Title	Lower extremity coordination and symmetry patterns during a drop vertical jump task following acute ankle sprain
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Publication date	2014-12
Publication information	Human Movement Science, 38 : 34-46
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/8438
Publisher's statement	This is the author's version of a work that was accepted for publication in Human Movement Science. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in Human Movement Science (VOL 38, ISSUE 2014, (2014)) DOI: 10.1016/j.humov.2014.08.002.
Publisher's version (DOI)	http://dx.doi.org/10.1016/j.humov.2014.08.002

Title: Acute ankle sprain alters lower extremity coordination and symmetry patterns during a drop vertical jump task.

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Abstract

Purpose: Evaluate the movement patterns associated with acute lateral ankle sprain (LAS) injury using biomechanical analyses.

Methods: Thirty participants with acute LAS and nineteen control participants performed a drop vertical jump (DVJ) task. 3D kinematics and sagittal plane kinetic profiles were plotted for the hip, knee and ankle joints of both limbs for the drop jump (phase 1) and drop landing (phase 2) phases of the DVJ. Inter-limb symmetry and the rate of force development (RFD) during both phases of the DVJ were also determined.

Results: The LAS group displayed reduced ankle plantarflexion on their injured limb during phase 2 of the DVJ, with greater associated inter-limb asymmetry for this movement compared to control participants ($p < 0.05$). The LAS group also displayed altered kinetic profiles, with increased inter-limb hip asymmetry, for both phases of the DVJ ($p < 0.05$). This was associated with a decrease in the LAS participants' injured limb RFD during phase 2 of the DVJ compared with that of controls (8517.52 ± 3012.41N/sec *vs* 10368.46 ± 2584.53N/sec; $p = 0.04$, $\eta^2 = 0.09$).

Conclusion: acute ankle sprain injury manifests in potentially aberrant coordination strategies as evidenced by an increased dependence on the non-injured limb.

Key terms: ankle joint [MEsH]; biomechanics [MEsH]; kinematics [MEsH]; kinetics [MEsH]; Task Performance and Analysis [MEsH].

1.0 Introduction.

The use of the inverse dynamics method to predict internal moments of force in the lower extremity from kinematic and force-plate data is widespread in experimental biomechanics (Pandy & Andriacchi, 2010). A variety of screening tests have been developed using lower extremity link-segment modelling and inverse dynamics to determine the movement patterns that develop as a consequence of injury, as well as those which may precede injury. The drop vertical jump (DVJ) is one such test that has been previously employed to quantify anomalous movement patterns predictive (Paterno et al., 2010) and consequent (Delahunt et al., 2012) of lower limb musculoskeletal injury. The DVJ requires a participant to drop off a stationary platform, land on both feet, and immediately execute a maximal vertical jump. The DVJ can be broken into two landing phases: the first phase follows the drop off the raised platform and precedes the maximal vertical jump (drop jump); the second phase follows the maximal vertical jump and completes the task (drop landing) (NA. Bates, KR. Ford, GD. Myer, & TE. Hewett, 2013). The first and second phases of the DVJ elicit dichotomous neuromechanical responses (Ambegaonkar, Shultz, & Perrin, 2011; NA. Bates, KR. Ford, GD. Myer, & TE. Hewett, 2013; NA. Bates et al., 2013).

The DVJ recreates the limb-synchronous rebounding mechanics and associated injury mechanisms typical of sports such as volleyball and basketball (KR. Ford, Myer, Schmitt, Uhl, & Hewett, 2011). Ankle sprain injury is a significant injury risk for participants of these sports (Doherty et al., 2014), secondary to the rapid impulse loads imparted bilaterally on each lower extremity during landing manoeuvres. A network of static and dynamic restraints control these impulse loads; the static stabilisers of the ankle joint (the lateral ligamentous complex) ensure joint integrity with limited laxity (otherwise known as “static joint stability”), while preparatory and reactive neuromuscular commands organise the motor apparatus in such a way as to limit the rate of force development (RFD) in its component parts (Wikstrom, Tillman, Chmielewski, & Borsa, 2006). These mechanisms combine as “dynamic joint stability”, defined as the ability to maintain normal movement patterns while performing high-level activities without ‘unwanted’ episodes of giving way (Lewek, Chmielewski, Risberg, & Snyder-Mackler, 2003). Disequilibrium between adequate dynamic joint stability and maximal movement efficiency in advanced skill (KR. Ford, van den Bogert, Myer, Shapiro, & Hewett, 2008) is at the heart of a performance conflict which may manifest in acute injury.

Acute injury can alter the sensorimotor system-controlled, dynamic restraining mechanisms of the lower extremity in skilled movement (Wikstrom et al., 2006); dynamic restraining mechanisms are then centred around minimising specific joint loading (Fleischmann, Gehring, Mornieux, & Gollhofer, 2011), thus protecting against further injury. However, in limb-synchronous movement tasks, such as the DVJ, these injury induced mechanisms may distort the inter-limb symmetry necessary for the absorption of the forces associated with explosive rebounding-based skills, therefore potentially placing the contralateral limb at increased risk of trauma (Fousekis, Tsepis, & Vagenas, 2012).

