EFFECT OF FOOT ROTATION ANGLE ON TRUNK ROTATIONAL STRENGTH AND PHYSICAL QUANTITY TO ROTATE THE BODY

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The purposes of this study were to investigate the influence of foot rotation angle on trunk rotational strength and physical quantity to rotate the body. Ten healthy males participated in this study who exerted the maximum trunk rotational strength 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. The force was measured by force gauge sensor. Biomechanical analysis was performed with an optical motion capture system and two force plates. No significant difference was observed in the rotational strength between any conditions, but as the foot rotation angle increased externally, the free moment acting on the right foot decreased and the moment around the center of mass by the ground reaction forces acting on both feet increased.

KEY WORDS: the central angle, force gauge, free moment, moment around the center of mass, lever arm

INTRODUCTION: Rotation range and rotation power of trunk is considered as key motion for performance improvement and injury prevention for sports such as golf, tennis and baseball (Okuda, Gribble, & Armstrong, 2010, Ellenbecker & Roetert, 2004, Fleisig, Hsu, Fortenbaugh, Cordover, & Press, 2013). Regarding the foot rotation angle, the relationship with exercise performance has been reported (Escamilla et al., 2001). Almosnino, Kingston, & Graham, (2013) reported that the knee’s internal rotation moment magnitude was significantly reduced with external foot rotation while performing the body weight squat. 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, the effect of foot rotation angle on trunk rotational strength has not been clarified. The purposes of this study were to investigate the effect of foot rotation angle on the trunk rotational strength and to provide an optimal foot rotation angle.

METHODS: Ten healthy males participated in this study (age: 22.5 ± 1.6 years old, height: 173.2 ± 4.5cm, mass: 65.4 ± 7.7kg; mean ± SD). They performed the maximum trunk rotational strength to full exertion in a standing posture on the conditions of five different foot rotation angles. The trunk rotational strength was measured with a force gauge sensor (DPZS-DPU-500N, IMADA Co., Ltd., Japan, sampling Freq. 100Hz). The sensor and the handle were connected with non-stretch rope, and the handle was set to be in front of the subject. Subjects were instructed to grasp the handle with both hands and pull it with maximum effort for five seconds. We measured the drag force pulling the handle during the isokinetic trunk rotation, and regarded it as trunk rotational strength (Fig.1). In order to limit the lateral movement of the pelvis during the task, the antennas were placed on both sides of the pelvis. The foot rotation angles were determined based on “the central angle” that was defined as the average of the maximum internal- and external-rotation of 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 capturing the motion. 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 between both heels under the measurement was fixed at 0.42m 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.

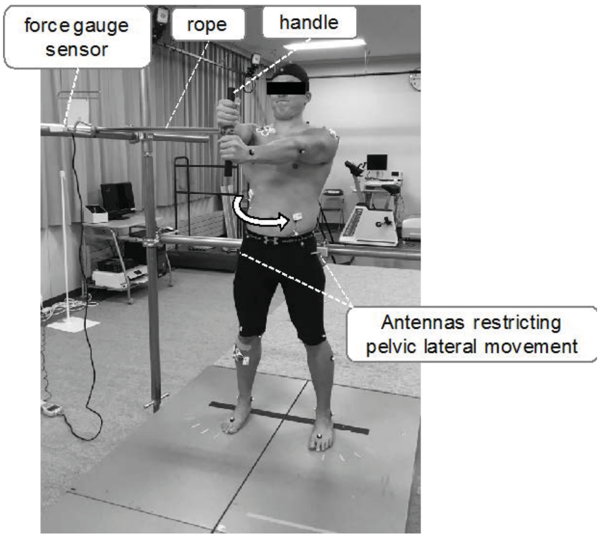

Fig.1: Experimental setting. The subject stood on the force plate and instructed to grasp the handle by both hands and perform isokinetic trunk rotation counterclockwise (a hollow arrow) so as not to move the body laterally. The handle was connected with the force gauge sensor by the non-stretch rope to measure the drag force that was regarded as trunk rotational strength.

