ORIGINAL

The effect of visual-vestibulosomatosensory conflict induced by virtual reality on postural stability in humans

Suetaka Nishiike[1], Suzuyo Okazaki[2], Hiroshi Watanabe[3], Hironori Akizuki[4], Takao Imai[2], Atsuhiko Uno[2], Tadashi Kitahara[2], Arata Horii[2], Noriaki Takeda[4], and Hidenori Inohara[2]

[1]*Department of Otorhinolaryngology - Head and Neck Surgery, Osaka Rosai Hospital, Osaka, Japan,* [2]*Department of Otorhinolaryngology - Head and Neck Surgery, Osaka University Graduate School of Medicine, Osaka, Japan ;* [3]*Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology, Osaka, Japan ;* [4]*Department of Otolaryngology, University of Tokushima School of Medicine, Tokushima, Japan*

Abstract : In this study, we examined the effects of sensory inputs of visual-vestibulosomatosensory conflict induced by virtual reality (VR) on subjective dizziness, posture stability and visual dependency on postural control in humans. Eleven healthy young volunteers were immersed in two different VR conditions. In the control condition, subjects walked voluntarily with the background images of interactive computer graphics proportionally synchronized to their walking pace. In the visual-vestibulosomatosensory conflict condition, subjects kept still, but the background images that subjects experienced in the control condition were presented. The scores of both Graybiel's and Hamilton's criteria, postural instability and Romberg ratio were measured before and after the two conditions. After immersion in the conflict condition, both subjective dizziness and objective postural instability were significantly increased, and Romberg ratio, an index of the visual dependency on postural control, was slightly decreased. These findings suggest that sensory inputs of visual-vestibulosomatosensory conflict induced by VR induced motion sickness, resulting in subjective dizziness and postural instability. They also suggest that adaptation to the conflict condition decreases the contribution of visual inputs to postural control with re-weighing of vestibulosomatosensory inputs. VR may be used as a rehabilitation tool for dizzy patients by its ability to induce sensory re-weighing of postural control. J. Med. Invest. 60 : 236-239, August, 2013

Keywords : *virtual reality, visual-vestibulosomatosensory conflict, motion sickness, visual dependency on postural control, sensory re-weighting*

INTRODUCTION

Computer graphics technology called virtual reality (VR) creates a visual scene, in which the user feels immersed. As the user makes active head movements, the computer determines the new direction of gaze and recreates the scene from the

---

Received for publication March 18, 2013 ; accepted April 30, 2013.

Address correspondence and reprint requests to Suetaka Nishiike, MD, PhD, Department of Otorhinolaryngology - Head and Neck Surgery, Osaka Rosai Hospital, 1179-3 Nagasonecho, Kita-ku, Sakai, Osaka 591-8025, Japan and Fax : +81-72-255-3349.

new point of view (1). The VR system allowed us to easily coordinate incoherent visual-vestibular conflict to induce motion sickness and postural instability. On the contrary, several previous studies including ours reported that adaptation to incoherent sensory inputs in VR decreases the visual dependency on postural control (1-3).

However, in our previous VR study, ready-made software showed limitations in the control of sensory inputs (1). In the present study, we strictly controlled and arranged the visual, vestibular and somatosensory inputs, and examined the effects of visual-vestibulosomatosensory conflict induced by VR on subjective dizziness, posture stability and visual dependency on postural control in humans.

MATERIALS AND METHODS

Subjects were 11 healthy young volunteers (10 males and 1 females, ranging from 22 to 38 years old, mean age : 29.7 years old). All subjects had a normal otoneurologic examination. Informed consent was obtained from all subjects, and all experimental procedures were approved by the Ethics Committee for Human and Animal Research of the Human Stress Signal Research Center at the National Institute of Advanced Science and Technology.

The VR system used in the present study was previously described (4-6). Briefly, it was a projection-based system that surrounds the subject with four screens : three rear projection screens for walls and a down-projection screen for a floor space 9 m^2 each (CAVE ; Electronic Visualization Laboratory, University of Illinois, Chicago, IL). Subjects wore polarized glasses to resolve the stereoscopic imaginary. An electromagnetic tracking system attached to the glasses determined the location and angle of the user's head orientation.

Subjects were then immersed in two different VR conditions. The background in both conditions was made of a randomized texture pattern (4). First, in the control condition, an interactive computer graphics synchronizes the background image proportionally to the subject motion. Under the condition, subjects were exposed to 5 minutes of immersion in the VR and went forward and backward straightly for 3 m at their own pace keeping their face forward. Subjects were at rest for 3 min after the control condition.

Second, in the conflict condition, subjects were kept still for 5 minutes, but a computer graphics reproduced the visual fields they experienced in the control condition where data were based on the tracking system.

