J. Phys. Ther. Sci. 29: 228–231, 2017

The Journal of Physical Therapy Science

Original Article

# Inclination of standing posture due to the presentation of tilted view through an immersive head-mounted display

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**Abstract.** [Purpose] The purpose of the present study is to clarify whether tilted scenery presented through an immersive head-mounted display (HMD) causes the inclination of standing posture. [Subjects and Methods] Eleven healthy young adult males who provided informed consent participated in the experiment. An immersive HMD and a stereo camera were employed to develop a visual inclination system. The subjects maintained a standing posture twice for 5s each while wearing the visual inclination system. They performed this task under two conditions: normal view and 20° leftward tilted view. A three-dimensional motion analysis system was used to measure the subjects' postures, and two force plates were used to measure the vertical component of the floor reaction force of each leg. [Results] In the 20° leftward tilted view, the head and trunk angles in the frontal plane were similarly inclined toward the left, and the vertical component of the floor reaction force increased in the left leg, whereas it decreased in the right leg. [Conclusion] When the view in the immersive HMD was tilted, the participants' trunk side bent toward the same side as that of the view. This visual inclination system seems to be a simple intervention for changing standing posture.

**Key words:** Standing posture, Vision, Head mounted display

*(This article was submitted Aug. 30, 2016, and was accepted Nov. 2, 2016)*

## INTRODUCTION

Vision and the somatosensory and vestibular sensory systems play an important role in posture control[1–5]. Vision, based on a change in the information projected on the retina, guides the relationship between the environment and the body. Plantar sensation provides information on the base of support and position of the center of gravity. Proprioceptive sensation provides information on the position and movement of the joints. Vestibular sensation detects gravity and acceleration to provide information about the position and movement of the head. If these sensory systems are damaged due to brain diseases, failures in standing posture control are elicited, even without motor paralysis. Pusher syndrome, Wallenberg's syndrome, thalamic astasia, unilateral spatial neglect, etc. contribute to these failures[6–9]. These disorders might be treated by intervention with

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sensory input. Although there are previous studies about the change in standing posture due to vibration stimulation and/or vestibular stimulation[10–12], there are few studies about the role of visual intervention in standing posture. Prism glasses can bias a view on sagittal and/or horizontal planes, but cannot shift it on coronal plane[13, 14]. Although there is a method of tilting seat surface during sitting, this method cannot be an intervention of only vision because it influences on somatosensory and vestibular sensory[15]. A tool to cause a lateral tilt of a view on the coronal plane was only a large screen[16, 17]. However, recently, an inexpensive immersive head-mounted display (HMD) has been developed and applied in rehabilitation[18]. In the present study, we developed a visual inclination system by using an HMD for investigating a visual intervention (tilted view) on standing posture control.

## SUBJECTS AND METHODS

Eleven healthy male university students (mean ± standard deviation: age, 21.5 ± 1.5 years; height, 170.9 ± 6.1 cm; weight, 64.4 ± 8.0 kg) participated in this experiment. Participants in their twenties and those who were right handed were included. We excluded participants who wore glasses on a daily basis and those with any orthopedic, neurological, ophthalmic or otolaryngological disease. The ethics committee of the International University of Health and Welfare approved all study procedures (No. 15-Io-58), which were consistent with the principles of the Declaration of Helsinki. The authors obtained written informed consent from all the subjects prior to their participation in the study.

An immersive HMD (Oculus Rift DK2, Oculus VR Inc., CA, USA), a small stereo camera (Ovrvision 1, Shinobiya Inc., Osaka, Japan), and a laptop PC (15X8550-i7-VSB, UNITCOM, Osaka, Japan) were employed to constitute a visual inclination system for the experiment (Fig. 1). The subjects were asked to maintain the standing posture twice for 5 s while wearing the experimental system. They were instructed to perform the experiment under two visual conditions: normal view and 20° leftward inclined view conditions, in that order. Two force plates were used to measure the vertical component of the floor reaction force of each leg. A three-dimensional motion analysis system was used to quantify the subjects' body movements (i.e. inclination angles of the head ($\theta_H$), trunk ($\theta_T$), and pelvis ($\theta_P$) in absolute coordinates). We adopted several angle definitions, $\theta_H$, $\theta_T$, and $\theta_P$, which are described in Fig 2. Furthermore, we defined the relative head and trunk bending angles as the difference between the inclination angles of the head and trunk, and those of the trunk and pelvis, respectively. We defined a leftward inclination angle as positive and a rightward inclination angle as negative.