All measured data were then transmitted to the motion analysis software Visual3D (C-Motion, Inc., USA) for final data analysis. Following four data were calculated. First, the maximum drag force during the task and second, the free moment acting on both feet. Third, the horizontal component of the moment around the center of mass (COM) by the ground reaction forces (GRF) on both feet (hereinafter M_{COM}) at that time and forth, the distance between the COPs of the left and right feet. The free moment is the reaction to the force couple generated by the foot on the ground acting about a vertical axis originating at the foot's center of pressure (COP) (Almosnino, Kajaks, & Costigan, 2009). The moment around COM was derived from the cross product of the GRF and the vector from the COP to the COM, and in the present study, the horizontal component of the moment was regarded as M_{COM}. The free moment and M_{COM} were regarded as the physical quantity to rotate the body in this study.
In the statistical processing, one-way analysis of variance (ANOVA) was used to compare means among conditions. Post hoc analysis (Bonferroni method) was performed with the multiple comparisons test when the F ratio for the ANOVA was significant at $p<.05$.

RESULTS: There was no significant difference in the maximum drag force between any conditions. The drag force under each condition was 72.3±16.8N (-30deg), 76.8±16.8N (-15deg), 78.9±23.3N (central angle), 84.2±20.7N (+15deg) and 90.3±21.1N (+30deg), respectively. The free moment acting on both feet when the maximum drag force was exerted were shown in Fig.2. The free moment acting on the right foot decreased as the foot rotation angle increased externally. Significant differences were observed between some conditions. On the other hand, the free moment acting on the left foot was so slight, and no significant difference was found between the conditions. The M_{COM} on the five conditions of foot rotation angles was shown in Fig.3. As the foot rotation angle increased, M_{COM} also increased. An example of measurement data under the three different conditions of foot rotation angle (central angle and +/-30deg) was visualized in Fig.4. It was observed that the GRF vector acting on the right foot became vertical under the internal condition (-30deg) and

L increased on the condition of external foot rotation (+30deg). The L under each condition was 0.37±0.03m (-30deg), 0.42±0.02m (-15deg), 0.47±0.02m (central angle), 0.53±0.02m (+15deg) and 0.59±0.03m (+30deg), respectively, and increased with increasing foot rotation angle externally. Significant differences were found in comparison of all conditions (P<.01).

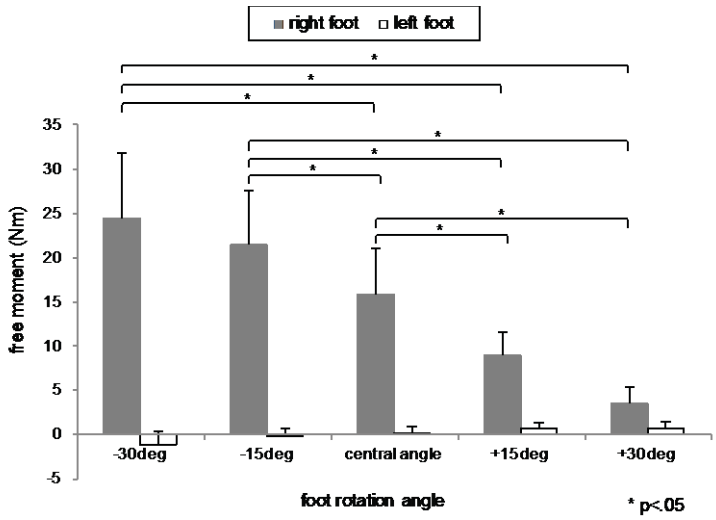

Fig.2: The free moment acting on both feet when the maximum drag force was demonstrated.

