Effects of Active Self-motion on VR Sickness Induced by Visual Motion Perpendicular to Self-motion

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ABSTRACT

We examined the effect of active physical self-motion on VR sickness induced by visual motion not consequent to the self-motion. We found participants experienced stronger sickness while walking than standing still on the treadmill used. In addition, rotational visual motion has a stronger effect on sickness than translational visual motion.

1 INTRODUCTION

People sometimes experience uncomfortable symptoms of motion sickness while moving around inside virtual reality (VR) environment. Much research has already investigated various factors of such motion sickness in VR environment, or of VR sickness. Among the factors, whether active or passive movement in virtual space is unique to VR sickness in that people cannot actively walk around in a space shown in traditional moving image, such as movie or video image.

Past literature reported that active control of vehicle steering in virtual gaming has some effects of alleviating VR sickness [1, 2]. One possible reason is that the conflict between sensed and expected information of self-motion was reduced during the active control according to the sensory conflict theory [3]. In the active control situation, we will focus on two points. The first one is about “active” movement. While the experiments reported in the literature controlled ambulation of vehicle movement using game controllers, we are interested in the effect of self-motion induced by active physical movement of participants’ self-body, like walking. The second point is about whether visual motion is the consequence of active control. The experiments mentioned above presented visual motion as the consequence of active control of vehicle movement; little research investigated the effect of visual motion not consequent to self-motion produced by active control.

Our purpose of the research is to examine active self-motion on VR sickness induced by visual motion not consequent to self-motion. For the purpose, we used a treadmill-based VR system to control the effect of other sensory information than that of walking straight-ahead on VR sickness.

2 METHODS

2.1 Participants

19 participants (6 females, 13 males; mean age 24.2 yr, SD 3.3 yr) were recruited to participate in the experiment. All participants had normal or corrected-to-normal vision and normal hearing, and they were naïve to the purpose of the experiment. Prior to the participation, all participants filled in informed written consent, in accordance with the provisions of the Ergonomics Experiment Policy of the National Institute of Advanced Industrial Science and Technology (AIST). The participants were free to withdraw at any time during the experiment. The experimental protocol was approved in advance by the Institutional Review Board of AIST.

2.2 Apparatus and stimulus

The treadmill (Daikou, DK-1533AC) was used for participants’ walking or standing still. Walking surface of the treadmill was 53 x 151 cm (width x length). Around the treadmill, a steel angles formed a frame for a rectangular solid (120 x 120 x 240 cm; width x height x length), on which a set of harness was hanged for the participants putting it on for their safety.

The virtual visual environment was produced by Unity3D and, presented on an HMD (HTC, HTC Vive). In the virtual environment, we set an infinite, 2m wide asphalt path. On both sides of the path, seven different types of car models were repetitively placed in a row in random order without any gap between each other (Fig.1). The car models were selected from "Extreme Vehicle Pack 1 Low-poly 3D model".

Fig. 1 The virtual visual environment used in the experiment

2.3 Experimental Conditions

In all conditions, the participants wearing the HMD viewed forward self-motion with one of three types of additional visual motion in the virtual environment while walking or standing still on the treadmill. Thus, there were a total of six conditions, the combinations of three types of "additional visual motion" sub-conditions and two types of "physical self-motion" sub-conditions ("Walking" or "Standing still"). All the participants basically participated in all six conditions (within-participants design); however, three of them participated in either one, two or three conditions only, and then, dropped out from the experiment due to severe nausea. The data of the participant participating in two conditions only were removed due to holding the handrails unexpectedly during the experiment; the data of completed conditions of other two dropout participants were included in the data analysis.

The three types of additional visual motion were sinusoidally cyclic roll ("Roll") and pitch ("Pitch") rotation, and sinusoidally cyclic vertical translation ("Vertical"). All types of the visual motion were perpendicular to the forward motion. The frequency of those types of visual motion was 0.2Hz; the amplitudes were 30 deg, 30 deg, 80 cm, respectively.