We measured the subjects' symptoms and postural instability before and after the two conditions. The levels of the severity of motion sickness were given numerical scores according to Graybiel's criteria as described previously (4, 7). Total score ranges from 0 to 50. The subjective balance symptom questionnaire of Hamilton *et al.*, was also applied (4, 8, 9), where total score ranges from 0 to 16. Higher scores on both questionnaires reflected more severe symptoms. The body sway was recorded with a force platform (1G06 ; NEC, Tokyo, Japan) before and after both conditions with eyes opened and closed. The area covered by the sway path was calculated. Each subject was asked to stand as still as possible on the force platform with both arms beside the body and feet close together with eyes open and closed for 60 seconds each. During the measurement with eyes open, subjects were asked to look at a fixed point over a plain dark screen at eye level of 3-m from the front wall. Romberg ratio was calculated as the area covered by the sway path with eyes closed divided by that with eyes open.

Differences of data between the two conditions as well as those collected before and after the conditions were analyzed by Wilcoxon's signed-rank test, using SPSS for Windows version 18.0 (IBM Japan, Tokyo, Japan).

RESULTS

After the conflict condition, scores of both Graybiel's and Hamilton's criteria were significantly increased (Fig. 1). However, no change in both scores was noticed in the control condition. After the conflict condition, the area of body sway path with both eyes open and closed was significantly increased (Fig. 2A, B). However, it was unchanged after the control condition. In addition, the mean Romberg ratio in post-conflict condition was slightly decreased compared with the pre-conflict one (0.937 ± 0.078 vs. 1.035 ± 0.074) (Fig. 2C).

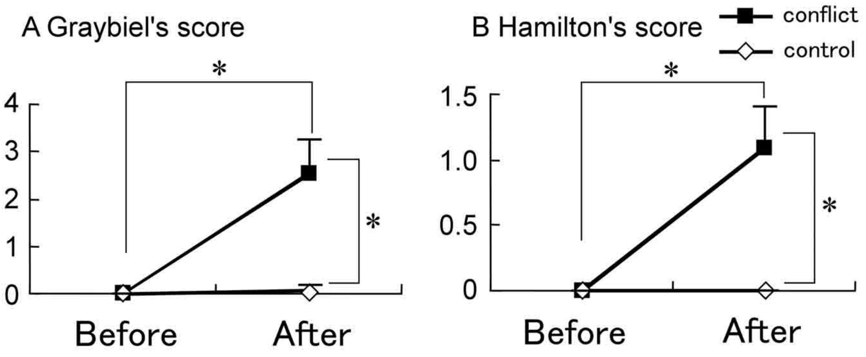

Fig. 1. The severity of the Graybiel's criteria (A) and Hamilton's criteria (B) before and after VR. Black square : the arranged condition. White circle : the control condition. *$p < 0.05$. Error bar : SE.

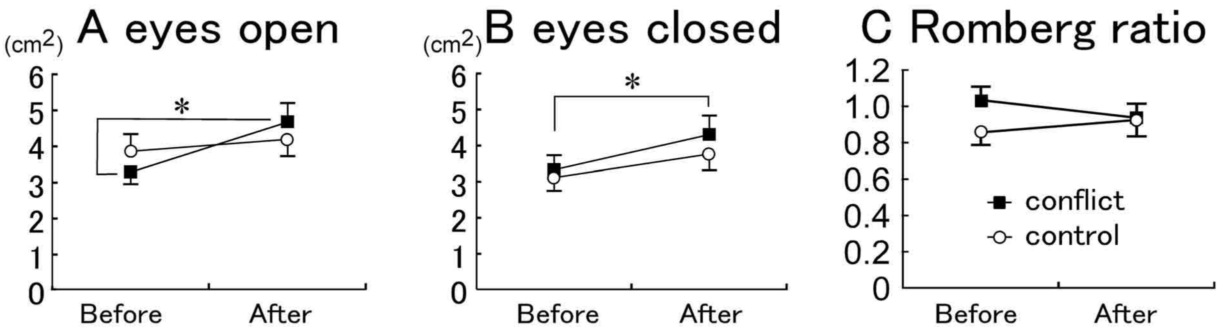

Fig. 2. The body sway area with eyes open (A) and eyes closed (B), and Romberg ratio (C) before and after VR. Black square : the arranged condition. White circle : the control condition. *$p < 0.05$. Error bar : SE.

DISCUSSION

In this study, we used VR technology and created different sensory conditions in VR world. In the control condition, subjects walked voluntarily with interactive computer graphics background images proportionally synchronized to their walking. However, in the visual- vestibulosomatosensory conflict condition, subjects kept still with the background images that they experienced in the control condition presented to them. After immersion in this conflict condition, scores of both Graybiel's and Hamilton's criteria and the area of body sway path with both eyes open and closed were significantly increased (Fig. 1). These findings suggest that sensory inputs of the visual-vestibulosomatosensory conflict in VR immersion induced motion sickness in these subjects, resulting in subjective dizziness and objective postural instability.

