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1 **Title**: Single-leg drop landing movement strategies in participants with chronic ankle

2 instability compared with lateral ankle sprain 'copers'.

3 Abstract

4 **Purpose**: Compare the movement patterns and underlying energetics of individuals with

5 Chronic Ankle Instability (CAI) to ankle sprain 'copers' during a landing task.

6 Methods: Twenty-eight (age 23.2 ± 4.9 years; body mass 75.5 ± 13.9 kg; height 1.7 ± 0.1 m)

7 participants with CAI and 42 (age 22.7 \pm 1.7 years; body mass 73.4 \pm 11.3kg; height 1.7 \pm

8 0.1 m) ankle sprain 'copers', were evaluated 1-year after incurring a first-time lateral ankle

9 sprain injury. Kinematics and kinetics of the hip, knee and ankle joints from 200ms pre-initial

10 contact (IC) to 200ms post-IC, in addition to the vertical component of the landing ground

11 reaction force, were acquired during performance of a drop land (DL) task.

12 **Results:** The CAI group adopted a position of increased hip flexion during the landing

13 descent on their involved limb. This coincided with a reduced post-IC flexor pattern at the hip

14 and increased overall hip joint stiffness compared to copers (-0.01 \pm 0.05°/Nm·kg⁻¹ vs 0.02 \pm

15 $0.05^{\circ}/\text{Nm}\cdot\text{kg}^{-1}$, 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

21 injury, and to develop rehabilitation protocols accordingly.

22 Level of evidence: Level III

23 Key terms: ankle joint [MeSH]; biomechanics [MeSH]; kinematics [MeSH]; kinetics

24 [MeSH]; task performance and analysis [MeSH]; joint instability [MeSH].

27 Introduction

The neuromechanical requirements of landing from a height necessitate the fulfilment of 28 29 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 30 during landing, balancing control of the trunk and preventing total collapse of the system 31 32 [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 33 34 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 35 ability of the musculoskeletal system to 'select' from a series of otherwise redundant landing 36 37 strategies is impaired.

38 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 39 40 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 41 42 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 43 44 range of debilitating insufficiencies characterised by injury recurrence and symptom sequalae 45 [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 46 pathology, and would allow for the development of a rationale for rehabilitative intervention. 47 48 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 49 50 first-time lateral ankle sprain injury. This lateral ankle sprain cohort was divided on the basis

51 of their injury-associated self-reported disability and functional capacity into chronic ankle 52 instability participants (who suffer symptom recurrence) and lateral ankle sprain 'copers' (who report no symptom recurrence). To the authors' knowledge, no laboratory analysis of 53 54 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 55 within each group. Based on the established movement patterns of participants with a 2-week 56 [12] and 6-month [13] history of lateral ankle sprain injury during a unipodal landing task, 57 we hypothesised that individuals with chronic ankle instability would exhibit increased 58 59 reliance on their hip joint during landing, as evidenced by an increase in hip joint flexion and 60 a reduction in its flexor moment pattern.

61

62 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.

71

72 As part of the longitudinal analysis, seventy-one participants were recruited from a

73 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-

75 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].

82 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 83 84 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 85 ankle sprain 'copers' were labelled as such if they scored ≥ 24 . Furthermore, the activities of 86 87 daily living and sports subscales of the Foot and Ankle Ability Measure (FAAMadl and 88 FAAMsport) were used to assesself-reported ankle and foot functional ability[7]. According to these scoring criteria, twenty-eight individuals were designated as having 89 90 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 91 92 activity participation[30]. Participant characteristics and questionnaire scores are presented for these seventy individuals in Table 1. Participants provided written informed consent, and 93 the study was approved by the Human Research Ethics Committee of University College 94 95 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 96 their injury was recorded ("yes" or "no") on arrival to the testing site but not controlled as 97 98 part of the current experimental protocol.