For the physical self-motion, the treadmill speed was set to 4 km/h for "walking" and 0 km/h for "standing still". In both cases, the speed of visually presented self-motion was set to 4.59km/h to achieve the equivalent speed perception between treadmill and optic flow based on a pilot experiment. For the "walking" physical self-motion sub-condition, visual forward motion was produced based on the speed information of encoder (Omron, E6A2-CW3C 360P/R 0.5M) detecting the movement of walking surface in the treadmill.

2.4 Procedure

Before starting the experimental sessions, each participant closed the eyes and wore an eye mask for 5 minutes to be rapidly adapted to luminance level of HMD. Then, they performed 50-second session in which they practiced walking on the treadmill during viewing forward motion on the HMD. For the experimental sessions, they wore prepared socks and shoes, the harness, the HMD, and noise-cancelling headphones with which pink-noise was presented with the sound pressure of 76 dB. The pink-noise was used to minimize the influence of sound produced by the treadmill on self-motion perception while walking.

The six conditions were performed in six experimental sessions; each session corresponds to each condition. There was at least 20-minute break between each session. The order of the conditions was randomized between the participants.

Before each session, each participant filled in Simulator Sickness Questionnaire (SSQ) [4]. Then, the treadmill started according to the condition, and the virtual visual environment was displayed in the HMD. Each session lasted for 4 minutes. The participant did not move the head and kept looking straight until the end of the session. During each session, the participant was requested to answer a 5-point Likert scaled Fast Motion Sickness (FMS) scale every 30 s from 15 s after starting the session. The participant, again, filled in the SSQ right after the session.

Table. 1 FMS scale used in the experiment

Score	Symptom
0	No symptom
1	Slight symptom without nausea
2	Some symptom without nausea
3	Slight nausea
4	Moderate nausea

3 RESULTS

3.1 Fast Motion Sickness Scale

The result of the FMS scale is shown in Fig.2. To model the ordinal response of 5-point Likert scaled FMS for the statistical analyses, we fitted a cumulative link mixed model (CLMM) with the Laplace approximation with FMS score as the outcome variable, "additional visual motion" and "physical self-motion" as the fixed factor, time as the covariate, and participant as the random factor. Statistics were done using R 3.6.0, the car (v3.0-9), the ordinal (v2019.12-10), the RVAideMemoire (v0.9-78), and emmeans (v1.3.4) packages.

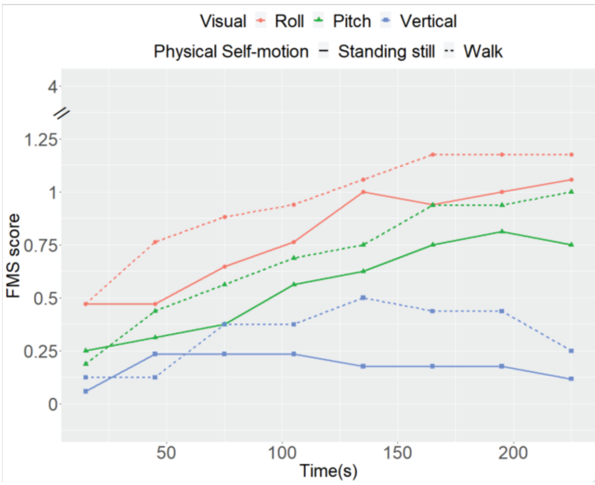

Fig. 2 Result of FMS scale

A type II ANOVA table of the model indicated that there was significant effects for the "additional visual motion" sub-condition ($\chi^2(2) = 176.248$, $p < .0001$) and for "physical self-motion" sub-condition ($\chi^2(1) = 20.771$, $p < .0001$), with the FMS score in "Walking" (M = 0.663, SE = 0.037) was higher than in "Standing still" (M = 0.508, SE = 0.034). In addition, there was a significant effect for the time covariate ($\chi^2(1) = 71.685$, $p < .0001$). However, there was no significant effect for the interaction between "additional visual motion" and "physical self-motion" sub-conditions ($\chi^2(2) = 4.788$, $p = .0913$).