The purpose of the current investigation was to evaluate the adaptive, lower-extremity dynamic restraining movement preferences of the sensorimotor system in response to acute lateral ankle sprain (LAS) injury using a 3-dimensional link segment model and the inverse dynamics method. We compared a group with acute LAS to a non-injured control group during the performance of the first and second phases of a DVJ task. Multiple hypotheses were proposed for both the kinematic and kinetic data produced from this dataset: (i) acute LAS would result in significant between group differences for temporal kinematic and kinetic variables; (ii) these kinematic and kinetic variables would be contingent with offloading the injured limb of LAS participants, manifesting in excessive inter-limb asymmetries and potentially placing the non-injured limb at increased risk of injury; (iii) these motor control patterns would be expressed in the RFD during the DVJ task.

2.0 Methods

2.1 Participants

Thirty injured participants (twenty-two males and eight females; age 23.2 ± 5.3 years; body mass 74.1 ± 14.3 kg; height 1.75 ± 0.1 m) were recruited from a university-affiliated hospital emergency department within 2 weeks of sustaining a first-time acute LAS for inclusion in the current study. A group of nineteen control participants (fifteen males and four females; age 22.5 ± 1.7 years; body mass 71.55 ± 11.30 kg; height 1.74 ± 0.1 m) were recruited from the hospital catchment area using posters and flyers.

The following inclusion criteria were applied: 1) no previous history of ankle sprain injury (excluding the recent acute episode for the injured group); 2) no other lower extremity injury in the last 6 months; 3) no history of ankle fracture; 4) no previous history of major lower limb surgery; 5) no history of neurological disease, vestibular or visual disturbance or any other pathology that would impair their motor performance.

2.2 Protocol

Prior to testing, all participants completed the Cumberland Ankle Instability Tool (CAIT) and the activities of daily living and sports subscales of the Foot and Ankle Ability Measure

(FAAMadl and FAAMsport) to assess overall ankle joint function(Hiller, Refshauge, Bundy, Herbert, & Kilbreath, 2006) and patient reported functional ability(Carcia, Martin, & Drouin, 2008) respectively.

Participants wore athletic shorts and t-shirts and were instrumented with 22 infrared markers as part of the Codamotion (CODA) bilateral lower limb gait set-up (Charnwood Dynamics Ltd, Leicestershire, UK). Following the collection of the anthropometric measures required for the calculation of internal joint centres at the hip, knee and ankle joints, lower limb markers and wands were attached as described by Monaghan et al.(Monaghan, Delahunt, & Caulfield, 2006, 2007). For each subject an initial neutral stance trial was acquired to function as a reference position for kinematic analyses and to align the subject with the laboratory coordinate system as recommended in previously published literature(McLean et al., 2007).

The DVJ protocol began with each participant standing on top of a 40 cm platform and instructed to keep their feet positioned ‘shoulder width’ apart with their hands on their hips. Participants were then instructed to drop straight down from the raised platform without any vertical launch and land on both feet simultaneously (phase 1), and immediately execute a maximal vertical jump upon contact with the force plates (phase 2). No specific instructions were provided for the execution of either the first or the second landing. A trial was repeated if participants performed a vertical launch when dropping off the platform, if one or both of their feet did not land on separate force plates, if their hands came off their hips, or if they lost balance during the test(Hewett et al., 2005).

These testing procedures were approved by the institution’s ethical review board and informed written consent was obtained from each participant prior to involvement in study protocol.

2.3 Data processing and analysis

Kinematic data were acquired at 250 Hz using three Codamotion cx1units (Charnwood Dynamics Ltd, Leicestershire, UK) while the kinetic data was acquired at 1000 Hz using two fully integrated AMTI (Watertown, MA) walkway embedded force-plates for each limb during performance of the DVJ. The CODA mpx1 units were time synchronized with the force-plates. Ground reaction force data were passed through a fourth-order zero phase Butterworth low-pass digital filter with a 5-Hz cut-off frequency.

Kinematic and kinetic data for both limbs were analysed using the Codamotion software (x-axis = frontal-plane motion; y-axis = sagittal-plane motion; z-axis = transverse-plane motion) and then converted to Microsoft Excel file format. The number of output samples for temporal kinematic and kinetic data was set at 100 + 1 per DVJ phase in the data-export option of the Codamotion software, which represented 100% of the DVJ phase for averaging and further analysis.

Time-averaged profiles were calculated for the hip, knee and ankle joints for each participant, with a subsequent calculation of group mean profiles. All time-averaged profiles were plotted during the period from 200-ms pre-initial contact (IC) to 200-ms post-IC for the first and second phases of the DVJ for each limb. The temporal kinematic variables of interest were 3-dimensional hip, knee and ankle angular displacements. Angular displacement profiles were constructed by comparing the angular orientations of the coordinate systems of adjacent limb segments using the coupling set ‘‘Euler angles’’ to represent clinical rotations in three dimensions. The marker positions were processed within a Cartesian frame into rotation angles using vector algebra and trigonometry (Codamotion User Guide, Charnwood Dynamics Ltd. Leicestershire, UK).