A three-dimensional motion analysis system consisting of 10 infrared cameras (Vicon MX, Vicon, Oxford, UK) and two force plates (AMTI, Watertown, MA, USA) was used to record three-dimensional marker displacements and floor reaction force data at a sampling frequency of 100 Hz. Thirty-three reflective markers (Helen-Hayes marker set) were attached to each subject. In the analysis, we used seven markers, which were attached to the top of the head, the bilateral acromions, anterior superior iliac spine, and posterior superior iliac spine of the participants.

A two-tailed paired t-test was used to assess individual differences between the inclined view and normal view conditions. P-values less than 0.05 were considered statistically significant. The statistical analysis was conducted using the software package SPSS version 20 (IBM Inc., Armonk, NY, USA).

## RESULTS

The result of the paired t-test demonstrated that the vertical component of floor reaction forces in both legs significantly changed in the inclined view condition. The vertical component of floor reaction forces decreased in the right leg (324.4 ± 38.6 vs. 303.4 ± 51.3 N, p=0.03), whereas it increased in the left leg (322.3 ± 53.3 vs. 345.9 ± 52.2 N, p=0.02).

Table 1 represents the mean inclination angles of the head, trunk, and pelvis, and the relative bending angle of the head and trunk. In the comparison between the normal view and inclined view conditions, the paired t-test indicated that there was a significant increase in the inclination angle of the head and trunk and the relative bending angle of the trunk, but not in the inclination angle of the pelvis and the relative bending angle of the head.

## DISCUSSION

In this study, we created a novel HMD system to alter inclined standing posture in a group of male university students. By using this system, the head and trunk of participants inclined leftward and the vertical component of the floor reaction force of the lower extremities inclined leftward due to the view presented on the display. These results are identical to those of a previous experiment with a large-sized screen[16, 17]. The present study proves that it is possible to elicit a change of standing posture due to a visual stimulus using an immersive HMD, and a large-scale apparatus is no longer necessary.

As for the inclination angle of each body segment, even though the head and trunk angles inclined toward the tilted direction, the angle of the pelvis did not incline. The reason why inclination in the pelvis did not occur is that it could not physically occur when the participant stood with both legs extended. Therefore, inclination of the pelvis might occur in dynamic movements such as walking.

As for the relative head and trunk bending angles, the effect of the tilted view was confirmed only in the trunk. The reason why the neck did not bend to the side is that a very large number of muscle spindles were distributed in the neck muscles[19];

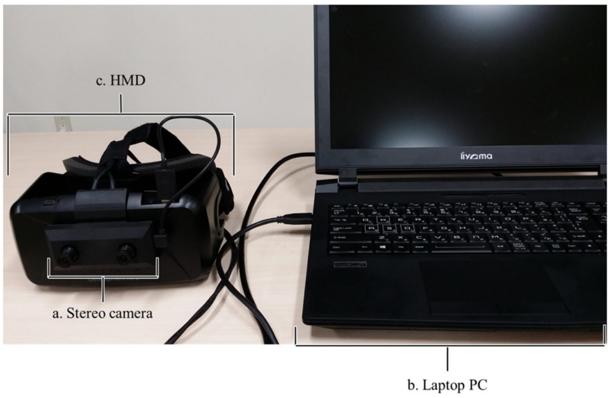


**Fig. 1.** Visual inclination system
(a) A stereo camera captures visual information from view. (b) A laptop PC is used to tilt the visual information. (c) An HMD shows the tilted visual information to the wearer.

**Table 1.** The mean inclination angles of the head, trunk, and pelvis, and the relative bending angle of the head and trunk

| | Normal view condition | Inclined view condition |
|---|---|---|
| Head leftward inclination angle (°) | −0.2 ± 2.3 | 1.7 ± 3.7* |
| Trunk leftward inclination angle (°) | 0.8 ± 0.8 | 2.0 ± 0.9* |
| Pelvis leftward inclination angle (°) | 1.2 ± 2.0 | 0.9 ± 1.8 |
| Neck leftward bending angle (°) | −1.0 ± 2.7 | −0.3 ± 3.3 |
| Trunk leftward bending angle (°) | −0.4 ± 1.9 | 1.1 ± 2.1* |

Values are expressed as a mean ± standard deviation
*Significant difference ($p<0.05$) between the normal view condition and the inclined view condition.

