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Abstract

Purpose: Compare the movement patterns and underlying energetics of individuals with Chronic Ankle Instability (CAI) to ankle sprain 'copers' during a landing task.

Methods: Twenty-eight (age 23.2 ± 4.9 years; body mass 75.5 ± 13.9 kg; height 1.7 ± 0.1 m) participants with CAI and 42 (age 22.7 ± 1.7 years; body mass 73.4 ± 11.3kg; height 1.7 ± 0.1 m) ankle sprain 'copers', were evaluated 1-year after incurring a first-time lateral ankle sprain injury. Kinematics and kinetics of the hip, knee and ankle joints from 200ms pre-initial contact (IC) to 200ms post-IC, in addition to the vertical component of the landing ground reaction force, were acquired during performance of a drop land (DL) task.

Results: The CAI group adopted a position of increased hip flexion during the landing descent on their involved limb. This coincided with a reduced post-IC flexor pattern at the hip and increased overall hip joint stiffness compared to copers (-0.01 ± 0.05°/Nm·kg^{-1} *vs* 0.02 ± 0.05°/Nm·kg^{-1}, p = 0.03).

Conclusions: Individuals with CAI display alterations in hip joint kinematics and energetics during a unipodal landing task compared to LAS 'copers'. These alterations may be responsible for the increased risk of injury experienced by individuals with CAI during landing manoeuvres. Thus, clinicians must recognise the potential for joints proximal to the affected ankle to contribute to impaired function following an acute lateral ankle sprain injury, and to develop rehabilitation protocols accordingly.

Level of evidence: Level III

Key terms: ankle joint [MeSH]; biomechanics [MeSH]; kinematics [MeSH]; kinetics [MeSH]; task performance and analysis [MeSH]; joint instability [MeSH].

Introduction

The neuromechanical requirements of landing from a height necessitate the fulfilment of specific roles by each of the lower extremity joints in the avoidance of trauma to the motor apparatus [10,15,28]. The hip in particular plays a central role in absorbing impact forces during landing, balancing control of the trunk and preventing total collapse of the system [10,13,15]. Further distally, the knee and ankle function primarily to prevent collapse of the lower extremity by balancing force attenuation and conservation according to the constraints of the task [13,31]. Musculoskeletal injury has the capacity to distort the established role the hip, knee and ankle play in completing the landing manoeuvre; in instances of injury, the ability of the musculoskeletal system to 'select' from a series of otherwise redundant landing strategies is impaired.

For example, it has been recently shown that individuals with acute lateral ankle sprain injury exhibit altered motor control and movement patterns at the primary joints of the lower extremity[12], and that some of these alterations persist 6-months later [13]. This is of pertinence, as the capability to effectively execute landing manoeuvres is considered to at least partly predicate recovery at the 1-year time-point following lateral ankle sprain injury [23]. Therefore, because of the significant capacity for a lateral ankle sprain to degrade into a range of debilitating insufficiencies characterised by injury recurrence and symptom sequalae [collectively known as chronic ankle instability][19,21,22], evaluating populations with a history of lateral ankle sprain injury is essential in advancing our understanding of the pathology, and would allow for the development of a rationale for rehabilitative intervention. Thus, for the current investigation, kinematic and kinetic measures were combined to quantify the neuromuscular control of a group of participants tested 1-year after incurring a first-time lateral ankle sprain injury. This lateral ankle sprain cohort was divided on the basis of their injury-associated self-reported disability and functional capacity into chronic ankle instability participants (who suffer symptom recurrence) and lateral ankle sprain 'copers' (who report no symptom recurrence). To the authors' knowledge, no laboratory analysis of chronic ankle instability and lateral ankle sprain 'coper' participants performing a unipodal landing task is currently available, wherein the time since injury is homogenous between and within each group. Based on the established movement patterns of participants with a 2-week [12] and 6-month [13] history of lateral ankle sprain injury during a unipodal landing task, we hypothesised that individuals with chronic ankle instability would exhibit increased reliance on their hip joint during landing, as evidenced by an increase in hip joint flexion and a reduction in its flexor moment pattern.