A post hoc test with Bonferroni correction was used to examine the pairwise effect between different "additional visual motion" sub-condition and the result showed that the FMS score in "Roll" (M = 0.777; SE = 0.047) was significantly higher than those in "Pitch" (M = 0.621; SE = 0.043) (z = 3.915, p = .0003) and in "Vertical" (M = 0.25; SE=0.03) (z = 11.812, $p < .0001$). The FMS score in "Roll" was also significantly higher than that in "Vertical".

3.2 Simulator Sickness Questionnaire

To analyze the effect of "additional visual motion" and "physical self-motion" sub-conditions on SSQ total scores, the difference score between the pre-exposure and post-exposure to VR was calculated. The result of the difference score of SSQ is shown in Fig.3.

We fitted a linear mixed model with difference score of SSQ as the outcome variable, "additional visual motion" and "physical self-motion" as the fixed factor, and participant as the random factor. Statistics were done using R 3.6.0, the lme4 (v1.1-21), the lmerTest (v3.1-0), and emmeans (v1.3.4) packages.

A type II ANOVA table with Satterthwaite's method of the model indicated that there was a significant effect for "additional visual motion" sub-condition (F(2, 75.483) = 5.543, p = .006), while there was no significant effect for "physical self-motion" sub-condition (F(1, 75.351) = 1.747, p = .19). Besides, the interaction between "additional visual motion" and "physical self-motion" was not significant (F(2, 75.32) = 0.111, p = .9).

A post hoc test with Bonferroni correction was conducted and the Satterthwaite's method was used to calculate the degrees of freedom. The result showed that the difference score of SSQ in "Roll" (M = 11.754, SE = 3.885) was higher than in "Vertical" (M = 1.927, SE = 0.878) (t(77.7) = 3.336, p = .004). The difference score of SSQ in "Pitch" (M = 4.675, SE = 1.163) were not significantly different from those in other two types of "additional visual motion" sub-condition.

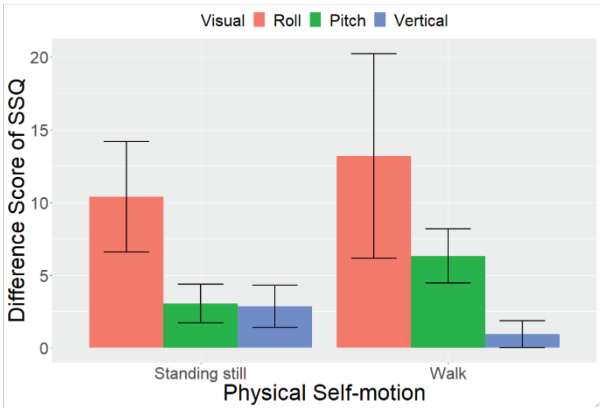

Fig. 3 Result of difference score of SSQ. Error bars represent the standard error of conditions

4 DISCUSSION and CONCLUSIONS

The significant results of the FMS score indicate that the active physical self-motion has a positive effect on the VR sickness. The result is superficially inconsistent with the past research. However, this suggests that active physical self-motion, like walking, increases the sensitivity to the conflict from the visual motion not consequence of active motion. However, the effect of physical self-motion was not significant in the gain score of SSQ. One of possible reason causing the difference between the results of FMS and of SSQ might be because the induced sickness was rather short-term in the experiment. Further research is necessary to confirm the indication.

Both the results of FMS score and SSQ score showed that the rotational visual motion induced stronger VR sickness than the translation visual motion. The result might indicate that visuo-vestibular conflict is more sensitive with information from semi-circular canals than from otolith organs.

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