DIFFERENCES IN INTRA-FOOT MOVEMENT STRATEGIES DURING THE CUTTING TASK AMONG CAI, COPERS, AND HEALTHY INDIVIDUALS

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Individuals with chronic ankle instability (CAI) suffer from the resulting sequela of repetitive lateral ankle sprains (LAS), whilst copers appear to cope with initial LAS successfully. Therefore, the aim of this study was to explore the intra-foot biomechanical differences among CAI, copers, and healthy individuals. Twenty-two participants per group were included and required to perform a cutting task. A five-segment foot model with eight degrees of freedom was used to explore the intra-foot movement. Joint moment differences were not found among these three groups, however, Copers presented greater eversion angles compared to others. Copers rely on more eversion positioning to prevent over-inversion of the subtalar joint compared to CAI. These findings may help in designing and implementing interventions to restore functions of the ankle joint in CAI individuals.

KEYWORDS: multisegmented foot model, chronic ankle instability, lateral ankle sprain, motor control.

INTRODUCTION: The ankle joint is the most frequently injured body site in sports activities, with lateral ankle sprain (LAS) being the most common, which accounts for ~80% (Fong et al., 2009). Structural damage caused by LAS is mainly focused on the lateral ankle ligaments, especially the anterior talofibular and calcaneofibular ligaments, and these changes may lead to a high recurrence rate of ankle sprain (Doherty et al., 2016). Accordingly, chronic ankle instability (CAI) may be developed and characterized by the following symptoms with pain, instability, and swelling as well as “giving way” (Yu et al., 2021). In contrast, individuals who sprain their ankle once but successfully cope with resulting damage are categorized as copers, remaining free from recurrent sprains, and typically return to their pre-injury levels of function (Wikstrom & Brown, 2014). Therefore, understanding the differences between CAI and copers would provide valuable information about potential mechanisms of repetitive LAS.
Multisegmented foot models (MFM) would help enhance the insight of the foot function in a CAI group (De Ridder et al., 2013). To the best of our knowledge, few studies have been conducted to explore the multisegmented foot biomechanics in a CAI group. Among these studies, two MFM were commonly used (De Ridder et al., 2013; Wright et al., 2013). Within these MFM, each segment allows movement in the sagittal, frontal, and transverse planes. However, MFM are more prone to result in measurement errors when multi segments all have the three rotational degrees of freedom (DOF) (Kim & Kipp, 2019).
Based on previous findings (Kim & Kipp, 2019), five segment foot models with 8-DOF could provide more accurate intra-foot kinematics and kinetics. Therefore, the primary aim of this study was to explore whether the intra-foot biomechanics of CAI individuals during a cutting task were different compared to copers and a healthy control group using a 5-segment 8-DOF model. We hypothesized that CAI individuals would alter joint kinematics compared to copers and the healthy group, including dorsiflexion reduction and less eversion.

METHODS: Considering the variable (ankle sprain history), the sample size was calculated in G*Power 3.1.9.7 (effect size =0.4, α value = 0.05, power value =0.8)(Kang, 2021), 66 physically

active male participants, with 22 individuals per group were included (**Table 1**). The selection criteria of CAI individuals were based on International Ankle Consortium guidelines (Gribble et al., 2013), including: i) at least one significant ankle sprain and the initial ankle sprain should occur more than one year before the study enrollment; but the latest injury should occur more than 3 months; ii) scoring ≤24 on the Cumberland Ankle Instability Tool (CAIT). For individuals who were defined as CAI for both limbs, the involved limb was selected as the one with lower CAIT scores. For copers, participants presented with one significant ankle sprain, had no episodes of 'giving way' and scored 25-28 on the CAIT. For individuals who were defined as a coper for both limbs, the limb with lower CAIT scores was considered. Control participants were defined as those without any ankle sprain histories and scored ≥28 on CAIT. The involved limb of the control group was the dominant limb which was used to kick a ball. Individuals were excluded if they had lower limb fractures, surgery history, or acute lower limb musculoskeletal injuries within 6 weeks before the experiment. Prior to the experiment, all participants provided informed consent. The study protocol was approved by the University Human Ethics Committee.

Table 1: Demographical description of participants (mean ± standard deviation).