Materials and Methods

Participants included in the current study were recruited at convenience as part of a longitudinal analysis; published data for cohorts of these participants completing the same protocol utilised in the current study within 2-weeks [12] and 6-months[13] of their injury is already available and details measures of injury severity.

This study will involve exploratory analysis to compare different measures to assess performance of a DL after LAS. Therefore, no formal sample size calculation was performed, although we aimed to recruit a sufficient number of patients to allow meaningful data analysis.

As part of the longitudinal analysis, seventy-one participants were recruited from a University affiliated hospital emergency department within 2-weeks of sustaining a first-time acute lateral ankle sprain injury. These participants attended the research laboratory 12-months following recruitment to complete the protocol detailed in this report. The following exclusion criteria were applicable for all participants at the time of recruitment: (i) no previous history of ankle sprain injury (excluding the initial acute episode); (ii) no other severe lower extremity injury in the last 6 months; (iii) no history of ankle fracture; (iv) no previous history of major lower limb surgery; (v) no history of neurological disease, vestibular or visual disturbance or any other pathology that would impair their motor performance[11].

Participants were labelled as having chronic ankle instability or as lateral ankle sprain 'copers' according to recent recommendations[19,21,22]. Specifically, self-reported ankle instability was evaluated with the Cumberland Ankle Instability Tool (CAIT)[24] wherein individuals with a score of <24 were labelled as having chronic ankle instability while lateral ankle sprain 'copers' were labelled as such if they scored ≥24. Furthermore, the activities of daily living and sports subscales of the Foot and Ankle Ability Measure (FAAMadl and FAAMsport) were used to assessself-reported ankle and foot functional ability[7].

According to these scoring criteria, twenty-eight individuals were designated as having chronic ankle instability, and forty-two as lateral ankle sprain 'copers'; one lateral ankle sprain 'coper' participant was excluded because he did not return to pre-injury levels of activity participation[30]. Participant characteristics and questionnaire scores are presented for these seventy individuals in Table 1. Participants provided written informed consent, and the study was approved by the Human Research Ethics Committee of University College Dublin (LS-11-115). Whether lateral ankle sprain 'copers' or chronic ankle instability participants sought additional formal medical health services for rehabilitation or counsel of their injury was recorded ("yes" or "no") on arrival to the testing site but not controlled as part of the current experimental protocol.

Protocol

Collection methods for this study have been previously documented [12,13]. Briefly, the CAIT and subscales of the FAAM were completed by all participants on arrival to the biomechanics laboratory. Then, each participant was instrumented with the Codamotion bilateral lower limb gait set-up (Charnwood Dynamics Ltd, Leicestershire, UK) and asked to perform a number of practice trials of a single-leg drop land (DL) task on both their injured and non-injured limbs from a 0.4m platform (Figure 1). Following a short rest period, participants then completed three 'test trials' during which data were acquired. Kinematic data acquisition during the DL task 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 and the force plates were time synchronized. Kinematic and kinetic data for the three DL trials were analysed using the Codamotion software. The time window from 200-ms pre-initial contact (IC) to 200-ms post-IC for a single DL trial was evaluated. The vertical component of GRF (force plate registered vertical GRF greater than 10 N) was used to identify IC. GRF data were passed through a third-order Butterworth low-pass digital filter with a 20-Hz cut-off frequency[32].

Data management

All kinematic and kinetic data were acquired for each limb of all participants and averaged across the three completed trials for each limb. Separate group mean profiles for each limb and outcome were then calculated.

Time-averaged 3-dimensional angular displacement profiles for hip, knee, and ankle joints were calculated in the time window of interest. Total flexion displacements for the hip, knee, and ankle were also calculated as the difference between the joint angle at IC and the peak joint angle.

Time averaged sagittal plane hip, knee and ankle moments from the kinematic and force-plate data were calculated from 200-ms pre IC to 200-ms post IC using an inverse dynamics procedure.

