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EFFECT OF ANKLE INVERSION ON LOWER EXTREMITY JOINT MOMENTS DURING WALKING WITH ANKLE BRACING

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SUMMARY
The purpose of this study was to evaluate the effects of different ankle inversion conditions on the peak joint moment of the lower extremity joints during walking with lace-up ankle bracing. Kinematic and force plate data were collected from thirteen subjects performing walking trials across different tilted force plates (0°, 15° and 30°) respectively by a motion capture system (250 Hz) and three force plates (1000 Hz). One-way ANOVA was used to compare the differences of peak joint moments between the tilted conditions with an alpha level of $p < .05$. During the 30° ankle inversion, all the lower extremity peak joint moments had significant differences compared to the control condition, expect the ankle dorsiflexion moment at push-off ($p< .05$). During the 15° ankle inversion, the knee and hip joint moments in the both sagittal and frontal planes had significant differences in comparison of the control condition ($p< .05$). It was concluded that the musculature of hip and knee joints in sagittal and frontal planes contributed primarily to accommodate the uneven surface in the 15° condition. The excessive joint moments were generated in the 30° condition might increase the risk of lateral joint structures injury.

INTRODUCTION
Each day one out of ten thousand people suffer from ankle inversion injury resulted in long-term disability and higher costs on medical care [1,2]. Ankle bracing has been used to prevent ankle injury extensively. Previous studies have demonstrated the ability of ankle bracing in restricting ankle inversion movement [3] but also had the detrimental effect on restraining ankle sagittal plane motion which would increase the ground reaction force [4]. However, little was known about the compensatory mechanism of lower extremity joint moments and the effeteness of ankle bracing during different ankle inversion movements. It was very important to understand the effect of ankle bracing on human movement and muscles. The purpose of this study was to evaluate the effect of different ankle inversion conditions (0°, 15° and 30°) on lower extremity peak joint moments during walking with ankle bracing.

METHODS
Thirteen male college physical education students (age: 23.8 ± 2.1 yrs, height: 173.5 ± 6.1 cm, weight: 68.5 ± 8.0 kg) participated in this study. Each subject was asked to walk at their natural speed over three different ankle inversion plates (0°, 15° and 30°) with lace-up ankle brace. Vicon motion analysis system (10 cameras, 250Hz, with 49 body land markers) and three Kistler force plates (1000Hz) were used to record the 3D kinematic and kinetic data in conjunction with Visual 3D software respectively.

Raw data were filtered using a Butterworth 4th-order low-pass filter with a cut-off frequency of 6 Hz. Kinetic variables were normalized to a percentage of subject's body weight (B.W.) and transferred to 100% of the right foot contact time on the force plate. A one-way ANOVA with repeated measures was used to compare group differences with a significance level of $\alpha< .05$. All statistical analyses were performed by SPSS 12.0 software.

RESULTS AND DISCUSSION
At ankle joint moments (Figure 1a), the greater peak ankle eversion moment was found in the 30° condition at initial heel contact compared with 15° and control conditions ($F_{1.41,16.87}=27.33$, $p< .05$), indicating that the lateral ankle structures were resisting a greater inversion stress which might be generated by ankle bracing to protect ankle inversion [6]. In addition, the increased ankle eversion moments could adjust the increased medial accelerations of the center of body mass (COM) created by ankle inversion as well [7]. Therefore, the increased ankle eversion moments might also represent an excessive lateral displacement of COM occur at initial heel contact while ankle inverted to 30°. The peak ankle internal rotation moments were greater in tilted conditions than control condition during the braking phase ($F_{2,24}=3.49$, $p< .05$) and subsequently exhibited a great amount in the 30° condition during the propulsive phase ($F_{2,24}=11.87$, $p< .05$). Based on the joint coupling mechanism, the talus externally rotated as the calcaneus inverted which would increase the external rotation and resulted in a higher lateral shearing force loading at the ankle, especially at push-off [8]. Therefore, when we step on an uneven surface, we should avoid the continuing propulsive progression to prevent the dramatically increased ankle rotation.

At knee joint moments (Figure 1b), the greater extension moments and flexion moments were generated in the tilted conditions during the braking and the propulsive phases respectively ($F_{2,24}=3.46$ and $F_{2,24}=2.38$, $p< .05$). This increased knee flexion-extension moment might increase stability by reducing lateral joint opening and enhancing joint surface load distribution [9]. Therefore, the significantly decreased knee abduction moments in the tilted conditions might due to the greater knee moments in sagittal plane by reducing the lateral varus motion ($F_{2,24}$=19.68 and $F_{2,24}$=12.74, p < .05). In the transverse plane, the knee in the 30° condition generated greater peak internal rotation moment than other two conditions during the braking phase ($F_{2,24}$=12.41, p< .05) then reversed to a smaller external rotation moment during the propulsive phase ($F_{2,24}$=7.92, p< .05). The external rotation might result from the contralateral limb swinging forward past the weightbearing limb [10]. Therefore, as the ankle inverted, the weightbearing limb might increase the external rotation created by the excessive lateral postural sway. However, the increased knee internal rotation moments were likely to increase the stress on the lateral knee ligament which might increase the risk of knee injury [11].

