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# Unilateral jump landing neuromechanics of individuals with chronic ankle instability

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## ABSTRACT

Objective: To assess the neuromechanical (kinematic, kinetic and electromyographic (EMG)) differences between individuals with and without chronic ankle instability (CAI) during unilateral jump landing.

Design: Case-control study

Methods: Kinematic, kinetic and EMG data of 32 participants with CAI and 31 control participants were collected during unilateral side jump landing (SIDE) and unilateral drop landing on three surfaces (even (DROP), unstable (FOAM) and laterally inclined (WEDGE)). Each participant had to complete five trials of each task in a randomised sequence. To compare the neuromechanical differences between groups, a one-dimensional statistical non-parametric mapping analysis was performed.

Results: Compared to the control group, the CAI group exhibited increased biceps femoris muscle activity during the preactivation and landing phases, decreased gluteus medius and peroneus longus muscles activity during the preactivation phase and increased knee extension moment during the landing phase of the WEDGE task. The CAI group also exhibited increased ankle dorsiflexion during the landing phase of the FOAM task and decreased vastus lateralis muscle activity during the preactivation phase of the DROP task. Finally, the CAI group exhibited decreased biceps femoris muscle activity during the preactivation and landing phases and decreased gluteus medius muscle activity during the preactivation phase of the SIDE task compared to the control group.

Conclusions: Individuals with CAI present neuromechanical differences during unilateral jump landing compared to healthy individuals. The results of this study will improve our understanding of underlying deficits associated with CAI and will help researchers and clinicians to better target them during rehabilitation.

**Keywords**: Electromyography; kinematics; kinetics; locomotion; neuromechanics

**Practical implications**

- Individuals with CAI exhibit task-related neuromechanical deficits during unilateral jump landing.
- The decreased peroneus longus muscle activity during the WEDGE could make the individuals with CAI more at risk of sustaining a lateral ankle sprain.
- Individuals with CAI exhibit neuromechanical deficits at the ankle and knee joints during unilateral jump landing.

## 1. Introduction

Lateral ankle sprain (LAS) is a common injury that occurs during sports with jump landing, cutting and running such as volleyball, basketball, football and soccer, representing more than 15% of all injuries [1]. Up to 42% of the individuals sustaining a LAS will report a recurrent episode in the 48-month period following the first injury [2]. Of all the individuals that sustain a LAS, up to 74% will report feeling of functional impairments and these individuals are likely to develop chronic ankle instability (CAI) [2]. Most individuals with CAI will develop functional limitations such as deficits in proprioception [3], postural control [3] and neuromuscular recruitment [4] that will predispose them to sustain a recurrent LAS [5], develop long-term joint degenerative sequelae such as post-traumatic ankle osteoarthritis [6] and decrease their physical activity level [7] and health-related quality of life [8]. These deficits may contribute to alter the neuromechanics of specific sport-related maneuvers such as unilateral jump landing [9] during which individuals with CAI exhibit greater ankle dorsiflexion [10] and inversion [11], greater knee flexion [10], lower peroneus longus muscle preactivation [11] and greater peak vertical ground reaction forces [12]. The effects of having a CAI on ankle and knee joints moments during unilateral jump landing have yet to be determined.

Most studies exploring unilateral jump landing neuromechanics in individuals with CAI investigated landing on a level surface [9] even though they can laterally sprain their ankles on surfaces with a variety of hardness or inclination. During jump landing on a laterally inclined [13] or an unstable [14] surface, lower-limb neuromechanics is altered which may predispose individuals with CAI to sustain recurrent LAS. Investigating lower-limb neuromechanics during more challenging and clinically meaningful jump landing tasks is essential to improve clinicians' and researchers' understanding of the underlying landing adaptations in CAI. Increased knowledge about CAI underlying neuromechanics could help target deficits associated with CAI and ultimately inform the development of more specific and patient-oriented treatment rehabilitation programs.

