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Original Article

Effect of neck and trunk rotation speeds on cerebral cortex activity and standing postural stability: a functional near-infrared spectroscopy study

Tsubasa Mitsutake, PT[1, 2)]*, Maiko Sakamoto, PhD[2)], Etsuo Horikawa, PhD[2)]

[1)] Department of Rehabilitation, Shiroishi Kyoritsu Hospital: 1296 Hukuta, Shiroishi, Kishima, Saga 849-1112, Japan
[2)] Division of Cognitive Neuropsychology, Graduate School of Medicine, Saga University, Japan

Abstract. [Purpose] The aim of the present study was to determine whether different neck and trunk rotation speeds influence standing postural stability or frontal and temporal cortical activity during rotation in healthy young adults. [Subjects and Methods] Twelve healthy volunteers participated in this study. A custom turn-table operated by one of the experimenters was placed on a platform to assess postural perturbation. Subjects were asked to stand barefoot on the turn-table in an upright position with their feet together, and measurements were obtained during high- and low-speed rotations. Postural stability was tested using a force platform and a head sensor. Cerebral cortex activity was measured using functional near-infrared spectroscopy. Brain activity, center of pressure, and head perturbation were measured simultaneously for each subject. [Results] Significant differences were found in the center of pressure and the head angular velocity between high- and low-speed rotations. However, compared to baseline, oxygenated hemoglobin levels were not significantly different during high- or low-speed rotations. [Conclusion] Automatic postural responses to neck and trunk rotation while standing did not significantly activate the cerebral cortex. Therefore, the response to stimuli from the feet may be controlled by the spinal reflex rather than the cerebral cortex.

Key words: Rotation speed, Brain activity, Postural stability

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INTRODUCTION

The sensory strategy for postural control involves the visual, vestibular, and somatosensory systems. In particular, the vestibular system provides information regarding head position and movement with respect to gravity and inertial forces[1)]. This sensory system contributes to postural stability during directional changes. More specifically, the vestibulo-ocular and vestibulospinal reflexes are significantly associated with postural control, eye movement, and neck and trunk rotation[2)]. A previous study reported that stroke patients and healthy elderly adults exhibit increased postural instability during head rotations in the standing position compared to that during static standing[3)]. With regard to vestibular information related to cortical activation, areas of the superior temporal gyrus related to postural control are activated in subjects who primarily receive vestibular sensory input in the standing position[4)]. Increased brain activity has also been observed in the supplementary motor area during adjustment for postural perturbation[5)]. However, it is unknown whether neck and trunk rotation speeds influence postural perturbation and cortical activation. Thus, measuring changes in cortical activation and postural stability simultaneously would provide valuable information regarding vestibular function in activities of daily living.

The purpose of this study was to determine if different neck and trunk rotation speeds influence standing postural stability or frontal and temporal cortical activity during rotation in healthy young adults.

SUBJECTS AND METHODS

Twelve healthy volunteers (mean age, 25.8 ± 2.1 years) participated in this study. Self-reported history of vestibular, balance, and mobility impairment was obtained from all subjects. Written informed consent was taken from all volunteers prior to study participation, and the study protocol was approved by the ethics committee of University of Saga, Japan.

The following three parameters were measured simultaneously for each subject: brain activity, center of pressure (COP), and head perturbation. Evaluations were performed with a block design comprising an initial resting during standing condition (15 seconds), a task condition (30 seconds), and a second resting during standing condition (15 seconds). This procedure was repeated five times for each

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*Corresponding author. Tsubasa Mitsutake (E-mail: mitutuba1012@gmail.com)

Table 1. Comparison of head sensor and center of pressure (COP) measurements between different neck and trunk turning speeds

			Low turning speed	High turning speed
Head sensor	Velocity	Anterior–posterior, m/s	16.43 (10.98)	21.02 (13.88)
		Left–right, m/s	5.99 (4.21)	5.97 (4.24)
		Up–down, m/s	87.04 (3.75)	86.63 (3.95)
	Angular velocity	Roll plane, deg/sec	2.16 (0.94)	5.03 (1.41)*
		Pitch plane, deg/sec	1.61 (0.19)	2.86 (0.88)*
		Yaw plane, deg/sec	4.21 (1.69)	10.39 (6.47)*
COP		Area of body sway, cm^2	13.8 (4.9)	36.2 (18.6)*
		Total body length, cm	105.9 (21.6)	303.5 (113.9)*

All values are presented as median (interquartile range).
*p < 0.01

subject.

