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The correlation between movement of the center of mass and the kinematics of the spine, pelvis, and hip joints during body rotation

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ABSTRACT

Body rotation is associated with many activities. The concomitant movement of the center of mass (COM) is essential for effective body rotation. This movement is considered to be influenced by kinematic changes in the spine, pelvis, and hip joints. However, there is no research on the association between COM movement and kinematic changes during body rotation.

We aimed to investigate the association between COM movement and the kinematics of the spine, pelvis, and hip joints during body rotation in standing. Twenty-four healthy men were included in the study. COM movement during active body rotation in a standing position was measured. We evaluated pelvic shift and changes in the angles of the spine, pelvis, and hip joints. We calculated the Pearson correlation coefficients to analyze the relationship between COM movement and kinematic changes in the spine, pelvis, and hip joints. There were significant correlations between lateral COM movement to the rotational side and pelvic shift to the rotational side, and between posterior COM movement and pelvic shift to the posterior side. In addition, lateral COM movement to the rotational side showed significant and negative correlation with spinal flexion and was significantly and positively correlated with the change in anterior pelvic tilt. Clinicians need to take particular note of both spinal and pelvic motion in the sagittal plane, as well as the pelvic shift, to speculate COM movement during body rotation in standing.

1. Introduction

A significant proportion of motion in activities of daily living, such as looking back and reaching, involves body rotation in the standing position. Body rotation requires the ability to maintain body stability, because trunk movement can disturb standing balance considerably. Movement of the center of mass (COM) during body rotation is crucial for understanding falls in older adults, because about 30% of falls occur during standing body rotation or while bending [1]. In addition, Liao et al. [2] showed a correlation between COM displacement and forward-reach distance. Thus, a concomitant movement of the COM may be essential to safely and effectively perform activities that include body rotation.

The factors that influence COM movement during body rotation are not clearly understood. COM movement is expected to be affected by trunk position [3,4], which is controlled by spinal motion. Body rotation will necessitate some degree of spinal rotation. In addition, the complex, three-dimensional structure of the spine results in the combination of rotation, flexion/extension, and lateral bending (i.e., coupled motion) when the spine is twisted [5,6]. If the spinal motion was composed solely of rotation, COM movement might not be much affected by spinal motion. However, spinal flexion/extension and lateral bending, accompanied by spinal rotation, might shift the trunk position and affect COM movement during body rotation. Therefore, we hypothesized that spinal flexion/extension and lateral bending, rather than spinal rotation, would influence COM movement during body rotation in standing.

Body rotation is a composite of both spinal rotation and pelvic rotation. COM movement is likely influenced by the motion of all body segments, including the pelvis. In the standing position, medial–lateral balance is controlled by pelvic shift, which is dominated by hip abduction/adduction [7–9]. Therefore, pelvic shift should have great influence on COM movement during standing body rotation. In addition, previous research [10–13] demonstrated the effects of pelvic tilt, particularly anterior/posterior tilt, on lumbar alignment. It may be that pelvic anterior/posterior and lateral tilt influence spinal movement,

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which controls trunk position, and consequently affect COM movement during body rotation. Thus, our hypothesis was that pelvic tilt may also influence COM movement.

Sung et al. [14] reported the kinematics of the lumbar spine and hip joints during body rotation, but they did not investigate the relationship between kinematics and COM movement. Baird et al. [15] examined COM movement during body rotation in young and older adults. They attributed the changed COM movement to the kinematic change in the spine. However, the direct relationship between COM motion and kinematics of the spine still remains to be analyzed. A better understanding of the effect of kinematic changes in the spine, pelvis, and hip joints on COM movement during body rotation would be beneficial in providing insight into balance and posture control during body rotation, and consequently helpful in considering the safety and efficiency of the motion that involves body rotation.

The aims of the present study were: (1) to examine the kinematic changes in the spine, pelvis, and hip joints in the sagittal and frontal planes during body rotation and (2) to investigate the association between COM movement and kinematic change in the spine and pelvis.

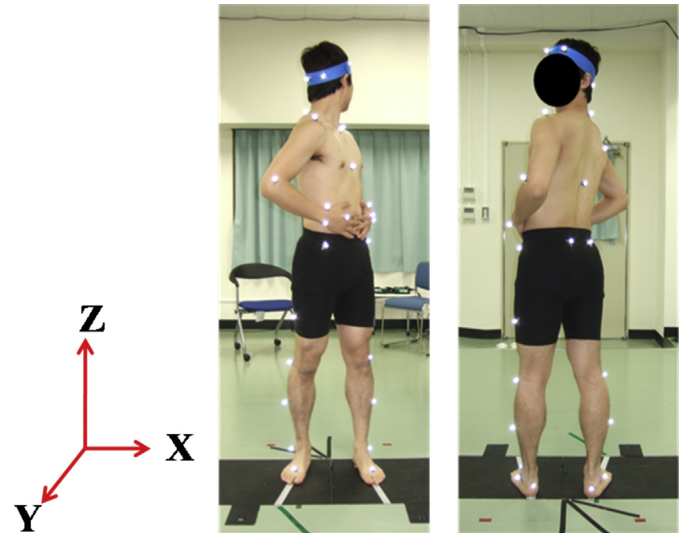

Fig. 1. Body rotation with marker set applied.