The purpose of this study was to investigate the neuromechanical differences between individuals with and without CAI during unilateral jump landing on level, unstable and laterally inclined surfaces.

## 2. Methods

Thirty-two individuals with CAI and thirty-one healthy controls (matched according to age, sex and body mass index) were recruited among students and staff of the XXXX in XXXX, but also through the university's outpatient podiatry clinic and advertisement on social media. The sample size was determined a-priori from two previous studies that assessed jump landing kinematics and EMG on an inclined surface [15, 16] with G-Power software (Version 3.1, Kiel, Germany). It was determined that for ankle inversion, peroneus longus preactivation and knee flexion, a total of 38 to 58 participants was necessary to obtain alpha, beta and Cohen's d effect size of respectively 0.05, 0.2 and 0.75 to 0.94. A sample size of 63 participants was chosen to still have adequate power in case of technical difficulties and due to the statistical analyses differences with the current study. All participants of the CAI group met the following criteria, based on the International Ankle Consortium statement [17]: (1) A history of one or more LAS that occurred more than 12 months prior to the study onset, (2) a history of ankle giving way and/or having recurrent LAS and/or perceive the ankle as unstable, (3) a score of respectively <90% and <80% for the Foot and Ankle Ability Measure (FAAM) Activity of daily living (ADL) and Sport (S) subscales. Participants of the control group never sustained LAS. Exclusion criteria for both groups were: (1) a history of a previous surgery to the lower extremity musculoskeletal structures, (2) a history of a fracture that required surgical realignment, (3) a lower extremity musculoskeletal injury in the 3-month period prior to the experimentations, (4) a history of any known condition that could affect walking and jump landing neuromechanics. All participants were age 18 to 45. Group demographics are shown in supplementary materials.

Kinematic data were collected at a sampling frequency of 100 Hz with an active three-dimensional motion analysis system (Optotrak Certus, Northern Digital, Waterloo, Ontario, Canada). Four 3-marker rigid plates were placed on the sacrum, the distal one third of the thigh, the distal one third of the leg and on the posterior aspect of the calcaneum with a heel plate and a wand [18]. A rectangular hole of approximately 30mm x 30mm was cut in the shoe heel counter (Athletic Works, Model: Rupert) over a standardised location to allow the insertion of the wand into the heel plate. During a static trial, a digitising probe was used to create virtual markers on the bilateral anterior superior iliac spines, bilateral posterior superior iliac spines, greater trochanter, lateral and medial femoral epicondyles, fibular head, tibial tuberosity, medial and lateral malleoli, proximal posterior surface of calcaneus, distal attachment of the Achilles' tendon, sustentaculum tali and fibular tubercle. A force plate (Bertec Corp, OH, USA) embedded in the floor was used to measure ground reaction forces at a sampling rate of 2000 Hz. A 3.8cm x 3.8cm footswitch (Trigno 4-Channel FSR Adapter, Boston, USA) was also positioned in the shoe, under the tested limb's heel for event detection. EMG data were collected at a sampling rate of 2000 Hz using a wireless surface EMG system (Delsys Trigno, Boston, USA). The gluteus medius, vastus lateralis, vastus medialis, biceps femoris, gastrocnemius lateralis, gastrocnemius medialis, peroneus longus and tibialis anterior muscle activities were recorded using the electrodes placement suggested in the SENIAM's recommendations [19]. The electrodes were made of 99% silver contact material and had a four-bar formation and a dimension of 27mm x 37mm x 15mm. The inter-electrode distance was 10mm, the common noise removal ratio of the amplifier was >80dB and a 16 bits A/D converter was used. The gain was 1000 and the maximum intraelectrode impedance was 6 kOhm.

