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Title: Single-leg drop landing motor control strategies following acute ankle sprain injury.

Running title: Landing strategies following acute ankle sprain injury.

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Abstract

No research currently exists investigating the effect of acute injury on single-limb landing strategies. The aim of the current study was to analyse the coordination strategies of participants in the acute phase of lateral ankle sprain (LAS) injury. Thirty-seven participants with acute, first-time, LAS and nineteen uninjured participants completed a single-leg drop landing task (DL) on both limbs. 3-dimensional kinematic (angular displacement) and sagittal plane kinetic (moment of force) data were acquired for the joints of the lower extremity, from 200ms pre-initial contact (IC) to 200ms post IC. The peak magnitude of the vertical component of the ground reaction force (GRF) was also computed. Injured participants displayed a bilateral increase in hip flexion, with altered transverse plane kinematic profiles at the knee and ankle for both limbs ($p < 0.05$). This coincided with a reduction in the net supporting flexor moment of the lower extremity ($p < 0.05$) and magnitude of the peak vertical GRF for the injured limb (21.82 ± 2.44 N/kg *vs* 24.09 ± 2.77 N/kg; $p = 0.013$) in injured participants compared to control participants. These results demonstrate that compensatory movement strategies are utilized by participants with acute LAS to successfully reduce the impact forces of landing.

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

Introduction

A recent meta-analysis has elucidated that jump-landing sports such as volleyball, gymnastics and basketball present the greatest risk of ankle sprain injury of any sport group, with a total of 7 [CI 95%: 6.82-7.18] ankle sprains per 1,000 exposures (Doherty et al., 2014). The vigorous landing maneuvers that are typical of these sports expose the joints of the lower extremity to large impact forces (Stacoff et al., 1988). The dissipation of these forces must be controlled in order to avoid excessive strain of the lower extremity muscle-tendon complex and associated ligamentous structures (Olsen et al., 2004).

The natural ease with which athletes perform landing movements however belies the complexities of the neural control that enables them. The intrinsic dynamics of a system determine the organization and control of its motor apparatus during a landing maneuver; the system's preferred states, given its current morphology and previous history of activity, play a central role in its coordination (Bernstein, 1967). Experimental quantification of lower extremity coordination, defined as the organisation of control of the motor apparatus (Bernstein, 1967), in landing scenarios has previously focused on the prediction of impact forces (Dufek et al., 1992), the comparison of landing techniques (DeVita et al., 1992) and the effects of different landing velocities (McNitt-Gray, 1991). An additional research focus has been on participants with a history of injury, particularly people in the chronic phase of lateral ankle sprain injury (Brown et al., 2008; Delahunt et al., 2006; Gribble et al., 2009; Wikstrom et al., 2007). Lateral ankle sprain injury is compounded by high rates of recurrence and morbidity (between 40% and 50% of individuals who incur a lateral ankle sprain will develop chronic sequelae (Gerber et al., 1998; van Rijn et al., 2008)), and researchers investigating these populations during landing movements have sought to characterise the kinematic and kinetic characteristics of chronicity (Konradsen, 2002). However, to date, no

research has been undertaken to analyse the landing coordination strategies of participants in the acute phase of lateral ankle sprain injury.

Coordination strategies during landing are adjusted according to the constraints of the task and its potential risk to the system (Glasgow et al., 2013). In the presence of an acute lateral ankle sprain injury, the central nervous system may seek to reorganise the landing coordination strategies used by the motor apparatus so as to minimise specific joint loading (Fleischmann et al., 2011). Controlling an expected landing impact typically involves 'predictive' and 'reactive' components in order to regulate the magnitude of the resultant ground reaction forces (GRF) (Santello, 2005). Greater dissipation of the forces associated with this landing impact reduces the loading of passive tissues such as the lateral ligaments of the ankle joint (DeVita et al., 1992). This dissipation can be quantified using energetic analyses of kinematic (segmental rotations) and kinetic (net joint moments) variables (Norcross et al., 2013). Specifically, during landing, internal hip, knee, and ankle extension moments must be produced via eccentric muscle contractions, with greater total lower extremity joint motion in the sagittal plane to control joint motion and absorb the kinetic energy of the body, producing smaller peak impact forces (DeVita et al., 1992). In populations who have recently sustained an acute lateral ankle sprain injury, biomechanical analysis may elucidate the adoption of a more dissipative, flexible postural orientation, which may serve as a protective mechanism for the recently injured lateral ligamentous complex. The potential benefit of such an analysis would advance current understanding of the capacity of the central nervous system to modify coordination patterns in the interest of short-term health outcomes, decreasing task-associated pain or perceived risk. Furthermore, it is plausible that these coordination patterns may be precursors to long-term recovery, with links to the motor control strategies which precede recovery or the onset of chronicity.

Therefore, the purpose of this study was to examine the lower extremity joint coordination strategies induced by acute lateral ankle sprain injury. We hypothesized that acute lateral ankle sprain injury would result in more dissipative landing coordination strategies with lower peak impact forces during a drop land (DL) task.

