Optic Flow, but Not Retinal Flow, Is Essential to Induce VR Sickness

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ABSTRACT

We conducted an experiment measuring VR sickness using HMD, manipulating optic flow and retinal flow in three conditions. The results showed that sickness scores increased according to the amount of optic flow, but not of retinal flow, indicating that optic flow, not retinal flow, is essential to induced VR sickness.

1 Background and Objectives

The purpose of the present study is to investigate whether optic flow is the essential factor to induce VR sickness.

Recent advanced technology of moving images developed head mounted displays, HMDs, with higher resolution, lighter weight, and less expensive, which promotes the distribution of those products in the general market, and thus, to general consumers. One of the primary characteristics of VR type of HMDs is to let viewers "look around" virtual world, by changing the direction of viewed images. Because of this characteristics of the HMDs, visual motion simulating self-motion of viewers in the first-person view can be different when the viewing direction was changed by rotating the head wearing the HMD.

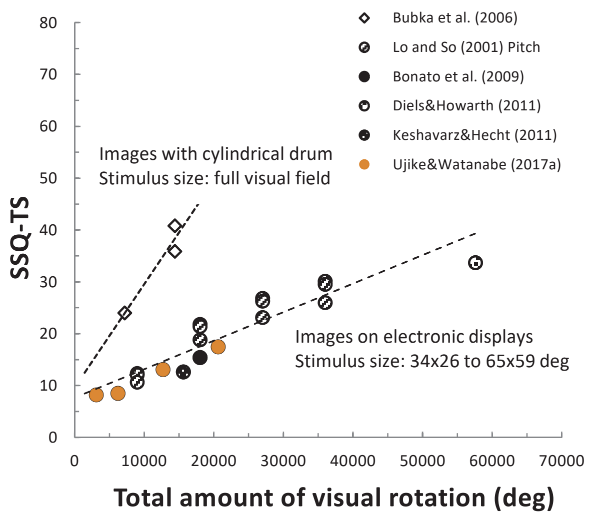

Fig. 1 SSQ-TS as a function of total amount of visual rotation
Plotted data are corrected from studies reporting both SSQ-TS and any kind of information leading to total amount of visual rotation.

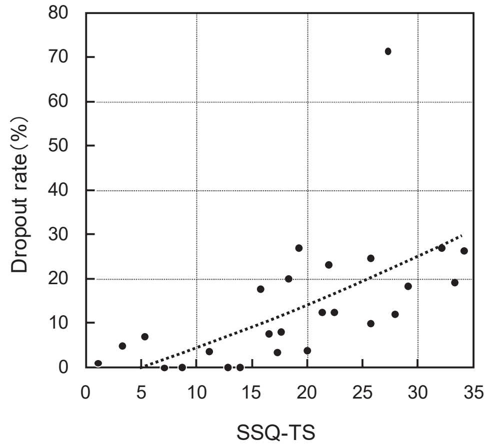

Fig. 2 Dropout rate as a function of SSQ-TS
The dotted line is the fitting line of the data. The significant correlation was found.

Our previous researches[1],[2] indicated that total amount of visual image motion simulating rotation around yaw, pitch, and roll axes is well correlated with the total score of Simulator Sickness Questionnaire [3], or SSQ-TS, (see Fig. 1), which is also correlated with dropout rate representing the rate of people suffering motion sickness while viewing moving images (see Fig. 2). Therefore, we concluded that total amount of visual image rotation predicts the severity of visually induced motion sickness (VIMS) [4], or the ratio of people suffering form VIMS.

However, considering VR sickness induced during viewing images on HMDs, it is important to investigate whether the "visual image rotation" mentioned above is to be considered as optic flow or as retinal flow especially when we try to evaluate or predict severity of VR sickness. When the head rotates, image motion on the retina, which is retinal flow, can be changed depending on the head position, despite that the optic flow is not changed.

To achieve the purpose, mentioned above, we conducted an experiment in which we manipulated and control optic flow and retinal flow, and try to find out which flow information determines severity of motion sickness, by measuring mainly SSQ-TS but also by other subjective scores and physiological measurement, such as electrocardiogram (ECG).

2 Methods

2.1 Participants

Twenty-four adults (11 females and 13 males, aged 33.2±13.5 years) were participated in the experiment after providing 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. The participants were naïve as to the purpose of the experiment, and had normal or corrected-to-normal visual acuity.

