



Title	Recovery From a First-Time Lateral Ankle Sprain and the Predictors of Chronic Ankle Instability: A Prospective Cohort Analysis
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1 **TITLE:** Recovery from a first-time lateral ankle sprain and the predictors of chronic ankle
2 instability: a prospective cohort analysis

3

4 **ABSTRACT**

5 **Background:** Impairments in sensorimotor control may underpin the paradigm of “Chronic
6 ankle instability” (CAI) that may develop in the year following an acute lateral ankle sprain
7 (LAS) injury. No prospective analysis is currently available which has sought to identify the
8 mechanisms by which these impairments develop and contribute to long-term outcome
9 following LAS.

10 **Purpose:** To identify the sensorimotor deficits predicating CAI outcome following a first-
11 time LAS injury

12 **Study Design:** Cohort study

13 **Methods:** Eighty-two individuals were recruited after sustaining a first-time LAS injury.
14 Several biomechanical analyses were performed on these individuals completing five
15 movement tasks at three time-points: 1) 2-weeks, 2) 6-months and 3) 12-months following
16 LAS onset. A logistic regression analysis of several ‘salient’ biomechanical parameters
17 identified from the movement tasks, in addition to scores from the Cumberland Ankle
18 Instability Tool (CAIT) and Foot and Ankle Ability Measure (FAAM) recorded at the 2-week
19 and 6-month time-points, were utilised as predictors of 12-month outcome (CAI or LAS
20 “coper”).

21 **Results:** 40% of participants who completed the study protocol developed CAI with the
22 remaining 60% being designated as LAS “copers”. Preliminary analyses revealed that the
23 deficits exhibited by the CAI group during one of the movement tasks [reach distances and
24 sagittal plane joint positions at the hip, knee and ankle during the Star Excursion Balance
25 Test (SEBT)] and their scores in the activities of daily living subscale of the FAAM at the 6-

26 month time-point had potential to be predictive of long-term outcome. When entered into the
27 prediction equation, these outcomes correctly classified 84.8% of cases (sensitivity: 75%,
28 specificity 91%; $P < 0.001$).

29 **Conclusion:** Poorer dynamic postural control as measured with the SEBT and poorer self-
30 reported function as measured using the activities of daily living subscale of the FAAM 6-
31 months following a first-time LAS are predictive of eventual CAI outcome.

32 **Clinical Relevance:** Individuals who exhibit deficits during the SEBT with reduced reach
33 distances and impaired range of motion at the hip, knee and ankle joints, and who report
34 poorer function based on the activities of daily living subscale of the FAAM 6-months
35 following a first-time LAS are more likely to develop CAI.

36 **Key terms:** ankle joint [MeSH]; biomechanical phenomena [MeSH]; kinematics [MeSH];
37 kinetics [MeSH]; postural balance [MeSH]; ankle instability [MeSH].

38

39 **What is known about the subject:** Previous cross-sectional studies have established that
40 individuals with Chronic Ankle Instability exhibit poorer performance during the Star
41 Excursion Balance Test and report poorer function on the basis of the Foot and Ankle Ability
42 Measure.

43 **What this study adds to existing knowledge:** Due to its design, this is the first study to
44 establish that some of the deficits that have previously been documented in participants with
45 Chronic Ankle Instability are actually predictive of this outcome when identified earlier in
46 the disease process.

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51 INTRODUCTION

52 Acute sprain of the ankle joint represents a significant risk for participants of a diverse range
53 of activities, with lateral ankle sprain (LAS) constituting the most prevalent sub-classification
54 of this injury¹³. Despite its high incidence¹³, LAS is typically regarded as an innocuous injury
55 that resolves readily with minimal treatment³⁸.

56 The inaccuracy of this perception²² should be of particular pertinence to healthcare
57 practitioners as the first incurrence of LAS is a potential ‘gateway’ to an array of chronic
58 symptom sequelae in the year following²³⁻²⁵. Freeman et al. were the first to propose that this
59 gateway was erected primarily on a foundation of local “articular deafferentation” at the
60 ankle joint; that damage to local sensory receptors following LAS creates a proprioceptive
61 deficit which impairs the central nervous system’s ability to accurately position the ankle
62 joint during movement¹⁷⁻¹⁹.

63 This ‘feedback’ model of chronicity has since evolved and expanded to include ‘feed-
64 forward’ mechanisms of sensorimotor control^{35,41} and the capability (or indeed, incapability)
65 of the nervous system to exploit motor control degeneracies^{8,16,32,34,47,50} in the fulfilment of
66 required movements. Still, it is accepted that anomalous movement patterns are at the crux of
67 the LAS injury paradigm, the chronic symptoms of which are now universally described by
68 the term “Chronic Ankle Instability” (CAI)^{9,23-25}.

69 In 2008, Hertel suggested that CAI is belied by a range of motor control deficits which
70 should be evaluated along a continuum of sensorimotor measures²⁹. His proposition was that
71 this would accommodate the formulation of a robust theoretical model which could delineate
72 the contributory factors of CAI and on which the basis of its conservative management be
73 developed^{23-25,29}. A ‘spectrum’ of human movement comprises a section of the continuum,
74 and researchers have sought to identify movement pattern anomalies in cohorts with CAI
75 across this spectrum: during static^{31,50,54} (ref) and dynamic^{26,27,30,37} (ref) postural control

76 assessments, gait^{7,11,14,39}(ref), and jumping/landing^{10,11,48,55}(ref) tasks. Consequently, the
77 gateway to CAI is considered to be partially composed of the anomalous movement patterns
78 to which individuals ‘fall victim’ in the year post-injury. This hypothesis is borne out of the
79 existence of a group who exhibit no such movement aberrancy with symptom recurrence^{3,52}:
80 LAS ‘copers’. ‘Copers’ represent the ‘polar’ end-point to CAI participants in the LAS injury
81 paradigm^{23-25,52}: it has been theorized that they are better able to exploit kinematical
82 degeneracies²¹ following LAS in the formulation of movement strategies appropriated to the
83 post-injury composition of their motor apparatus⁵², a feat their chronically impaired
84 counterparts are unable to realize. This is evidenced by a number of observational analyses
85 which have identified differences between copers and participants with CAI across the
86 movement spectrum^{3,4,54-56}(refs).

87 Importantly however, it is unknown whether the conglomeration of movement patterns that
88 characterise these groups in this spectrum is a manifestation of their outcome or contributed
89 to it. Currently, no prospective analysis tracking an LAS population during their settlement
90 into the dichotomous outcomes of CAI or LAS coper status is available. A collection of
91 exploratory reports from our laboratory were intended to culminate in such an analysis. These
92 reports have documented separate observational evaluations of participants with LAS
93 completing tasks across the spectrum of human movement. Specifically, participants were
94 recruited after sustaining a first-time LAS and required to complete static and dynamic
95 balance assessments, and gait, jumping and landing tasks. Biomechanical evaluations of
96 participants performing each task were completed first within 2-weeks of injury occurrence,
97 and then 6- and 12-months following.

98 By extracting the most ‘salient’ biomechanical outcomes from these reports, the objective of
99 the current prospective cohort study is to identify which of the anomalies across the
100 movement spectrum exhibited within 2-weeks and 6-months of injury contribute to final

101 outcome (CAI or coped, determined at the 12-month time-point). Our hypothesis was that 12-
102 month outcome is belied by deficits across the spectrum of the movement patterns analysed,
103 that CAI is underpinned not by one anomalous movement pattern during one of the
104 prescribed movements, but a group of movement anomalies in the postural control,
105 jumping/landing and gait tasks combined²⁹. We further hypothesise that the self-report rating
106 scales of ankle joint function and disability utilised at each time-point would be of predictive
107 value.

108

109 **MATERIALS AND METHODS**

110 Study design

111 1-year cohort study

112 Participants

113 Eighty-two participants were recruited at convenience from a University-affiliated hospital
114 emergency department (ED) within two weeks of sustaining an acute first-time LAS injury.

115 All LAS participants were provided with basic advice on applying ice and compression for
116 the week on discharge from the Emergency Department. Activities of daily living were
117 encouraged: participants were instructed to weight-bear and walk within the limits of pain
118 when possible. An additional cohort of twenty non-injured participants was recruited at
119 convenience from the hospital catchment area using posters and flyers to act as a control
120 group. All participants were recreationally active.

121 Recruitment for the current study was completed between March 1st, 2012 and September
122 29th, 2013.

123 Participant demographics for the LAS and control groups are presented in Table 1. Exclusion
124 criteria for participants of the current study are presented in Table 2.

125 The Human Research Ethics Committee of the university where the study was completed
126 approved this research. All participants signed an informed consent form prior to testing.

127 Design

128 As part of this prospective cohort study, LAS participants were required to attend the
129 University biomechanics laboratory at three time-points to complete the same experimental
130 protocol: 1) within 2-weeks of injury (time-point 1), 6-months (+/- 1 week of recruitment)
131 following injury (time-point 2), and then 12-months (+/- 1 week) following injury (time-point
132 3). At the 12-month time-point, the LAS cohort was stratified into CAI and LAS 'coper'
133 groups⁵². Whether LAS participants sought additional rehabilitative medical services for the
134 treatment of their injury was recorded ("yes" or "no") at time-point 3.

135 The control group of participants attended the laboratory on a single occasion within 2-weeks
136 of recruitment.

137 In a series of separate exploratory reports, the control cohort was compared to the LAS cohort
138 at the 2-week and 6-month time-points, and to the CAI and 'coper' groups at the 12-month
139 time-points (refs). A pictorial representation of this experimental design is depicted in the
140 supplementary documents (Figure S1).

141 The current investigation will use these exploratory reports to identify suitable ('salient')
142 input variables for a regression analysis to predict final outcome (CAI vs coper) at the 2-week
143 and/or 6-month time-points.

144 A table of operational definitions relevant to the above paragraphs is available in the
145 supplementary documents (Table S1).

146 The dependent variables for this prospective analysis were divided into three groups:
147 questionnaire, biomechanical and performance.

