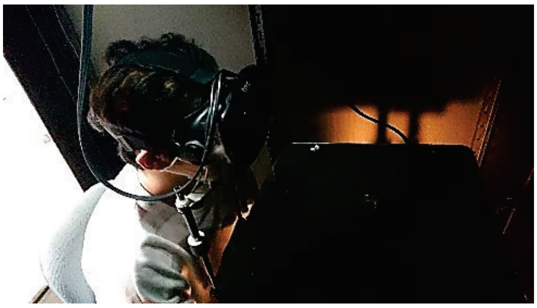

Fig. 2 Experiment environment

2.2 Visual stimulus

A visual stimulus that simulated the motion that observer goes straight (7 (m/s)) with oscillation on an ordinary mountain road rendered as stereoscopic images on Windows-based PC (LITTLEGEAR i330SA4, GTUNE) with Unity. As for the visual stimuli, frame rate was 90 (fps), height was 110 (deg), and width was 110 (deg).

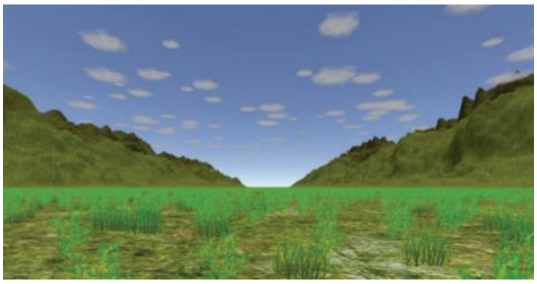

Fig. 3 Visual stimulus

2.3 Experimental Conditions

A visual stimulus oscillated by the rotation of observer's horizontal axis, such as pitch. We used seven different types of frequency condition (0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 Hz). The frequency conditions were decided form previous studies [5, 6, 7]. Amplitude of the oscillation varied according to the frequency conditions so that maximum velocity induced by the oscillation did not excess 30 (deg/s) in pitch.

2.4 Observers

Twenty-seven adults (twenty-four male, three females; 21.9 ± 0.97 years) participated in the study after providing informed written consent, in accordance with the provisions of the Ergonomics Experiment Policy of the Niigata University. The observers were naïve to the purpose of the experiments and had normal or corrected-to-normal visual acuity.

2.5 Procedure

Before starting the experiment, observers are given an explanation of the tasks in the experiment. The observer then viewed the visual stimulus for about 5 minutes.

To measure the VIMS strength, we used simulator sickness questionnaire (SSQ). The obtained SSQ results were divided into 3 groups of 16 questions each, and the respective sub-scores and, the total score indicating the overall severity of VIMS were calculated. The observers were asked to complete a SSQ before and after viewing the 5-minute as one of the psychological evaluations. In this study, scores were calculated from the difference in SSQ before and after stimulus viewing. The SSQ questionnaire consisted of 16 questions which were adjusted Japanese translation of previous study [8] and four choices of answers (none, slight, moderate, severe) on VIMS.

Upon completion of these tasks, each observer rested for 20-minute in the quasi-dark room. All the observers participated on four different days, with two trials per day. However, only on day 4, the observers conduct one trial.

3 RESULTS

There was a statistically significant difference between the frequency conditions in the Total Score and three sub scores (Total Score: χ^2 (6) = 35.9, p = .31*10^{-7}; Nausea: χ^2 (6) = 31.6, p = .27*10^{-6}; Oculomotor: χ^2 (6) = 28.4, p = .14*10^{-5}; Disorientation: χ^2 (6) = 27.0, p = .28*10^{-5}).

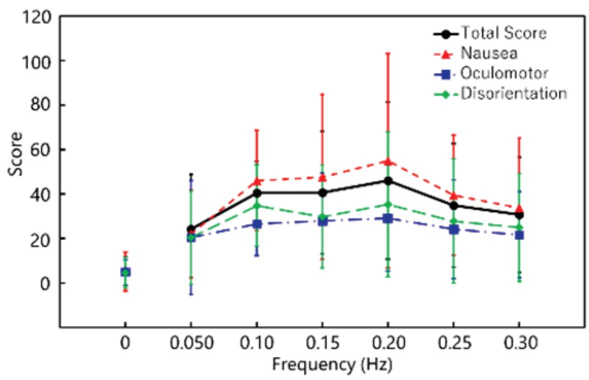

Fig. 4 The effect of frequency of pitch oscillation on SSQ error bar is standard deviation

4 EXPERIMENT 2

4.1. Apparatus and Visual stimulus

The experiment was conducted using the same apparatus and visual stimulus as in Experiment 1.