2.2 Stimulus images

Moving images, simulating self-forward motion of participants, were CG images produced with Unity graphics software on a Windows10 PC (Core-i7) with a graphics card (GeForce GTX1080), and were presented on a HMD (Fove, Fove0). The size of the visual field was approx. 100 deg, and frame rate was 70 fps.

The images were a first person view simulating flying over the mountain area (see Fig. 3). There is a red-colored-ring almost at around the boundary of stimulus visual field; the ring was a kind of target used for differentiating stimulus conditions (see the next section). Translucent balls were falling in the virtual images, to enhance optic flow viewed through the HMD. The simulated motion of the images, which was common in all the experimental conditions was yaw mation. In an experimental trial of 270 s, both turning left of 90 deg and right of 90 deg were included 24 times each. Therefore, there were a total of 2160 deg turning left and 2160 deg of turning right. The images were also turning either up and down (pitch motion) or additional left and right (yaw motion) depending on the experimental condition explained in the next section.

Fig. 3 Stimulus image presented on the HMD
Size of the image viewed with the HMD is almost the size of the red-colored ring. Yellow particles are the translucent balls presented for enhancing optic flow.

2.3 Stimulus conditions

There were mainly three different experimental conditions: “Passive”, “Active”, and “Control” conditions. In the passive condition, virtual camera shooting the image changed its direction either in pitch or in yaw automatically. In this condition, participants viewed the stimulus image on the HMD without head movements. In the active condition, the virtual camera changed its direction according to the participants head movements either in pitch or in yaw. Thus, in this condition, the participants moved the head in yaw or in pitch directions, which was instructed in advance. The speed and extent of head motion was adjusted by the participants by adjusting the position of the red-colored ring to be just at the boundary of stimulus visual field. In the control condition, the virtual camera did not change the direction. In this condition, participants viewed the stimulus image on the HMD without head movements.

In the passive and active conditions, retinal flow produced by the image motion was almost equivalent; however, in the passive condition, the participants did not move the head, while in the active condition, the participants moved the head in pitch or in yaw direction, which produced corresponding retinal motion. In the active and control conditions, optic flow produced by the image motion was basically equivalent; however, in the active condition, the participants moved the head in pitch or in yaw direction, while in the passive condition, the participants did not move the head.

2.4 Procedure

The participants attend the experimental sessions in two days. The additional image motion in yaw and in pitch was viewed in the different day. The order of the yaw and pitch was counterbalanced among the participants. In each experimental day, there were three trials of viewing images with the HMD. Each trial consisted of performing Simulator Sickness Questionnaire (SSQ) just before and just after viewing image and 270 s of viewing image. During viewing image, the participants subjectively evaluated the sickness level every 30 s, which was cued with a tone. The sickness level was in five point scale shown in Table 1. During viewing image, electrocardiogram was also measured. Between each trial, there were 45 min of resting period.

Table. 1 Subjective score with five point scale

Score	Description
0	No symptoms
1	Minimal symptoms of motion sickness, except any nausea
2	Weak symptoms of motion sickness, except any nausea
3	Weak nausea
4	Moderate nausea

3 RESULTS

3.1 SSQ

The differential SSQ total score (SSQ-TS) averaged among the paticipants, which was obtained by subtracting the score of "just before" watching moving image from that of "just after" watching moving image, of three different conditions appears in Fig. 4. The panel (a) shows the results during the additional image motion in pitch, while the panel (b) shows the results during in yaw. The one-way ANOVA indicates significant main effect of stimulus condition for both in pitch (F(2, 46) = 5.50, $p < 0.01$) and in yaw (F(2, 44) = 5.11, $p < 0.05$). Moreover, Tukey HSD shows that the SSQ-TS in passive condition is significantly larger than that in both active and control conditions ($p < 0.05$).

