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What is This?

Recovery From a First-Time Lateral Ankle Sprain and the Predictors of Chronic Ankle Instability

A Prospective Cohort Analysis

Cailbhe Doherty,*† PhD, Chris Bleakley,‡ BSc(Hons), PhD, Jay Hertel,§ PhD, ATC, Brian Caulfield,† PhD, John Ryan,|| FCEM, FRCSEd, FFSEM, DCH, DipSportsMed, and Eamonn Delahunt,†¶ PhD

Investigation performed at the School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland

Background: Impairments in motor control may predicate the paradigm of chronic ankle instability (CAI) that can develop in the year after an acute lateral ankle sprain (LAS) injury. No prospective analysis is currently available identifying the mechanisms by which these impairments develop and contribute to long-term outcome after LAS.

Purpose: To identify the motor control deficits predicating CAI outcome after a first-time LAS injury.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: Eighty-two individuals were recruited after sustaining a first-time LAS injury. Several biomechanical analyses were performed for these individuals, who completed 5 movement tasks at 3 time points: (1) 2 weeks, (2) 6 months, and (3) 12 months after LAS occurrence. A logistic regression analysis of several ''salient'' biomechanical parameters identified from the movement tasks, in addition to scores from the Cumberland Ankle Instability Tool and the Foot and Ankle Ability Measure (FAAM) recorded at the 2-week and 6-month time points, were used as predictors of 12-month outcome.

Results: At the 2-week time point, an inability to complete 2 of the movement tasks (a single-leg drop landing and a drop vertical jump) was predictive of CAI outcome and correctly classified 67.6% of cases (sensitivity, 83%; specificity, 55%; $P = .004$). At the 6-month time point, several deficits exhibited by the CAI group during 1 of the movement tasks (reach distances and sagittal plane joint positions at the hip, knee and ankle during the posterior reach directions of the Star Excursion Balance Test) and their scores on the activities of daily living subscale of the FAAM were predictive of outcome and correctly classified 84.8% of cases (sensitivity, 75%; specificity, 91%; $P < .001$).

Conclusion: An inability to complete jumping and landing tasks within 2 weeks of a first-time LAS and poorer dynamic postural control and lower self-reported function 6 months after a first-time LAS were predictive of eventual CAI outcome.

Keywords: ankle joint; biomechanical phenomena; kinematics; kinetics; postural balance; ankle instability

Acute ankle joint sprain represents a significant risk for participants engaged in exercise, with lateral ankle sprain (LAS) constituting the most prevalent subclassification of this injury.[21] Despite its high incidence,[21] LAS is regarded as an innocuous injury that resolves quickly with minimal treatment. The inaccuracy of this perception[1] is of pertinence to health care practitioners because the first ocurrence of LAS is a potential gateway to a sequela of chronic symptoms in the following year.[26-28] Freeman[23] was the first to propose that this gateway is established by local "articular deafferentation" at the ankle joint.

This "feedback" model of chronicity has since evolved and expanded to include "feed-forward" mechanisms of motor control[37] and the capability (or indeed, incapability) of the nervous system to exploit motor control redundancies[36] in the fulfillment of movement. In 2008, Hertel[31] suggested that chronic ankle instability (CAI) is characterized by a range of deficits that can be evaluated along a continuum of sensorimotor measures. A spectrum of human movement comprises one part of the continuum. Researchers have sought to identify movement pattern anomalies in cohorts with CAI across this spectrum: during static[20,43] and dynamic[8,29,32] postural control assessments and gait[4,10] and jumping/landing[6,16,45] tasks. Consequently, the gateway to CAI is

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considered to be partially composed of the anomalous movement patterns which individuals fall victim to in the year after injury. This hypothesis is borne out by the existence of LAS "copers," who exhibit no such movement aberrancy or symptom recurrence.[2,42] It has been theorized that copers are better able to exploit kinematical redundancies[25] after the LAS, a feat their chronically impaired counterparts are unable to realize. This is evidenced by a number of observational analyses that have identified differences between LAS copers and participants with CAI across the movement spectrum.[2,6,8,10,16,20,43,45]

Importantly, however, it is unknown whether the movement patterns that characterize these groups in this spectrum are a manifestation of their outcome or contribute to it. To our knowledge, no prospective analysis tracking a LAS population on the dichotomous outcomes of CAI or LAS coper status is currently available. Descriptive reports from our laboratory were developed to culminate in such an analysis.[6,8-10,12,14-20] Participants were recruited after sustaining a first-time LAS and were required to complete static and dynamic balance assessments and gait, jumping, and landing tasks. Biomechanical evaluations of participants performing each task were completed first within 2 weeks of injury occurrence and then 6 and 12 months later.