The temporal kinetic variables of interest were sagittal plane hip, knee, ankle and net lower extremity supporting moments. The supporting moment, Ms, during landing was calculated as follows: Ms = Mk – Ma - Mh, where Mk, Ma and Mh are the sagittal plane moments at the knee, ankle and hip respectively(Winter, 1980). Positive Ms values are associated with extensor moments as they are believed to prevent collapse while negative values are associated with flexor moments as they are believed to facilitate collapse(Kepple, Siegle, & Stanhope, 1997). All moments were reported as external joint moments derived from the GRFs created during contact with the force platforms.

The discrete kinetic variable of interest was the RFD of the vertical GRF for each limb and was calculated as the peak vertical GRF divided by the time from IC to peak vertical GRF (Decker, Torry, Noonan, Riviere, & Sterett, 2002) separately for the first and second phases of the DVJ (N/sec).

Symmetry between temporal waveform data (angular displacement and moment profiles) was analysed using an eigenvector approach. The measure of trend symmetry (TS) was calculated to compare the time-normalised data for right and left limbs separately during phase 1 and phase 2 of the DVJ for the LAS and control groups as per previous research (Crenshaw & Richards, 2006). The output of the TS calculation is a percentage value, where 0% indicates perfect symmetry between the two waveforms. TS was performed using a sliding window approach, whereby data samples were analysed for symmetry sequentially in groups of 50 samples with a window overlap of 50%. This resulted in three separate TS windows to assess the preparatory (Santello, 2005; Stelmach, 1976) and reactive (Lees, 1977, 1981) activities of each landing event, in addition to IC; window 1 analysed from 200ms pre-IC to IC, window 2 analysed from 100ms pre-IC to 100ms post-IC and window 3 analysed from IC to 200ms post IC (figure 1).

A symmetry angle (SA) calculation (Zifchock, Davis, Higginson, & Royer, 2008) was utilised to evaluate the inter limb RFD symmetry for each individual subject over each phase of the DVJ, with a subsequent calculation of group means (LAS *vs* control). A SA value of 0% between matched data points indicates perfect symmetry, while 100% indicates that the two values are equal and opposite in magnitude (Zifchock et al., 2008).

2.4 Statistical analysis

The average of each subjects' three trials for all variables was utilized for further analysis (i.e. LAS *vs* control). For the LAS group, limbs were labelled as ''involved'' and ''uninvolved'' based on FAAM and CAIT results. For all outcomes, the mean and standard deviation (SD) scores for the involved and uninvolved limbs in the LAS group, and the left and right limbs in the control group were calculated. In all cases, the involved (injured) limb was compared to side-matched limbs in the control group, such that an equal proportion of right and left limbs were labelled as "involved" and "uninvolved" in each group.

Participant characteristics were compared between the LAS and control groups using multivariate analysis of variance. The dependent variables were age, mass, sex and height. The independent variable was group (LAS *vs* control).

In order to test the hypothesis that acute LAS would cause between-group kinematic and kinetic differences for each limb, during both the first and second phases of the DVJ, two separate analyses were performed: (i) A series of independent samples t-tests for each data point of the time-averaged group 3 dimensional angular displacement and sagittal plane supporting moment profiles. The significance level for these analyses was set a priori at $p < 0.05$. (ii) Independent samples t-tests for group (LAS *vs* control) RFD mean profiles for each phase of the DVJ for each limb. The significance level for this analysis was set a priori at $p < 0.05$.

In order to test the hypothesis that acute LAS would cause an increase in inter-limb asymmetries in the LAS group compared to the control group, a further two analyses were performed: (i) Independent samples t-tests for group (LAS *vs* control) TS windows for those temporal kinematic and kinetic data with significant between-group differences. The significance level for these analyses was set a priori at $p < 0.05$. (ii) Independent samples t-tests for group (LAS *vs* control) RFD SA profiles for each phase of the DVJ for each limb. The significance level for temporal analyses was set a priori at $p < 0.05$. Effect sizes were not calculated for temporal data analyses secondary to the number of separate comparisons for each kinematic and kinetic variable. All data were analyzed using Predictive Analytics Software (Version 18, SPSS Inc., Chicago, IL, USA).

3.0 Results

There was no statistically significant difference between the LAS group and the control subject group on the combined dependent variables of age, sex height and body mass: $F(4, 44) = 0.44$, $p = 0.78$; Wilk's Lambda = 0.96; partial eta squared = 0.04. Questionnaire results and participant characteristics are detailed in table 1.

3.1 Kinematic and kinetic analyses

(i) Time-averaged 3-dimensional kinematic profiles revealed that the LAS group displayed no difference in 3D angular displacement for the hip, knee or ankle for phase 1 of the DVJ compared to the control group. During phase 2 of the DVJ, LAS participants displayed reduced plantarflexion on their involved limb compared to control participants (figure 2). Time-averaged sagittal plane kinetic profiles revealed that the LAS group displayed statistically significant differences in hip, knee, ankle and net supporting moment profiles for the first and second phases of the DVJ compared to the control group. Between-group differences in temporal kinetic profiles for phase 1 and phase 2 of the DVJ are presented in figure 3.