Sagittal-plane hip, knee, and ankle joint stiffnesses were calculated as the change in normalized net internal moment (Nm) divided by the angular change (degrees) from IC to peak flexion excursion $(\mathrm{Nm} \cdot \mathrm{Kg}^{-1} \cdot \mathrm{degrees}^{-1})$ in the time window of interest [16,29].

Finally, absolute peak magnitude of the vertical component of the GRF within the first 200ms post-IC was calculated. Prior to data analysis all values of force were normalised with respect to each subject's body mass (BM).

Statistical analyses

For both the chronic ankle instability and lateral ankle sprain "coper "groups, the limb to which the lateral ankle sprain was sustained at the time of recruitment was labelled as ''involved'' and the non-injured limb as ''uninvolved''.

Between-group differences in involved and uninvolved limb angular displacement and net internal moment profiles for the hip, knee and ankle joints were tested for statistical significance using independent-samples t-tests for each data point. The significance level for these analyses was set a priori at $p < 0.05$.

Independent samples, two-sided t-tests were undertaken for each limb to test for significant differences in sagittal plane hip, knee and ankle joint torsional stiffness in the time interval from 0 to 200-ms post-IC, and 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 significance level for this analysis was set a priori at $p < 0.03$ (2 x limb).

All statistical analyses were performed with IBM SPSS Statistics 20 (IBM Ireland Ltd, Dublin, Ireland).

Results

Forty-two participants (60 percent) of the lateral ankle sprain cohort in the current study sought additional medical services and/or counsel for their injury while 40% (28 participants) did not.

A Chi-square test for independence indicated no significant association between rehabilitation and outcome, χ^2 (1, n = 80) = 1.21, p = 0.27, phi = 0.17.

Time-averaged 3-dimensional kinematic and kinetic profiles revealed that the CAI group displayed altered movement and joint moment patterns in the sagittal plane for the hip (kinematic: involved limb only; joint moments: bilateral). Kinematic profiles for the hip are detailed in Figure 2. Sagittal plane kinetic profiles for the hip, knee and ankle are presented in Figure 3.

There was no significant difference in sagittal plane joint stiffnesses on either limb at the a-priori alpha in the time period from IC to 200ms post-IC (Table 2). Stiffness values for the involved and uninvolved limbs are depicted in figures 4 and 5 for chronic ankle instability and lateral ankle sprain 'coper' participants respectively.

There was no between-groups differences in the magnitude of the peak vertical GRF in the 0-200ms post-IC time interval for either the involved or uninvolved limbs (Table 3).

Discussion

The most important finding of the present study was that individuals with chronic ankle instability exhibited significantly greater preparatory (pre-IC) hip joint flexion, a reduced flexor moment following IC and an associated increase in hip joint stiffness during the landing task. This was in agreement with the experimental hypotheses. These characteristics have been demonstrated in this group as a whole over the course of the recovery process when they previously completed this task and reported significantly reduced function and greater disability compared to a non-injured control group, 2-weeks [12]and 6-months[13] following the initial lateral ankle sprain injury. Therefore, it is plausible that full recovery and a subsidence of these patterns are corollaries of one another.