Materials and methods

Participants

Thirty-seven participants (26 males and 11 females; age 23.54 ± 5.65 years; body mass 73.83 ± 13.98 kg; height 1.75 ± 0.09 m) with acute, first-time, lateral ankle sprain injury were recruited from a University-affiliated hospital Emergency Department within 2 weeks of sustaining their injury. An additional group of 19 uninjured participants (15 males and 4 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 population using posters and flyers to act as a control group. All injured participants were provided with basic advice on applying ice and compression for the week on discharge from the hospital Emergency Department: they were each encouraged to weight-bear and walk within the limits of pain. Activities of daily living were encouraged. The following inclusion criteria were applicable to all participants (including both legs): (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. Participants gave written informed consent before partaking in this study as approved by the Institute's Human Research Ethics Committee

where the study was conducted. All testing procedures were completed at our University's biomechanics laboratory.

Instrumentation The Cumberland Ankle Instability Tool (CAIT) was used to assess overall ankle joint function and symptoms (Hiller et al., 2006). The activities of daily living and sports subscales of the Foot and Ankle Ability Measure (FAAM_{adl} and FAAM_{sport}) were used to quantify self-reported function, patient reported symptoms and functional ability as measures of lateral ankle sprain severity (Carcia et al., 2008). All participants completed the CAIT and subscales of the FAAM on arrival to the laboratory, prior to testing.

Ankle joint swelling was assessed using the figure-of-eight method; high intra-rater and inter-rater reliability has been reported using this technique (ICC = 0.99) (Tatro-Adams et al., 1995). To determine the degree of swelling, the mean value (of 2 measures) was subtracted from the mean value of the non-injured ankle. For control participants the mean value of the non-dominant limb was subtracted from the mean value of the dominant limb.

Prior to completion of the landing task, participants were instrumented with the Codamotion bilateral lower limb gait set-up (Charnwood Dynamics Ltd, Leicestershire, UK). Following the collection of 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 et al., 2006). A neutral stance trial was used to align the subject with the laboratory coordinate system and to function as a reference position for subsequent kinematic analysis as recommended in previously published literature (Wu et al., 2002).

Procedures

Participants were instructed to complete a minimum of three practice DLs on the test leg or until they were comfortable performing the task prior to data acquisition at each laboratory assessment. The task began with participants standing barefoot on a 0.4 m high platform (placed 5 cm from the edge of the force plate) with their test leg initially held in a non-weight bearing position and the knee flexed. Participants were then required to drop forward onto the test leg, landing on the force plate in front of the platform, adopting their own unique natural landing style. Upon landing, participants were required to balance as quickly as possible on the test leg and hold this position for approximately 4–6 sec. A land was repeated if the participant was unable to maintain a unilateral stance position with a stationary foot. Each participant was required to complete three DLs on both limbs. The order of DL performance was randomized using a random sequence of number generation for each limb. If an injured participant was unable to complete the task on their injured limb, they completed the DL on their non-injured limb solely.

Data analysis

Kinematic data acquisition was made at 200 Hz using 3 Codamotion cx1 units and kinetic data at 1000 Hz using 2 fully integrated AMTI (Watertown, MA) walkway embedded force-plates. The Codamotion cx1 units were time synchronized with the force-plates.

Kinematic data were calculated by comparing the angular orientations of the coordinate systems of adjacent limb segments using the angular coupling set ‘‘Euler Angles’’ to represent clinical rotations in 3 dimensions (Winter, 2009). Marker positions within a Cartesian frame were processed into rotation angles using vector algebra and trigonometry (CODA mpx30 User Guide, Charnwood Dynamics Ltd, Leicestershire, UK). Kinematic and kinetic data for both limbs were analysed using the Codamotion software, with the following axis conventions: x axis = frontal-plane motion; y = sagittal-plane motion; z = transverse-

plane motion, and then converted to Microsoft Excel file format with the number of output samples per trial set at $100 + 1$ in the data-export option of the Codamotion software, which represented the timeframe of interest during the DL trial as 100%, for averaging and further analysis. GRF data were passed through a third-order Butterworth low-pass digital filter with a 20-Hz cut-off frequency (Winter, 2009).

The variables of interest were identified during the period from 200-ms pre-initial contact (IC) to 200-ms post-IC for the 3 successful DL trials for each subject on each limb. Thus 1% of the DL trial represented a 4ms time interval. The vertical component of GRF (force plate registered vertical GRF greater than 10 N) was used to identify IC.

