EFFECT OF FOOT ROTATION ANGLE ON THE ROTATIONAL RANGE OF MOTION OF TRUNK AND PELVIS

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The purposes of this study were to investigate the effect of foot rotation angle on the rotational range of motion (ROM) of trunk and pelvis. Eleven healthy males participated in this study who performed a maximum rotation of the trunk in a standing posture on the conditions of five different foot rotation angles based on “the central angle” that was defined as the average of the maximum internal- and external-rotation of hip joint in a static standing. Kinematic and kinetic analysis was performed with an optical motion capture system and two force plates. The ROM of the pelvis segment decreased significantly on the conditions of -30deg or +30deg compared to the ROM on the condition of the central angle. The load on the foot on the rotating side increased and the free moment decreased as the foot rotation angle increased externally.

KEY WORDS: the central angle, symmetry index, weight bearing, free moment

INTRODUCTION: In sports, during movements such as the swinging in golf and pitching in baseball, the trunk horizontal-rotation is considered to be an important factor in determining performance and preventing injuries (Okuda, Gribble, & Armstrong, 2010 and Fleisig et al., 2013). According to the Okuda et al. (2010), highly skilled golfers performed an earlier trunk rotation with a rapid weight transfer to the trail foot during the backswing than low skilled golfers. Regarding the foot rotation angle, the relationship with exercise performance has been clarified. It was reported that the knee’s internal rotation moment magnitude was significantly reduced with external foot rotation while performing the body weight squat (Almosnino, Kingston, & Graham, 2013). Lynn, Kajaks, & Costigan (2008) reported that internal rotation of the foot increased the knee adduction moment and lateral-medial shear force magnitude during late stance of the gait. However, in the previous study, the standard of foot rotation angle was set to parallel or self-selection (Almosnino et al., 2013; Escamilla, 2001; Ninos, Irrgang, Burdett, & Weiss, 1997; and Signorile et al., 1995), and the evidence-based optimal angle has not been clear. The purpose of this study was to investigate the effect of foot rotation angle on the rotational range of motion of trunk and pelvis. Particularly, we focused on the free moment of the ground reaction force and weight bearing between the left and right limb at the maximum trunk rotation.

METHODS: Eleven healthy males participated in this study (age: 21.5 ± 1.7 years old, height: 1.713 ± 0.065m, mass: 65.4 ± 9.1kg; mean ± SD). They performed a maximum rotation of the trunk in a standing posture on the conditions of five different foot rotation angles. The subject’s feet were fixed on the self-made turntable that was able to set the foot rotation angle arbitrarily (Fig.1a). Those foot rotation angles were determined based on “the central angle” that was defined as the average of the maximum internal- and external-rotation of the hip joint in a standing posture. The central angle was measured with a STANCER (GB08004, gyro-technology Co., Ltd., Japan) that is composed of two turntables and angle sensors installed on each turntable. Subjects were instructed to stand on the turntable and gaze at the black dots in front of the subject at eye level. For all the subjects, the central angle was measured immediately before the motion capturing of trunk rotation. The five conditions of the foot rotation angle were the central angle and plus/minus 15deg and plus/minus 30deg from the central angle. In this study, plus, and minus means external- and internal-rotation of the foot, respectively. The stance width under the measurement was fixed at 42cm which was close to the shoulder width of subjects in the current study. An optical motion capture system (MAC3D, Motion Analysis Corp., USA, 12 infrared cameras, sampling Freq. 100Hz) and the two force plates (BP6001200, AMTI Inc., USA, sampling Freq. 1kHz) were used for the kinematic and kinetic measurement. The reflective markers were attached on the subject based on HelenHays marker set except for trunk. The trunk segment was divided into four segments, those were named T1-, T4-, T7- and L1-segment. The reflective markers were attached on the spinous process of the spine (T1, T4, T7 and L1), then two other markers were put so as to form a triangle under each spinous process (Fig.1b). The local coordinate systems were created using the triangular marker clusters on the trunk.