99

100 Protocol

101 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 102 biomechanics laboratory. Then, each participant was instrumented with the Codamotion 103 104 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 105 and non-injured limbs from a 0.4m platform (Figure 1). Following a short rest period, 106 participants then completed three 'test trials' during which data were acquired. Kinematic 107 data acquisition during the DL task was made at 200 Hz using 3 Codamotion cx1 units and 108 109 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. 110 Kinematic and kinetic data for the three DL trials were analysed using the Codamotion 111 112 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 113 GRF greater than 10 N) was used to identify IC. GRF data were passed through a third-order 114 Butterworth low-pass digital filter with a 20-Hz cut-off frequency[32]. 115

116

117 *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 (Nm · Kg⁻¹ · 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).

134

135 *Statistical analyses*

136For both the chronic ankle instability and lateral ankle sprain "coper "groups, the limb to

137 which the lateral ankle sprain was sustained at the time of recruitment was labelled as

138 "involved" and the non-injured limb as "uninvolved".

139 Between-group differences in involved and uninvolved limb angular displacement and net

140 internal moment profiles for the hip, knee and ankle joints were tested for statistical

141 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

147 analysis was set a priori at p <0.03 (2 x limb).

148 All statistical analyses were performed with IBM SPSS Statistics 20 (IBM Ireland Ltd,

149 Dublin, Ireland).

151 **Results**

152 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)
- 154 did not.

157

155 A Chi-square test for independence indicated no significant association between

156 rehabilitation and outcome, χ^2 (1, n = 80) = 1.21, p = 0.27, phi = 0.17.

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

Time-averaged 3-dimensional kinematic and kinetic profiles revealed that the CAI group

161 Figure 3.

162 There was no significant difference in sagittal plane joint stiffnesses on either limb at the a-

163 priori alpha in the time period from IC to 200ms post-IC (Table 2). Stiffness values for the

164 involved and uninvolved limbs are depicted in figures 4 and 5 for chronic ankle instability

and lateral ankle sprain 'coper' participants respectively.

166 There was no between-groups differences in the magnitude of the peak vertical GRF in the 0-

167 200ms post-IC time interval for either the involved or uninvolved limbs (Table 3).

168

169 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 179 controls has elucidated that the chronically impaired cohorts display increased ankle joint 180 inversion[9] and changes in sagittal plane knee joint motion[8,20]. The findings of the current 181 study are in contradiction to this, as no differences were observed between the chronic ankle 182 183 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 184 study did compare discrete parameters of lower extremity joint movement between chronic 185 186 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 187 instability, both of which were included in a number of different investigations [4,5,18]: 188 189 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 190 first kinematic analyses to utilise lateral ankle sprain 'copers' as a comparison cohort for a 191 chronic ankle instability group, elucidating that these individuals (lateral ankle sprain 192 193 'copers') display a greater degree of ankle joint plantar flexion at IC with a corresponding 194 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 195 of the current study, and may be explained by differences in the task (the landing height was 196 197 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 198 detailing the required methodological processes for defining chronic ankle instability 199

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].

204

205

With regards to the current study, the alterations in hip kinematics and kinetics displayed by 206 the chronic ankle instability group may be representative of a poor or 'non-coping' landing 207 208 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 209 in its extensor pattern (\simeq 140ms post-IC) on the involved limb, and an increase in the extensor 210 pattern on the uninvolved limb ($\simeq 140$ ms post-IC). It is apparent on reflection of this pattern 211 that the hip, more-so than the knee and ankle (which displayed relatively simple extensor and 212 plantarflexor moments respectively), plays a significant role in achieving an equilibrium 213 between the combined goals of arresting the downward velocity of the body and preventing 214 215 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 216 preparatory strategy utilised by chronic ankle instability participants for attenuating the 217 218 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 219 following IC [26]. It is plausible then that the increase in hip flexion is one component of 220 such a preparatory strategy for the chronic ankle instability group at reducing the risk of the 221 impact. However, because of the high incidence of lateral ankle sprain injury in landing-222 based sports[14], the high rate of sprain recurrence in chronic ankle instability populations[1] 223 and thus the potential for a landing manoeuvre to be injurious for individuals with chronic 224

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.

