Proceedings of the 26th Annual International Conference of the IEEE EMBS
San Francisco, CA, USA • September 1-5, 2004

Effects of Virtual Body Motion on Visually-Induced Motion Sickness

H. Ujike, T. Yokoi, S. Saida
Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

Abstract— **To reduce possibilities of visually-induced motion sickness caused by animations, video games and movies, we need to develop an evaluation method of visually-induced motion sickness. Our previous results have shown that virtual roll motion had the most effective for producing the sickness. In the present study, we focused on the effectivity of image types, such as random dots and ordinary scene, and also the effectivity of virtual rotation speed on the sickness. In the first experiment, we confirmed our former results that virtual roll motion produced the highest score relating motion sickness, regardless of image types. In the second experiment, virtual rotation speed of 30 to 60 deg/s gave the highest scores regardless of the rotation types, yawing, pitching and rolling. We concluded that moving images simulating non-reciprocating rolling has robust effects on the sickness. Moreover, we speculated that the effect of rotation speed is determined by inconsistency of visual and non-visual information, but not by retinal image speed.**

Keywords—**Roll motion, speed, torsional eye movement, virtual motion, visually-induced motion sickness**

I. Introduction

Recent evolution of imaging technique makes movies more enjoyable and video games more attractive. The images are created and edited by computerized system, and therefore, the creators can easily produce visual images, which simulate motion and actions in virtually three-dimensional space. The broad diffusion of these techniques, however, increases the possibility for us to be suffered from visually-induced motion sickness. Moreover, we are recently getting familiar for video acquisition devices and also large size of TV screen at home. Thus, we can easily record images with video camera and watch them with wide visual display, which may effectively yield sickness from unexpected vibrations in a video footage mainly induced by handheld camera motion.

An actual example of the visually-induced motion sickness were socially reported last summer in Japan. Local junior high school students, total of 294, had watched a 20-minitute movie presented on a large screen in an auditorium during class. The movie was shot by a handheld video camera, and includes unexpected whole image motion and vibration, which were caused by both intended and unintended camera motion. During and after the class, some of the students complained of feeling nausea and head ache; finally 36 students were treated at a hospital for a symptom of motion sickness. Besides this particular case, the sickness from motion pictures and also video games became recently popular and sometimes reported on web sites. Among video game players, the word, "3D sickness", is often used for representing visually-induced motion sickness caused during playing video games.

To reduce the possibility for us to be suffered from visually-induced motion sickness while keeping attractiveness of visual images created by latest technique, we need to investigate the effective factors for the sickness. As Lo and So [1] categorized the causative factors of cybersickness, there are three factors to be focused on: those are related to (i) how moving image is presented, (ii) who watches moving image, and (iii) what is presented as moving image. For examples, size and type of image display will be categorized as above item (i), while gender and age of viewers are categorized as the item (ii). In the present study, we focused on the item (iii), such as types and speed of virtual body motion, which is presented as visual information.

The literature reported visually-induced motion sickness under scene rotation along each of the three axes: yaw axis, pitch axis and roll axis (e.g., [1]-[3]). Although most of those did not compare the sickness with different axes of rotation, Lo and So [1] and Ujike et al. [3] did it. Ujike et al. showed that one-directional rotation along roll axis, i.e. roll motion, produced the highest score relating the sickness. Moreover, the results analyzed for individual participant by Lo and So [1] showed that the roll axis oscillation had the highest value of mean nausea rating, though they focused on the fact that the yaw axis oscillation had the lowest rating value.

In the present study, we examined the robustness of the previous finding that roll axis rotation are the most effective for visually-induced motion sickness in light of two factors: image types and rotation speed. In the first experiment, effects of image types, such as random dots and ordinary scene, on visually-induced motion sickness were examined. In the second experiments, effects of virtual rotation speed were examined. Moreover, in the third experiments, we investigated the correlation between the sickness scores and torsional eye movements during virtual roll motion, to examine the eye movement as an objective indicator.

II. EXPERIMENT 1

Based on the sensory conflict theory [4], degree of motion sickness becomes larger with that of sensory conflict.

The research was supported by Image Safety project of Ministry of Economy, Trade and Industry in Japan.

Among the virtual rotation along each of the three axes during observers' sitting still physically, pitch and roll motion involve conflict about gravitational direction information detected by vision and otolith organs. When the image pattern consists of random dots, gravitational direction information provided by visual cue is weak. In this experiment, we examined the effects of image types, random dots and ordinary scene, on visually-induced motion sickness during virtual rotation along yaw, pitch and roll axes.