By extracting the most "salient" biomechanical outcomes from these reports, the objective of the current prospective cohort study was to identify which of the deficits across the movement spectrum exhibited within 2 weeks and 6 months of injury contribute to final outcome (CAI or LAS coper, determined at the 12-month time point[28]). Identifying such deficits will potentiate the development of specific rehabilitative interventions designed to reduce the risk of developing CAI after acute LAS. Our hypothesis was that 12-month outcome is underpinned by deficits across the spectrum of the movement patterns analyzed, with CAI being predicated not by 1 anomalous movement pattern during 1 of the prescribed movements but by a group of movement anomalies in the postural control, jumping/landing, and gait tasks combined. We further hypothesized that the self-reported rating scales of ankle joint function and disability utilized at each time point would be of predictive value.

METHODS

Participants

The University College Dublin Human Research Ethics Committee approved this research. All participants signed an informed consent form before testing.

A convenience sample of 82 participants was recruited from a university-affiliated hospital emergency department within 2 weeks of sustaining an acute first-time LAS injury. All participants were given basic advice on applying ice and compression for the week on discharge from the emergency department. Activities of daily living were encouraged. All participants were recreationally active. Recruitment for the current study was completed between March 1, 2012 and September 29, 2013.

Participant demographics for the LAS group are detailed in Table 1. Exclusion criteria for participation in the current study are presented in Table 2.

Design

As part of this prospective cohort study, participants were required to attend the University College Dublin biomechanics laboratory at 3 time points: within 2 weeks of injury (time point 1), 6 months (±1 week) after injury (time point 2), and then 12 months (±1 week) after injury (time point 3). Whether participants sought additional rehabilitative medical services for the treatment of their injury was recorded ("yes" or "no") at time point 3.

In a series of separately published articles, participants in the LAS cohort were evaluated as a whole at the 2-week and 6-month time points and were subsequently stratified into CAI and LAS coper subgroups at the 12-month time point.[6-20] A pictorial representation of this experimental design is depicted in Appendix Figure A1 (available online at http://ajsm.sagepub.com/supplemental).

The current investigation used the previously published articles to identify suitable ("salient") input variables from the 2-week and/or 6-month time points for a regression analysis to predict final outcome (CAI vs LAS coper). Appendix Table A1 presents operational definitions relevant to the above paragraphs.

Dependent Variables

The dependent variables for this prospective analysis were divided into 3 groups: questionnaires, biomechanical tasks, and performance.

Questionnaires. Self-reported ankle instability and ankle joint function were assessed and documented for all participants at each visit to the biomechanics laboratory, using the Cumberland Ankle Instability Tool (CAIT)[33,47] and the activities of daily living and sports subscales of the Foot and Ankle Ability Measure (FAAMadl and FAAMsport),[3] respectively. The FAAMadl and FAAMsport were considered as separate outcomes for subsequently completed data

*Address correspondence to Cailbhe Doherty, PhD, School of Public Health, Physiotherapy and Sports Science, University College Dublin, A101 UCD Health Science, Belfield, Dublin 4, Ireland (email: cailbhe.doherty@ucdconnect.ie).

†School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland.

‡Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, Co. Antrim, Northern Ireland.

§Department of Kinesiology, University of Virginia, Charlottesville, Virginia, USA.

‖St Vincent's University Hospital, Dublin, Ireland.

¶Institute for Sport and Health, University College Dublin, Dublin, Ireland.

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TABLE 1
Patient Demographics[a]

	LAS (n = 82)[b]	CAI (n = 28)[c]	LAS Coper (n = 42)[c]
Sex, n			
Male	54	17	26
Female	28	11	16
Age, y	22.78 (21.89-23.67)	23.21 (21.62-24.81)	22.74 (21.42-24.07)
Body mass, kg	76.6 (73.66-79.54)	75.53 (70.14-80.91)	73.43 (69.66-77.20)
Height, m	1.72 (1.70-1.74)	1.72 (1.69-1.75)	1.73 (1.70-1.76)

[a]Data are reported as the mean (95% confidence interval) unless otherwise indicated. CAI, chronic ankle instability; LAS, lateral ankle sprain.
[b]At the time of recruitment (within 2 weeks of injury).
[c]At time point 3 (12 months after injury).