Time-averaged 3-dimensional angular displacement profiles for hip (flexion-extension; abduction-adduction; internal-external rotation), knee (flexion-extension; valgus-varus; internal-external rotation), and ankle joints (plantarflexion-dorsiflexion; inversion-eversion; foot abduction-adduction) were calculated for each limb of all participants from 200-ms pre-IC to 200-ms post-IC. Inverse dynamics were used to calculate time averaged, sagittal plane hip, knee and ankle moments from the kinematic and force-plate data, with a net-supporting moment profile of all three joints from 200-ms pre IC to 200-ms post IC being identified for each limb of all participants during the DL task to identify the net-flexor/extensor pattern of all three joints (Winter, 1983). Net internal moments are described and represent the body's reaction to the external load on each joint. The supporting moment, M_s , during landing is defined as $M_s = M_k - M_a - M_h$, where M_k , M_a and M_h are the moments at the knee, ankle and hip respectively (Winter, 1980). The support moment has been used to determine the relative contribution of the lower extremity joint moments in preventing lower limb collapse (Winter, 1980). Positive 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 et al., 1997). Absolute peak magnitude of the vertical component of the GRF within the first 200ms post IC was also calculated for all participants. Prior to data analysis all values of force were normalised with respect to each subject's body mass (BM).

Statistical analysis

For the injured group, limbs were labelled as “involved” and “uninvolved” based on FAAM and CAIT results. Limbs in the control group were side-matched to limbs in the injured group as “involved” and “uninvolved”.

To evaluate ankle sprain severity and to determine whether the injured group would demonstrate decreased function compared to the control group a multivariate analysis of variance was undertaken. The independent variable was group (injured *vs.* control). The dependent variables were CAIT score, FAAMadl score, FAAMsport score and degree of swelling as determined using the figure-of-8 method for the involved limb. The significance level for this analysis was set a priori at $p < 0.05$.

Between-group differences in involved and uninvolved limb 3-dimensional, time-averaged angular displacement profiles were tested for statistical significance using independent-samples t-tests for each data point. The significance level for this analysis was set a priori at $p < 0.05$.

Between-group differences in involved and uninvolved limb sagittal plane time-averaged net supporting moment profiles with their hip, knee and ankle constituents were tested for statistical significance using independent-samples t-tests for each data point. The significance level for this analysis was set a priori at $p < 0.05$.

Effect sizes were not calculated for the temporal kinematic and kinetic profiles secondary to the number of separate comparisons for each variable. This approach has been previously undertaken by our research group (Delahunt et al., 2007; Delahunt et al., 2006)

An independent samples, two-sided t-test was undertaken for each limb (involved and uninvolved) to test for significant differences in the magnitude of the peak vertical GRF in the time interval from 0 to 200-ms post-IC during the DL task. The time interval of 200ms post-IC was chosen to quantify the 'impact absorption' phase of the landing, based on the recommendations of Lees et al. (Lees, 1981) The significance level for this analysis was set a priori at $p < 0.05$.

All data were analysed using Predictive Analytics Software (Version 18, SPSS Inc., Chicago, IL, USA).

Results

All thirty-seven injured participants successfully completed the DL task on their uninvolved limb, with 18 successfully completing the task on their involved limb. The nineteen participants who did not attempt the DL on their involved limb cited fear of task-associated pain and/or risk of further injury as primary reasons for not completing the task. All control participants completed the task on their involved and uninvolved limbs.

Regarding self-reported function, disability and swelling, a statistically significant main effect was observed for the combined dependent variables, $F(4, 36) = 50.39$, $p < 0.01$, Wilks' Lambda = 0.15, partial eta squared = 0.85.

Furthermore, an exploratory analysis was performed to determine if there were any differences in self-reported function, disability or swelling between those participants who

successfully completed the DL task on both their involved and uninvolved limbs, and those who completed the task on their uninvolved limb only. The independent variable was group (injured participants who completed the task on both limbs [subgroup 1] vs. injured participants who completed the task on their uninvolved limb only [subgroup 2]). The dependent variables were CAIT score, FAAMadl score, FAAMsport score and degree of swelling for the involved limb. The significance level for this analysis was set at $p < 0.05$. A statistically significant main effect was observed for the combined dependent variables, $F(4, 17) = 9.04$, $p < 0.01$, Wilks' Lambda = 0.32, partial eta squared = 0.68. Questionnaire scores and swelling with details of relevant statistical analyses for the injured (including subgroups 1 & 2) and control groups are detailed in Table 1.

Time-averaged 3-dimensional kinematic profiles revealed that the injured group displayed increases in hip flexion for the involved (from 108ms pre-IC to 168ms post-IC) and uninvolved limbs (from 200ms pre-IC to 120ms post-IC), an increase in knee external rotation on the involved limb (from 152ms to 40ms pre-IC) and in knee internal rotation on the uninvolved limb (from 176ms to 192ms post-IC). Finally at the foot there was an increase in adduction on the involved limb (from 192ms to 12ms pre-IC) and an increase in foot abduction on the uninvolved limb (from 52ms to 76ms post-IC). Profiles for temporal kinematic data are presented in Figure 1.

Time-averaged sagittal plane kinetic profiles revealed between group differences for the net-support moment (increased overall flexor moment from 32ms to 20ms pre-IC and reduced overall flexor moment from 36ms to 56ms post IC) and hip moment (reduced extensor moment from 44ms to 52ms post-IC and reduced flexor moment from 76ms to 88ms post IC)

profiles on the involved limb only. Time-averaged sagittal plane kinetic profiles are presented in Figure 2.