The neural mismatch hypothesis of motion sickness stipulating that conflicting inputs from visual, vestibular and somatosensory systems produce motion sickness is widely accepted (10, 11). Accordingly, inputs from the vestibular, visual, and somatosensory systems converge on the vestibular nuclei, cerebellum, and parietal cortex, where they are integrated into a common signal, of which function is to determine the individual's motion status relative to his or her environments (11). A conflict occurs when the integrated sensory signal is compared and found at variance with previously recognized and stored motion paradigms (12). This results in a mismatch signal that initiates motion sickness symptomatology, leading to the subjective dizziness and objective postural instability (Fig 1 & Fig 2A, B).

In this study, the Romberg ratio was slightly decreased after VR immersion in the conflict condition (Fig. 2C), suggesting a reduction of visual dependency on postural control. In our previous study, visual-vestibular conflict in VR immersion for 39 minutes significantly decreased Romberg ratio without evident motion sickness and postural instability (1). Since motion sickness is induced by the neural mismatch signal in the process of adaptation (11), it is suggested that after adaptation to visual-vestibular conflict, the visual dependency on postural control was definitely decreased by ignoring the conflicting delayed visual input in the VR world. In the present study, however, immersion in VR lasted 5 minutes, suggesting that incomplete adaptation to visual-vestibulosomatosensory conflict induced motion sickness with a limited contribution of visual inputs to postural control. Visual-vestibulosomatosensory conflict is so complex that longer immersion for adaptation is probably needed to induce sensory re-weighing in postural control.

In this study, the control condition was followed by the conflict condition. Because in the conflict condition a computer graphics reproduced the visual fields in the previous control condition, testing order was not able to be changed. One can assume that there can be a sequence bias of the condition affecting the subjective and objective measures. We cannot completely exclude this possibility, but the subjective and objective measures before the conflict condition was not significantly different from that before the control condition (Fig. 1 and 2). Thus it is suggested that the bias effects may be little and can be ignored.

In conclusion, by its ability for sensory re-weighing in postural control (1), VR can be used as rehabilitation tool for dizzy patients with unsuccessful compensation to vestibular lesion. However, the problem of symptoms including nausea and postural instability associated with VR immersion must be resolved. Instead of ready-made software, the conflict due to the combination of visual, vestibular and somatosensory inputs in VR world that is strictly arranged and controlled will be more effective in reducing the visual dependency on postural control with less motion sickness.

CONFLICT OF INTEREST

None of the authors have any conflicts of interest to declare.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number 18591897 and 21592155.

REFERENCES

1. Akizuki H, Uno A, Arai K, Morioka S, Ohyama S, Nishiike S, Tamura K, Takeda N : Effects of immersion in virtual reality on postural control. Neurosci Lett 379 : 23-26, 2005
2. Black FO, Paloski WH : Computerized dynamic posturography : What have we learned from space? Otolaryngol Head Neck Surg 118 : S45-51, 1998
3. Bronstein AM : Suppression of visually evoked postural responses. Exp Brain Res 63 : 655-658, 1986
4. Akiduki H, Nishiike S, Watanabe H, Matsuoka K, Kubo T, Takeda N : Visual-vestibular conflict induced by virtual reality in humans. Neurosci Lett 340 : 197-200, 2003
5. Ohyama S, Nishiike S, Watanabe H, Matsuoka K, Akizuki H, Takeda N, Harada T : Autonomic responses during motion sickness induced by virtual reality. Auris Nasus Larynx 34 : 303-306, 2007
6. Ohyama S, Nishiike S, Watanabe H, Matsuoka K, Takeda N : Effects of optokinetic stimulation induced by virtual reality on locomotion : a preliminary study. Acta Otolaryngol 128 : 1211-1214, 2008
7. Graybiel A, Wood CD, Miller EF, Cramer DB : Diagnostic criteria for grading the severity of acute motion sickness. Aerosp Med 39 : 453-455, 1968
8. Hamilton KM, Kantor L, Magee LE : Limitations of postural equilibrium tests for examining simulator sickness. Aviat Space Environ Med 60 : 246-251, 1989
9. Cobb SV, Nichols SC : Static posture tests for the assessment of postural instability after virtual environment use. Brain Res Bull 47 : 459-464, 1998
10. Oman CM : Motion sickness : a synthesis and evaluation of the sensory conflict theory. Can J Physiol Pharmacol 68 : 294-303, 1990
11. Reason JT : Motion sickness adaptation : a neural mismatch model. J R Soc Med 71 : 819-829, 1978
12. Nachum Z, Shupak A, Letichevsky V, Ben-David J, Tal D, Tamir A, Talmon Y, Gordon CR, Luntz M : Mal de debarquement and posture : reduced reliance on vestibular and visual cues. Laryngoscope 114 : 581-586, 2004