TABLE 2
Exclusion Criteria for the LAS Group[a]

1. No previous history of LAS injury on either limb (excluding the initial acute episode)
2. No other severe lower extremity injury in the past 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 pathologic abnormality that would impair the patient's motor performance

[a]LAS, lateral ankle sprain.

analyses. Participants' designation as CAI or LAS coper status at time point 3 was based on CAIT scores[26-28,47]: participants with a CAIT score <24 were designated as having CAI, whereas participants with a CAIT score ≥24 were designated as LAS copers.[47] Furthermore, to be designated as a LAS coper, participants also must have returned to preinjury levels of activity and function and must have reported no instances of giving way at their ankle joint.[42]

Biomechanical Tasks. After completion of the questionnaires, participants were tested with the Codamotion bilateral lower limb gait setup (Charnwood Dynamics Ltd). The Codamotion setup was fully integrated with 2 walkway-embedded force plates (AMTI) and was time synchronized for the experimental protocol. Force plate data were integrated with kinematic data using an inverse dynamics procedure to calculate internal joint moments.[46] Ground-reaction force and center of pressure data were also acquired. A full description of this Codamotion setup and link segment model construction with inverse dynamics is published in greater detail elsewhere[39] and is reported separately in previously published articles.[6-20]

Participants were familiarized with the experimental protocol before commencement. After familiarization, participants attempted to complete a protocol of 5 movement tasks. The 5 movement tasks utilized for evaluation were as follows: single-limb stance (SLS; eyes open and eyes closed); the anterior (ANT), posterolateral (PL), and posteromedial (PM) reach directions of the Star Excursion Balance Test (SEBT); a single-leg drop landing (DL); a drop vertical jump (DVJ); and walking gait. All unilateral tasks (SLS, SEBT, and DL) were completed on both the limb affected by the initial LAS (designated the involved limb) and the contralateral limb (designated the uninvolved limb). The tasks were completed in the order in which they are described above. The task order was not randomized so as to avoid any potential injury exacerbation early in the test protocol; for this reason, we deemed it necessary to complete the less dynamic tasks (including the SLS and SEBT) before completing the jumping/landing and gait tasks. All tasks were completed in the barefoot condition.

The experimental protocol for each task is described in Appendix 1. A pictorial representation of the biomechanical dependent variables for each task is available in Figure 1, and definitions of these are presented in Appendix 2. A thorough description of the biomechanical dependent variables relevant to each task has been published previously[6-20] and is presented in Appendix Table A2.

Performance. The performance-related dependent variables for this investigation were scores accomplished in an assessment of ankle dorsiflexion range of motion (ROM) (the knee to wall test as described by Denegar et al[5]) and during the reach attempt for the specified reach directions of the SEBT at each time point.

Reach distances during the SEBT were averaged across the 3 completed trials for each participant in each direction (ANT, PL, and PM) at each time point and were normalized to leg length before data aggregation and analysis.[30]

Data Management and Statistical Analysis

In the previously published articles on each task at each time point,[6-20] dependent variables were calculated separately for every task attempt and averaged across the required number of task repetitions. In all data analyses, the involved and uninvolved limbs of each group were analyzed.

In attempting to identify the predictors at time point 1 and/or time point 2 of CAI/LAS coper status (which was confirmed at time point 3), our approach consisted of a 3-step process: (1) identify the salient biomechanical dependent variables for regression analysis on the basis of the previously published articles, (2) prepare these variables for regression, and (3) perform regression analysis in a model that also includes questionnaire and performance