(a) (b)

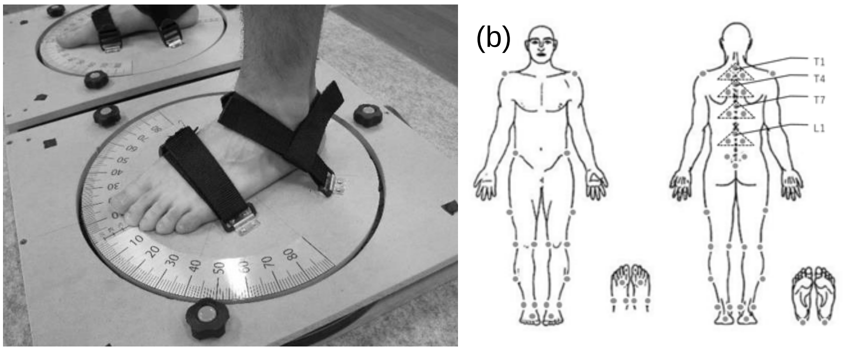

Fig.1: Experimental setting. (a) Self-made turntable that enable to set the foot rotation angle arbitrarily. (b) Position of reflective markers (gray dots). Four local coordinate systems were created on the back with the triangular marker clusters with T1, T4, T7 or L1 as its vertex.

Experimental data were analyzed using the Visual3D (C-Motion, Inc., USA). The analysis items were rotational range of motion (ROM) of each segment (T1-, T4-, T7-, L1-segment and pelvis segment). Those angles were obtained relative to the global coordinate system. The ground reaction force (GRF) including the free moment at the maximum rotation of trunk were obtained. The free moment is the reaction to the force couple exerted by the foot on the ground acting about a vertical axis originating at the foot's center of pressure (Almosnino, Kajaks, & Costigan, 2009). In this study, the free moment on the foot on rotating side was measured and normalized by subject’s body weight. The symmetry index (SI) of the weight bearing between the left and right limb was calculated by the following equation;

$$SI = \frac{vGRF_R - vGRF_L}{0.5(vGRF_R + vGRF_L)} \times 100\ (\%)$$

where, $vGRF_R$ and $vGRF_L$ are vertical components of the GRF acting on the right and left foot, respectively.

In the statistical processing, one-way analysis of variance (ANOVA) was used to compare means among the foot angle conditions, with effect size reported as eta-squared (Cohen, 1988). Post hoc analysis (Bonferroni method) was performed with the multiple comparisons test when the F ratio for the ANOVA was significant at $p<.05$. The effect sizes values were interpreted as large (≥.14), moderate (≥.06) or small (≥.01).

RESULTS: The rotational ROM of each segment in the trunk and pelvis segment were shown in Table 1. There were significant differences in the T1-, L1-segment and pelvis segment. It was observed that the ROM reached the maximum under the central angle condition and the ROM decreased as the foot rotation angle became larger or smaller. The ROM of the pelvis segment decreased significantly on the conditions of -30deg or +30deg compared to the ROM on the condition of the central angle. The effect sizes exceeded 0.14 in all segments except T7 segment. The SI of the weight bearing between the left and right limb at the maximum rotation of trunk was depicted in Fig.2. The magnitude of SI increased on the leg of the rotational side as the foot rotation angle increases. The SI on the condition of +30deg was significantly greater than that on the condition of -30deg in both the right or left rotation of the trunk ($p<.05$). The free moment acting on the foot of rotational side at the maximum rotation of trunk was shown in Fig.3. In contrast to SI, the absolute value of free moment decreased as the foot rotation angle increases.