(ii) There was no significant difference in RFD between LAS and control participants of the DVJ for phase 1: Involved limb; LAS: 8090.38 ± 3807.43N/sec *vs* control: 9616.79 ± 3592.99N/sec; $t(43) = -1.252$, $p = 0.217$, $\eta^2 = 0.04$, two tailed; Uninvolved limb; LAS: 10676.07 ± 4284.08N/sec *vs* control: 9562.72 ± 4770.89 ; $t(43) = 0.79$, $p = 0.45$, $\eta^2 = 0.01$, two tailed; however, during phase 2, LAS participants exhibited a significant reduction in RFD on their involved limb only: Involved limb; LAS: 8517.52 ± 3012.41N/sec *vs* control: 10368.46 ± 2584.53N/sec; $t(43) = -2.032$, $p = 0.04$, $\eta^2 = 0.09$, two tailed; uninvolved limb; LAS: 9822.88 ± 3358.97N/sec *vs* control: 10732.31 ± 3055.62N/sec; $t(43) = -0.881$, $p = 0.38$, $\eta^2 = 0.02$, two tailed.

3.2 Symmetry analyses

(i) TS analyses of kinematic data revealed that the LAS group displayed significantly greater inter-limb asymmetry in the second window (from 100ms pre-IC to 100ms post-IC) compared to the control group for angular displacement of the ankle joint in the sagittal plane in phase 2 of the DVJ. TS analyses of kinetic data revealed that the LAS group displayed significantly greater inter-limb asymmetry in the third window (from IC to 200ms post-IC) compared to the control group for hip moment of force in phases 1 and 2 of the DVJ. TS values for all significantly different temporal kinematic and kinetic data between LAS and control groups are detailed in table 2.

(ii) There was a significant difference in inter-limb RFD symmetry between LAS and control groups. LAS participants displayed increased RFD asymmetry compared to control participants during the DVJ phase 1 (15.02 ± 13.09% vs 5.76 ± 4.16%; $t(38.63) = 3.53$, p =

0.001, two-tailed), and phase 2 (10.62 ± 8.64% vs 4.35 ± 3.49%; $t(41.78) = 3.45$, $p = 0.001$, two-tailed) of the DVJ.

The magnitude of the differences in the means was large for both phase 1 (mean difference = 9.25, 95% CI: 3.95 to 14.55, eta squared = 0.25) and for phase 2 (mean difference = 6.26, 95% CI: 2.60 to 9.93, eta squared = 0.23).

4.0 Discussion

Temporal kinematic and kinetic data for the current investigation were acquired in the time period from 200ms pre IC to 200ms post IC in the aim of capturing the important features of landing (Lees, 1981): the preparatory (pre-IC) action of the neuromuscular 'motor programme' which commences in the airborne phase of landing and endures IC (Santello, 2005; Stelmach, 1976), and the reactive (post-IC) 'impact absorption' phase of landing in which acceleration is controlled (Lees, 1977, 1981).

The kinetic profiles, specifically those examining the total motor pattern of the lower extremity (i.e. the support moment), are critical to understanding the energetics of the LAS participants' adapted neuromuscular command strategies (Winter, 1993) in response to the significant functional impairment (based on the FAAM and CAIT questionnaire results). During IC of phase 1, LAS participants displayed a small but significant reduction in the net flexor moment compared to control participants on their involved limb ($\simeq$ -0.17 vs $\simeq$ -0.36 Nm/kg) from 12 ms pre-IC to 8 ms post-IC. This pattern was repeated during impact absorption phase of landing (from 32 to 52 ms post-IC), where LAS participants again displayed a reduction in the net flexor pattern of the lower extremity compared to control participants on their involved limb ($\simeq$ -0.61 vs $\simeq$ -1.06 Nm/kg). These results indicate that acute LAS may have resulted in a smaller ratio of net supporting flexion to extension moments (caused by increased extension dominance compared to control participants) on the involved limb during the drop jump component of the DVJ. Impact absorption at landing for the drop jump component of the DVJ serves two functions: to decelerate the body in a controlled pattern so as to optimise joint loading and to reproduce as much of the potential energy associated with the land in the performance of a maximal vertical jump. While we didn't analyse measures of performance such as DVJ jump height or power, the reduced net flexor pattern of LAS participants in phase 1 of the DVJ could indicate a hesitancy to seek achieving maximal performance during the DVJ in the interest of injury protection.

The primary focus of impact absorption at landing for the drop land component of the DVJ is the controlled dissipation of landing forces in the completion of the prescribed movement (DeVita & Skelly, 1992). Reflection of the net extensor pattern for phase 2 of the DVJ may indicate decreased capacity of the LAS group to control dissipation in symmetry due to the higher extensor pattern on the uninvolved limb, potentially indicating a compensatory role of the uninvolved limb in unloading the involved limb.