Previous research comparing individuals with chronic ankle instability to non-injured controls has elucidated that the chronically impaired cohorts display increased ankle joint inversion[9] and changes in sagittal plane knee joint motion[8,20]. The findings of the current study are in contradiction to this, as no differences were observed between the chronic ankle instability and lateral ankle sprain 'coper' groups in ankle or knee joint angular displacement, energetics or the coinciding ground reaction forces associated with the landing. One previous study did compare discrete parameters of lower extremity joint movement between chronic ankle instability and lateral ankle sprain 'coper' participants during a similar task [3]. This specific paper utilised two cohorts representative of the homogenous subsets of chronic ankle instability, both of which were included in a number of different investigations[4,5,18]: individuals with functional and mechanical instability of the ankle joint were compared to lateral ankle sprain 'copers' in addition to a healthy control group[3]. This was one of the first kinematic analyses to utilise lateral ankle sprain 'copers' as a comparison cohort for a chronic ankle instability group, elucidating that these individuals (lateral ankle sprain 'copers') display a greater degree of ankle joint plantar flexion at IC with a corresponding greater magnitude of total ankle sagittal plane angular displacement compared to their chronically impaired counterparts[3,18]. Once again, these findings are in conflict with those of the current study, and may be explained by differences in the task (the landing height was 0.32m in the aforementioned study[3]) and how the chronic ankle instability cohort were defined. Since the publication of this article [3], a consensus statement has been published detailing the required methodological processes for defining chronic ankle instability cohorts[19,21,22] The chronic ankle instability sample included in the current study were defined explicitly according to these guidelines, whereas in the study by Brown et al.[3] that we previously alluded to, the chronic ankle instability samples were likely representative of heterogenous subsets of CAI populations[18].

With regards to the current study, the alterations in hip kinematics and kinetics displayed by the chronic ankle instability group may be representative of a poor or 'non-coping' landing strategy. The mean hip moment of force profile for the chronic ankle instability group revealed a significant reduction in its flexor pattern (≃90ms post-IC) followed by an increase in its extensor pattern (≃140ms post-IC) on the involved limb, and an increase in the extensor pattern on the uninvolved limb (≃140ms post-IC). It is apparent on reflection of this pattern that the hip, more-so than the knee and ankle (which displayed relatively simple extensor and plantarflexor moments respectively), plays a significant role in achieving an equilibrium between the combined goals of arresting the downward velocity of the body and preventing collapse of the lower extremity [10,13,15]. The coinciding increase in hip flexion on the involved limb descent lends weight to this hypothesis, and can be considered part of a preparatory strategy utilised by chronic ankle instability participants for attenuating the resultant impact forces. Such preparatory strategies must commence in the airborne phase if they are to be successful in reducing the force levels associated with impact absorption following IC [26]. It is plausible then that the increase in hip flexion is one component of such a preparatory strategy for the chronic ankle instability group at reducing the risk of the impact. However, because of the high incidence of lateral ankle sprain injury in landing-based sports[14], the high rate of sprain recurrence in chronic ankle instability populations[1] and thus the potential for a landing manoeuvre to be injurious for individuals with chronic ankle instability, these alterations in hip energetics and motion compared to the lateral ankle sprain 'coper' group must be considered fundamentally flawed, and potentially contributing to their injury paradigm. Furthermore, if these strategies were employed in the vein of reducing the landing associated vertical ground reaction force they were not successful based on the current findings, as there were no between-groups differences in the peak value of the vertical ground reaction forces.

The joint stiffness parameter integrates the kinematic and kinetic data, giving an indication of the extent to which an applied force causes a change in the movement pattern displayed by the respective joint. Although the finding of increased hip joint stiffness was not statistically significant on the basis of the a priori p-value for the chronic ankle instability group, that the confidence interval for the mean between-groups difference did not cross zero with a medium effect size implies that this difference is potentially meaningful[25]. Therefore, and similar to the study at the 6-month time-point, the individuals characterised by greater self-reported disability displayed increased hip joint stiffness, seemingly resorting to their hip joint to arrest downward velocity of the falling body.