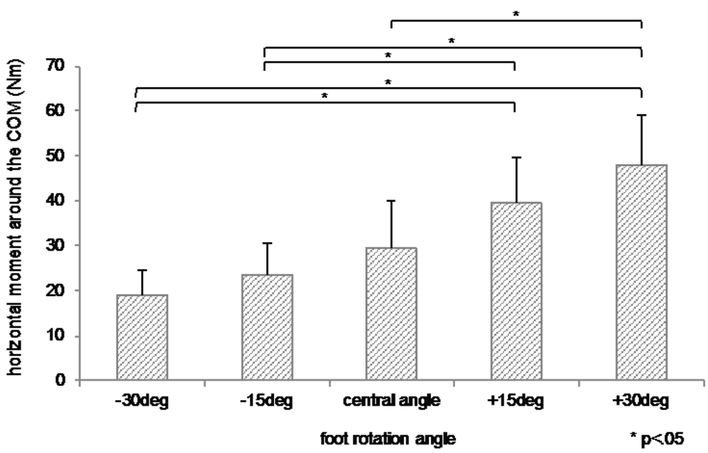

Fig.3: The horizontal moment around the COM (M_{COM}) when the maximum drag force was demonstrated.

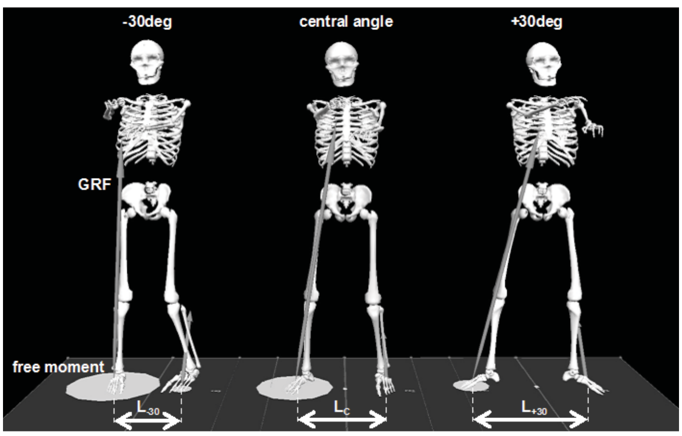

Fig.4: An example of measurement data under three different conditions of foot rotation angle was visualized (left: -30deg, center: central angle, right: +30deg). the GRF vector was represents by the arrow pointing upward from the ground, and the magnitude of the free

moment was depicted by the radius of the circle drawn on the ground surface. L_{-30}, L_C and L_{+30} indicate the distance between the COPs of the left and right feet on each condition.

DISCUSSION: We hypothesized that the condition of foot rotation angle in the standing posture influences trunk rotational strength. However, there was no difference in trunk rotational strength between the conditions. Interestingly, however, it was shown that the bio-mechanisms that exert trunk rotational strength differ between the conditions of foot rotation angle (Fig.2 and 3). When the foot rotation angle was small, the conditions of internal foot rotation (-15deg, -30deg), the trunk rotational strength was exercised mainly by using the free moment acting on the right foot, and contrarily, on the conditions of external foot rotation (+15deg, +30deg), the trunk rotational strength was mainly produced by M_{COM}. In the internal conditions, since the hip joint is internally rotated, it is considered that it was in a posture capable of generating the hip external rotation moment. This seemed to be the reason why the free moment was increased. Almosnino et al., (2009) reported that the time-history pattern of the free moment during walking was affected by the foot rotation angle. On the other hand, the reason why the M_{COM} increased in the external condition was thought to be because the L corresponding to the lever arm of the M_{COM} was lengthened (Fig.4).

CONCLUSION: It was suggested that the foot rotation angle did not affect the trunk rotational strength. However, it became clear that this angle greatly influences the biomechanical mechanism in generating the trunk rotational strength. Based on the central angle, free moment in the internal condition and the M_{COM} in the external condition mainly affected the trunk rotational strength. From this study, it was suggested that the central angle plays an important role in searching for optimal foot rotation angle for individuals.

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