This theory is supported by analysis of specific joint extensor patterns: kinetics at the knee joint revealed significant between-group differences on the involved limb always preceding those of the uninvolved limb, and a contrast in the magnitude of the extensor pattern on the involved limb and the uninvolved limb compared to controls. During phase 1 of the DVJ on the involved limb, the LAS group had a reduction in the knee extensor moment compared to controls ($\simeq$ 0.68 vs $\simeq$1.17 Nm/kg) from 64 to 92 ms post-IC. This was followed by a pattern of increased extensor moment on the uninvolved limb of LAS participants compared to controls ($\simeq$ 1.94 vs $\simeq$ -1.33 Nm/kg), from 188 to 200 ms post-IC. A similar trend was observed during phase 2 of the DVJ, where a reduction in involved limb knee extensor moment in LAS participants compared to control participants ($\simeq$ 0.70 vs $\simeq$ 1.70 Nm/kg) from 56 to 184 ms post-IC preceded an increase in uninvolved limb knee extensor moment compared to control participants ($\simeq$ 1.49 vs $\simeq$ 1.06 Nm/kg) from 164 to 196 ms post-IC. This pattern of re-weighting the motor apparatus from the involved to the uninvolved limb is also evident at the kinetic profile for the ankle joint, where during phase 1 of the DVJ, LAS participants exhibited a reduced extensor moment pattern from 4 ms pre-IC to 108ms post-IC compared to control participants on their involved limb (≃ 0.86 vs ≃ 1.30 Nm/kg) and an increased extensor moment pattern from 24 ms to 92 ms post-IC compared to control participants on their uninvolved limb (≃ 1.62 vs ≃ 1.20 Nm/kg). During phase 2 of the DVJ this pattern was not replicated, as LAS participants only displayed a reduced extensor moment on their involved limb compared to control participants from 36 to 40 ms post-IC (≃ 0.13 vs ≃ 0.33 Nm/kg); although LAS participants displayed a preparatory reduction in involved limb ankle plantarflexion (from 200 ms pre-IC to 40 ms post-IC), there was no between-groups difference in uninvolved limb extensor pattern at the ankle for phase 2 of the DVJ. The decrease in ankle plantarflexion positioning observed in the acutely injured group concurs with the movement patterns observed in the same task in groups of participants in the chronic phase of ankle sprain injury (Brown, Padua, Marshall, & Guskiewicz, 2008), and may serve to decrease the risk of re-sprain by increasing bony reliance in place of the static stabilisers of the ankle joint (Brown et al., 2008; Wright, Neptune, van den Bogert, & Nigg, 2000). That this observation was only present during phase 2 may be the result of better task sensitivity afforded by the greater impact absorption demands of the second phase of the DVJ compared to those of the first (NA. Bates et al., 2013). Alternatively, as technique instructions focused each participant on the body mechanics during the first landing and the goal of achieving a maximal vertical jump subsequently diverted this attention in the second landing (NA. Bates et al., 2013), it is possible that LAS participants naturally sought to offload their injured limb when concentrating on the mechanics of the second landing component only.

It is significant that the trend of altered motor control patterns presenting on the involved limb prior to the uninvolved limb for the knee and ankle persisted throughout all temporal experimental data for both phases of the DVJ. This may indicate that the joint forces experienced by the involved limb are dampened by sequentially increasing the joint forces on the uninvolved limb. This theory is also consistent with the discrete kinetic symmetry analyses, with LAS participants displaying 15% RFD asymmetry for phase 1 of the DVJ (compared to 6% in controls), and 11% RFD asymmetry for phase 2 of the DVJ (compared to 4% in controls). The source of this discrete asymmetry can easily be postulated on inspection of the RFD data, with LAS participants' involved limb displaying a reduction in the RFD relative to their uninvolved limb for both phases, which was significant with a moderate effect size on the involved limb during phase 2. Dissipation of the vertical GRF of landing over a longer time period with an appropriate neuromuscular command resulting in reduced RFD serves to reduce the exposure of the injured limb to excessive landing forces (DeVita & Skelly, 1992). The disadvantage of this asymmetry is that there is increased exposure on the uninvolved limb.

Asymmetry is also evident in the third window (from IC to 200 ms post-IC) of the hip moment of force profiles for both phase 1 and phase 2 of the DVJ. The hip joint plays a central role in unloading the injured joints of the lower extremity due to the mechanical advantage of its surrounding musculature (Alexander & Ker, 1990), and has previously been shown to have a primary role in the dissipation of impact forces (DeVita & Skelly, 1992; Dufek & Bates, 1990; Zhang, Bates, & Dufek, 2000). The observed asymmetry may have arisen secondary to a neuromuscular overload with a performance conflict between needing to specifically unload the acutely injured ankle joint, globally dissipate impact forces and maintain control between the lower extremity and the head, arms and trunk (Winter, 1993), thus becoming victim to the attempted mastery of the degrees of freedom coordination problem of the motor apparatus (Bernstein, 1967).This conflict is particularly evident in the involved limb angular displacement and increased trend asymmetry at the ankle joint for LAS participants, and in comparing LAS and control participants' hip kinetics during phase 2 of the DVJ; preparatory action of the involved limb precedes a more reactive strategy of the uninvolved limb and the inter-limb post-IC landing strategy is out of sync for LAS participants.

The clinical relevance of these findings is twofold: first, clinicians must be aware that acute ankle sprain injury has the capacity to cause bilateral impairment, and potentially increase the risk of injury to the non-injured limb secondary to the asymmetry created by its compensatory role in protecting the injured joint. Second, acute ankle sprain injury manifests in neuromuscular control strategies with similar features to those noted in populations in the chronic phase of injury. The persistence of these strategies may underlie the onset of chronicity and therefore patients must only be allowed to return to activity having completed rehabilitation exercises to self-reported pre-injury levels.