148

149 Dependent variables

150 Questionnaires

151 Self-reported ankle instability and ankle joint function were assessed and documented for all
152 participants at each visit to the biomechanics laboratory using the Cumberland Ankle
153 Instability Tool (CAIT) ^{23,59} and the activities of daily living and sports subscales of the Foot
154 and Ankle Ability Measure (FAAMadl and FAAMsport) ²³ respectively. Furthermore,
155 participants' designation as CAI or LAS copers status at time-point 3 was completed on the
156 basis of the CAIT ²³⁻²⁵: participants with a CAIT score of <24 were designated as having CAI
157 while participants with a CAIT score ≥ 24 were designated as LAS "copers"⁵⁹.

158

159 Biomechanical

160 Following completion of the questionnaires, participants were instrumented with the
161 Codamotion bilateral lower limb gait setup (Charnwood Dynamics Ltd, Leicestershire, UK)
162 which relayed marker data to 3 Codamotion cx1 units during the experimental protocol. The
163 Codamotion setup was fully integrated with two AMTI walkway-embedded force plates
164 (Watertown, MA) and time synchronized for the experimental protocol. This allowed
165 construction of lower limb link-segment model in the Codamotion software for
166 biomechanical (kinematic and kinetic) analyses. Force plate data were integrated with
167 kinematic data using an inverse dynamics procedure to calculate joint moments⁵⁸.
168 Ground reaction force (GRF) and centre of pressure (COP) data were also acquired. A neutral
169 stance trial was used to align each participant with the laboratory coordinate system and to
170 function as a reference position for subsequent kinematic analysis ⁶⁰. This was performed for
171 all participants at each visit to the laboratory. A full description of this Codmation setup and
172 link segment model construction with inverse dynamics is published in greater detail
173 elsewhere⁴⁰, and is separately reported in the exploratory analyses (refs).

174 Participants were familiarised with experimental protocols prior to commencement.
175 Following familiarisation, participants attempted (injury and/or ability permitting) to
176 complete a protocol of five movement tasks which were considered to detail comprehensively
177 the spectrum of human movement. The five movement tasks utilised for evaluation were as
178 follows: single-limb stance (SLS) (eyes-open and eyes-closed), the anterior (ANT), posterior-
179 lateral (PL) and posterior-medial (PM) components of the Star Excursion Balance Test
180 (SEBT), a single-leg drop land (DL), a drop vertical jump (DVJ) and gait. All unilateral tasks
181 (SLS, SEBT and DL) were completed on both the limb affected by the initial LAS
182 (designated the 'Involved' limb) and the contralateral limb (designated as the 'Uninvolved'
183 limb). The tasks were completed in the order they are described above. The experimental
184 protocol for each task is described in Table 3. A pictorial representation of the biomechanical
185 dependent variables for each task is available in Figure 1 and definitions of these are
186 presented in Table 4. A thorough description of the biomechanical dependent variables
187 relevant to each task is presented in the supplementary documents (Table S2).
188 Experimental procedures (including data acquisition and management) for each task at each
189 time-point have been previously documented (refs).

190 All tasks were completed in the barefoot condition.

191

192 Performance

193 The performance related dependent variables for this investigation were scores accomplished
194 in an assessment of ankle dorsiflexion range of motion (ROM) (the knee to wall test as
195 described by Denegar et al.¹²), and during the reach attempt for the specified components of
196 the SEBT at each time-point. To determine the ankle dorsiflexion ROM, the mean value (of
197 2 knee to wall test measures) was calculated separately for each limb at each time-point.

198 Reach distances during the SEBT were averaged across the three completed trials for each

199 participant at each time-point, and normalised to leg length prior to data aggregation and
200 analysis²⁸.

201

202 Data management and statistical analysis

203 In the exploratory reports of each task at each time-point (refs), dependent variables were
204 calculated separately for every task attempt and averaged across the required number of task
205 repetitions. Group mean profiles were subsequently calculated and compared. In all data
206 analyses, the involved and uninvolved limbs of each group (LAS/CAI vs control/coper) were
207 analysed.

208 In attempting to identify the predictors at time-point 1 and/or time-point 2 of CAI/coper
209 status (which was confirmed at time-point 3), our approach consisted of a three step process:
210 1) identify the ‘salient’ biomechanical dependent variables for regression analysis; 2) prepare
211 these variables for regression (including missing value analysis and dimension reduction); 3)
212 perform regression analysis in a model that also includes questionnaire and performance
213 dependent variables where appropriate. This statistical analysis model for the biomechanical
214 group of dependent variables is described in Table 5.

215 To complete the first step, we first extracted the results for the biomechanical dependent
216 variables of the exploratory case-reports from the three time-points (refs). The specifics of
217 this extraction process are detailed in the supplementary documents of this article (Methods
218 S1). The extracted variables are presented for time-point 1 in Figure 2, for time-point 2 in
219 Figure 3 and for time-point 3 in Figure 4. In summary, this process identified twenty-one
220 ‘salient’ biomechanical dependent variables for the commencement of step 2. These ‘salient’
221 biomechanical variables are described in Table 6, and are herein referred to using their
222 tabular numerical value (#1to #21).

223 Step 2 (preparation of the identified variables for regression) was necessary because a notable
224 proportion of biomechanical data were missing at time-points 1 and 2, and because of the
225 large number of identified salient dependent variables, which was potentially problematic for
226 statistical power in any regression analyses.

227 Of the participants that attended the laboratory at each time-point, complete datasets were
228 available only for the questionnaire group of dependent variables. With regard to task
229 performance and the biomechanical groups, a frequent occurrence was that participants were
230 unable to complete the prescribed task. These occurrences varied according to each time-
231 point: at time-point 1, injury severity was the primary reason cited predicating an inability to
232 complete a given task, while at time-point 2, task difficulty was alluded to most commonly
233 by participants. Such instances manifested in incomplete data sets, one at the single-subject
234 level (wherein the movement spectrum was only partially evaluated for an individual
235 participant) and the other at the group level (wherein data for a given task was only
236 representative of those participants actually able to complete that task). To accommodate
237 missing data values a multiple imputation procedure was implemented. This served the dual
238 purpose of limiting bias associated with some participants being unable to complete a task
239 (assuming these participants were a random subset of the total cohort) and allowing for
240 dimension reduction procedures to be completed for the salient biomechanical dependent
241 variables. We adopted two pre-requisites for imputation eligibility. At the single-subject
242 level, 60% data availability was required for each participant during all five tasks. At the
243 group level, 60% data availability for a given task was required from the total study cohort.
244 Therefore, if data were unavailable for $\geq 40\%$ of variables for one participant, that participant
245 was not considered for data imputation and if $\geq 40\%$ of participants were unable to complete a
246 task, this task (and its associated biomechanical parameters) was not considered.

247 Based on these criteria, sixteen individuals were removed from analysis at time-point 1 and
248 four were removed from time-point 2. Furthermore, of the total of twenty-one 'salient'
249 biomechanical dependent variables, those relating to the DL (3), DVJ (3) and eyes-closed
250 SLS (2) tasks from time-point 1 and eyes-closed SLS (2) from time-point 2 were removed
251 from analysis (Table 6). The methods for imputing missing salient biomechanical dependent
252 variable data are presented in the article supplementary material (Methods S2).

253 After imputation, the complete data set were subjected to a principal components analysis to
254 reduce their dimensionality. Specifically, the thirteen remaining variables at time-point 1 and
255 the nineteen remaining variables from time-point 2 were considered 'latent', and reduced into
256 significant 'factors' where possible. This was performed separately for the 2-week and 6-
257 month time-points due to differences in data availability.

258 Preliminary analyses (scree test and parallel analysis) informed our decision to retain two
259 factors for time-point 1 and three factors for time-point 2. With regards to the PCA for time-
260 point 1, outcome #11 had low communality (<0.3) to both factors and outcome #20 was
261 factorially complex. At time-point 2, outcomes #1 and #16 displayed low communalities to
262 the three factors, and outcome #13 was factorially complex. In both instances these outcomes
263 were removed from the PCA analysis for the relevant time-point, and were considered as
264 separate input variables for the analyses detailed below. Therefore, the thirteen
265 biomechanical variables from time-point 1 were reduced to two factors, with two independent
266 salient outcomes (#11 and #20). For time-point 2, the nineteen biomechanical variables were
267 reduced to three factors and three independent salient outcomes (#1, #13 and #16). The
268 pattern and structure coefficients are presented for these factors in Table 7 for time-points 1
269 and 2 separately.

270 These four potential biomechanical predictors for time-point 1 (two factors + two
271 independent salient outcomes) and six potential predictors for time-point 2 (three factors +

272 three independent salient outcomes), in addition to the questionnaire and performance groups
273 of dependent variables, were then subjected to preliminary univariate statistical analysis to
274 evaluate their potential value in two separate prediction models for each time-point (2-week
275 and 6-month). Specifically, the correlation of questionnaire scores, SEBT reach distance
276 performances, ankle dorsiflexion ROM and the salient biomechanical dependent variables
277 (following PCA) to outcome at the 12-month time-point was evaluated using Pearson's r.
278 This was performed separately for the 2-week and 6-month time-points to identify the likely
279 'predictors' of CAI or coper status following initial LAS. Variables were entered into a direct
280 logistic model provided their correlation to outcome was significant at the level of $p < 0.05$.
281 No adjustment was made to the p-value to accommodate multiplicity at this stage to guard
282 against the potential exclusion of important variables for the regression model.
283 All statistical analyses were performed with IBM SPSS Statistics 20 (IBM Ireland Ltd,
284 Dublin, Ireland).

285

286 **RESULTS**

287 Follow-up and rehabilitation

288 Seventy-one of the original 82 injured participants completed the 6-month follow-up, with 70
289 participants completing the 1-year follow-up; these final seventy were included in the
290 prospective analysis. Of the final seventy, 28 (40%) were designated as having CAI with 42
291 (60%) being designated as LAS "copers" (Figure S1). Twenty-eight (40%) of these
292 participants did not seek rehabilitative medical services while forty-two (60%) did.
293 Univariate statistical analyses revealed no significant trends between rehabilitation and
294 outcome (CAI/coper) ($r = 0.11$; $p = 0.372$).