Evaluation of cortical activity during postural stability requires an accurate definition of rotation stimulation. Postural stability was evaluated using a force platform (GS-31; Anima, Inc., Tokyo, Japan) and head sensor (TSND121; ATR-Promotions, Kyoto, Japan). A custom turn-table operated by one of the experimenters was placed on the platform to assess postural perturbation. Subjects were asked to stand barefoot on the turn-table with their feet together; the platform rotated at an angle of up to 180°. Subjects were randomly assigned to either the high- or low-rotation speed condition (180°/s or 90°/s peak angular velocity, respectively). To avoid excessive eye movement during testing, subjects were asked to keep their head as still as possible while focusing on a target placed at a distance of 5 m in front of them. Subjects were permitted to familiarize themselves with the platform's movement prior to the measurement. To evaluate postural stability, we measured COP for both, area of body sway and total body length. A sensor was placed on the top of each subject's head to detect perturbations. The following two head movements were evaluated: head velocity was measured in the anterior–posterior, left-right, and up-down directions, and angular velocity was measured in the roll, pitch, and yaw planes. COP positions and head perturbations were recorded at a sampling rate of 50 Hz.

Cerebral cortex activity was evaluated using a functional near-infrared spectroscopy (fNIRS) system (OMM-3000; Shimadzu Corp., Kyoto, Japan) equipped with 16 light sources and 16 detectors. This system captured changes in oxygenated hemoglobin (oxyHb) level through 51 channels. We adopted an interoptode distance of 3.0 cm from the near-infrared light source to ensure propagation to the gray matter underlying the optodes. The light source at the center of the third row was set in a position that corresponded to Cz, T3, T4, F3, and F4 of the 10–20 International system. We defined each fNIRS channel by the midpoint of the corresponding light source-detector pair. Regarding anatomical information, the location of each optode on the plastic cap was marked using a 3D digitizer (FASTRAK; Polhemus, Inc., Colchester, VT, USA). The estimated locations of the fNIRS channels on the cortex were transformed using the affine transformation matrix in the Fusion software program (Shimadzu Corp). Data were analyzed with NIRS-SPM using MATLAB 2014a software (The MathWorks, Inc., Natick, MA, USA)[6].

All statistical analyses were performed using SPSS version 21 software (IBM Corp., Armonk, NY, USA), with the significance level set at $p < 0.05$. Data collected by the head sensor were used to calculate the absolute value at each plane during platform rotation. Each subject's COP and head movement are expressed as the mean of values measured at five time points. The Wilcoxon signed-rank test was used to assess differences in postural stability between high and low rotation speeds. Using the data obtained from fNIRS, task-related cortical activity during each condition was estimated using a general linear model.

RESULTS

Significant differences were found between the high- and low-speed rotations with regard to head perturbation in the roll, pitch, and yaw planes; COP of the ellipse area; and displacement (all $p < 0.01$) (Table 1). In both, high- and low-speed rotation conditions, oxyHb levels were not significantly different between the resting and task conditions (all $p > 0.05$).

DISCUSSION

The aim of the present study was to determine whether different neck and trunk rotation speeds influence standing postural stability or frontal and temporal cortical activity during rotation. There was an increase in the subjects' COP and head perturbation in the roll, pitch, and yaw planes during high-speed rotation. With regard to movement strategies, ankle and hip strategies are critical for fine motor coordination and dynamic motor coordination, respectively[1]. The high rotation speed in this study increased body perturbation in order to control postural stability; this would affect both ankle and hip strategies. Moreover, a previous study showed that the obliquus capitis inferior, rectus capitis posterior major, and splenius muscle responses are affected during body rotation when the head position is fixed[2]. These muscles have a high spindle density, and a high rotation speed could be one factor that allows for highly sensitive postural control.

The fNIRS results in this study showed that oxyHb levels did not increase significantly during high- or low-speed rotation compared to those in the resting condition. Regarding the effect of rotation during standing, automatic postural responses suggest that the spinocerebellum and basal ganglia play complementary roles in adapting postural responses to changing conditions[7]. The cerebral cortex exerts more control over anticipatory postural adjustments than automatic postural responses[7]; therefore, neck and trunk rotation during standing may not significantly activate the cerebral cortex. Thus, regardless of rotation speed, rehabilitative neck and trunk actions might be able to activate automatic postural responses. On the other hand, the vestibular system senses head position during tilting and acceleration[1]. One reason for the lack of significant differences between speed conditions could be that subjects were asked to keep their head as still as possible during platform rotation.

There are a few limitations in the current study. First, although spinal reflexes are associated with postural stability, they were not evaluated here. It is important to assess spinal reflexes in future studies. Second, in experimental conditions, the distance between a subject and a visual target is usually set at 2 m, but we chose 5 m due to space restrictions. In addition, the scalp and the skull could have interfered with fNIRS signal measurement, and fNIRS fiber movement during neck and trunk rotation could have introduced an artificial noise source. Future studies should employ other neuroimaging methods to clarify the neural mechanisms of postural control.

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