Acknowledgements

This study was supported by the Health Research Board (HRA_POR/2011/46). There were no conflicts of interest to report.

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Figure legends

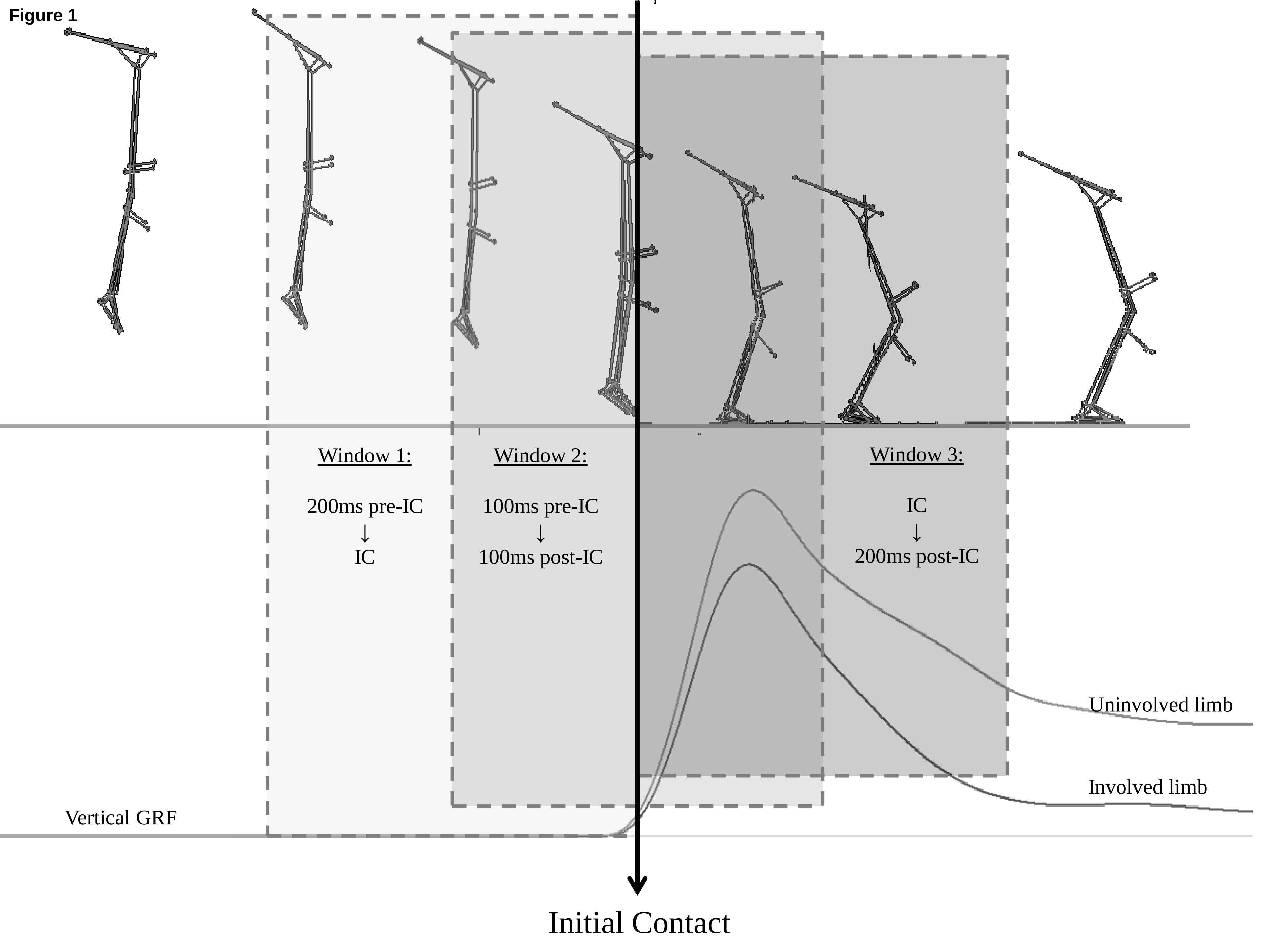
Figure 1. Illustrative depiction of a link segment model completing window 1 (200ms pre-IC to IC), window 2 (100ms pre-IC to 100ms post-IC) and window 3 (IC to 200ms post-IC) of phase 1 and phase 2 of the DVJ used for the calculation of lower extremity inter-limb trend symmetry. Abbreviations: IC = initial contact; DVJ = drop vertical jump; GRF = ground reaction force.

Figure 2. Ankle joint plantarflexion-dorsiflexion angle during performance of phase 2 of the DVJ task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of the LAS and control groups. Dorsiflexion is positive; plantarflexion is negative. Black line with arrow = initial contact. Dashed lines = LAS group; continuous lines = control group; black lines = involved limb; grey lines = uninvolved limb. Bold abscissa axis indicates area of statistically significant greater trend asymmetry for the LAS group. Shaded area enclosed by black line = statistically significant between groups difference for the involved limb. Abbreviations: IC = initial contact; DVJ = drop vertical jump; LAS = lateral ankle sprain.

