THE MUSCLE ACTIVATION AND LANDING KINEMATICS OF CAI ATHLETES IN SINGLE-LEG LANDING AND LATERAL JUMPS

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This study investigated the motor control of chronic ankle instability (CAI) athletes in different landings. 16 athletes participated (8 CAI and 8 control) and performed single-leg landing, inward lateral jump, and outward lateral jump. Electromyography of tibialis anterior, peroneus longus, medial gastrocnemius and lateral gastrocnemius (LG), ankle angle, and time to peak vertical ground reaction force were analysed. Statistics using two-way ANOVA with people and motion as independent variables. The data showed that CAI had different feedforward and feedback strategies with larger inversion angle pre and post initial contact (IC), larger plantarflexion pre and at IC, and lower LG activation pre IC. The large inversion ankle angle post IC could be the risk factor for reinjury. Injury prevention programs of CAI should pay attention to the activation of LG muscle in the landing.

KEYWORDS: Chronic ankle instability, landing, biomechanics.

INTRODUCTION: Jump landing is a common reason of lateral ankle sprain injury (Herb et al., 2018). Individuals who have suffered one sprain are vulnerable to reinjured and are prone to chronic ankle instability (CAI). CAI is defined as recurrent ankle sprains due to trauma, or recurrent symptoms of ankle "giving away" lasting for at least 1 year. Understanding neuromuscular control of the injured subjects can help to understand the injury mechanism, develop rehabilitation programs, and prevent re-injury. Neuromuscular control includes both feedforward and feedback control. Feedforward is triggered prior to the ground contact in landing, during which the lower limb muscles are preactivated to prepare the lower limbs (Han et al., 2022). Feedback refers to the reflexive adjustments and corrective measures taken by the joint in response to external disturbances. Landing is the classic motion for evaluating feedforward and simulates ankle injury scenarios realistically. Compared to normal subjects, CAI exhibits shorter time to peak vGRF and increased ankle inversion angle; these changes in motor control may be responsible for repetitive sprains in the CAI (Watabe et al., 2021; Jeon et al., 2021). Most previous studies investigate single leg landing only, the evidence of lateral jump landing of CAI athletes is limited. The purpose of this study is to investigate motor control of CAI in single leg landing, inward, and outward lateral jump landing. We hypothesis that CAI had shorter time to peak vGRF and larger inversion angle than normal athletes.

METHODS: 16 fencing and martial arts athletes participated in this study, participants were recruited from a professional fencing team of 45 athletes and a martial arts team of 30 athletes. The athletes were divided into control group (n=8, 6F2M, Age 17.4$\pm$2.0 years, Height 176.4 $\pm$9.3cm, Weight 65.5$\pm$8.9kg) and CAI group (n=8, 7F1M, Age 17.6$\pm$3.1 years, Height 163.0 $\pm$9.1cm, Weight 56.5$\pm$6.3kg) according to the score of Cumberland ankle instability tool (CAIT). Inclusion criteria for CAI is CAIT<24. The normal group had no ankle sprain injury up to the time of participation. Exclusion criteria for both groups are lower limb surgery/fracture.
After 5 minutes warm up, reflective markers were attached to the participants' skin according to the Davis Heel Model. After the standard cleaning of skin, surface electromyography electrodes were attached to tibialis anterior (TA), peroneus longus (PL) and medial gastrocnemius (MG) and lateral gastrocnemius (LG) of the dominant side of control group and the injured side of CAI group according to European Recommendations for Surface Electromyography (www.seniam.org). The muscles were chosen as they dominant the ankle movement. Five seconds maximum voluntary contraction (MVC) of the above muscles were measured according to the suggested movement in previous literature (Konrad, 2005).

Kinematic data, ground reaction force and EMG data were collected by automatically synchronized 8-camera motion capture system (BTS engineering, 200Hz, Italy), force plate (1000Hz) and BTS FreeEMG 300 (1000Hz). Athletes performed single-leg inward lateral jump (30cm wide, to mimic inversion landing), single-leg outward lateral jump (30cm wide, to mimic external landing), and single-leg landing (40cm height) on the force plate with hands on hips and barefoot in a random sequence. Each motion only includes one landing. Up to 2 practices are allowed. All participants are forefoot landing strike and required to keep balance after landing for at least 2 seconds. Movements that are not single leg landed or are unstable landed are invalid. For each motion, three valid tests of each athlete were analysed. The experiment was approved by the Ethics Committee of the Research Institute.
Kinematics data processing was performed in Visual 3D (cut off frequency 13.3Hz). EMG data were band-pass filtered at a bandwidth of 20–500 Hz and normalised to MVC EMG. Root Mean Square (RMS) was calculated. Vertical ground reaction force (vGRF) was normalized to body weight. Initial contact (IC) was identified as vGRF over 10N. RMS and ankle angle at IC, in the 200ms pre IC and 100ms post IC were analysed. Time to peak vGRF (the time from the IC on the ground to maximum vGRF) were analysed. Two-way ANOVA was used to determine the main effects and interaction of motion and groups on each variable. The independent variables were motion and groups. If the interaction exists, then a one-way ANOVA was used to compare whether there was a difference between the different landings and groups separately. Using the Shapiro-Wilk normality test to test data normality. Using Levine's equivalence test to test variance alignment. Results are presented as mean ± standard deviation; level of significance was set at $P<0.05$. Effect size using partial η^2. η^2 greater than 0.01, 0.06, and 0.14 means small, medium, and large respectively (Watabe et al., 2021).