A. Methods

Thirty-one adults, (17 females and 14 males), participated as observers. All were naïve as to the purpose of the experiments. They had normal or collected-to-normal acuity. They gave their informed consent and were free to withdraw at any time.

Moving image was produced by a Windows based system with OpenGL and was back-projected on a flat large screen; the image size was 82 x 67 deg from a viewing distance of 1 m. Moving image was virtually simulated an observer either rotated along one of three axes, (yawing, pitching and rolling), or translated reciprocatingly along one of the three axes, when the observer initially located at the center of the rectangular solid (see Fig. 1). The rotation speed was 20.8 deg/s, and the temporal frequency and amplitude of the translation were 0.17 Hz and 0.9 m. The moving stimulus image was presented for 69 s, before and after which stationary image was presented for 5 s.

There were two conditions: RD condition, in which random dot pattern was textured on an inside-wall of the rectangular solid, and RR condition, in which texture simulated usual room was pasted on the wall. Observers' task was to watch the stimulus for 79 s, and then, to gave both sickness-related score and vection-related score. The sickness-related score is 11-point rating scale (see Table 1).

In the experiment, each observers had two experimental sessions. In each session, either of the conditions was provided, and there were nine trials; the three trials were from reciprocating translation along each of the three axes, and the remained six were from rotation along each of the three axes with both directions. The resting period between the adjacent trials were approximately three minutes. The period between the sessions was more than 30 minutes.

TABLE I
THE SICKNESS RELATED SCALE (ENGLISH TRANSLATION)

Symptom Description	Rating
No Problems	0
Feeling Very Slight Unusual Sensation	1
Feeling Slight Unusual Sensation	2
Tendency to Feel Unusual Sense in the Head	3
Sometimes Feeling Unusual Sense in the Head	4
Feeling Unusual Sense in the Head	5
Tendency to Feel Sick and Dizziness	6
Feeling Slight Sick and Dizziness	7
Feeling Sick and Dizziness	8
Feeling Very Sick and Dizziness	9
Can Not See the Motion, or Feel Vomiting	10

B. Results

The results showed that the values of sickness-related scores were almost the same between the two conditions, RD and RR (see Fig.2). Moreover, the highest value of sickness-related score was obtained with rotation along roll axis; the result is consistent with what we had found earlier. We also found that the vection-related scores and sickness-related scores were well correlated; however, when the vection-related scores were low, the sickness-related scores were almost flat at zero.

The results were also analyzed for individual observer's data. When we examined the relation between each observer's subjective scores in RD condition and RR

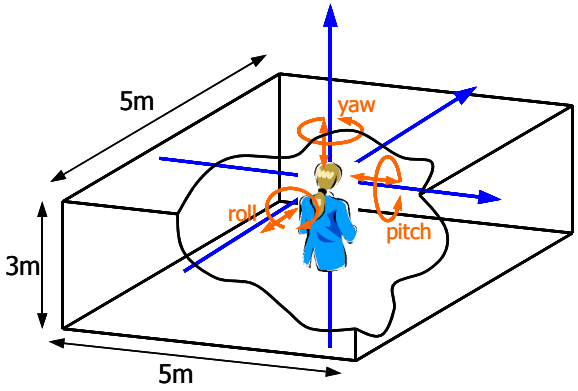

Fig. 1. Virtually presented rotation and translation along each of. the three axes. The observer was initially located at the center of rectangle solid.

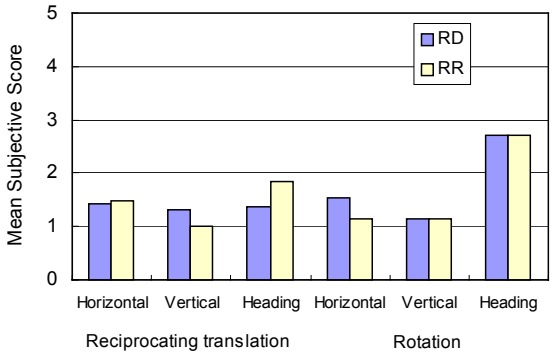

Fig. 2. The sickness-related subjective scores for virtual rotation and translation along each of the three axes. .