Figure 3. Sagittal plane joint moment-of-force profiles for the hip, knee and ankle during performance of phase 1 and phase 2 of the DVJ task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of the LAS and control groups. Extension moments are positive; flexion moments are negative. Black line with arrow = initial contact. Dashed lines = LAS group; continuous lines = control group; black lines = involved limb; grey lines = uninvolved limb. Bold abscissa axis indicates area of statistically significant greater trend asymmetry for the LAS group. Shaded area enclosed by black line = area of statistically significant between groups difference for the involved limb. Shaded area enclosed by grey line = area of statistically significant between groups difference for the uninvolved limb.

Abbreviations: Mh = Hip moment; Mk = Knee Moment; Ma = Ankle moment; Ms = Support moment (Mk-Mh-Ma); IC = initial contact; DVJ = drop vertical jump; LAS = lateral ankle sprain.

Figure 1



Window 1:
200ms pre-IC
↓
IC
Window 2:
100ms pre-IC
↓
100ms post-IC
Window 3:
IC
↓
200ms post-IC
Uninvolved limb
Involved limb
Vertical GRF
Initial Contact

Figure 2

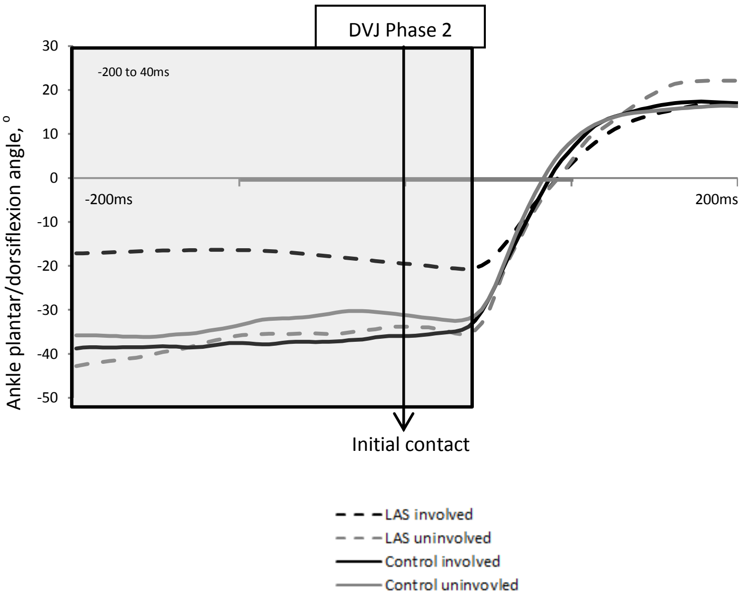
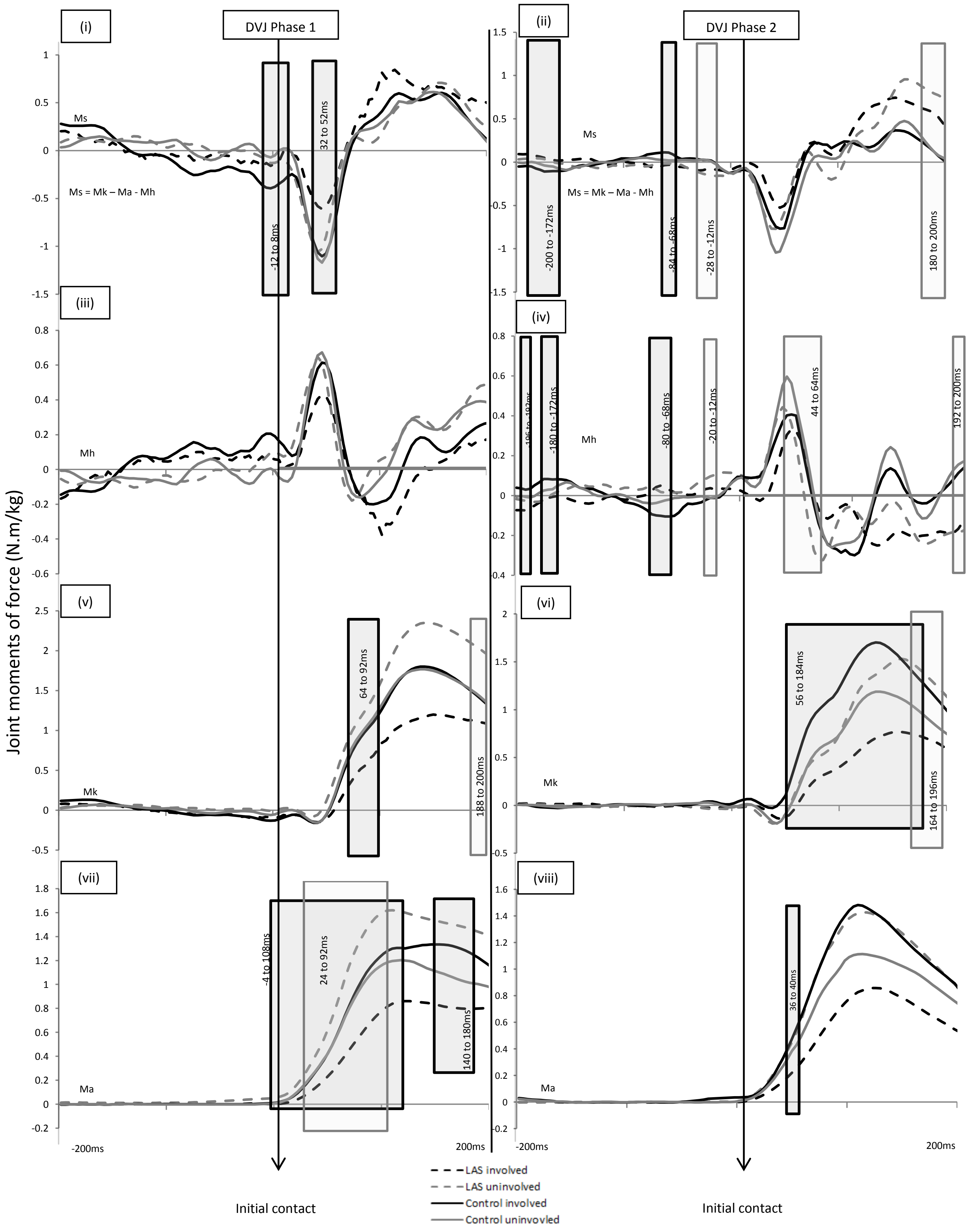