RESULTS: All data conformed to normal distribution. The results of two-way ANOVA showed that no interaction between groups and motions for all indicators were found (Table 1) ($P>0.05$). All data pass Levine's equivalence test except for pre IC LG.
Regardless of the movement, the pre IC LG of CAI was smaller than that of control ($P<0.05$); the plantarflexion angle at IC ($P<0.01$), inversion/external rotation angle at IC ($P<0.05$), max plantarflexion angle pre IC ($P<0.01$), max inversion angle of pre and post IC ($P<0.05$), as well as time to peak vGRF ($P<0.01$) of CAI were larger than that of control (Table 2-3).

Table 1: Significant main effects and interact effects of Two-way ANOVA.

	Motion main effects				Groups main effects				Motion*groups interact effects			
	df	F	*P*	η^2	*df*	F	*P*	η^2	*df*	F	*P*	η^2
Pre IC LG EMG	2	0.4	0.683	0.02	1	10.9	0.002	0.22	2	0.1	0.899	0.01
Plantarflexion angle at IC	2	15.7	0.000	0.43	1	8.2	0.006	0.16	2	0.3	0.747	0.01
Inversion/external rotation angle at IC	2	0.6	0.570	0.03	1	5.5	0.023	0.12	2	0.0	0.984	0.00
Max plantarflexion angle pre IC	2	15.5	0.000	0.43	1	7.7	0.008	0.16	2	0.1	0.901	0.01
Max inversion angle pre IC	2	1.7	0.204	0.07	1	6.2	0.017	0.13	2	1.3	0.271	0.06
Max dorsiflexion angle post IC	2	11.0	0.000	0.34	1	1.1	0.299	0.03	2	1.9	0.162	0.08
Max inversion angle post IC	2	0.2	0.785	0.01	1	6.4	0.016	0.13	2	0.0	0.980	0.00
Time to peak vGRF(s)	2	6.0	0.005	0.22	1	5.9	0.019	0.12	2	1.8	0.184	0.08

Note. IC=initial contact. EMG=electromyography. TA=tibialis anterior, PA=peroneus longus, MG=medial gastrocnemius, LG=lateral gastrocnemius. *df*=degrees of freedom.

Table 2: Muscle activities (%MVC RMS) before and after initial contact (Mean±SD).

Muscle activities	CAI (n=8)			Control (n=8)		
	Single-leg landing (%MVC)	Inward lateral jump (%MVC)	Outward lateral jump (%MVC)	Single-leg landing (%MVC)	Inward lateral jump (%MVC)	Outward lateral jump (%MVC)
Pre IC TA	1.06±0.96	1.06±0.44	1.05±0.43	0.85±0.35	0.96±0.37	1.09±0.31
Pre IC PL	1.70±0.88	1.52±0.55	1.76±0.62	1.73±1.01	1.28±0.55	1.35±0.46
Pre IC MG	1.07±0.69	1.22±0.39	1.26±0.71	1.13±0.40	1.16±0.42	1.22±0.33
Pre IC LG	1.12±0.80[f]	0.96±0.39[f]	1.01±0.38[f]	2.34±1.76	1.83±1.31	2.12±1.17
Post IC TA	0.58±0.31	0.55±0.31	0.66±0.24	0.50±0.19	0.74±0.36	0.90±0.40
Post IC PL	1.22±0.41	1.42±0.63	1.25±0.28	1.06±0.54	1.09±0.61	1.08±0.50
Post IC MG	1.71±0.93	1.32±0.59	1.63±0.84	2.00±0.85	1.55±0.71	1.71±0.93
Post IC LG	0.87±0.37	0.85±0.43	1.03±0.46	1.56±1.67	1.21±0.75	1.50±1.10

Note. IC=initial contact. TA=tibialis anterior, PA=peroneus longus, MG=medial gastrocnemius, LG=lateral gastrocnemius. [f] denotes comparisons of the control group with the CAI group, *P*<0.01.

Table 3: Ankle angles before and after initial contact (Mean±SD).