At the hip joint moments (Figure 1c), the greater peak extension and flexion moments were observed significantly different in the tilted conditions compared with the control condition during braking and propulsive phases respectively ($F_{1.36,16.27}$=12.42 and $F_{2,24}$=19.08, p< .05). According to previous study, the increased hip extension moment was to assist in reinforcing the knee from collapsing and decelerated the forward rotating trunk [12]. The hip flexion moment was to decelerate the backward rotating thigh and propelled the leg into swing during propulsive phase [13]. Previous study has found that ankle and hip flexion moments had similar types of actuation to pull the leg forward at push-off [14]. Since the ankle plantarflexion moment did not change, the hip flexors might compensate for the demand. The two peaks of hip abduction moments significantly decreased as the ankle inversion increased which was associated with the increased ankle inversion due to the fine tuning of COM location ($F_{1.29,15.44}$=3.35 and $F_{2,24}$=8.68, p< .05). In the transverse plane, the hip rotators generated a greater internal rotation moment to resist an increased external rotation in the 30° condition at the first 20% of stance ($F_{2,24}$=12.41, p< .05) then converted to a smaller external rotation moment ($F_{2,24}$=7.92, p< .05). According to the closed kinetic chain, the tibial external rotation increased while the ankle inversion increased at initial heel contact. In order to maintain the joint congruity, hip would increase the external rotation, which in turn forced the hip muscles to exert larger internal rotation moment on the hip. Afterwards, the hip muscles produced a smaller external rotation moment in the 30° condition which might be due to the extension posture maintained at the hip joint resulting in a smaller lever arm of the external rotation moment.

CONCLUSIONS

Ankle inversion in 30° had a great impact on the musculature of lower extremity joints. Great internal rotation moments accompanied with large flexion-extension moments at lower extremity joints might increase the risk of lateral joint structures injury. However, ankle inversion in 15° had no significant effect on ankle joint moment because the musculature of hip and knee joints in sagittal and frontal planes contributed primarily to accommodate the uneven surface. Therefore, ankle bracing might be more effective in preventing ankle inversion under 15° condition.

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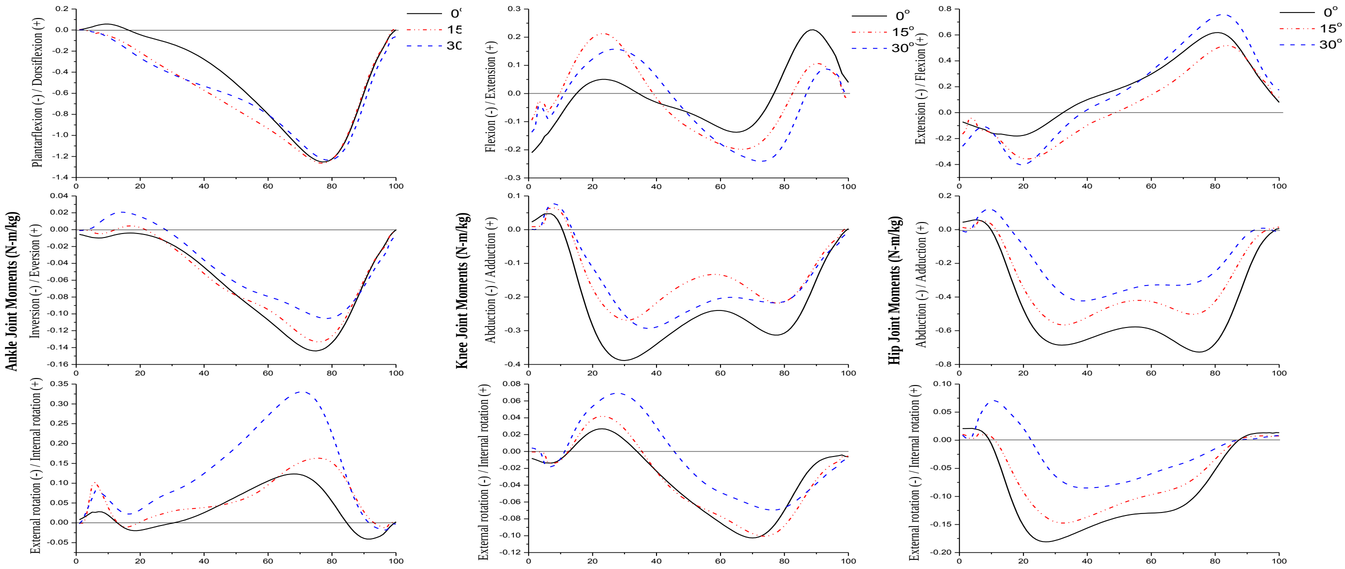

Figure 1: The average of ankle joint moments (a), knee joint moments (b) and Hip moments (c) in 0°, 15° and 30° conditions