DVJ Phase 2
-200 to 40ms
Ankle plantar/dorsiflexion angle, °
30
20
10
0
-10
-20
-30
-40
-50
-200ms
200ms
Initial contact
LAS involved
LAS uninvolved
Control involved
Control uninvovled

Figure 3



(i)
DVJ Phase 1
Ms
Ms = Mk – Ma - Mh
-12 to 8ms
32 to 52ms
(ii)
DVJ Phase 2
Ms
Ms = Mk – Ma - Mh
-200 to -172ms
-84 to -68ms
-28 to -12ms
180 to 200ms
(iii)
Mh
(iv)
Mh
-196 to -192ms
-180 to -172ms
-80 to -68ms
-20 to -12ms
44 to 64ms
192 to 200ms
Joint moments of force (N.m/kg)
(v)
Mk
64 to 92ms
188 to 200ms
(vi)
Mk
56 to 184ms
164 to 196ms
(vii)
Ma
-4 to 108ms
24 to 92ms
140 to 180ms
(viii)
Ma
36 to 40ms
-200ms
200ms
Initial contact
LAS involved
LAS uninvolved
Control involved
Control uninvovled

Table 1

Table 1. Participant characteristics and questionnaire scores (mean ± SD with 95% CIs) for the LAS and control groups. LAS = ankle sprain

	Age (years)	Mass (kg)	Height (m)	CAIT	FAAMadl	FAAMsport
LAS	23.2 ± 5.26; [95% CI: 22.34 to 25.16]	74.12 ± 14.29; [95% CI: 68.78 to 79.45]	1.75 ± 0.10; [95% CI: 1.71 to 1.78]	15.00 ± 6.62; [95% CI: 12.43 to 17.57]	70.26 ± 27.44%; [95% CI: 59.41 to 81.12]	60.13 ± 35.70%; [95% CI: 46.01 to 74.25]
Control	22.53 ± 1.68; [95% CI: 21.72 to 23.34]	71.55 ± 11.31; [95% CI: 66.01 to 77.01]	1.75 ± 0.08; [95% CI: 1.71 to 1.78]	30 ± 0; [95% CI: 30 to 30]	100 ± 0%; [95% CI: 100 to 100]	100 ± 0%; [95% CI: 100 to 100]

Table 2

Table 2. Trend symmetry data between involved and uninvolved limbs for LAS and control participants during phases 1 and 2 of the drop vertical jump task. Window 1 = 200ms pre-IC to IC; Window 2 = 100ms pre-IC to 100ms post-IC; Window 3 = IC to 200ms post-IC.

Variable		Trend symmetry (%)						P value		
		LAS			Control			LAS vs Control		
Sagittal plane	DVJ phase	Window 1	Window 2	Window 3	Window 1	Window 2	Window 3	Window 1	Window 2	Window 3
Net support moment of force	1	14.62	31.72	26.22	16.13	20.15	13.04	0.78	0.18	0.15
Hip moment of force	1	20.16	29.28	27.60	18.80	23.43	14.65	0.77	0.46	0.04[a]
Knee moment of force	1	10.95	10.15	2.84	5.21	3.15	1.88	0.09	0.07	0.60
Ankle moment of force	1	18.27	1.59	5.04	21.25	0.20	3.49	0.68	0.25	0.70
Ankle angular displacement	2	12.66	8.75	1.24	13.11	1.11	1.49	0.93	0.00[a]	0.72
Net support moment of force	2	22.59	41.68	25.54	11.11	22.22	10.59	0.24	0.42	0.14
Hip moment of force	2	21.69	23.75	26.60	21.86	15.03	11.81	0.98	0.11	0.01[a]
Knee moment of force	2	21.95	15.69	3.25	13.66	5.77	1.98	0.17	0.12	0.27
Ankle moment of force	2	27.50	0.63	3.15	25.35	0.34	1.39	0.88	0.45	0.30

[a]Denotes statistically significant between groups difference. Abbreviations: LAS = lateral ankle sprain; IC = initial contact.