2. Materials and methods

Twenty-four healthy male volunteers [mean age (SD): 23.5 (2.9) years, weight 64.3 ± 5.3 kg, height: 172.7 ± 4.8 cm, foot length 25.1 ± 1.1 cm] participated in this study. None of the subjects had been injured or had surgery in the previous 6 months, none had ever had spinal surgery, and all were free of known neurological problems. Subjects provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine.

Body kinematics was recorded using a 6-camera Vicon motion system (Vicon Nexus; Oxford Metrics Ltd., Oxford, UK) at a sampling rate of 200 Hz. The subjects were clothed in close-fitting briefs, and 38 reflective markers were attached to the body according to the Vicon Plug-in-Gait marker placement protocol (full body) by a single investigator. The thoracic segment contained 6 markers: the 7th cervical and 10th thoracic vertebrae, jugular notch, xiphoid process of the sternum, and left and right acromioclavicular joints. The pelvic segment had 4 markers: the left and right anterior superior iliac spines and left and right posterior superior iliac spines. The thigh segment had 2 markers: the lower lateral 1/3 surface of the thigh and the epicondylus femoris lateralis. All data were low-pass filtered using a Woltring filter with a cut-off frequency of 6 Hz.

Subjects performed active body rotation to the right and left, starting from a relaxed upright position, with their arms folded across their abdomen [16]. They stood with a toe-out angle of 10° with the distance between their calcaneums equal to their foot length. Subjects were instructed as follows: "Rotate your trunk as far as possible, like when you look over your shoulder," and "Keep the sole of your foot flat on the floor." A metronome was set at 1 Hz to pace active rotation. The subjects completed their maximum rotation in 3 s, and then returned to the starting position in 3 s. This movement was repeated 3 times. The subjects were allowed to practice this movement until they felt comfortable with the pace (Fig. 1).

Kinematic parameters included the angles of the pelvis, the hip joints, and the thoracolumbar spine. In the present study, we defined the thoracolumbar spine angle as the relative angle between the thoracic segment and the pelvic segment. The angles of the thoracic and pelvic segments were measured with reference to the global frame. The hip joint angle was defined as the relative angle between the pelvic segment and the thigh segment. The change in the angles of the pelvis, the thoracolumbar spine, and the hip joints from static upright position to maximal rotation were calculated in 3 dimensions. In addition, we defined pelvic shift as the movement of the midpoint between both ASIS markers from a static position to maximal trunk rotation in the sagittal plane (posterior movement) and the horizontal plane (lateral movement). The COM was calculated using the Plug-in-Gait model. A 5-segment model was used to estimate the location of the COM [17]. We measured the medial–lateral and the anterior–posterior movement of the COM from the static position to maximal rotation. Because the COM movement is presumably influenced by the area of the base of support, the movement of the COM was normalized to each subject's base of support (i.e., the subject's foot length) to eliminate the effect of the area of the base of support on the COM movement during body rotation [18–20].

The subject's dominant side was identified by asking with which hand the subject preferred to throw a ball. With regard to daily activities, in particular sports (e.g., golf and tennis), we posit that subjects tend to rotate the body toward the non-dominant side more than the dominant side. Therefore, we analyzed the data regarding the turns to the non-dominant side in the present study (i.e., when a subject was right-handed, we analyzed the data of rotation to the left side). The change in the angles of the thoracolumbar spine, pelvis, and hip joints, and the pelvic shift and movement of the COM in body rotation to the non-dominant side was used for analysis. The mean value of 3 trials was determined for each subject. A paired *t*-test was used to compare the static position and the maximal rotation position. We calculated the Pearson correlation coefficients to analyze the relationship between COM movement and kinematic changes in the spine, pelvis, and hip joints. If several correlations were found between COM movement and kinematic changes, we used a stepwise multiple linear regression analysis to identify which kinematic change has a great influence on COM movement. The dependent variables were medial–lateral COM movement and anterior–posterior COM movement with each kinematic change in the spine, pelvis, and hip joints as independent variables. The α level was set at 0.05. SPSS software (Windows version 12.0, SPSS Inc., Chicago, IL) was used for the data analysis.

3. Results

Twenty-one subjects were right-handed, and 3 subjects were left-handed. During active body rotation, the COM shifted to the rotational and posterior side (Fig. 2). The maximum rotation