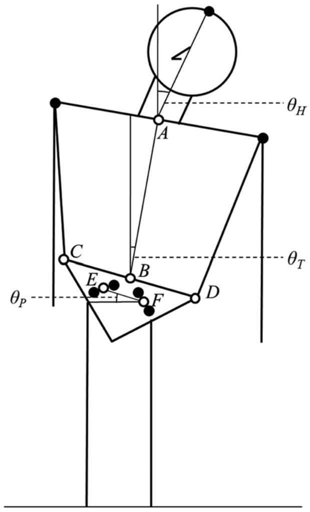


**Fig. 2.** Definition of the $\theta_H$, $\theta_T$, and $\theta_P$
·The black dots are reflective markers on top of the head, bilateral acromions, anterior superior iliac spine, and posterior superior iliac spine.
·Point *A* is the midpoint of the right and left acromions.
·Point *B* is the midpoint of points *C* and *D*.
·Points *C* and *D* are iliac crests estimated from the position of the markers on the pelvis.
·Points *E* and *F* are midpoints of the anterior superior iliac spine and posterior superior iliac spine.
·$\theta_H$ is the angle between the axis connecting from the top of the head to point *A* and the vertical axis.
·$\theta_T$ is the angle between the axis connecting from point *A* to *B* and the vertical axis.
·$\theta_P$ is the angle between the axis connecting from point *E* to *F* and the horizontal plane.

therefore, it seemed that these muscle spindles compensated for the proprioceptive sensation. The previous research about siting posture using an electric balance board also showed lateral bending of trunk and no lateral bending of the neck during tilting the seat surface[15]. These experimental results suggest that lateral bending of the trunk is more available than the neck in the postural control using vision.

The inclination angle of the standing posture observed in the present study was smaller than the tilt angle of view. It seemed that the reason was compensation by the somatosensory or the vestibular sensory systems. Somatosensory function decreases with age, and therefore the elderly tend to rely on vision for postural control[20, 21]. Thus, it seems that visual inclination has a large effect in the elderly. In addition, if the presented tilted view is combined with a vibration stimulus or vestibular stimulation, compensation due to the somatosensory and the vestibular sensory systems will be difficult. Therefore, the body inclination effect might be enhanced.

The tilt angle of view was 20° in the present study. When the tilt angle is too small, the effect of inclining the body is low. On the other hand, even if the tilt angle is too large, the effect of inclining the body becomes low too, because the subject is no longer trust the view. There is a previous study examining the effect of the standing posture when changing the tilt angle of the view projected on a large screen[17]. The study compared three tilt angle conditions (5.1°, 9.1° and 20.1°) and reported that 20.1° is the most effective. It suggests that the tilt angle of view in the present study is appropriate.

Since the immersive HMD is wearable, unlike large screens or mirrors, its advantage is that it continues to provide visual information to the wearer even when moving forward or changing direction. Therefore, it is possible to use this system to reveal the effects of the tilted view during walking or turning movements. Furthermore, we may be able to use the visual inclination system for balance exercises to treat vertical misperception in brain disease patients. The balance exercises should be adjusted to the degree of difficulty for maintaining balance for individuals[22]. If patients who cannot maintain an upright posture because of severe impairment of vertical perception, it may be easier for them to hold the upright posture by seeing a view that is inclined opposite to the inclination of the vertical axis that the patient is aware of. On the other hand, there are patients with unstable gait due to the mild impairment of vertical perception. For such patients, the balance exercises in normal visual conditions are less effective because the degree of difficulty is low. Thus, presenting an inclined view that emphasizes the inclination of the vertical axis that the patients are aware of might be able to increase the degree of difficulty of the balance exercises to an appropriate level. Moreover, if the presented tilted view is combined with vibration and vestibular stimuli, the training effect may be increased further[10–12].

This study has several limitations. The first is the possibility that the weight of the HMD affected somatosensory perception, although it was truly a lightweight device. Use of a lighter HMD may increase the effect of inclination in the standing posture. The second is that we did not strictly define the visual environment in the experimental room. However, we wanted to ensure that our results would not be affected by the presence or absence of vertical products. The third is that what we measured is only the effect of the presentation of the leftward tilted view in order to avoid the burdens of the subjects. So we did not clarify the presentation of the rightward tilted view. Inclination of standing posture due to brain disease is likely to occur more toward the left than right[6]. Therefore, the effect of the presentation of the rightward tilted view may be less than that of the leftward tilted view. The fourth is that we did not measure the sensory modality that the subject was focused upon. A method to determine the sensory modality that the subject focused on should be developed. The fifth limitation is that we did not consider the effects of aging, since our study group consisted of young male participants. Further studies should verify the effect of aging.

However, the current study revealed that presenting a tilted view using immersive HMD can shift the relative trunk bending angle and center of gravity toward the same direction of the tilted view. The developed visual inclination system seems useful and it can be applicable to various psychophysical experiments in future research.


## ACKNOWLEDGEMENT

This work was partially supported by JSPS KAKENHI Grant No. 26120005.


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