All participants filled the International Physical Activity Questionnaire (IPAQ) and Foot and Ankle Ability Measure (FAAM) Sport (S) and Activity of Daily Living (ADL) subscales. They also reported the number of sustained LAS, the time since the last LAS and the frequency of ankle giving way. The Foot Posture Index (FPI) [20] was used to assess the participants' foot morphology. All participants gave their written informed consent according to the protocol ethics certification approved by the university ethics committee (CER-18-244-07.04). Descriptive data were collected for all participants (see supplementary materials). In case of bilateral CAI, the leg with the less stable ankle, subjectively decided by the participants, was used to complete the experimental protocol. First, a static trial was recorded for all participants. Then four tasks were completed in a random order across participants: Unilateral maximal side jump landing (SIDE), unilateral drop landing (DROP), unilateral drop landing on an unstable surface (FOAM) and unilateral drop landing on a 25-degree laterally inclined surface (WEDGE). During the SIDE task, the participants were asked to stand on the tested leg, to push off and jump laterally to reach the maximal distance and land with the same leg on a force plate. For the FOAM, WEDGE and DROP tasks, the participants had to stand on a 46 cm high platform. Then they had to propel themselves with the contralateral leg and land with the tested leg. Although most studies used a lower platform of 30 to 40 cm [10-13, 21, 22], it was chosen for this study to increase the tasks' difficulty by using a higher platform. For the DROP task, participants landed directly on the centre of a force plate. For the FOAM task, they landed on a 10 cm foam pad on top of a force plate. For the WEDGE task, they landed on a 25 degrees laterally inclined wood surface placed over the force plate. For all tasks, the participants were asked to always face forward, put their hands on their waist and stay in balance on the landing surface for two seconds. Trials were rejected and immediately retaken if the foot moved after the landing and if the participants lost balance or used hands to restore balance. Participants had to complete five trials of each task for a total of 20 trials.

All data were imported and processed using Visual 3D software (C-motion, Inc., Germantown, MD, USA). Kinematic markers trajectories were filtered at 6 Hz and force plate data at 50 Hz with a zero-lag, fourth-order, low-pass Butterworth filter. Local coordinate systems for the ankle, knee and hip were defined. Ankle and knee joints angles were computed with an X-Y-Z order of rotations. Rotation around the X-axis was defined as extension (+) and flexion (-), rotation around the Y-axis as adduction (+) and abduction (-) and around the Z-axis as internal rotation (+) and external rotation (-). Ankle and knee joints internal moments were computed using inverse dynamics, resolved in the proximal segment coordinate system and normalised to body mass. EMG data were filtered with a zero-lag 20-450 Hz bandpass, fourth-order Butterworth filter and were smoothed using a root mean square (RMS) algorithm with a 100 ms moving window. Each muscle was normalised to the average peak RMS activity during the five trials of each task and all EMG activations are reported as percentage of this reference value. Joint angles and moments were normalised to 0 to 100% of the landing phase (from the initial contact to the maximal knee flexion). EMG data were quantified during the landing and the preactivation (from heel off to initial contact) phases and were normalised to 0 to 100% of each phase. Initial contact was determined with the force plate using a 10N threshold [18] and the heel lift was determined with the footswitch under the heel.

Between-group comparisons of the baseline characteristics that were normally distributed according the Shapiro-Wilk test were performed with an independent t-test. Mann-Whitney U tests were used for the data that were not normally distributed. The level of significance was set at $p < 0.05$. To compare EMG, kinematic and kinetic differences between groups, the one-dimensional non-parametric permutation method (SnPM) was used to compare each individual point of the curves of each task with a threshold of $\alpha = 5\%$ [23, 24]. When statistically significant differences between groups were observed, Cohen's d effect sizes were calculated. Effects sizes were considered weak ($d < 0.40$), moderate ($0.40 \leq d < 0.80$) and large ($d \geq 0.80$) [25]. All SnPM analyses were conducted using the open-access SPM1D code (www.spm1d.org) with Python software (Version 2.7).

## 3.Results

There was no statistically significant difference in age, weight, height, FPI and IPAQ scores between groups. The CAI group scored lower on the FAAM-ADL and FAAM-S ($p<0.01$) (see supplementary material).