Muscle activities	CAI (n=8)			Control (n=8)		
	Single-leg landing	Inward lateral jump	Outward lateral jump	Single-leg landing	Inward lateral jump	Outward lateral jump
Plantarflexion angle at IC (°)	44.6±4.0[abf]	32.0±7.1[f]	27.8±5.4[f]	38.9±16.8[ab]	21.1±11.1	20.3±7.8
Inversion/external rotation(-) angle at IC (°)	2.4±1.9[e]	4.2±2.3[e]	3.8±2.2[e]	-2.2±9.3	0.4±8.2	-0.3±7.2
Max plantarflexion angle pre IC (°)	39.5±6.4[abf]	21.7±9.4[f]	18.7±7.4[f]	30.3±19.4[ab]	11.1±9.5	11.6±10.1
Max inversion angle pre IC (°)	3.2±2.8[e]	6.3±2.5[e]	7.3±2.2[e]	3.0±3.1	3.2±3.3	3.1±5.6
Max dorsiflexion angle post IC (°)	5.4±5.3[a]	15.9±2.1[c]	5.2±3.7	5.7±5.3[a]	10.1±8.4[c]	5.8±4.3
Max inversion angle post IC (°)	5.8±2.2[e]	5.1±1.9[e]	6.0±2.6[e]	2.0±5.5	1.3±6.9	2.8±7.4
Time to peak vGRF (s)	0.052±0.015[abf]	0.076±0.020[f]	0.081±0.023[abf]	0.052±0.008	0.062±0.014	0.060±0.013

Note. IC=initial contact. Negative sign for external rotation. [a], [b], and [c] denote comparisons of single-leg landing with inward lateral jump, single-leg landing with outward lateral jump, and inward lateral jump with outward lateral jumps, respectively. [e] denotes comparisons of the control group with the CAI group, *P*<0.05. [f] denotes comparisons of the control group with the CAI group, *P*<0.01.

DISCUSSION: This study aims to clarify the muscle activation pattern and landing kinematics of CAI athletes compared with normal athletes during landing and lateral jump landing. In this study, all participants were suggested to land with a forefoot strike style for the error reduction. This style uses more platarflexors to attenuate the impact of the contact by a larger ankle range of movement. The CAI was observed with larger plantarflexion pre and at IC than controls, which supported the previous finding that the higher ankle plantarflexion at IC of CAI could be a protective mechanism for them to reduce injury risk (Lee, Song & Shin, 2018).

It is interesting to notice that although the plantarflexion angle at IC is larger in CAI, the muscle activity of LG was lower in CAI. Previous study observed that CAI had less MG, forcing the ankle joint to be in a more vulnerable position for possible reinjury (Han et al., 2022). In the pre landing, greater MG muscle activity during landing indicates a large eccentric action of plantarflexors and increased eccentric peak plantarflexion torque and corresponding joint

stiffness to prevent injury (Neptune et al., 1999). Both MG and LG are part of gastrocnemius. In this study, although no significant changes were found in MG, the lower LG pre-activation in CAI indicates the joint stiffness of CAI may be lower than the control group, which needs further study. Furthermore, as LG contributes to not only plantarflexion but also external rotation, the less pre-activation of LG in CAI seems to be related to the significant lager pre IC inversion angle in CAI than the control ($P<0.05$), both could increase reinjury risk.
The study disagrees with the previous study that CAI had a shorter time to peak vGRF than the control in single-leg drop landing (De Ridder et al (2015). The reason could be attribute to the large ankle plantarflexion lead by the forefoot strike style, as a larger ankle plantarflexion at landing was significantly related to longer time to peak vGRF (Lee, Song & Shin, 2018).
Post landing motion was to a large degree influenced by initial landing motion and it was suggested that post IC characteristics was of more importance than IC (Lysdal et al., 2022). In our study, CAI was observed with a larger post IC inversion angle than the control in all motions. The 100ms post landing was used to investigate feedback, as laboratory injury cases identified the first peak ankle inversion angle occurred within 100ms after foot strike (Lysdal et al., 2022). Previous study suggested that the increased plantarflexion at post landing could improve the ability of ankle to absorb and attenuate impact of IC (Lee, Song & Shin, 2018). However, Lysdal et. al asserted that internal rotation plays a greater role in lateral ankle sprain injury than plantarflexion and was regarded as injury mechanism (Lysdal et al., 2022). Our study supports the protective effect of internal rotation. Further study could investigate the relationship between plantar flexion and internal rotation in CAI to assist rehabilitation program design and prevent reinjury. The limitation of this study is that the results were obtained mainly from female athletes. Therefore, the results of this study may not be applicable to most male CAI individuals.

CONCLUSION: CAI athletes was observed with different feedforward and feedback strategies compared with the control. CAI had large inversion ankle angle pre, at and post IC, and a large plantarflexion angle and small LG activation before landing. The large inversion ankle angle post IC could be a risk factor for reinjury. Injury prevention programs of CAI should pay attention to the activation of LG muscle in the landing.

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