There was a significant reduction in the magnitude of the peak vertical GRF in the 0-200ms post-IC time interval for the involved limb of injured participants compared to control participants (21.82 ± 2.44 N/kg vs 24.09 ± 2.77 N/kg; $t(35) = -2.631$, $p = 0.013$, two-tailed).

The magnitude of the differences in the means (mean difference = 2.26, 95% CI: -4.01 to -0.52) was large (eta squared = 0.17). There was no significant difference in the magnitude of the peak vertical GRF in the 0-200ms post-IC time interval for the uninvolved limb of injured participants compared to control participants (24.05 ± 2.13 N/kg vs 24.07 ± 2.08 N/kg; $t(35) = -0.32$, $p = 0.975$, two-tailed).

Discussion

The current investigation provides an analysis of the effect of acute lateral ankle sprain injury on coordination strategies during a DL task. The injured group included in this investigation reported significantly reduced function, when compared to the non-injured control group, on their involved limb secondary to injury, as elucidated by the CAIT and the subscales of the FAAM. Less than half of the injured group were able to complete the DL task on their involved limb, only completing the task on their uninvolved limb. This prompted an exploratory analysis, which elucidated that those participants who were able to complete the task on both their involved and uninvolved limbs had better self-reported function and less disability than those who did not attempt the task on their involved limb.

The 3-dimensional, temporal kinematic profiles of the injured group revealed preparatory (pre-IC) increases in hip flexion bilaterally, and knee external rotation with foot adduction on the involved limb only, when compared to the control group. On the uninvolved limb, in addition to the increase in preparatory hip flexion, injured participants exhibited a reactive

(post-IC) increase in knee internal rotation with foot abduction compared to control participants. Temporal support moment profiles revealed a reduction in the overall flexor moment of the involved lower extremity in injured participants, and this was associated with a reduction in the magnitude of the peak vertical GRF for this limb. These results were observed in the time period that extended from 200ms pre-IC to 200ms post-IC. Many of the important features of landing are said to occur in this timeframe (Lees, 1981), and because it is shorter than human reaction time, any attempt at attenuating the forces of impact will require preparatory action of the neuromuscular 'motor programme' employed by the sensorimotor system (Lees, 1981).

The preparatory (feed-forward) and reactive (feedback) components of this motor programme are the products of a neuromuscular control strategy that is implemented by the sensorimotor system, and that operates within the static restraints of the organism. Successful joint stability during the DL task is therefore dependent on the accuracy of sensory afferents and the appropriateness of the preparatory and reactive efferent response (Wikstrom et al., 2006).

Distortion of somatosensory afferents, as may occur with lateral ankle sprain injury, may compromise the sensorimotor system and the accuracy of the resultant neuromuscular control. In the current investigation, we delineate the effect of this somatosensory distortion on the basis of whether differences observed are preparatory (pre-IC) or reactive (post-IC). The injured group exhibited an increase in hip flexion on both the involved and uninvolved limbs during the DL task that began prior to IC and persisted following. The presence of this bilateral, feed-forward response following unilateral injury suggests that lateral ankle sprain may have caused damage to the fast adapting mechanoreceptors with associated pain and swelling, producing gamma motor neuron loop dysfunction with spinal level inhibition (Khin-Myo-Hla et al., 1999). It is plausible that this subsequently provoked an alteration in the expression of neuromuscular control by the sensorimotor system, appropriated to the

deficiencies introduced by injury. Specifically, acute injury of a static restraint (the lateral ligaments of the ankle joint complex) may have resulted in a distortion of somatosensory afferents. The centrally mediated, compensatory mechanism of increased sagittal plane joint displacement at a proximal segment of the kinetic chain was then employed to maintain joint stability during the dynamic task (Riemann et al., 2002). This preparatory coordination strategy of increased hip flexion persisted into the post-IC phase of landing. These results suggest that the hip is ideally suited to unload the other joints of the lower extremity following injury, perhaps due to the mechanical advantages of its surrounding musculature (greater cross-sectional area, longer muscle fibres and relatively shorter tendons) (Alexander et al., 1990), when compared to that of the knee and ankle. This is in agreement with the findings of previous research, confirming the central role the hip plays in the dissipation of impact forces (DeVita et al., 1992; Dufek et al., 1990). These results also display the capacity of the central nervous system to organise its motor apparatus in such a way as to use the hip to better attenuate impact forces (Fleischmann et al., 2011), ultimately unloading passive tissues such as the lateral ligament complex of the ankle joint and confirming our experimental hypothesis.