For the SIDE task, the CAI group exhibited decreased biceps femoris muscle activity from respectively 73 to 100% ($p<0.01$) and 0 to 12% ($p=0.01$) of the preactivation (see Fig.1a) and landing phases (see Fig.1b) compared to the control group. Gluteus medius muscle activity was also decreased from 0 to 5% ($p=0.01$) of the preactivation phase for the CAI group (see Fig.3c.). No between-group difference was observed for all other muscles and joint angles and moments.

For the DROP task, the CAI group exhibited decreased vastus lateralis muscle activity from 80 to 88% ($p=0.01$) of the preactivation phase compared to the control group (see Fig.2a). No between-group difference was observed for all other muscles and joint angles and moments.

For the FOAM task, the CAI group exhibited increased ankle dorsiflexion from 73 to 88% ($p=0.02$) of the landing phase compared to the control group (see Fig.2b). No between-group difference was observed for all other muscles and joint angles and moments.

For the WEDGE task, the CAI group exhibited increased biceps femoris muscle activity from 39 to 40% ($p=0.02$) of the preactivation phase (see Fig.3a) and from 33 to 56% ($p=0.02$) of the landing phase (see Fig.3b) compared to the control group. The CAI group also exhibited decreased muscle activity of the gluteus medius from 87 to 100% ($p<0.01$) of the preactivation phase (see Fig.3c) and peroneus longus from 92 to 94% ($p=0.02$) and 96 to 97% ($p=0.02$) of the preactivation phase (see Fig.3d). Finally, knee extension moment was increased at 22% ($p=0.03$) of the landing phase for the CAI group compared to the control group (see Fig.3e). No between-group difference was observed for all other muscles and ankle angles and moments.

## 4. Discussion

It was hypothesised in a recent systematic review that increased ankle dorsiflexion for individuals with CAI during jump landing could represent centrally mediated alterations of the motor program that could manifest from the unstable ankle, to place the talo-crural joint in a tightly packed position to protect the lateral ankle ligaments from excessive inversion [9]. The results of this study are consistent with this hypothesis. The FOAM task was the only task during which the CAI group exhibited an increased ankle dorsiflexion during the landing phase. However, during the DROP, SIDE and WEDGE tasks, the SPM(t) curves almost reached the critical threshold of significance and maximum Cohen's d reached respectively 0.63, 0.61 and 0.53, indicating moderate effect sizes (see supplementary materials). The lack of significant between-group differences for ankle sagittal angles during the DROP, SIDE and WEDGE tasks could perhaps be due to insufficient statistical power. However, contrary to hypothesis raised by Simpson et al. [9], the altered ankle sagittal motion did not directly influence knee joint movements when landing from a jump in the current study. They suggested that for individuals with CAI, greater reliance is transferred to the knee joint to attenuate rapid loads when landing from a jump to further protect the unstable ankle from unexpected joint perturbations. Caufield and Garrett [10] indeed showed an increased knee flexion during unilateral drop landing for individuals with CAI compared to healthy controls. In the current study, no significant between-group differences were observed for knee angles during the drop landing tasks. The type of analyses performed could perhaps explain the absence of significant between-group knee kinematic difference, as using one-dimensional analyses decreases the rate of false positive (erroneously yielding statistical significance) [26]. The absence of significant between-group knee kinematic difference could also be explained by the height of the platform (46 cm). In previous studies assessing unilateral drop landing neuromechanics, the initial drop height ranged from 30 to 40 cm [10, 11, 13, 21, 22, 27]. Although, drop height alters landing kinematics [28], it is still unknown whether these changes are different for individuals with and without CAI. From a higher platform, they could exhibit a stiffer landing pattern to attenuate the high impulse loads, which could hide significant differences between individuals with and without CAI that are observed during drop landing from a lower height. However, the results of the current study during the WEDGE task show that the CAI group exhibit kinetic and EMG differences compared to the control group that could represent proximal joints neuromechanical compensation. Even though there were no between-group difference for knee kinematics, the increased knee extension moment during the landing phase and the increased biceps femoris muscle activity for the CAI group could represent an attempt for the individuals with CAI to attenuate the rapid impulse loads with the knee joint. Also, the decreased gluteus medius muscle activity shortly before the initial contact could represent proximal compensations at the hip joint.