295

296 Preliminary univariate statistics and regression

297 Following preliminary correlation analysis, no potential predictors at the two-week time-
298 point were identified. However, six potential predictors were identified at the 6-month time-
299 point [CAIT and FAAMadl scores; reach distances in the ANT and PL directions of the
300 SEBT (involved limb); Factor 1 and salient parameter #16]. Results of preliminary
301 correlation analyses for time-points 1 and 2 are presented in the article supplementary
302 documents (Tables S3 and S4 respectively). Descriptive statistics for the six potential
303 predictors at time-point 2 are presented in Table 8.

304 These potential predictors were entered into a direct logistic regression model in a
305 hierarchical fashion, whereby clinically accessible measures (questionnaire scores and SEBT
306 reach distances) were entered first, followed by the salient biomechanical variables. Thus,
307 one logistic regression analysis was completed for the predictors identified at the six-month
308 time-point. CAIT score, ANT reach distance and salient parameter #16 were then removed
309 sequentially from the model using a backward elimination technique because they displayed
310 low beta weights in the model despite significant correlation to outcome (likely indicating
311 shared predictive power taken up by the remaining predictor variables due to correlation⁴³).
312 The regression analysis was then repeated with the remaining predictors (FAAMadl score, PL
313 reach distance score and factor 1).

314 The model was statistically significant after the first block of variables were entered, $\chi^2(2, N$
315 $= 68) = 21.75, p < 0.001$, explaining between 28.1% (Cox and Snell R square) and 38.4%
316 (Nagelkerke R squared) of the variance in outcome, and correctly classifying 81.8% of cases.

317 When the final variable (factor 1) was entered into the model, the explained variance
318 increased to between 34.7% and 47.5%, and correctly classified 84.8% of cases. The
319 sensitivity and specificity of the final model was 75% and 91% respectively. Factor 1 was
320 the strongest predictor of outcome, with an odds ratio of 2.48. Reflection of the structure and
321 pattern coefficients for this factor revealed that it represented salient biomechanical

322 parameters #3 to #12 inclusive (involved limb: sagittal plane joint positions at the hip, knee
323 and ankle in the PL and PM directions, and at the knee and ankle for the ANT direction;
324 uninvolved limb: sagittal plane joint positions at the knee in the PL and PM directions).

325 Therefore, this indicates that participants who exhibited less flexion and dorsiflexion
326 displacement (bilaterally) during specified directions of the SEBT at the 6-month time-point
327 were over twice as likely to be CAI participants⁴³.

328 Due to the potential value these measures possess for clinicians, separate specificity and
329 sensitivity analyses were completed for several of the predictors identified via the preliminary
330 correlation analysis (CAIT, FAAMadl scores; ANT and PL reach distances). These analyses
331 revealed cut-off scores of 18 for the CAIT (sensitivity: 0.929; specificity: 0.375), 94.05% for
332 the FAAMadl (sensitivity: 0.93; specificity: 0.63), and 59.34% (sensitivity: 0.71; specificity:
333 0.63) and 91.35% (sensitivity: 0.69; specificity: 0.71) of leg length for the ANT and PL
334 directions of the SEBT respectively.

335 The results from the preliminary correlation and subsequent regression analyses with multiple
336 imputation were largely consistent with those from a complete case analysis. The results from
337 the complete cases analysis are presented in this article's supplementary material (Results
338 S1).

339

340 DISCUSSION

341 The ankle sprain literature is replete with studies which have sought to identify the movement
342 patterns that characterise and thus predicate the CAI condition^{1,2,3-6,8,9,13}. The use of LAS
343 copers in these case-control analyses^{3,4,54-56} (refs) is a recent development which has afforded
344 superior statistical validity to the deductions made compared to those of a more traditional
345 framework using non-injured controls; it is envisaged that because CAI and LAS coper
346 participants have a shared injury exposure, any discrepancies in their movement strategies are

347 more likely to be representative of coping or non-coping mechanisms for long-term injury
348 outcome^{52,54,55}. Unfortunately, the observational design of these studies has meant that the
349 deductions made regarding the true coping mechanisms of LAS remain speculative. While a
350 number of longitudinal studies have identified several risk factors for the first instance of
351 ankle sprain^{15,46,57}, no such research is available evaluating the mechanisms that predispose
352 an individual to a dichotomous post-LAS outcome of CAI or coper status. Herein lies the
353 novelty of our research as, to our knowledge, this is the first prospective analysis of a
354 population recruited after they incurred a first-time LAS and which has tracked this 12-month
355 divergence.

356 LAS can be considered the ‘gateway’ to these dichotomous states, and findings from this
357 study have identified that a number of variables at the 6-month time-point following injury
358 are directly predictive of 12-month outcome. Inconsistencies in the literature concerning the
359 ‘bona-fide’ CAI-defining movement deficits³⁶ compelled us to use a series of exploratory
360 analyses of this LAS cohort (refs) to inform our choice of dependent variables for the
361 subsequent regression analyses. Our hypothesis was that the ‘salient’ biomechanical
362 outcomes identified via this process would represent a conglomeration of deficits across a
363 spectrum of human movement in the CAI group²⁹. Contrary to our primary hypothesis, the
364 deficits exhibited were generally isolated to only one part of this spectrum (a measure of
365 dynamic postural control: the SEBT task).

366 The SEBT is both a rehabilitative and objective balance assessment tool popularised in the
367 clinical setting due to its excellent reliability and validity in injury risk and performance
368 assessment²⁸. One of the many advantages of this test is that it can be modelled on an
369 assessment hierarchy²²: simple documentation of the reach distance achieved by the
370 participant (which in itself has great clinical value⁴⁴) can be advanced using instrumented
371 biomechanical acquisition methods in the research setting to discern the movement patterns

372 belying the reach performance achieved. Such methods have been shown to advance the
373 discriminatory ability of the SEBT⁴⁵, and have revealed that the ANT, PL and PM reach
374 components best consummate overall SEBT performance, reducing the redundancies
375 associated with evaluating all eight of its original reach directions³⁰. As such, a number of
376 investigations in the CAI literature have documented differences in both reach distance
377 performance and its underlying movement compared to non-injured controls^{26,27,30,45} and LAS
378 copers⁴⁵. Indeed the inclusion of salient biomechanical outcomes relating to the SEBT in the
379 current investigation was based on a persistent observation of deficits in hip, knee and ankle
380 ROM in the sagittal plane in the LAS group 2-weeks and 6-months following injury onset
381 (compared to non-injured controls), and in the CAI group at the 12-month time-point
382 (compared to LAS copers and controls)(refs). PCA was utilised to reduce the dimensionality
383 of the salient biomechanical outcomes, and in retrospect it is unsurprising that this dimension
384 reduction procedure grouped the SEBT-based salient outcomes together (factor 1), because
385 they are likely to be highly correlated⁴³. Factor 1 represented sagittal plane joint positions for
386 both the involved (ANT: knee, ankle; PL/PM: hip, knee and ankle) and uninvolved (PL/PM:
387 knee) limbs. Due to the positive correlation of factor 1 to the aforementioned sagittal plane
388 motions during the SEBT (Table 7), and in light of the negative mean value for the CAI
389 group for this outcome (Table 8), we can deduce that the odds that participants had CAI at the
390 final evaluation increased the likelihood that they displayed a reduction in sagittal plane
391 ROM at these joints during the SEBT at the 6-month time-point. Not only does this contradict
392 the notion that the limb contra-lateral to the side of injury is ‘uninvolved’, but also implicates
393 proximal joints (hip/knee) in the coping mechanisms of LAS.

394 Whether these deficits in ROM at the hip and knee joints originate from restrictions at the
395 distal ankle magnifying proximally, or from central motor control mechanisms deserves
396 consideration. Deficits in ankle dorsiflexion ROM as determined using the knee to wall test

397 have been shown to impair reach performance in the ANT direction of the SEBT³³, yet in the
398 current study, this performance measure (the knee to wall test) yielded no significant
399 correlation to outcome at any of the time-points. Therefore, it is likely that the observed
400 sagittal plane ROM deficits are a manifestation not of structural or morphological ‘blocks’ at
401 the ankle, but of spinal and/or supraspinal alterations in motor control mechanisms following
402 the initial LAS^{15,29}. The presence of static and dynamic postural control deficits in LAS
403 participants both within 2-weeks (refs) and 6-months (refs) following injury incurrence lend
404 to this hypothesis, implicating centrally mediated sensorimotor control changes²⁹. These
405 findings were consistent with the 12-month data, wherein many of the deficits exhibited
406 earlier in the disease process persisted in CAI participants (refs). While a recent systematic
407 review and meta-analysis has determined that there is a subsidence of the bilateral deficits
408 that initially affect individuals with an acute LAS as they proceed to CAI, the pooled
409 outcomes in that study were generally limited to observational reports of stabilometric
410 measures acquired during static postural control tasks⁵³. Findings from the current
411 investigation imply that individuals with CAI do indeed exhibit deficits in postural control,
412 some of which are bilateral in nature (as factor 1 represented sagittal plane knee motion on
413 the uninvolved limb). Therefore, based on the current findings it is likely that centrally
414 mediated (spinal and/or supraspinal) mechanisms of sensorimotor control are implicated in
415 the development of chronicity following an initial, first-time acute LAS²⁹. This is of clinical
416 importance, as rehabilitation programmes must be thus designed with the bilateral nature of
417 these deficits in mind.