Distal to the hip, it is interesting to note that in comparing the injured and non-injured groups, injured participants exhibited primarily preparatory changes in coordination strategies following injury on their involved limb (increase in knee external rotation [$\approx 2^\circ$ internal rotation in controls vs $\approx 6^\circ$ external rotation in injured participants] and foot adduction [$\approx 0^\circ$ adduction in controls vs $\approx 8^\circ$ adduction in injured participants]), and reactive changes in coordination strategies on their uninvolved limb (increase knee internal rotation [$\approx 6^\circ$ internal rotation in controls vs $\approx 10^\circ$ external rotation in injured participants] and reduced foot adduction [$\approx 3^\circ$ adduction in controls vs $\approx 1^\circ$ adduction in injured participants]). The

preparatory action on the involved limb of increased knee external rotation and foot adduction, combined with the increase in hip flexion previously outlined, may have played a key role in the reduction of peak GRFs. The absence of between-group kinematic differences for the uninvolved limb at the knee and ankle/foot (in contrast to the involved limb) prior to IC suggests that pre-IC strategies are necessary for any reduction of impact forces of landing are to occur. The post-IC increase in knee internal rotation and foot abduction of injured participants on their uninvolved limb may be corollary to an alteration in the centrally mediated motor programme control mechanisms previously outlined. Although the coordination strategies are centrally mediated, they are specific to the limb they govern. Ultimately, in the presence of an acute injury, the sensorimotor system is in a state of somatosensory disarray where there is dissociation between predicted and actual sensory input on landing (McCabe et al., 2005). A centrally-mediated, preparatory 'motor programme' is developed by the sensorimotor system because of injury to the involved limb to compensate for this dissociation, thus providing a protective mechanism against further damage. Alteration in centrally mediated neuromuscular control may then also produce potentially anomalous reactive movement patterns elsewhere in the kinetic chain, such as the contralateral limb (as evidenced by the changes on the uninvolved limb of injured participants in the current study). It may be that recovery is dependent on an appropriated mastery of previously redundant degrees of freedom in the formulation of new 'coping' coordination strategies thus avoiding the onset of joint instability (Wikstrom et al., 2014).

The joint moment profile data presented for the involved limb in the current investigation provide insight into the effect that an injury-induced coordination strategy has on joint loading. The advantage of the support moment is its consistency despite the high variability of its constituents (ankle joint moment variability is usually small compared to that of the hip

and knee during gait), and its ability to give an indication of overall integrated synergy of lower limb support patterns in a given movement task (Winter, 1980; Winter, 2009). The moment curves for the ankle and knee display no difference between injured and control participants, with internally generated extension moments in resisting the rapid joint flexion caused by impact forces consistent across groups; the primary objective of the ankle and knee was to prevent collapse of the lower extremity (DeVita et al., 1992), regardless of the ankle sprain injury. Specifically, on initial contact, the ankle muscles generated a positive (eccentric plantarflexion) moment, controlling the deceleration of the descending limb, in conjunction with a similarly positive, eccentric flexion moment at the knee joint, mutually peaking at 150ms post-IC. At 150ms post-IC the acting eccentric activity of the ankle plantarflexors was ≈ 1.30 Nm/kg, and of the knee flexors is ≈ 2.03 Nm/kg.

While the two distal joints of the lower limb function primarily to prevent the collapse, it is the hip that displays a more complex activity in the control of the landing descent. The moment curve for the hip displays a sinusoidal type pattern whereby an initial positive (extensor) moment (≈ 0.5 Nm/kg) is produced following IC to prevent immediate collapse at ≈ 50 ms post-IC, which is closely followed by a negative (flexor) pattern (≈ -0.5 Nm/kg) in the attenuation of the landing force. Between-group differences in the overall support moment identified a reduction in the initial flexor pattern in the injured group compared to controls. This may be directly linked to the preparatory strategies of increased flexion at the hip for the injured group, or more likely due to the significant decrease in hip extensor moment present in the same timeframe in this group, thus reducing the overall extensor pattern. It is unknown whether this overall reduction in the hip moment extensor pattern, those preparatory kinematics specific to the involved limb previously outlined, or both, were responsible for the reduction in peak vertical GRF that was present only on the involved limb.

The novelty of the current investigation is that it provides the first evaluation of the coordination strategies used following acute musculoskeletal injury in the form of lateral ankle sprain during a fast dynamic task. Thus we are using a surrogate measure of the effect of acute injury on the mechanoreceptors specifically involved in dynamic joint stability by using a functional task. As no previous research has been performed which has identified the potential movement strategy risk factors during a DL task for acute ankle sprain injury, it is unknown as to whether the movement patterns observed in the injured group in the current study preceded or occurred as a result of injury. However, previous research of groups in the chronic phase of ankle sprain injury during a similar DL task has identified that those with chronicity display increased dorsiflexion at the ankle joint and flexion at the knee joint (Caulfield et al., 2002), in addition to increased inversion at the ankle joint (Delahunt et al., 2006), features which are not displayed in their acutely injured counterparts (based on the current study); the connotations of an injury constraint on movement strategies are broadly dependent on the stage of injury recovery: the time since the injury event may produce a specific appropriated movement response, which may not be consistent throughout the recovery process; until research is produced that elucidates the coordination strategies that are linked to chronicity in this population, we cannot allude to which specific movement patterns are maladaptive due to the design of the current analysis. Clinicians must however be adept in recognising that bilateral compensatory mechanisms are often adopted following acute unilateral acute ankle sprain injury, which may potentially have long-term consequences, and should encourage goal-oriented rehabilitation programmes to be completed bilaterally.