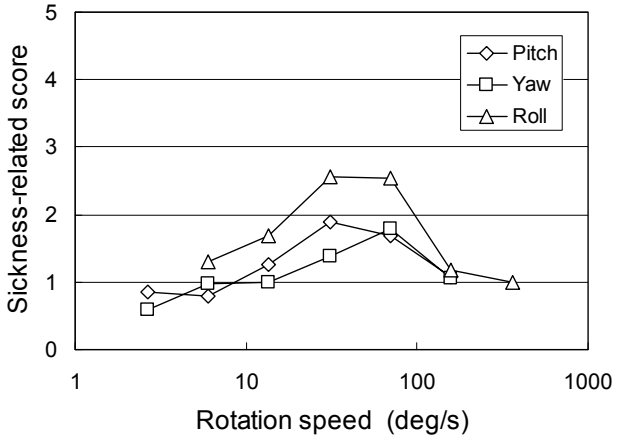

Fig. 3. Sickness-related subjective scores for virtual rotation along different three axes as a function of rotation speed

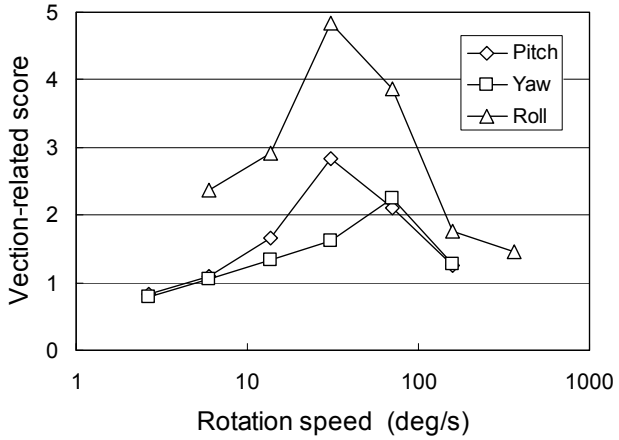

Fig. 4. Vection-related subjective scores for virtual rotation along different three axes as a function of rotation speed

condition, they are in proportion with each other. Therefore, there's no clear tendency of individual difference of susceptibility to different image patterns.

III. EXPERIMENT 2

This experiment examined effects of virtual speed of rotation along each of the three axes: yaw, pitch and roll.

A. Methods

Thirty-nine adults, (29 females and 10 males), participated as observers. All were naïve as to the purpose of the experiments. They had normal or collected-to-normal acuity. They gave their informed consent and were free to withdraw at any time.

Moving image was produced and presented in almost the same way as in the former experiment, and was virtually simulated an observer either rotated along one of three axes, (yawing, pitching and rolling), when the observer initially located at the center of the rectangular solid. There were seven different rotation speeds ranging from 0 to 360 deg/s. The moving stimulus image was presented for 15 s, before and after which stationary image was presented for 5 s. There were two types of image, the RD and RR, as in the former experiment; each observer, however, were presented either of the two types of the images. Observers' task was to watch the stimulus for 25 s at standing position on a force plate, and then, to gave both sickness-related score and vection-related score. During the stimulus presentation, observer's head position, two-dimensional gravity point and torsional eye-movement were measured.

In the experiment, each observer had three experimental sessions. In each session, virtual rotation along any of the three axes was provided, and there were seven trials; each trial corresponded to each of the different speed of virtual rotation. The resting period between the adjacent trials were approximately two minutes. The period between the sessions was more than 15 minutes.

B. Results

The results showed that the value of sickness-related score (see Fig.3) and that of vection-related score (see Fig.4) were the highest around 30 to 60 deg/s along each of the three axes of virtual body rotation. Moreover, for both sickness-related and vection-related scores, the highest value of the score was the highest for virtual rotation along rolling axis, the second for pitching axis and the third for yawing axis.

IV. EXPERIMENT 3

This experiment investigated the correlation between the sickness scores and torsional eye movements during virtual roll motion, to examine the eye movement as an objective indicator.

A. Methods

Nineteen adults, (11 females and 8 males), participated as observers. All were naïve as to the purpose of the experiments. They had normal or collected-to-normal acuity. They gave their informed consent and were free to withdraw at any time.