418 While the salient outcomes from the higher level measures of sensorimotor function (the DL
419 and DVJ tasks in the current study) did not contribute to the prediction equation, it is worth
420 noting that the outcome relating to hip flexion moment following ground contact would have
421 had some predictive value if entered into the regression equation independently (recall that it

422 was removed because it did not explain any additional variance when included in the model
423 with the other salient, performance and questionnaire dependent variables). We were
424 surprised by this ‘redundancy’ and the lack of significant independent contributors for
425 outcome for the variables from the dynamic movement tasks. However, their lack of
426 contribution to prediction is partly elucidated in lieu of the fact that as part of the data
427 imputation procedures, some of the ‘salient’ biomechanical outcomes relating to these tasks
428 were removed entirely due to excessive ‘missingness’. Indeed the variables relating to the
429 eyes-closed variant of the SLS task could not even be considered at either time-point for
430 regression due to data ‘missingness’, with the DL and DVJ tasks similarly oriented at time-
431 point 1. We would offer that these components of the movement spectrum are likely to be
432 useful in the assessment of LAS and CAI populations but due to problems with task
433 completion and data ‘missingness’, this is not reflected in the current study. This is evidenced
434 by the fact that findings from the exploratory reports, wherein findings were simply presented
435 for the data that were available, identified deficits which were persistent across time-points
436 [namely, increased hip-ankle coupling during SLS (ref), and increased hip flexion during the
437 DL (ref) and DVJ (ref) tasks].

438 That deficits in hip joint control seemed to be a continuous theme in both the exploratory
439 reports (refs) and in the final regression analysis of the current study is an interesting finding.
440 Reflection of the forest plots used to extract the salient biomechanical outcomes illustrates
441 this, whereby at the 12-month time-point, the hip was the predominant lower extremity joint
442 at which biomechanical deficits manifested in the CAI group (compared to copers and
443 controls). It is plausible that the aforementioned alterations in central motor control
444 mechanisms involve increasing weighted dominance on hip-joint movement strategies to
445 fulfil postural control (both static and dynamic)(refs) and jumping/landing tasks(refs). Thus,
446 hip joint stability and the strength or activation of its supporting musculature is likely to be a

447 central characteristic of the coping mechanisms exhibited by CAI or coper participants,
448 directly affecting global movement mechanics and foot positioning ²⁰. This may be due to the
449 extensive musculature at the disposal of this joint for performing the required movements¹,
450 which is recruited immediately following injury to compensate for ankle joint dysfunction,
451 but may become redundant during recovery if it persists. Individuals with CAI have
452 previously been shown to exhibit altered hip muscle activation onsets and patterns ⁵, with
453 reduced strength of the hip abductors on their involved limb also evident ²⁰, lending to this
454 hypothesis. Weakness or changes in activation patterns in a key stabilizing muscle groups
455 such as at the hip or ankle has the potential to produce deviations in joint motion which can
456 subsequently alter stability ⁶. Because the hip joint is appropriate for correcting large
457 deviations of the body's centre of mass and the ankle is more suited to the 'fine-tuning' of
458 postural control ^{42,49}, we speculate that in maintaining reliance on hip-dominant movement
459 strategies which begin following LAS incurrence, individuals who develop CAI do so partly
460 because of this persistence.

461 As such, we believe that rehabilitation following LAS should incorporate the full spectrum of
462 human movement and should contextually encourage the appropriate use of hip-based and/or
463 ankle based static and dynamic movement strategies. The current research cannot confirm the
464 potential efficacy of such an approach, however, but may inform future intervention studies
465 of LAS populations. The most recent currently available systematic review and meta-analysis
466 on the topic of rehabilitation efficacy for CAI based on twenty randomized controlled trials
467 has identified that more evidence is required in this area⁵¹. We believe that the "limited to
468 moderate" efficacy of training programs for CAI treatment compared to controls⁵¹ would be
469 advanced using a structured approach that that includes 1) the entire movement spectrum; 2)
470 both the injured limb and the contralateral limb; 3)hip- and ankle- based static and dynamic

471 movement tasks, for the reasons we have alluded to above. This can only be confirmed with
472 an appropriately designed intervention study however.

473 That our secondary hypothesis was confirmed by the results of the current study should be of
474 particular interest to clinicians: the predictive value of the self-report questionnaires and the
475 ANT and PL reach directions of the SEBT are likely to be of significant value to them.

476 Utilising the cut-off scores for these outcomes (in particular, the FAAMadl and PL reach
477 direction due to their contribution to the prediction equation) should be incorporated in a
478 goal-oriented rehabilitation programme design, and could be used to give an indication of the
479 likelihood that a patient will (or will not) develop CAI. With regards to the questionnaires,
480 these findings substantiate the recommendations of recent consensus statements^{9,23-25} to use
481 the CAIT and FAAMadl to both quantify the extent of the CAI associated disability and
482 functional deficits, and as an objective means to track recovery. Note however, that these
483 measures, and the identified salient biomechanical outcomes, were only predictive at the 6-
484 month time-point.

485 In many ways it is unfortunate that no predictors emerged at the 2-week time-point in the
486 current study, as this is the time that clinicians are most likely to encounter their patients and
487 have the ability to implement preventive measures, prior to the onset of chronic sequelae. It is
488 likely that the 2-week window of eligibility for assessment undermined the homogeneity of
489 our sample at this time-point, thus increasing the chance of sampling error: whether a patient
490 came to our lab for assessment the day after LAS incurrence probably had serious
491 implications for the extent of their disability compared to if they attended thirteen days after,
492 for example. This must be recognised as a serious limitation of the current study. However,
493 due to the high prevalence of LAS, the difficulty in actually recruiting patients with a first-
494 time LAS would have been compounded further if we were only able to assess them in a pre-
495 determined 24-hour interval, thus threatening the feasibility of the study. A further limitation

496 of this research is that because the LAS cohort were recruited after the initial injury, it is
497 unknown as to whether the deficits identified either in the exploratory research reports (refs)
498 or in this prospective analysis preceded or were caused by the first instance of LAS.
499 In conclusion, this analysis has identified several clinically accessible and biomechanical
500 outcomes which have predictive capacity of long term outcome, 6-months following a first-
501 time LAS injury. These findings have implications for clinicians, who can use the reported
502 cut-off scores in goal-oriented rehabilitation programs and to assess the risk a given patient
503 has for developing CAI, and for researchers, who should attempt to develop rehabilitation
504 programs on the basis of the biomechanical deficits identified.

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Table 1. Demographics for the LAS and control participants.

	Demographic:	Gender		Age (years)		Mass (kg)		Height (m)	
	n	Male	Female	Mean	95% CI	Mean	95% CI	Mean	95% CI
LAS	82	54	28	22.78	21.89 to 23.67	76.6	73.66 to 79.54	1.72	1.70 to 1.74
Control	20	15	5	22.53	21.77 to 23.28	71.55	66.46 to 76.64	1.75	1.71 to .178

Abbreviations: CI = Confidence Interval; LAS = Lateral Ankle Sprain

Table 2. Exclusion criteria for the LAS and control groups

Exclusion criteria	
LAS group	Control group
1. No previous history of LAS injury on either limb (excluding the initial acute episode)	1. No previous history of LAS injury on either limb
2. No other severe lower extremity injury in the last 6 months	2. No severe 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	

Abbreviations: LAS = lateral ankle sprain

Table 3. Experimental protocol for the five movement tasks, including the events analysed and the number of trials acquired.

Task	Conditions	Protocol	Event(s) analysed	N trials
SLS (●)	Eyes-open	Hands on hips Unilateral stance position.	Duration of SLS	3/limb
	Eyes-closed	20-seconds Refs		
SEBT (▲)	ANT	<u>Start position:</u> Hands on hips	<u>Kinematics:</u> Point of maximum reach <u>Kinetics:</u> duration of unilateral stance <u>Reach distance:</u> ANT, PL and PM directions.	3/limb
	PL	Bilateral stance <u>Task performance:</u> Unilateral stance		
	PM	Use non stance limb to reach in specified direction Return to start position Refs		
DL (■)		<u>Start position:</u> Standing atop a 40cm platform with the test limb flexed at the knee <u>Task performance:</u> Drop forward onto the force plate, landing on the test limb. Maintain position of unilateral stance x 3-5 sec. Refs	<u>Kinematics:</u> 200ms pre-ground contact to 200ms post-ground contact <u>Kinetics:</u> Ground contact to 200ms post-ground contact	3/limb
DVJ (x)		<u>Start position:</u> Bilateral stance atop a 40cm platform with hands on hips <u>Task performance:</u> Drop forward onto the two adjacent force plates (landing with both feet simultaneously) and immediately execute a maximal vertical jump. Return to ground in position of bilateral stance Refs	<u>Kinematics:</u> 200ms pre-ground contact to 200ms post-ground contact for first and second landings. <u>Kinetics:</u> Ground contact to 200ms post-ground contact for first and second landings	3
Gait (■)		Walk across a 10m walkway at a self-determined speed. Only 'clean' gait cycles were saved, and were defined by the participant landing with one foot in each force plate for each trial. Refs	<u>Kinematics:</u> 200ms pre heel-strike/toe-off to 200ms post heel-strike/toe-off. <u>Kinetics:</u> heel-strike/toe-off to 200ms post heel-strike/toe-off	5

Abbreviations: SLS = Single Limb Stance; SEBT = Star Excursion Balance Test; ANT = Anterior reach direction; PL = Posterior-lateral reach direction; PM = Posterior medial reach direction; DL = single-leg Drop Land; DVJ = Drop Vertical jump