During the WEDGE task, the CAI group also exhibited decreased peroneus longus muscle activity shortly before the initial foot contact which is consistent with previous studies that observed longer latency and decreased preactivation of this muscle [13, 15]. Even though the differences in peroneus longus muscle activity were observed for a short period of time (5% of the preactivation phase), we believe that this result is of clinical significance, especially as it was observed shortly before impact. The individuals with CAI also present a delayed peroneus longus reaction time and eversion strength deficits [29]. During unilateral jump landing on an inclined surface, the decreased peroneus muscle activity combined with the delayed reaction time and strength deficits could place the individuals with CAI more at risk of sustaining episodes of ankle giving way or recurrent ankle sprains, especially as the primary role of this muscle is to limit excessive ankle inversion during dynamic tasks. Fong et al. [30] observed increased ankle inversion of six degrees when sustaining a lateral ankle sprain during a dynamic task. The peroneus longus muscle activation is even more important during unilateral jump landing on a laterally inclined surface as individuals with CAI present increased ankle inversion of up to three degrees when they land on an inclined compared to an even surface [13]. Further studies are needed to determine how the individuals with CAI should change their landing neuromechanics to lower their risks of sustaining injuries.

Neuromechanical differences between the individuals with and without CAI varied according to the landing task performed, especially during the preactivation phase. This result could be explained by the fact that the participants knew the specific drop jump condition prior to impact, especially as landing on an expected changes the lower-limb neuromechanics compared to landing on an unexpected surface [13]. This could represent changes in the feedforward motor control strategies in an attempt to better cope with the task to perform.

The first limitation that should be taken into account for this study is that the hip movements were not assessed. Differences between the CAI and control groups could have been present but not be observed. The second limitation of this study is that, as the data collection session was lengthy, participants may have been influenced by fatigue, which is known to affect lower limb neuromechanics during jump landing [28]. To prevent fatigue, the participants were given rest periods as often as they needed and after each task.

## 5.Conclusion

The results of this study show that individuals with CAI present kinematic, kinetic and EMG differences compared to healthy individuals during unilateral jump landing and these differences are task dependent. These results will improve our understanding of the underlying deficits associated with CAI and will help researchers and clinicians to better target the deficits during rehabilitation.

## 6.Acknowledgements

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## 8.Figure legends:

Fig.1. Neuromechanical differences during SIDE

Fig.2. Neuromechanical differences during DROP and FOAM

Fig.3. Neuromechanical differences during WEDGE

**Figure captions :**

Fig.1. Muscle activity of the (a) biceps femoris during the preactivation phase, (b) biceps femoris during the landing phase and (c) gluteus medius during the preactivation phase. Means of the control (blue) and CAI (black) groups are respectively represented by dotted lines and standard deviations are observed between the full lines. Significant between-group differences are observed in the shadowed region.