Variables	CAI	Coper	Control
N	22	22	22
Age, yrs	22.59±1.92	22.45±2.02	23.50±2.50
Height, cm	182.30±7.23	174.95±5.08	177.64±5.21
Body mass, kg	79.02±8.72	71.09±8.05	73.98±7.01
CAIT Scores	19.63±3.35	25.91±0.81	29.63±0.49

After completing CAIT and recording their demographic information, participants conducted the experiment in barefoot conditions. The eight-camera motion analysis system with a sampling frequency of 200Hz was used to capture the kinematic data and was synchronized with an AMTI force plate with a sample frequency of 1000Hz. All participants were required to wear tight-fitting pants, and 43 reflective markers with the diameter of 8mm were placed on the pelvis and limbs, especially the involved foot (Malaquias et al., 2017). The multi-segment foot model used in this study contains 5-segments and 8-DOF as shown in **Figure 1**.

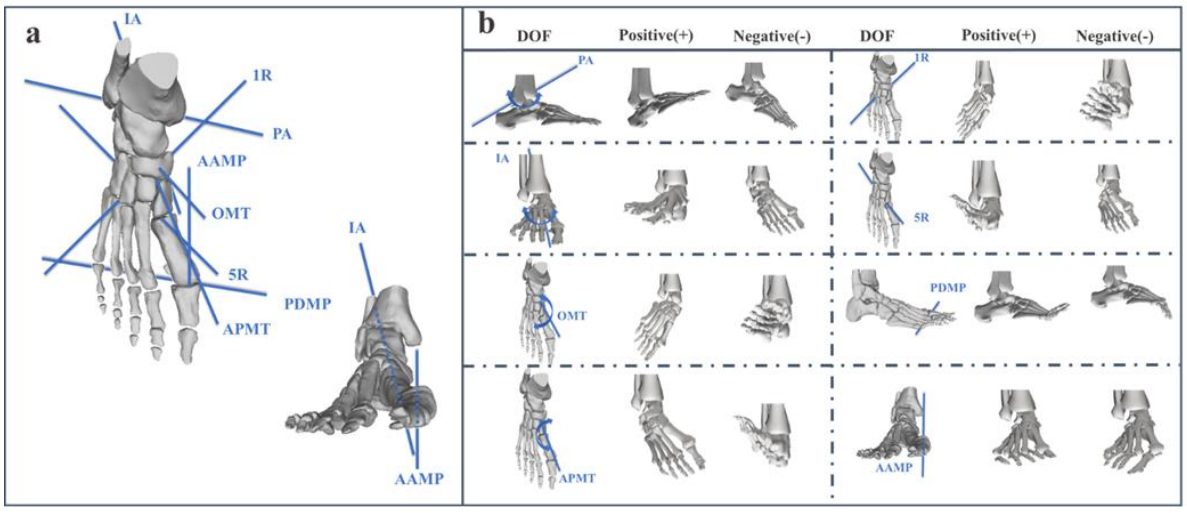

Figure 1: The axes of all foot joints (a) and sign conventions used for the multi segment foot model (b). PA: plantarflexion ankle axis; IA: inversion ankle axis; MOT: oblique mid-tarsal axis; APMT: antero-posterior mid-tarsal axis; 1R: 1st ray axis; 5R: 5th ray axis; PDMP: plantarflexion and dorsiflexion axis in metatarsophalangeal joint; AAMP: adduction and abduction axis in metatarsophalangeal joint.

After warm-up and familiarization, participants were required to walk at a self-selected speed, and stepped onto the force plate with their involved limb, with the other limb stepping out in a

45° direction. Three successful trials were included for further analysis. Between each trial, an interval of at least 30s was provided to avoid fatigue. OpenSim 4.0 was used to process and calculate the kinematic and kinetic data of the foot-ankle complex. Kinematic and kinetic data were filtered by a low-pass 4th order Butterworth filter with cut-off frequency of 6 Hz and 20 Hz, respectively. The stance phase of each cutting trial was analyzed, which was from initial to final ground contact (ground reaction forces above 10N). Joint angles of the foot-ankle complex were calculated via inverse kinematics and a residual reduction algorithm was used to improve the kinematic model as well as the experimentally collected ground reaction forces (GRF). Joint moments were calculated following this process based on the inverse dynamic algorithm (Malaquias et al., 2017). Each trial was normalized to 101 frames. Due to the one-dimensional time-varying characteristics of joint angles and moments, the one-way ANOVA in the factorial statistical nonparametric mapping (SnPM) was employed, which was performed in MATLAB R2018a (The MathWorks, MA, USA). The significance level was set as 0.05.