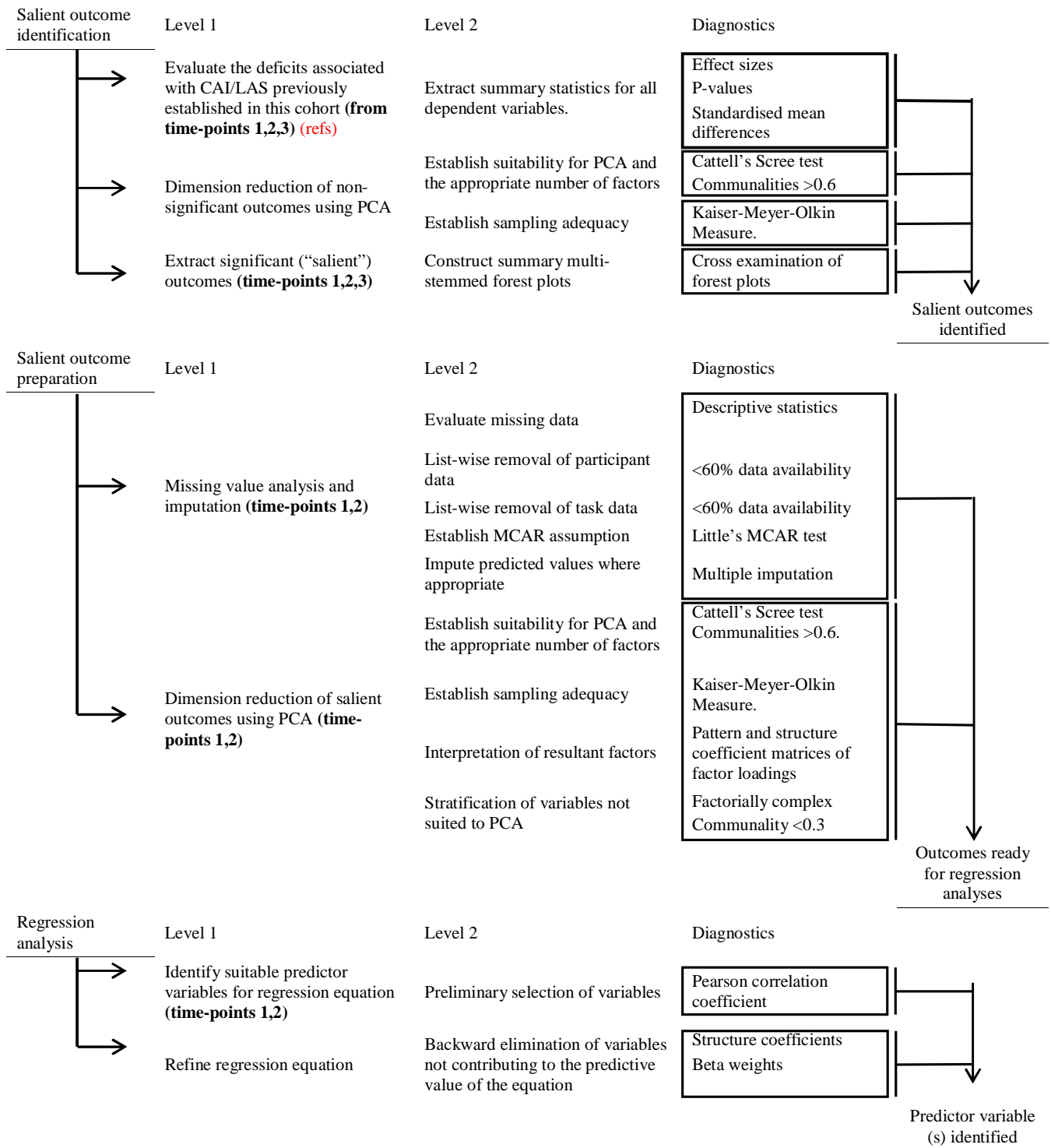
Table 4. Definitions of the acquired biomechanical dependent variables relative to this study

Variable	Abbreviation used	Relevant task(s)	Definition	References
Kinematic		SLS, SEBT, DL, DVJ, Gait	Concerns the details of movement: linear displacement and/or angular displacement of the lower limb joints (hip/knee/ankle).	(Winter, 2009)
Kinetic		DL, DVJ, Gait	Refer to the forces that cause movement such as the ground reaction forces, joint moments and joint powers. Joint moments were calculated for the hip, knee and ankle.	(Winter, 2009)
Adjusted coefficient of multiple determination	ACMD	SLS	A calculation that conceptualises the similarity between waveform data, the output of which is a discrete number between 0 (where there is no similarity between two waveforms) and 1 (where the waveforms have an identical shape). This allows for the conceptualisation of ‘coupling’ patterns between two joints, wherein greater ‘coupling’ is indicated by greater waveform similarity.	(Kadaba et al., 1989; Liu et al., 2012)
Centre of pressure	COP	SLS, SEBT	A bivariate distribution, jointly defined by the AP and ML coordinates which in a time series define the COP path of the stance limb relative to the origin of the force platform.	(Prieto et al., 1996)
Fractal dimension (FD)	FD	SLS, SEBT	A calculation that determines the complexity of the COP path trajectory by describing its shape using a discrete value between 1 (minimal complexity; straight line) and 2 (significant complexity; line the piles up in the plane). While it has yet to be determined whether there exists a linear relationship between postural control ability and the FD of the combined AP and ML COP path, a lower FD has been linked with a reduced capacity to avail of the supporting base.	(Doherty et al., 2014; Katz et al., 1985; Prieto et al., 1996)
Ground reaction force	GRF	DL, DVJ	The force exerted by the ground on a body in contact with it.	(Winter, 2009)
Rate of force development	RFD	DVJ	The peak vertical ground reaction force normalised to bodyweight divided by the time from ground contact with the force plate to the peak vertical ground reaction force.	(Decker et al., 2002)

Abbreviations: SLS = Single Limb Stance; SEBT = Star Excursion Balance Test; ANT = Anterior reach direction; PL = Posterior-lateral reach direction; PM = Posterior medial reach direction; DL = single-leg Drop Land; DVJ = Drop Vertical jump; COP = Centre of Pressure; ML = Medial-Lateral; AP = Anterior-Posterior.

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Table 5. Outline of the statistical model employed for the biomechanical dependent variables in the current analysis. Objectives are described in three hierarchical levels, with diagnostic tests listed where appropriate. Endpoints are described for each level of analysis.



Abbreviations: CAI = Chronic Ankle Instability; LAS = Lateral Ankle Sprain; PCA = Principal Components Analysis; MCAR = Missing Completely at Random.

Table 6. Numerical coding of the twenty-one identified ‘salient’ biomechanical dependent variables from the five movement tasks. Distribution of data-completeness is also depicted.

Task	Component	Parameter	Variable	Time-point 1		Time-point 2			
				Included	% missing	Included	% missing		
SLS	Eyes-closed	Kinematic	#1. ACMD Hip (flexion/extension)-ankle (inversion/eversion) ‘coupling’	✘	63%	✘	47%		
		Kinetic	#2. COP fractal dimension	✘	63%	✘	47%		
SEBT	ANT	Kinematic	#3. Knee flex	✓	6%	✓	3%		
			#4. Ankle d/f	✓	6%	✓	3%		
			#5. Hip flex	✓	6%	✓	3%		
	PL		#6. Knee flex	✓	6%	✓	3%		
			#7. Ankle d/f	✓	6%	✓	3%		
			#8. Knee flex	✓	4%	✓	3%		
	PM		#9. Hip flex	✓	6%	✓	3%		
			#10. Knee flex	✓	6%	✓	3%		
			#11. Ankle d/f	✓	6%	✓	3%		
			#12. Knee flexion	✓	4%	✓	3%		
			PL	Kinetic:	#13. COP fractal dimension	✓	6%	✓	3%
				Kinematic	#14. Hip flexion (max pre-initial contact)	✘	73%	✓	24%
#15. Hip flexion (max pre-initial contact)	✘	50%			✓	24%			
DL	Kinetic	#16. Hip flexion moment (max post-initial contact)	✘	73%	✓	24%			
	Part 1	Kinematic	#17. Hip flexion (max pre-initial contact)	✘	54%	✓	27%		
		18. Hip flexion moment (max post-initial contact)	✘	54%	✓	27%			
DVJ	Part2	Kinetic	#19. Hip flexion moment (max post-initial contact)	✘	54%	✓	27%		
	Gait	Kinematic	#20. Hip extension (max pre toe-off)	✓	6%	✓	3%		
#21. Ankle inversion (max pre toe-off)			✓	6%	✓	3%			

✓ = eligible for multiple imputation ($\geq 40\%$ data unavailability); ✘ = not eligible for multiple imputation ($\geq 40\%$ data unavailability). Bold text indicates that the variable relates to the ‘uninvolved’ limb. Abbreviations: SLS = single-limb stance; SEBT = Star Excursion Balance Test; DL = single-leg drop land; DVJ = drop vertical jump; ANT/PL/PM = anterior/posterior-lateral/posterior-

medial directional components of the SEBT; ACMD = Adjusted coefficient of multiple determination; COP = centre of pressure; flex = flexion; d/f = dorsiflexion.

Table 7. Pattern and structure matrices for the principal components analysis of the prominent biomechanical variables at the 2-week and 6-month time-points.

	Variable #	Pattern coefficients		Structure coefficients			Communalities	
		Factor 1	Factor 2	Factor 1	Factor 2	Factor 3		
2-week	10	.933	-.005	.933	.025		.696	
	4	.870	.087	.873	.115		.698	
	6	.867	.174	.872	.201		.769	
	9	.844	-.041	.843	-.014		.657	
	3	.833	.044	.834	.071		.791	
	7	.822	.144	.827	.170		.705	
	5	.780	.195	.786	.220		.575	
	8	.692	-.101	.689	-.079		.712	
	12	.664	-.112	.660	-.090		.870	
	13	.638	-.430	.625	-.409		.485	
	1	.127	.821	.153	.825		.448	
	21	.003	.748	.027	.748		.560	
	6-month		Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
10		.927	-.038	.088	.925	-.076	.064	.662
5		.922	.127	-.024	.920	.115	-.086	.730
9		.894	.073	.107	.893	-.060	-.164	.865
3		.893	.098	-.040	.893	.090	-.095	.821
6		.886	-.078	-.152	.889	.031	.058	.363
4		.845	.078	-.098	.847	.085	-.146	.803
12		.844	.118	-.044	.844	.112	-.101	.866
8		.812	.074	.008	.810	.056	-.038	.779
11		.722	-.223	.422	.712	-.337	.449	.803
7		.496	-.335	-.104	.507	-.320	-.043	.943
15		.117	.934	.032	.098	.924	-.191	.872
14		.081	.867	-.050	.066	.877	-.256	.591
20		-.005	.784	.089	.005	.822	-.539	.369
17		.007	.737	-.366	-.023	.764	-.095	.810
18		-.044	.054	.980	-.080	-.175	.969	.736
19		-.092	.040	.935	-.126	-.177	.928	.779
21	.050	-.068	.587	.031	-.207	.602	.869	