Follow-up analyses where participants are grouped according to their functional outcome in the months following the initial acute injury stand to advance current understanding of the recovery process.

Perspective

Acute ankle sprain injury may encourage neuromuscular adaptations in coordination strategies that result in greater dissipation of peak impact forces during a dynamic landing task.

This is in agreement with speculations made previously in seminal papers (DeVita et al., 1992; Lees, 1981), where it was projected that the hip plays a central role in the dissipation of landing forces and may serve to offload injured joints. These findings advance current understanding of the pleiotropic nature of the neurobiological system in accommodating morphological constraints in the production of an appropriated movement response.

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References

- Alexander, R., & Ker, R. (1990). The architecture of the muscles. In: *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York: Springer-Verlag.
- Bernstein, N. (1967). *The Coordination and Regulation of Movements*. London: Pergamon.
- Brown, C., Padua, C., Marshall, D., & Guskiewicz, K. (2008). Individuals with mechanical ankle instability exhibit different motion patterns than those with functional ankle instability and ankle sprain copers. *Clin Biomech (Bristol, Avon)*, 23(6), 822-831. doi: 10.1016/j.clinbiomech.2008.02.013
- Garcia, C., Martin, R., & Drouin, J. (2008). Validity of the Foot and Ankle Ability Measure in athletes with chronic ankle instability. *J Athl Train*, 43(2), 179-183. doi: 10.4085/1062-6050-43.2.179
- Caulfield, B., & Garrett, M. (2002). Functional instability of the ankle: differences in patterns of ankle and knee movement prior to and post landing in a single leg jump. *Int J Sports Med*, 23(1), 64-68. doi: 10.1055/s-2002-19272
- Delahunt, E., Monaghan, K., & Caulfield, B. (2007). Ankle function during hopping in subjects with functional instability of the ankle joint. *Scand J Med Sci Sports*, 17(6), 641-648. doi: 10.1111/j.1600-0838.2006.00612.x

- Delahunt, E., Monaghan, K., & Caulfield, B. (2006). Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. *Am J Sports Med*, 34(12), 1970-1976. doi: 10.1177/0363546506290989
- Delahunt, E., Monaghan, K., & Caulfield, B. (2006). Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. *J Orthop Res*, 24(10), 1991-2000.
- DeVita, P., & Skelly, W. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise*, 24(1), 108-115.
- Doherty, C., Delahunt, E., Caulfield, B., Hertel, J., Ryan, J., & Bleakley, C. (2014). The Incidence and Prevalence of Ankle Sprain Injury: A Systematic Review and Meta-Analysis of Prospective Epidemiological Studies. *Sports Med*, 44 (1) 123-140
- Dufek, J., & Bates, B. (1990). Regression models for predicting impact forces and knee joint moments and power during landings. *Proc. CSB*, 55-56.
- Dufek, J., & Bates, B. (1992). Lower extremity performance models for landing. *Hum. Mov. Sci.*, 299-318.
- Fleischmann, J., Gehring, D., Mornieux, G., & Gollhofer, A. (2011). Task-specific initial impact phase adjustments in lateral jumps and lateral landings. *Eur J Appl Physiol.* , 111(9), 2327-2337.
- Gerber, J., Williams, G., Scoville, C., Arciero, R., & Taylor, D. (1998). Persistent disability associated with ankle sprains: a prospective examination of an athletic population. *Foot Ankle Int*, 19(10), 653-660.
- Glasgow, P., Bleakley, C., & Phillips, N. (2013). Being able to adapt to variable stimuli: the key driver in injury and illness prevention? *Br J Sports Med*, 47(2), 64-65.
- Gribble, P., & Robinson, R. (2009). Alterations in knee kinematics and dynamic stability associated with chronic ankle instability. *J Athl Train*, 44(4), 350-355. doi: 10.4085/1062-6050-44.4.350
- Hiller, C., Refshauge, K., Bundy, A., Herbert, R., & Kilbreath, S. (2006). The Cumberland ankle instability tool: a report of validity and reliability testing. *Arch Phys Med Rehabil*, 87(9), 1235-1241. doi: 10.1016/j.apmr.2006.05.022
- Kepple, T., Siegle, K., & Stanhope, S. (1997). Relative contributions of the lower extremity joint moments to forward progression and support during gait. *Gait Posture*, 6, 1-8.
- Khin-Myo-Hla, Ishii, T., Sakane, M., & Hayashi, K. (1999). Effect of anesthesia of the sinus tarsi on peroneal reaction time in patients with functional instability of the ankle. *Foot Ankle Int*, 20(9), 554-559.
- Konradsen, L. (2002). Sensori-motor control of the uninjured and injured human ankle. *J Electromyogr Kinesiol*, 12, 199-203.
- Lees. (1981). Methods of impact absorption when landing from a jump. *Eng. Med.*, 10, 204-211.
- McCabe, C., Haigh, R., Halligan, P., & Blake, D. (2005). Simulating sensory-motor incongruence in healthy volunteers: Implications for a cortical model of pain. *Rheumatology*, 44(4), 509-516.
- McNitt-Gray, J. (1991). Kinematics and Impulse Characteristics of Drop Landing From Three Heights. *International Journal of Sport Biomechanics*, 7(2), 201-224.
- Monaghan, K., Delahunt, E., & Caulfield, B. (2006). Ankle function during gait in patients with chronic ankle instability compared to controls. *Clin Biomech (Bristol, Avon)*, 21(2), 168-174. doi: 10.1016/j.clinbiomech.2005.09.004
- Norcross, M., Lewek, M., Padua, D., Shultz, S., Weinhold, P., & Blackburn, J. (2013). Lower Extremity Energy Absorption and Biomechanics During Landing, Part I: Sagittal-Plane Energy Absorption Analyses. *J Athl Train*.
- Olsen, O., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med*, 32(4), 1002-1012.
- Riemann, B., & Lephart, S. (2002). The sensorimotor system, part I: The physiologic basis of functional joint stability. *J Athl Train*, 37(1), 71-79.