231 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 232 233 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 234 confidence interval for the mean between-groups difference did not cross zero with a medium 235 236 effect size implies that this difference is potentially meaningful[25]. Therefore, and similar to 237 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 238 arrest downward velocity of the falling body. 239

In light of the available evidence that the hip-based strategies exhibited by the current chronic 240 241 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 242 243 energetics in comparison to the lateral ankle sprain 'coper' group may be a particularly 244 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 245 'coper' and chronic ankle instability participants respectively by directly affecting global 246 247 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 248 249 muscle activation onsets and patterns[6], with reduced strength of the hip abductors on their

250 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 251 may also impair the capacity of the hip abductors in controlling for excessive or incorrect 252 253 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 254 hip is forced into a conflict between controlling motion of the head arms and trunk, 255 attenuating impact forces and preventing collapse of the lower extremity. Should weakness or 256 its preparatory position reduce its ability to tackle these issues, an injury event may manifest. 257 258 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 259 260 control strategies for landing. Therefore, bilaterally-completed landing exercises would have 261 potential value in a rehabilitation program following acute lateral ankle sprain, although the current study cannot confirm this. 262

Herein lays one of the primary limitations of this study, as it is unknown whether the 263 264 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. 265 Furthermore, the recovery of this cohort cannot be considered 'natural' as 60% of participants 266 included in this analysis sought additional medical counsel for the treatment of their injury. 267 While no obvious 'clusters' emerged during data analysis on this basis and as there was no 268 269 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 270 as a potential source of bias. 271

272

273 Conclusion

274	These	findings lend to the hypothesis that participants with chronic ankle instability exhibit
275	altered movement strategies during a landing task compared with ankle sprain 'copers'.	
276	These strategies manifest primarily at the hip joint, wherein alterations seem to persist from	
277	the acu	te stage of injury into chronicity.
278		
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282		
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Figure legends 380

381

Fig 1. Laboratory setup of the Drop Land task with full bilateral lower-limb Codamotion 382 setup. 383

384

Fig 2. Hip-joint adduction-abduction, flexion-extension and internal-external rotation during 385 performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and 386 uninvolved limbs of CAI and coper groups. Adduction, flexion and internal rotation are 387 388 positive; abduction, extension and external rotation are negative. Values are mean \pm SEM. Black line with arrow = IC. Shaded area = area of statistical significance. Abbreviations: IC = 389 initial contact; CAI = chronic ankle instability.

391

390

Fig 3. Knee-joint varus-valgus, flexion-extension and internal-external rotation during 392 performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved and 393 uninvolved limbs of CAI and coper groups. Varus, flexion and internal rotation are positive; 394 valgus, extension and external rotation are negative. Values are mean \pm SEM. Black line 395 with arrow = IC. Shaded area = area of statistical significance. Abbreviations: IC = initial 396 contact; CAI = chronic ankle instability. 397

398

399 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 400

the involved and uninvolved limbs of CAI and coper groups. Inversion, dorsiflexion and 401

402 adduction are positive; eversion, plantarflexion and abduction are negative. Values are mean

 \pm SEM. Black line with arrow = IC. Shaded area = area of statistical significance. 403

Abbreviations: IC = initial contact; CAI = chronic ankle instability. 404

381	Fig 5. Sagittal plane joint moment-of-force profiles for the hip, knee and ankle during
382	performance of the drop land task from 200ms pre-IC to 200ms post-IC for the involved limb
383	of CAI and coper groups. Extension and plantarflexion moments are positive; flexion and
384	dorsiflexion moments are negative. Values are mean \pm SEM. Black line with arrow=initial
385	contact. Shaded area = area of statistical significance. Abbreviations: Mh = Hip moment; Mk
386	= Knee Moment; Ma = Ankle moment; IC = initial contact; CAI = chronic ankle instability.
387	
388	Fig 6. CAI and coper relative joint stiffness on the involved limb during the drop land task.
389	Positive values indicate extensor dominance (greater stiffness); Negative values indicate
390	flexor dominance (greater flexibility). Abbreviations: CAI = chronic ankle instability.
391 392	^a Indicates statistically significant difference from CAI participants.
393	Fig 7. CAI and coper relative joint stiffness on the uninvolved limb during the drop land task.
394	Positive values indicate extensor dominance (greater stiffness); Negative values indicate
395	flexor dominance (greater flexibility). Abbreviations: CAI = chronic ankle instability.
396 397	
398	
399	