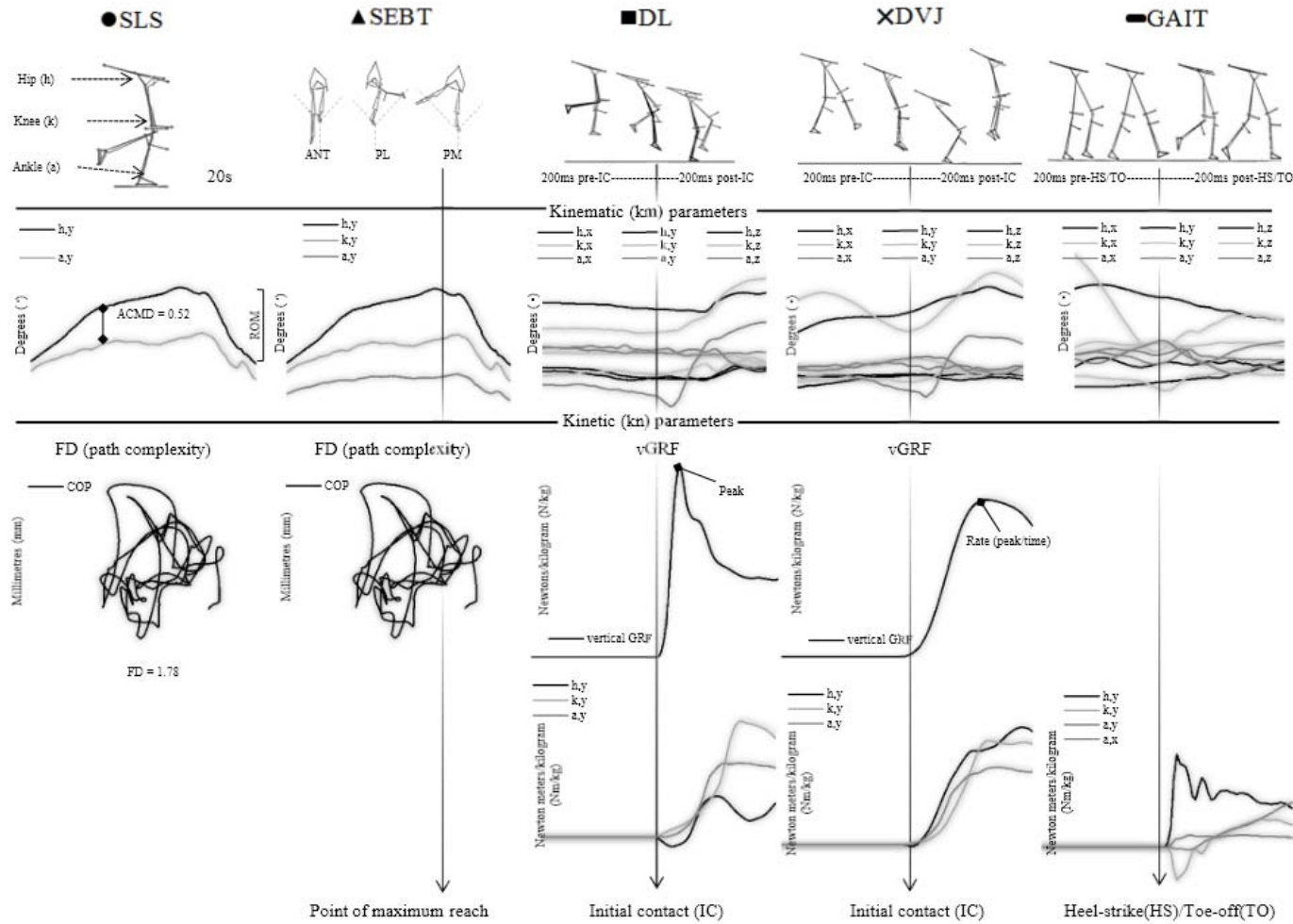
Major loadings for each variable are in bold. Variable # key is displayed in Table 6.

Table 8. Descriptive statistics (mean and SD) of the variables selected for regression analysis. Salient biomechanical variable #16 relates to hip flexion moment following ground contact during the single-leg drop land task.

	6-month time-point			
	CAI		Coper	
	Mean	SD	Mean	SD
CAIT (/30)	20.33	5.59	23.17	5.12
FAAMadl (%)	89.32	9.21	97.15	4.01
ANT (%LL)	59.09	4.01	61.98	5.75
PL (%LL)	86.81	11.58	94.51	10.27
Factor 1	-0.54	1.26	0.31	0.65
#16 (Nm/kg)	0.55	1.10	0.12	0.55

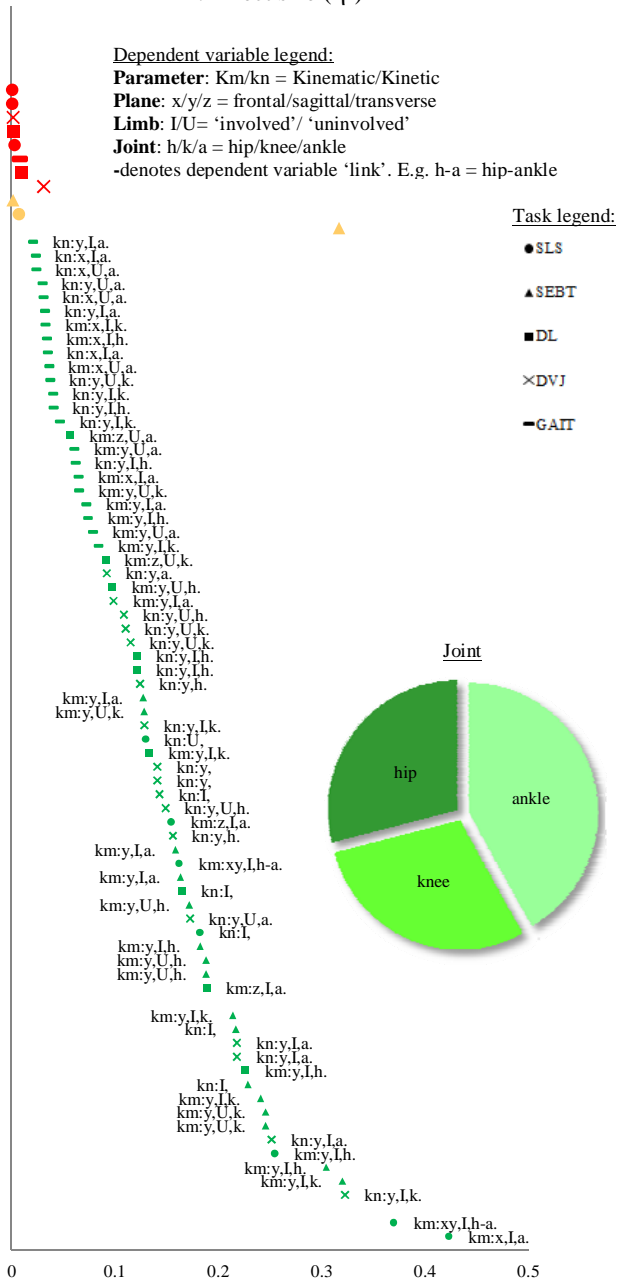
Abbreviations: CAIT = Cumberland Ankle Instability Tool; FAAMadl = Activities of Daily Living subscale of the Foot and Ankle Ability Measure; ANT/PL/PM = anterior/posterior-lateral/posterior-medial directional components of the Star Excursion Balance Test; %LL = percentage of limb length.

Figure 1. Pictorial representation of the five movement tasks, their dependent variables and the events analysed for each

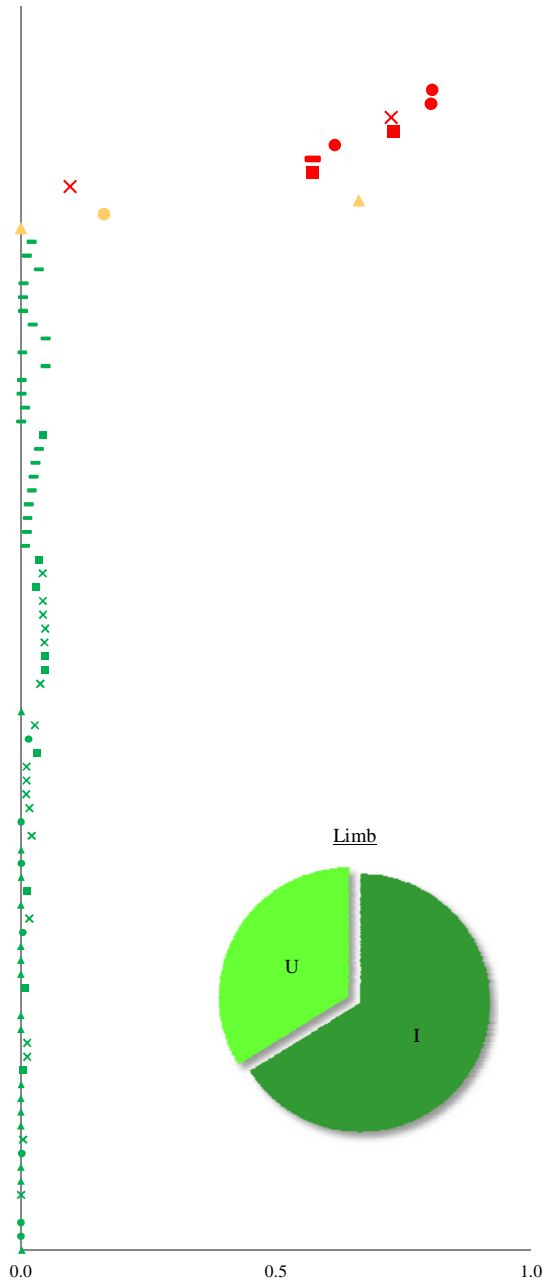


Abbreviations: SLS = Single Limb Stance; SEBT = Star Excursion Balance Test; ANT = Anterior reach direction; PL = Posterior-lateral reach direction; PM = Posterior medial reach direction; DL = single-leg Drop Land; DVJ = Drop Vertical jump; x/y/z = frontal/sagittal/transverse planes of motion; GRF = Ground Reaction Force; COP = Centre of Pressure; ACMD = Adjusted Coefficient of Multiple Determination; FD = Fractal Dimension