RESULTS: During the stance phase of cutting, group differences only existed in the subtalar joint, where copers presented greater eversion angles compared to CAI from 5% to 100% of the stance phase, and had greater eversion angles compared to the control group from 81% to 100% of the stance phase (**Figure 2**). No significant differences of joint moments were found among the three groups.

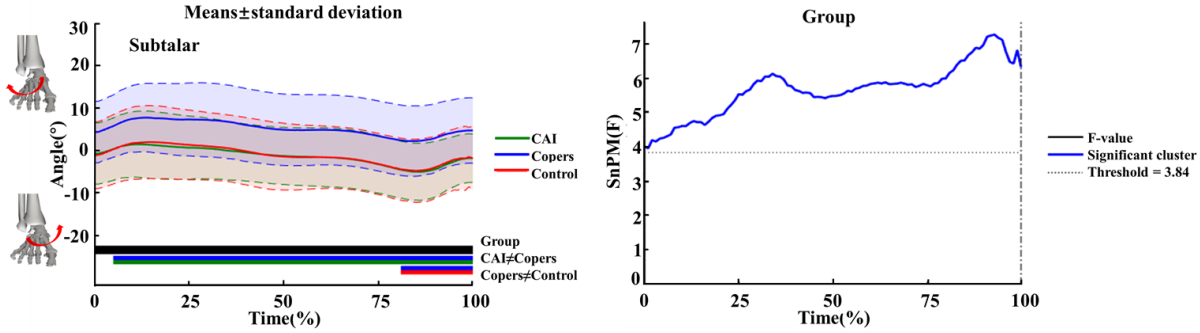

Figure 2: Group comparisons with significant differences of multi-segment foot angles across the stance phase of cutting.

DISCUSSION: The purpose of this study was to explore differences in intra-foot kinematics and kinetics of a CAI group during a cutting task, compared to copers and heathy individuals. Consistent with our hypothesis, our main findings indicated that key differences within these three groups existed in the subtalar joint. Copers presented a more eversion position compared to both the CAI and healthy groups during cutting.

Increased ankle eversion angles were found in copers compared to CAI and healthy individuals. No significant differences were found in inversion/eversion angles of the subtalar joint between CAI and control groups, which was consistent with a previous study(Kawahara et al., 2022). A more everted foot position was found in the coper group, indicating a relatively good neuromuscular control ability compared to CAI group. For CAI group, proprioceptive ligamentous structures of the ankle joint are damaged after repetitive LAS (Golanó et al., 2016), creating a void in the proprioceptive feedback to the central nervous system and characterizing CAI with the symptoms of “giving way”. Furthermore, in the previous study (Inman, 1976), the foot with a more laterally deviated subtalar-joint axis may be faced with recurrent ankle sprains. It may potentially indicate the compensatory strategy of copers to avoid repetitive LAS.

Several limitations should be considered for this study. Firstly, all locomotive tasks in this study were conducted in barefoot conditions. One should be cautious when extending conclusions to a shod condition. Further, even though SnPM is a good way for conducting ANOVA and post hoc tests for time-varying biomechanical variables, the results of the post hoc test with Bonferroni correction are relatively conservative and approximate. Furthermore, based on a previous review, males with LAS history appear to have a higher risk of suffering a subsequent

LAS (Wikstrom et al., 2021). Females may likely have subtle differences in intra foot biomechanics, which need further investigation in future studies.

CONCLUSION: In conclusion, our study found that although copers did not suffer from repetitive LAS, they did present different biomechanical characteristics compared to the control group. The intra-foot biomechanical characteristics of copers are similar to that of CAI to a great extent. However, copers may rely on a more everted position to prevent excessive inversion of the subtalar joint during a cutting task. The altered intra-foot movement strategies in copers and CAI groups could provide insight towards the impacts of LAS.

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