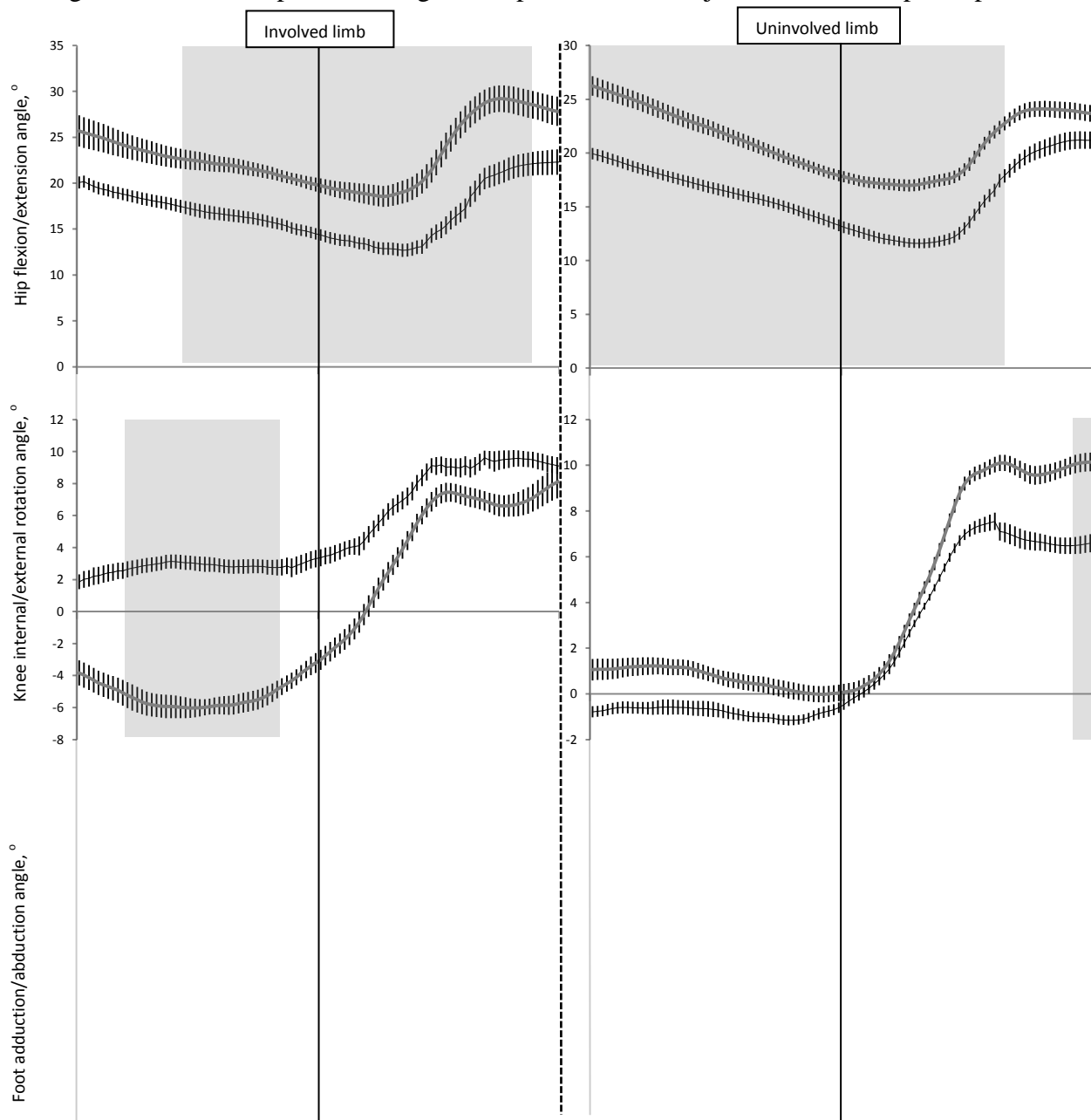
- Santello, M. (2005). Review of motor control mechanisms underlying impact absorption from falls. *Gait and Posture*, 21(1), 85-94.
- Stacoff, A., Kaelin, & Stuessi, E. (1988). *Biomechanics 10-B: The impact in landing after a volleyball block* (pp. 694–700.). Champaign, IL.: Human Kinetics.
- Tatro-Adams, D., McGann, S., & Carbone, W. (1995). Reliability of the figure-of-eight method of ankle measurement. *J Orthop Sports Phys Ther*, 22(4), 161-163.
- van Rijn, R., van Os, A., Bernsen, R., Luijsterburg, P., Koes, B., & Bierma-Zeinstra, S. (2008). What is the clinical course of acute ankle sprains? A systematic literature review. *Am J Med*, 121(4), 324-331 e326. doi: 10.1016/j.amjmed.2007.11.018
- Wikstrom, E., Tillman, M., Chmielewski, T., & Borsa, P. (2006). Measurement and evaluation of dynamic joint stability of the knee and ankle after injury. *Sports Med*, 36(5), 393-410.
- Wikstrom, E., Tillman, M., Chmielewski, T., Cauraugh, J., & Borsa, P. (2007). Dynamic postural stability deficits in subjects with self-reported ankle instability. *Med Sci Sports Exerc*, 39(3), 397-402.
- Wikstrom, E. A., & Brown, C. (2014). Minimum Reporting Standards for Copers in Chronic Ankle Instability Research. *Sports Med*, 44(2), 251-268.
- Winter, D. (1980). Overall principle of lower limb support during stance phase of gait. *J Biomech*, 13(11), 923-927.
- Winter, D. (1983). Moments of force and mechanical power in jogging. *J Biomech*, 16(1), 91-97.
- Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Hoboken, NJ: John Wiley and Sons, Inc.
- Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., . . . Stokes, I. (2002). ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics*, 35(4), 543-548. doi: [http://dx.doi.org/10.1016/S0021-9290\(01\)00222-6](http://dx.doi.org/10.1016/S0021-9290(01)00222-6)