Moving image was produced and presented in almost the same way as in the former experiments, and was virtually simulated an observer rotated along roll axis, when the observer initially located at the center of a sphere of which inside wall was textured with random dots. There were four different rotation speeds ranging from 15 to 120

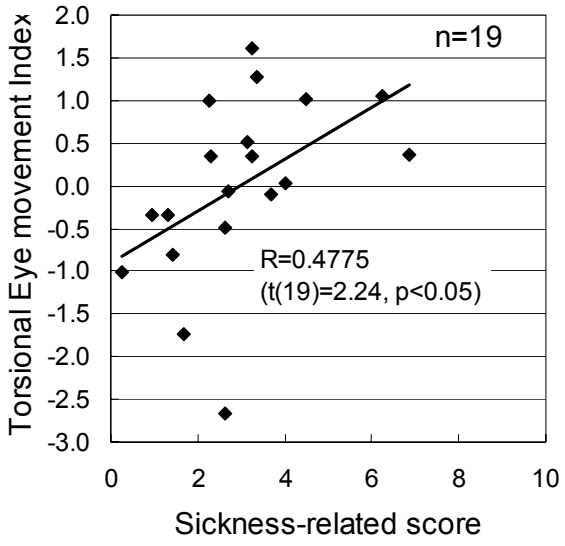

Fig. 5. Significant correlation between sickness-related score and torsional eye movement index.

deg/s. The moving stimulus image was presented for 25 s, before and after which stationary image was presented for 5 s. Observers' task was to watch the stimulus for 35 s with sitting on a chair, and then, to gave both sickness-related score and vection-related score. During the stimulus presentation, observer's torsional eye-movement was measured.

In the experiment, each observer had four experimental sessions. In each session, four different speeds of virtual roll motion were provided. Therefore, there were four trials for each speed of roll motion; the direction of the rotation was counter balanced. The resting period between the adjacent trials were approximately two minutes. The period between the sessions was approximately 10 minutes.

B. Results

We made Torsional Eye Movement Index, or T.E.M.I., representing averaged shift of torsional eye position during image motion using following equation.

T.E.M.I. = (Mean of eye position during image motion)
– (Mean of eye position during no image motion)

The values of T.E.M.I. and also those of the sickness-related subjective score were averaged across different speed of virtual roll motion. Then, the averaged T.E.M.I. for each observer was plot against the sickness-related score (see Fig. 5). The result showed that the T.E.M.I. and the sickness-related score were significantly correlated each other ($t(19)=2.24$, $p<0.05$). Therefore, the T.E.M.I. can be an objective measure for visually-induced motion sickness caused by virtual roll motion.

V. Discussion

The effectivity of visual rotation motion on visually-induced motion sickness was not affected by visual information of gravitational direction, at least when the motion was continuous and not unpredictable. It is still interesting, however, that the sickness-related score for the virtual rotation along yaw axis has tendency to be the smallest among virtual rotation of different three axes, (i.e., yaw, pitch and roll), which is shown in both Figs.2 and 3.

The averaged subjective scores of motion sickness across observers showed the highest value at around 30 to 60 deg/s regardless of rotation axes. We speculated that the effect of rotation speed is determined by inconsistency of visual and non-visual information, but not by retinal image speed.

VI. Conclusion

Our results showed that the virtual roll motion effectively produced visually-induced motion sickness. The sickness-related subjective score was the highest among virtual rotation of different three axes, (i.e., yaw, pitch and roll), regardless of types of visual image, such as random dots or ordinary scene, and regardless of different speed of those virtual rotation. Moreover, the degree of the sickness can be predicted by T.E.M.I.

Acknowledgment

We thank Y. Kita, K. Okamoto, S. Sugiyama, Y. Asano, Y. Okada for their great assistance with conducting the experiments.

References

[1] W. T. Lo, R. H. Y. So, "Cybersickness in the presence of scene rotational movements along different axes," *Applied Ergonomics*, vol. 32, no. 1, pp. 1–14, 2001.

[2] S. Hu, M. S. Davis, A. H. Klose, E. M. Zabinsky, S. P. Meux, H. A. Jacobsen, J. M. Westfall, M. B. Gruber, "Effects of spatial frequency of a vertically striped rotating drum on vection-induced motion sickness," *Aviat. Space. Environ. Med.*, vol. 68, no. 4, pp. 306–311, 1997.

[3] H. Ujike, K. Ukai, S. Abe and S. Saida, "Effects of rotation types of yaw, pitch and roll on visually-induced motion sickness," under preparation.

[4] J. T. Reason, J. J. Brand. (1975). Motion sickness (1st ed.) [Book].