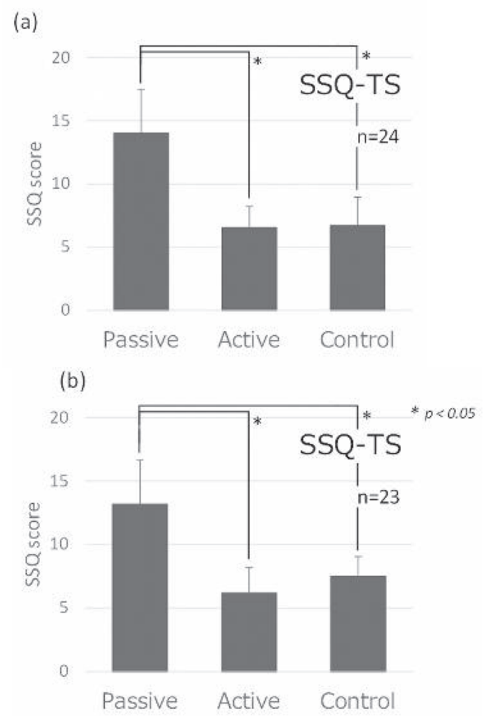

Fig. 4 SSQ total score
The differential SSQ total scores obtained with pitch (a) and with yaw (b) motion are shown in three different experimental conditions.

The differential SSQ subscores (SSQ-N, -O, -D) averaged among the paticipants, which was obtained by subtracting the score of "just before" watching moving image from that of "just after" watching moving image, of three different conditions appears in Fig. 5. The results of SSQ-N and SSQ-O with pitch motion and SSQ-O with yaw motion shows the same with the results in SSQ-TS; that is, there is a significant main effect of stimulus condition, and the score in passive condition is significantly larger than that in both active and control conditions.

3.2 Subjective scores every 30 s

The subjective scores, which was obtained by averaging among the participants, of three different conditions appears in Fig. 6. Here, the results are shown for additional pitch motion. The two-way ANOVA indicates significant main effects of both stimulus condition (F(2, 46) = 12.09, $p < 0.01$) and time (F(8, 184) = 10.07, $p < 0.01$), and also significance of the interaction (F(16, 368) = 2.14, $p < 0.05$)).

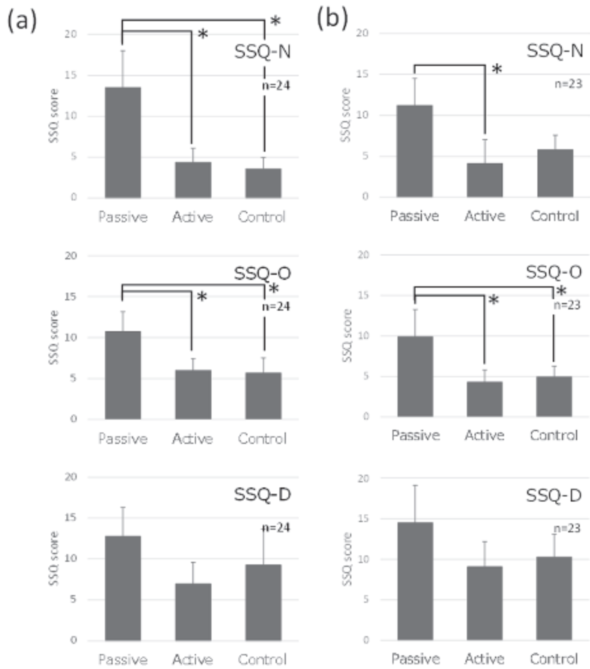

Fig. 5 SSQ sub-scores
The differential SSQ sub-scores obtained with pitch (a) and with yaw (b) motion are shown in three different experimental conditions.

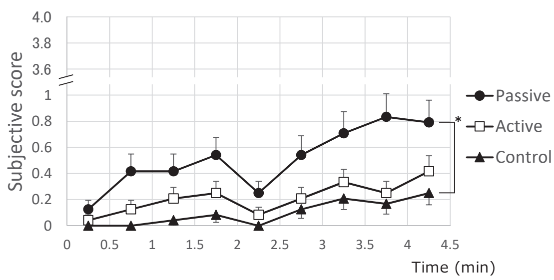

Fig. 6 Subjective scores every 30 s
The subjective scores obtained every 30 s with pitch motion are averaged among the participants for three different experimental conditions.

4 CONCLUSIONS

The results showed that sickness scores increased according to the amount of optic flow, but not of retinal flow, indicating that optic flow, not retinal flow, is essential to induced VR sickness.

The results indicate that VR sickness can be evaluated in the same manner for evaluating visually induced motion sickness using total amount of rotation of optic flow, but not rather complicated retinal flow.

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