1. Effect size (η^2)



2. P-value



3. SMD

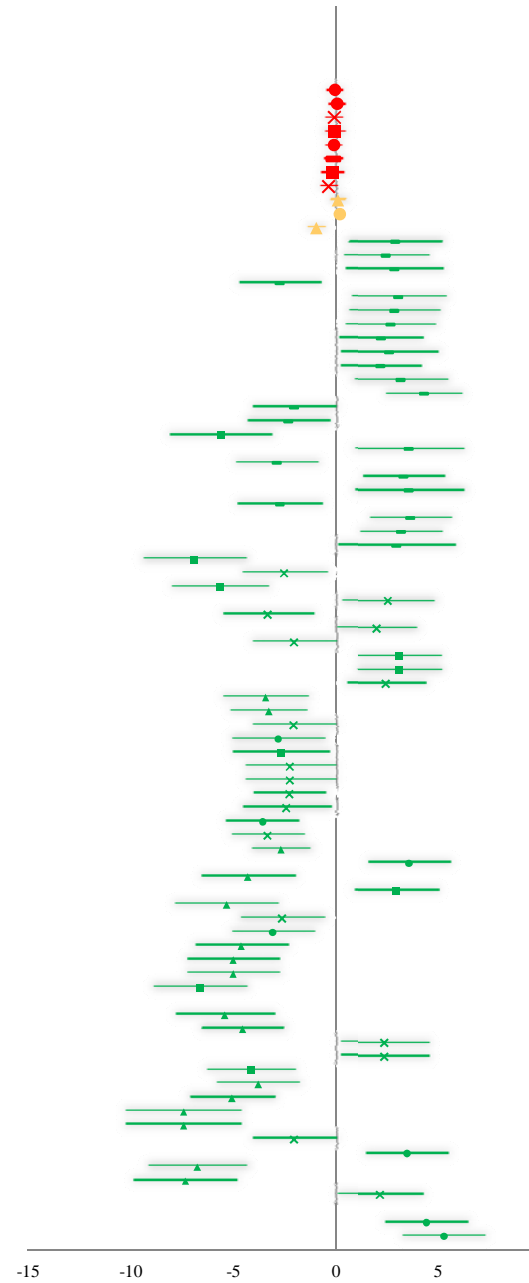


Figure 2.

Three-stemmed forest-plot summary of the results for all biomechanical dependent variables during the five movement tasks [time-point 1].

Stem 1 = effect size; stem 2 = associated p-value for stem 1; stem 3 = associated standardised mean difference (SMD) for stem 2. SMD is reported as LAS relative to control. Task-dependent variables reported as non-significant at $p > 0.05$ in the relevant study were subjected to PCA to reduce their dimensionality and are coloured red. Task-dependent variables reported with $p < 0.05$ but which did not reach the a-priori alpha level (and therefore considered non-significant) were subjected to PCA to reduce their dimensionality and are coloured amber. Individual results reported significant at the a-priori alpha level for biomechanical dependent variables are coloured green. Green variables were cross examined across time-points 1-3 to establish 'saliency' for inclusion in regression models. Pie charts describe dispersion of green variables by joint (hip/knee/ankle) and limb (involved/uninvolved). The task legend is presented in the top left corner of stem 1. For kinematic variables relating to joint, flexion/dorsiflexion are positive and extension/plantarflexion negative. For kinetic variables relating to joint extension/plantarflexion moments are positive and flexion/dorsiflexion moments negative.

Abbreviations: SLS = Single limb Stance; SEBT = Star Excursion Balance Test; DL = Single-leg Drop Land; DVJ = Drop Vertical Jump; U = Uninvolved; I = Involved; LAS = Lateral Ankle Sprain; PCA = Principal Components Analysis.

1. Effect size (η^2)

Dependent variable legend:

Parameter: Km/kn = Kinematic/Kinetic

Plane: x/y/z = frontal/sagittal/transverse

Limb: I/U= 'involved'/ 'uninvolved'

Joint: h/k/a = hip/knee/ankle

-denotes dependent variable 'link'. E.g. h-a = hip-ankle

Task legend:

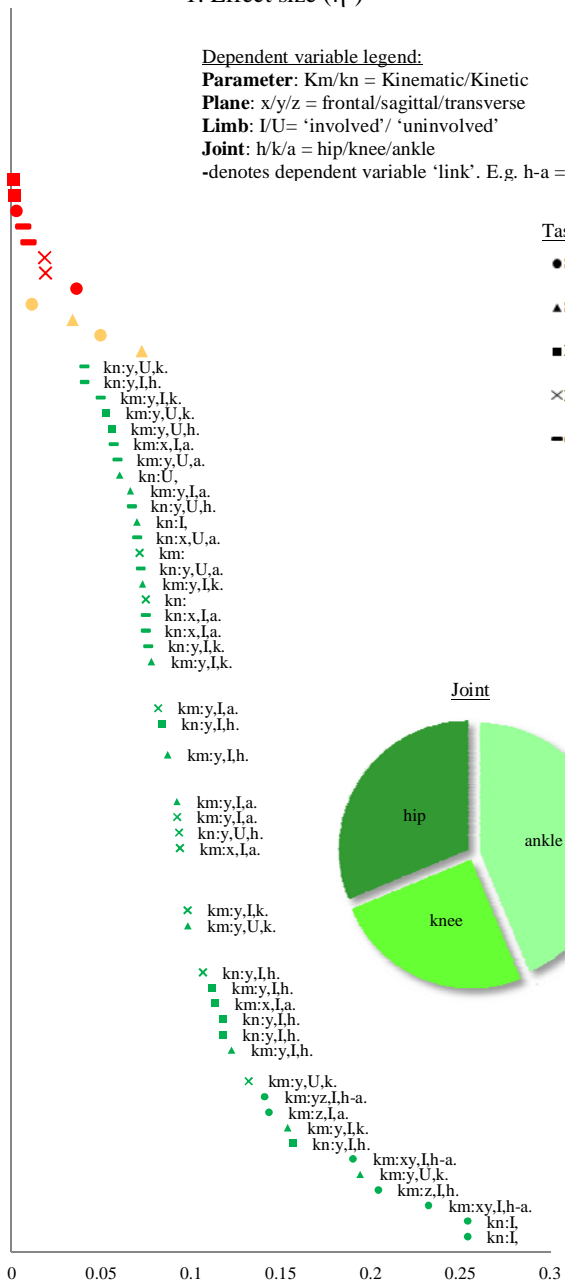
● SLS

▲ SEBT

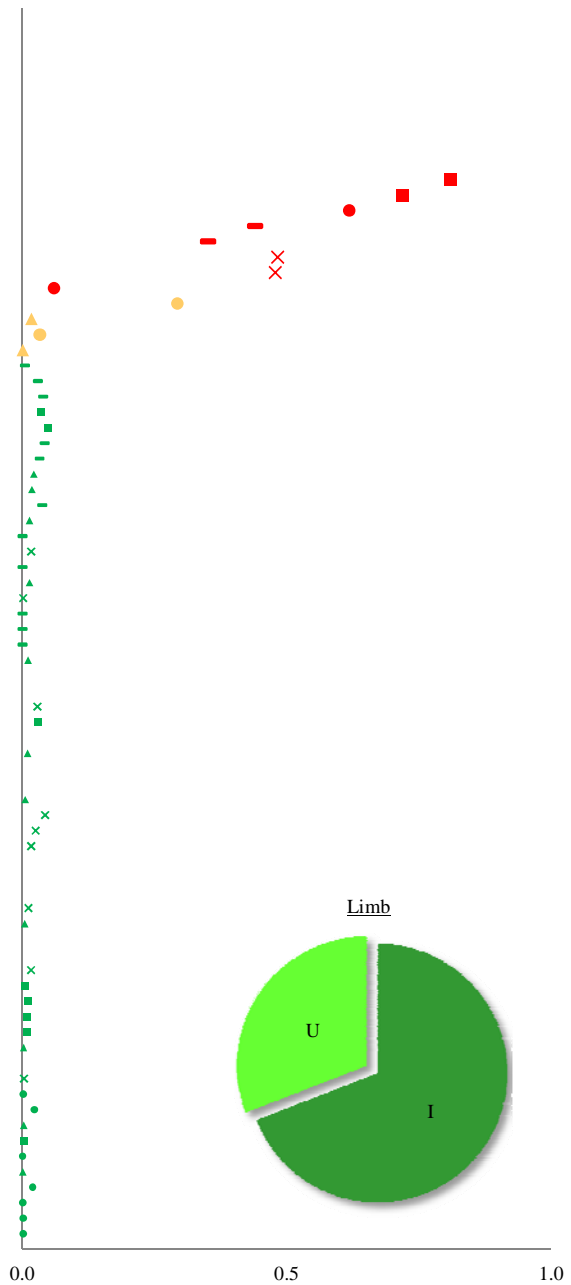
■ DL

× DVJ

— GAIT



2. P-value



3. SMD

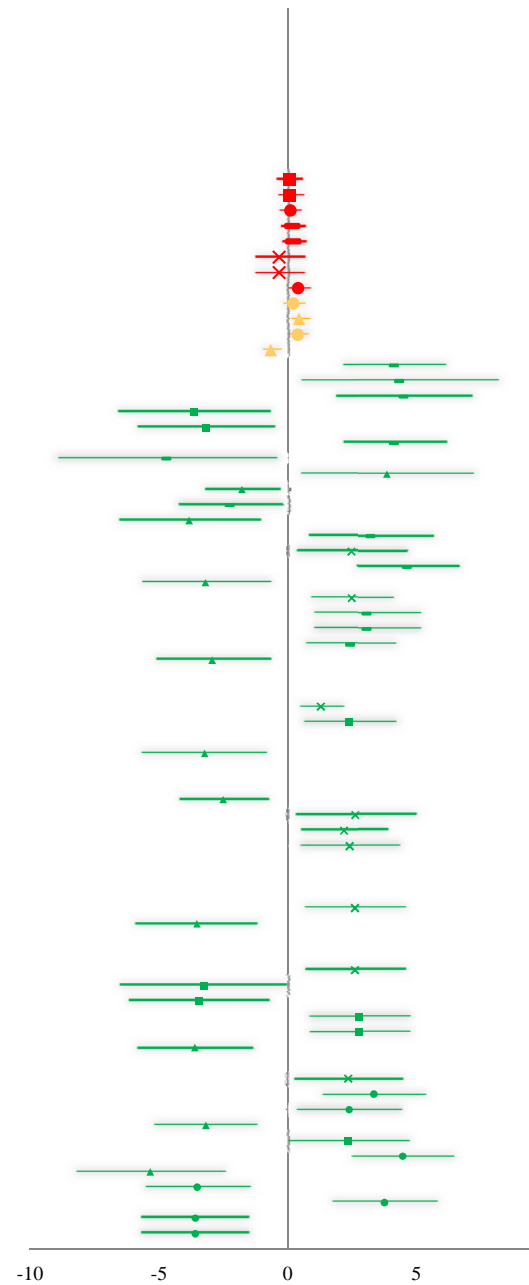


Figure 3.