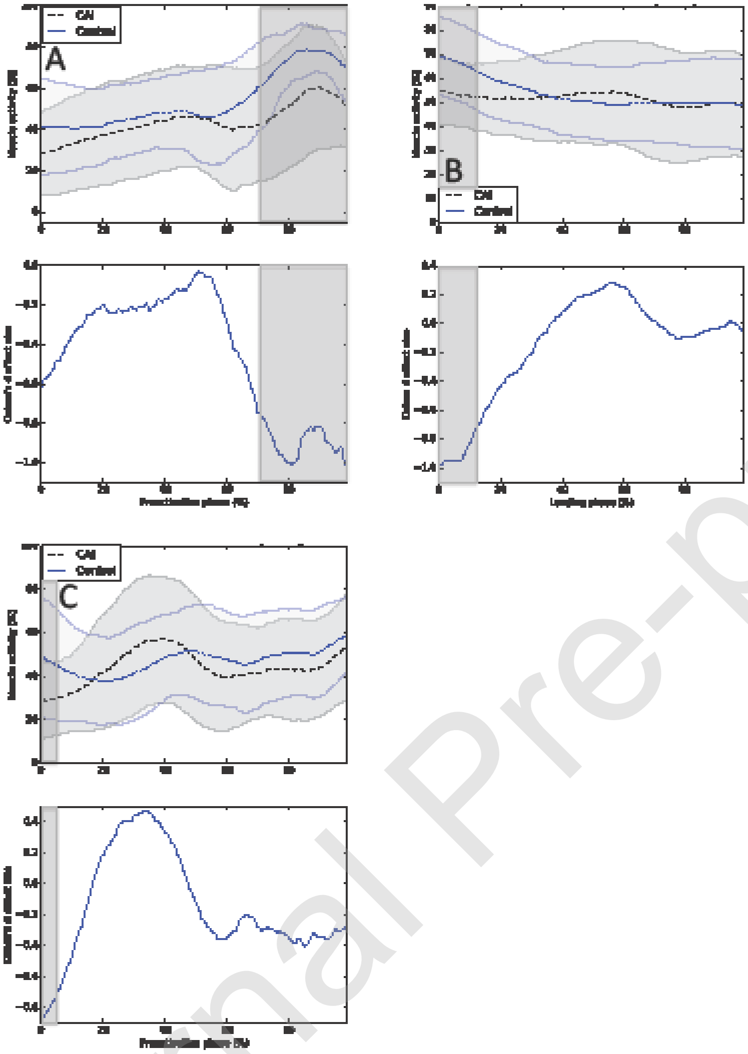


Fig.2. (a) Vastus lateralis muscle activity during the preactivation phase of DROP and (b) Ankle sagittal angle during the landing phase of FOAM. Means of the control (blue) and CAI (black) groups are

respectively represented by dotted lines and standard deviations are observed between the full lines. Significant between-group differences are found in the shadowed region.