4.2. Experimental Conditions

A visual stimulus oscillated by the rotation of observer's anteroposterior axis, such as roll. We used seven different types of frequency condition (0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 Hz) as in Experiment 1. Amplitude of the oscillation varied according to the frequency conditions so that that maximum velocity induced by the oscillation did not excess 30 (deg/s) in roll.

4.3. Observers

Thirteen adults (thirteen male; 21.7 ± 0.72 years) participated in the study after providing informed written consent, in accordance with the provisions of the Ergonomics Experiment Policy of the Niigata University, as in Experiment 1. Seven of the thirteen observes had participated in Experiment 1. The observers were naïve to the purpose of the experiments and had normal or corrected-to-normal visual acuity.

4.4. Procedure

The experiment was conducted using the same procedure as in Experiment 1.

5 RESULTS

There was no statistically significant difference between the frequency conditions in the Total Score and three sub scores (Total score: χ^2 (6) = 10.9, p = .18; Nausea: χ^2 (6) = 8.52, p = .40; Oculomotor: χ^2 (6) = 7.24, p = .60; Disorientation: χ^2 (6) = 5.06, p = 1.1).

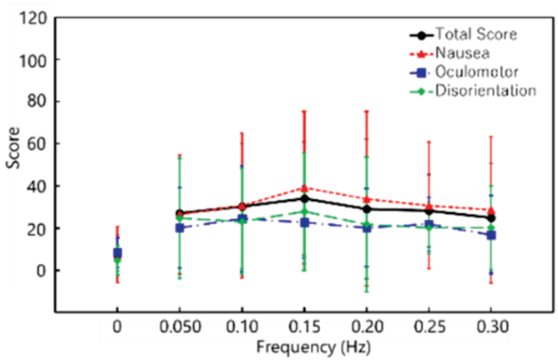

Fig. 5 The effect of frequency of roll oscillation on SSQ error bar is standard deviation

6 EXPERIMENT 3

6.1. Apparatus and Visual stimulus

The experiment was conducted using the same apparatus as in Experiment 1.

6.2. Experimental Conditions

A visual stimulus oscillated by the rotation of observer's vertical axis, such as yaw. We used seven different types of frequency condition (0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 Hz) as in Experiment 1 and 2. Amplitude of the oscillation varied according to the frequency conditions so that that maximum velocity induced by the oscillation did not excess 30 (deg/s) in yaw.

6.3. Observers

Eleven adults (eleven male; 21.7 ± 0.72 years) participated in the study after providing informed written consent, in accordance with the provisions of the Ergonomics Experiment Policy of the Niigata University, as in Experiment 1. Seven of the eleven observes had participated in Experiment 1. The observers were naïve to the purpose of the experiments and had normal or corrected-to-normal visual acuity.

6.4. Procedure

The experiment was conducted using the same procedure as in Experiment 1 and 2.

7 RESULTS

There was no statistically significant difference between the frequency conditions in the Total Score and three sub scores (Total Score: χ^2 (6) = 10.6, p = .20; Nausea: χ^2 (6) = 7.21, p = .60; Oculomotor: χ^2 (6) = 8.13, p = .46; Disorientation: χ^2 (6) = 4.55, p = 1.2).

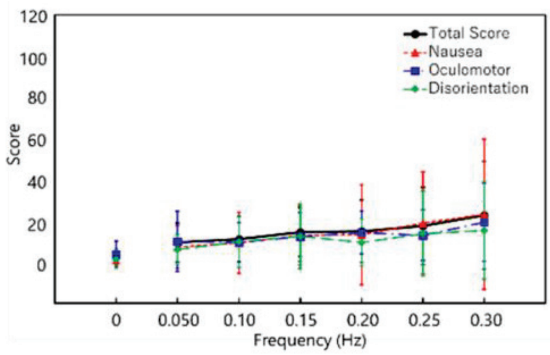

Fig. 6 The effect of frequency of yaw oscillation on SSQ error bar is standard deviation

8 DISCUSSION

The results of this study suggest that the severity of VIMS depends on oscillation. In this study, the severity of VIMS at 0 Hz was lower than that of VIMS at other frequencies. This result can be considered response effect of Momentum. Benson (1988) suggested that there is leaky integrator which accumulates the conflict in neural mismatch model [9]. According to Benson, when the conflict reaches the threshold, VIMS is induced. The visual stimuli used in this study had similar momentum at frequencies other than 0 Hz, so There was no statistically significant difference in the severity of VIMS at frequencies other than 0 Hz. The severity of VIMS under the yaw condition was lower than that under the pitch and roll conditions. According to Bos et al. (2008), this result can be considered the rotation axis of the visuomotor stimulus and the gravity axis viewed from the observer.

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