Three-stemmed forest-plot summary of the results for all biomechanical dependent variables during the five movement tasks [time-point 2].

Stem 1 = effect size; stem 2 = associated p-value for stem 1; stem 3 = associated standardised mean difference (SMD) for stem 2. SMD is reported as LAS relative to control. Task-dependent variables reported as non-significant at $p > 0.05$ in the relevant study were subjected to PCA to reduce their dimensionality and are coloured red. Task-dependent variables reported with $p < 0.05$ but which did not reach the a-priori alpha level (and therefore considered non-significant) were subjected to PCA to reduce their dimensionality and are coloured amber. Individual results reported significant at the a-priori alpha level for biomechanical dependent variables are coloured green. Green variables were cross examined across time-points 1-3 to establish 'saliency' for inclusion in regression models. Pie charts describe dispersion of green variables by joint (hip/knee/ankle) and limb (involved/uninvolved). The task legend is presented in the top left corner of stem 1. For kinematic variables relating to joint, flexion/dorsiflexion are positive and extension/plantarflexion negative. For kinetic variables relating to joint extension/plantarflexion moments are positive and flexion/dorsiflexion moments negative.

Abbreviations: SLS = Single limb Stance; SEBT = Star Excursion Balance Test; DL = Single-leg Drop Land; DVJ = Drop Vertical Jump; U = Uninvolved; I = Involved; LAS = Lateral Ankle Sprain; PCA = Principal Components Analysis.

1. Effect size (η^2)

Dependent variable legend:

Parameter: Km/kn = Kinematic/Kinetic

Plane: x/y/z = frontal/sagittal/transverse

Limb: I/U = 'involved'/'uninvolved'

Joint: h/k/a = hip/knee/ankle

-denotes dependent variable 'link'. E.g. h-a = hip-ankle

Task legend:

● SLS

▲ SEBT

■ DL

× DVJ

— GAIT

— km:y,U,h.

— km:y,I,h.

— km:x,I,a.

— km:y,I,k.

× km:y,I,h.

■ kn:y,I,h.

■ kn:y,I,h.

■ kn:y,I,h.

— km:y,U,k.

■ km:y,I,h.

× kn:y,U,h.

— kn:y,I,k.

× km:y,I,h.

× kn:y,U,h.

× km:y,U,h.

— km:y,U,h.

■ kn:y,I,h.

— km:y,I,h.

— kn:y,U,k.

▲ kn:I,

▲ km:y,I,k.

● kn:I,

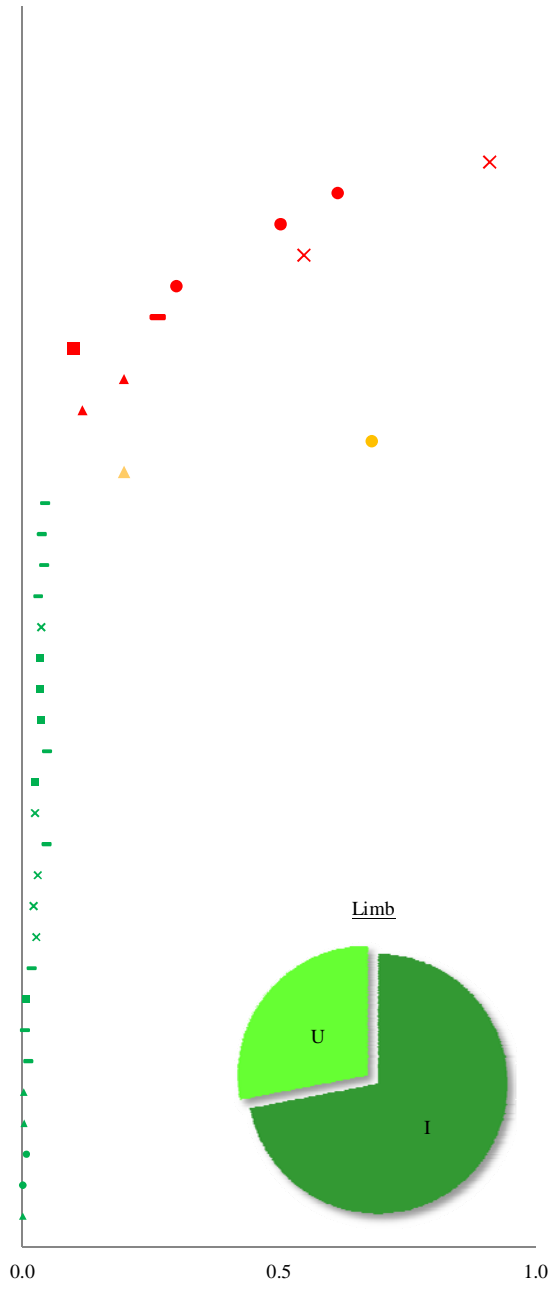
● km:xy,I,h-a.

▲ km:y,I,a.

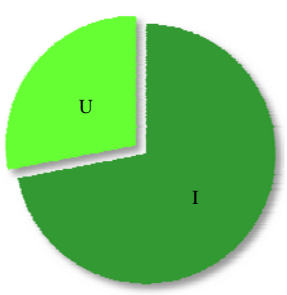
Joint



2. P-value



Limb



3. SMD

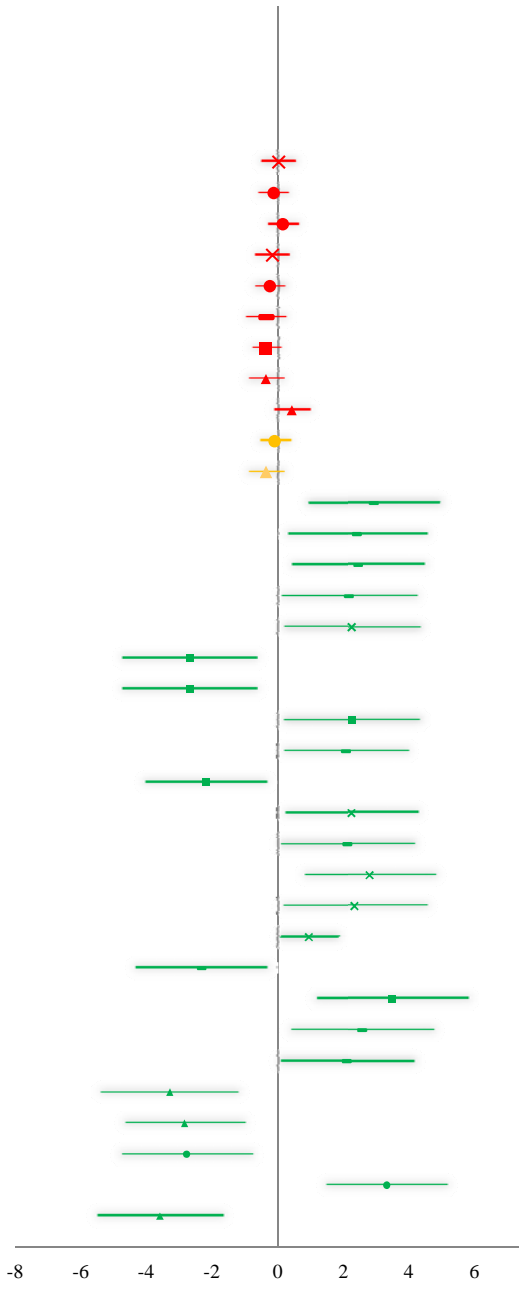


Figure 4. Three-stemmed forest-plot summary of the results for all biomechanical dependent variables during the five movement tasks [time-point 3]. Stem 1 = effect size; stem 2 = associated p-value for stem 1; stem 3 = associated standardised mean difference (SMD) for stem 2. SMD is reported as CAI relative to coper. Task-dependent variables reported as non-significant at $p > 0.05$ in the relevant study were subjected to PCA to reduce their dimensionality and are coloured red. Task-dependent variables reported with $p < 0.05$ but which did not reach the a-priori alpha level (and therefore considered non-significant) were subjected to PCA to reduce their dimensionality and are coloured amber. Individual results reported significant at the a-priori alpha level for biomechanical dependent variables are coloured green. Green variables were cross examined across time-points 1-3 to establish 'saliency' for inclusion in regression models. Pie charts describe dispersion of green variables by joint (hip/knee/ankle) and limb (involved/uninvolved). The task legend is presented in the top left corner of stem 1. For kinematic variables relating to joint, flexion/dorsiflexion are positive and extension/plantarflexion negative. For kinetic variables relating to joint extension/plantarflexion moments are positive and flexion/dorsiflexion moments negative. Abbreviations: SLS = Single limb Stance; SEBT = Star Excursion Balance Test; DL = Single-leg Drop Land; DVJ = Drop Vertical Jump; U = Uninvolved; I = Involved; CAI = Chronic Ankle Instability; PCA = Principal Components Analysis.