In light of the available evidence that the hip-based strategies exhibited by the current chronic ankle instability group are clearly not conducive to superior technique or performance during landing based activities[2], their reliance on these proximal alterations in joint motion and energetics in comparison to the lateral ankle sprain 'coper' group may be a particularly meaningful finding. Hip joint stability and the strength or activation of its supporting musculature could be central to the coping or non-coping mechanisms of lateral ankle sprain 'coper' and chronic ankle instability participants respectively by directly affecting global movement mechanics and foot positioning during landing [17]. In agreement with this, it has previously been shown that individuals with chronic ankle instability exhibit altered hip muscle activation onsets and patterns[6], with reduced strength of the hip abductors on their involved limb also evident[17]. Therefore, landing in a position of increased hip flexion could not only have implications for joint energetics and stiffness in the sagittal plane, but may also impair the capacity of the hip abductors in controlling for excessive or incorrect pelvic motion[27] by reducing the mechanical advantage of this muscle. Impairment in pelvic motion control may then initiate a cascade of events down the kinetic chain; on landing, the hip is forced into a conflict between controlling motion of the head arms and trunk, attenuating impact forces and preventing collapse of the lower extremity. Should weakness or its preparatory position reduce its ability to tackle these issues, an injury event may manifest. This should be of pertinence to clinicians: it is likely that successful rehabilitation following acute lateral ankle sprain is at least partially dependent on the re-development of motor control strategies for landing. Therefore, bilaterally-completed landing exercises would have potential value in a rehabilitation program following acute lateral ankle sprain, although the current study cannot confirm this.

Herein lays one of the primary limitations of this study, as it is unknown whether the observed movement patterns, which have been consistent with analyses completed earlier in the injury process [12,13], preceded or occurred as a result of the initial lateral ankle sprain. Furthermore, the recovery of this cohort cannot be considered 'natural' as 60% of participants included in this analysis sought additional medical counsel for the treatment of their injury. While no obvious 'clusters' emerged during data analysis on this basis and as there was no association to outcome (chronic ankle instability / lateral ankle sprain coper) for this, it is likely that undocumented treatment decisions undermine the generalisability of these results as a potential source of bias.

Conclusion

These findings lend to the hypothesis that participants with chronic ankle instability exhibit altered movement strategies during a landing task compared with ankle sprain 'copers'. These strategies manifest primarily at the hip joint, wherein alterations seem to persist from the acute stage of injury into chronicity.

Acknowledgements

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Figure legends

Fig 1. Laboratory setup of the Drop Land task with full bilateral lower-limb Codamotion setup.

Fig 2. Hip-joint adduction-abduction, flexion-extension and internal-external rotation during performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of CAI and coper groups. Adduction, flexion and internal rotation are positive; abduction, extension and external rotation are negative. Values are mean ± SEM. Black line with arrow = IC. Shaded area = area of statistical significance. Abbreviations: IC = initial contact; CAI = chronic ankle instability.

Fig 3. Knee-joint varus-valgus, flexion-extension and internal-external rotation during performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of CAI and coper groups. Varus, flexion and internal rotation are positive; valgus, extension and external rotation are negative. Values are mean ± SEM. Black line with arrow = IC. Shaded area = area of statistical significance. Abbreviations: IC = initial contact; CAI = chronic ankle instability.

Fig 4. Ankle-joint inversion-eversion, dorsiflexion-plantarflexion and foot adduction-abduction during performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and uninvolved limbs of CAI and coper groups. Inversion, dorsiflexion and adduction are positive; eversion, plantarflexion and abduction are negative. Values are mean ± SEM. Black line with arrow = IC. Shaded area = area of statistical significance. Abbreviations: IC = initial contact; CAI = chronic ankle instability.

Fig 5. 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 CAI and coper groups. Extension and plantarflexion moments are positive; flexion and dorsiflexion moments are negative. Values are mean ± SEM. Black line with arrow=initial contact. Shaded area = area of statistical significance. Abbreviations: Mh = Hip moment; Mk = Knee Moment; Ma = Ankle moment; IC = initial contact; CAI = chronic ankle instability.

Fig 6. CAI and coper relative joint stiffness on the involved limb during the drop land task. Positive values indicate extensor dominance (greater stiffness); Negative values indicate flexor dominance (greater flexibility). Abbreviations: CAI = chronic ankle instability.

[a] Indicates statistically significant difference from CAI participants.

Fig 7. CAI and coper relative joint stiffness on the uninvolved limb during the drop land task. Positive values indicate extensor dominance (greater stiffness); Negative values indicate flexor dominance (greater flexibility). Abbreviations: CAI = chronic ankle instability.