Table 1 The rotational range of motion of each segment

segment
T1

een -30deg and central angle
[b] Significant differences (p<.05) between central angle and +30deg

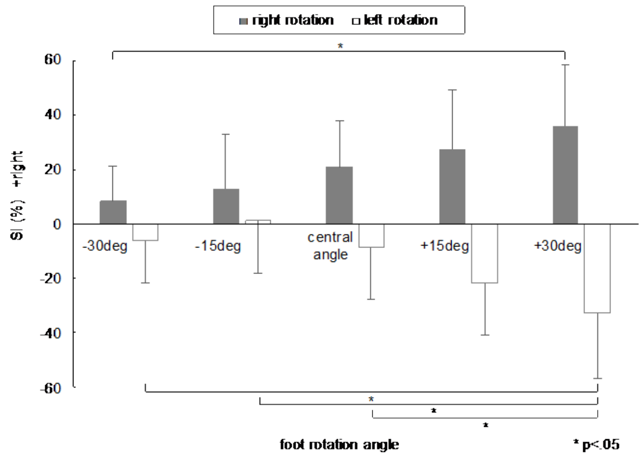

Fig.2: The symmetry index (SI) of the weight bearing between the left and right limb at the maximum rotation of trunk. Right/left rotation in the legend means the trunk rotation to the right/left direction, respectively.

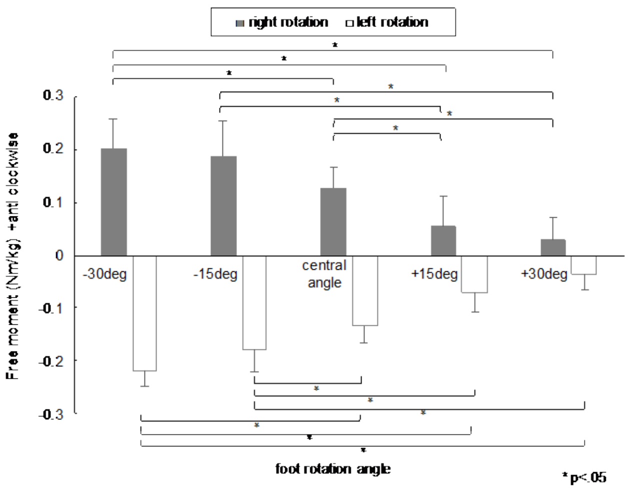

Fig.3: Free moment acting on the foot of rotational side at the maximum rotation of trunk. Data were normalized by subject's body weight. Right/left rotation in the legend means the rotation to the right/left direction, respectively.

DISCUSSION: The foot rotation angle had an influence on the rotational ROM of the pelvis and trunk (Table 1). It was considered that the foot rotation angle was mainly affected on the ROM of pelvis, as a result, the rotational ROM of trunk was changed. The effect of foot rotation angle on pelvic rotation was considered to be large. Mathematically, if the foot rotation angle changes 1 degree from the central angle, the ROM of the pelvis will decrease by about 1 degree. Fig.2 showed that the weight bearing asymmetry increased as the foot rotation angle increased externally. On the other hand, the larger the foot rotation angle externally, the smaller the free moment acting on the rotational side of the foot (Fig.3). These results indicate that when the foot rotation angle is excessively large or small, not only the rotations of the trunk or pelvis are restricted, but also a mechanical imbalance occurs when the trunk is rotated. There were some reports with regard to the free moment, Almosnino et al. (2009) reported that the time-history pattern of the free moment during walking was affected by the foot rotation condition. It was reported that the asymmetry of the free moment between the left and right feet influenced the twist between the pelvis and upper torso (Kramers-De Quervain, Müller, Stacoff, Grob, & Stüssi, 2004). It was suggested that the weight bearing asymmetry and the free moment would be the predictor to find the better foot rotation angle. This study also suggested that the central angle could be the criterion for determining the optimum stance angel for individuals.

CONCLUSION: The foot rotation angle was involved in the rotational ROM of the trunk and pelvis. Especially, the ROM of the pelvis was greatest on the condition of the central angle and decreased as the foot rotation angle became larger (external-rotation) or smaller (internal-rotation) than the central angle. The load on the foot on the rotating side increased and the free moment decreased as the foot rotation angle increased externally. The findings of this study can be the useful information when you're searching for optimum standing stance in sport such as golf or snowboarding. In determining the optimum standing stance, by using the central angle as a reference, it is possible to present a foot rotation angle suitable for individual physical characteristics.

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