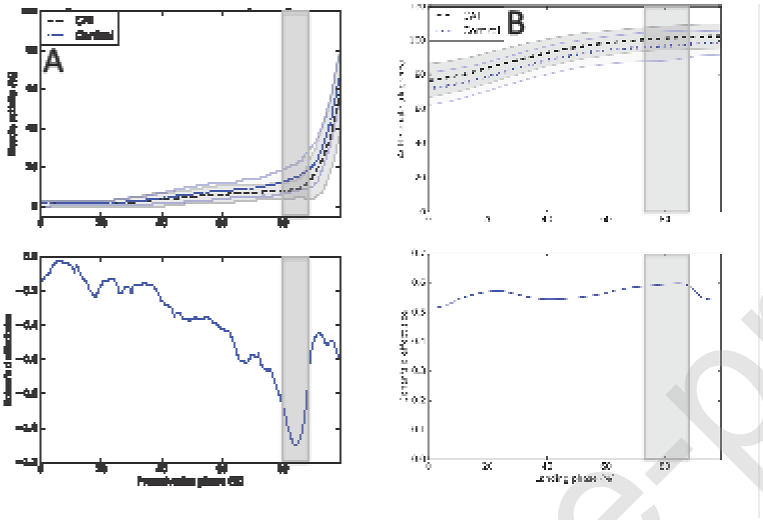
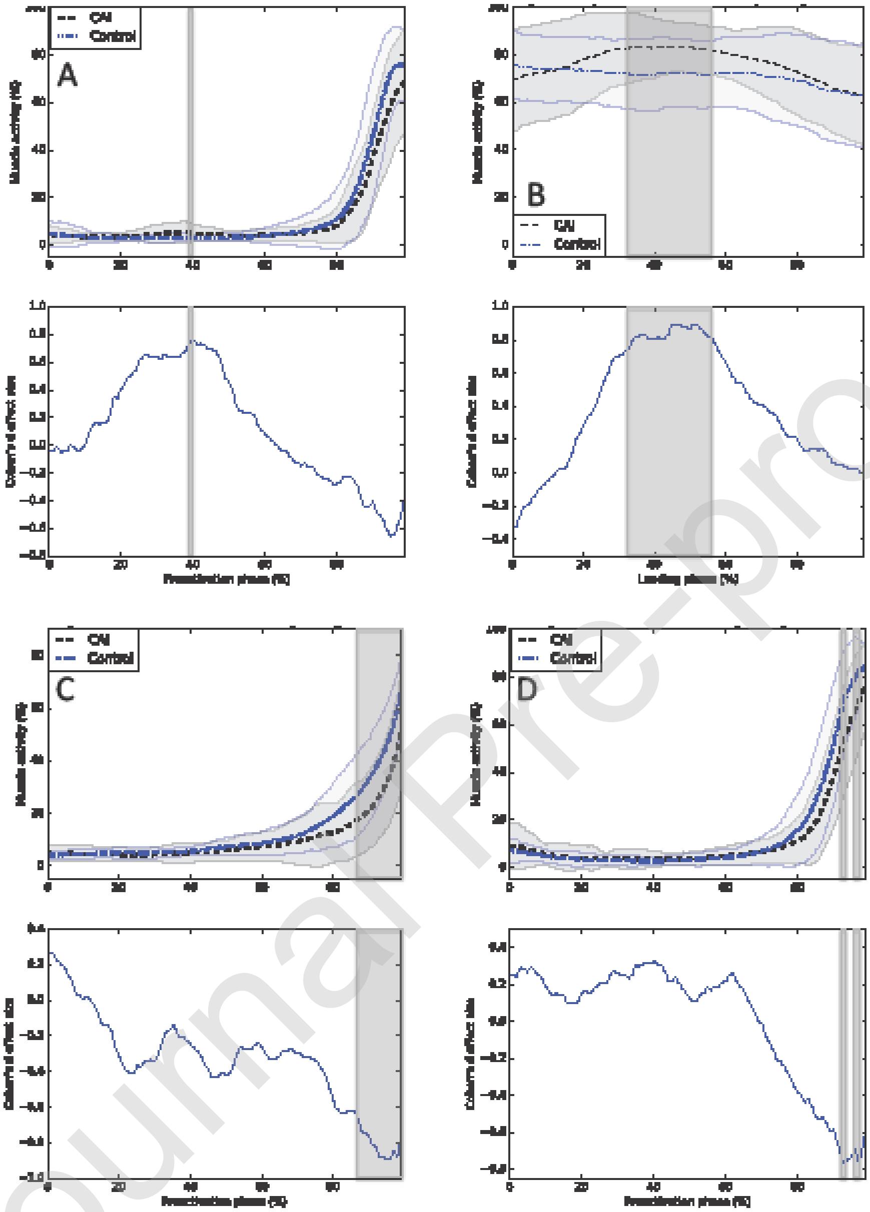


Fig.3. Muscle activity of the (a) biceps femoris muscle the preactivation phase, (b) biceps femoris during the landing phase, (c) gluteus medius during the preactivation phase and (d) peroneus longus during the preactivation phase and (e) knee extension moment during the landing phase. Means of the control (blue) and CAI (black) groups are respectively represented by dotted lines and standard deviations are observed between the full lines. Significant between-group differences are observed in the shadowed region.


A
B
C
D
CAI
Control
Muscle activity (%)
Cohen's d effect size
Preactivation phase (%)
Landing phase (%)
0
20
40
60
80
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6