Figure legends

Figure 1. Hip-joint flexion-extension, knee-joint internal-external rotation and foot abduction-adduction angle during performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of injured and control groups. Flexion, internal rotation and adduction are positive; extension, external rotation and abduction are negative. Black line with arrow=initial contact. Shaded area = area of statistical significance.

Figure 2. Sagittal plane joint moment-of-force profiles for the hip, knee and ankle during performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved limb of injured and control groups. Extension moments are positive. Black line with arrow=initial contact. Shaded area = area of statistical significance. Abbreviations: Mh = Hip moment; Mk = Knee Moment; Ma = Ankle moment; Ms = Support moment (Mk-Mh-Ma).

Figure 1. Kinematic profile during the drop land task for injured and control participants.



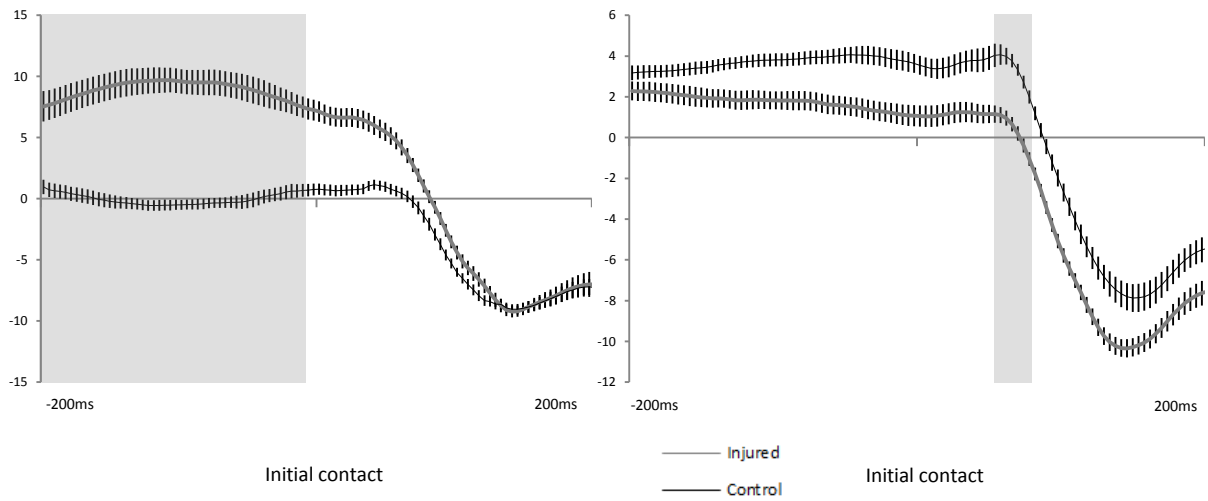


Figure 2. Kinetic profile during the drop land task for injured and control participants.