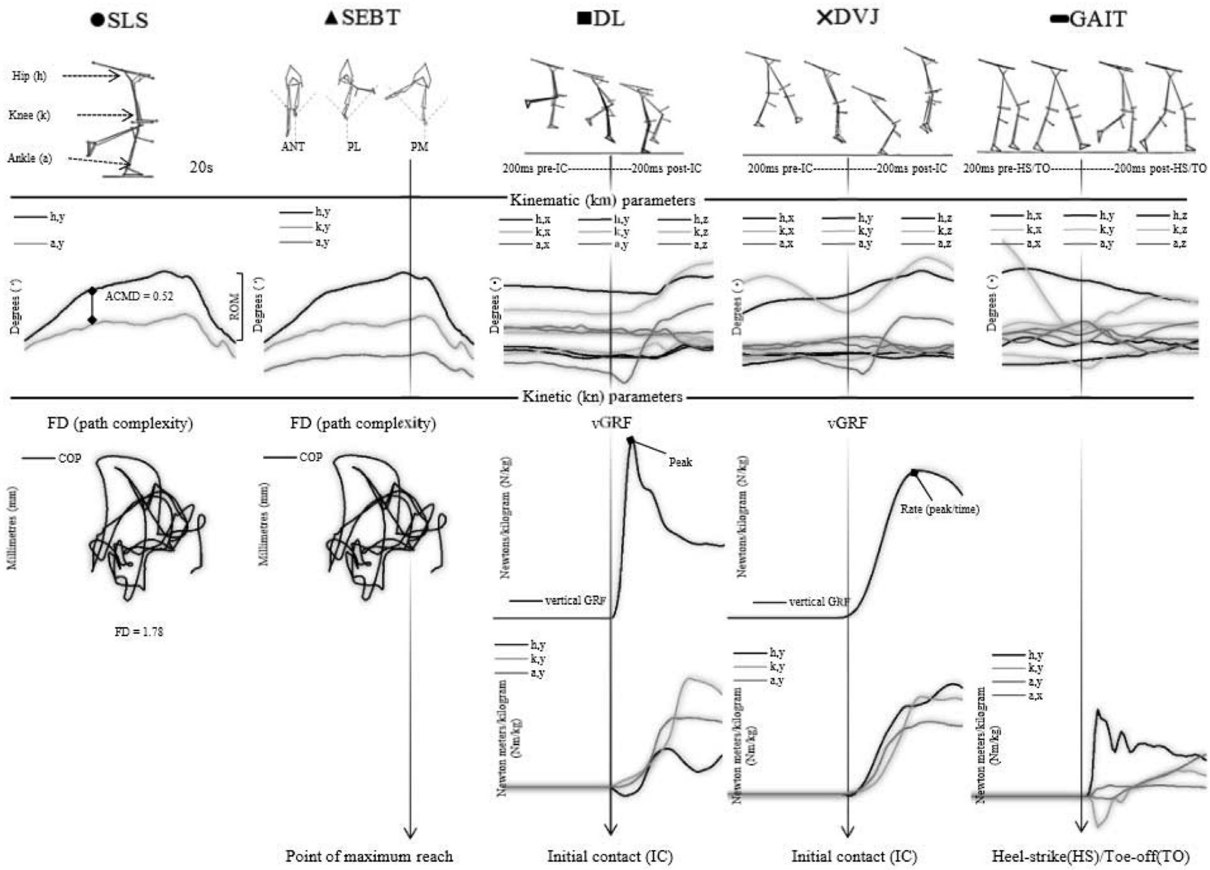

Figure 1. Pictorial representation of the 5 movement tasks, their dependent variables, and the events analyzed for each limb. ACMD, adjusted coefficient of multiple determination; ANT, anterior reach direction of the Star Excursion Balance Test; COP, center of pressure; DL, single-leg drop landing; DVJ, drop vertical jump; FD, fractal dimension; GRF, ground-reaction force; HS, heel strike; IC, initial contact; PL, posterolateral reach direction of the Star Excursion Balance Test; PM, posteromedial reach direction of the Star Excursion Balance Test; SLS, single-limb stance; SEBT, Star Excursion Balance Test; TO, toe off; x, frontal planes of motion; y, sagittal planes of motion; z, transverse planes of motion.

dependent variables where appropriate. This statistical analysis model for the biomechanical group of dependent variables is described in Appendix 3.

A full description of the stepwise approach completed as part of our analysis model is detailed in the online Appendices for this article. Briefly, 21 salient biomechanical dependent variables were first extracted from the previously published articles[6-20] (see Appendix Methods, section 1, available online). These variables are described in Table 3.

Of the participants that attended the laboratory at each time point, complete data sets were available only for the questionnaire group of dependent variables. With regard to task performance and the biomechanical variables, participants were frequently either unable or unwilling to complete or attempt the prescribed task. These occurrences were most frequent at time point 1, wherein injury severity was the primary reason cited predicating an inability/unwillingness to complete/attempt a given task. Such instances manifested in incomplete data sets. To accommodate missing data values, a multiple imputation procedure was implemented, provided that data availability reached predetermined thresholds (Appendix Methods, section 2).

After imputation, the complete data sets were subjected to a principal components analysis (PCA) to reduce their dimensionality. Of the remaining eligible variables after imputation procedures, 13 were included from time point 1 and 19 were included from time point 2. The methods for PCA of biomechanical dependent variable data are presented in the Appendix Methods (section 3).

In summary, 13 biomechanical variables from time point 1 were reduced to 2 factors, with 2 independent salient outcomes (relating to the SEBT and gait tasks) for separate consideration. For time point 2, 19 biomechanical variables were reduced to 3 factors, with 3 independent salient outcomes (relating to the SLS, SEBT, and DL tasks) for separate consideration. The pattern and structure coefficients are presented for the factors in Appendix 4 for time points 1 and 2 separately.

These 4 potential biomechanical predictors for time point 1 (2 factors plus 2 independent salient outcomes) and 6 potential predictors for time point 2 (3 factors

TABLE 3
Numerical Coding of the 21 Identified "Salient" Biomechanical Dependent Variables From the 5 Movement Tasks[a]

Task and Parameter	Variable	Time Point 1		Time Point 2	
		Included	% Missing	Included	% Missing
SLS					
Eyes closed					
Kinematic	ACMD hip (flexion/extension)–ankle (inversion/eversion) "coupling"	X	63	X	47
Kinetic	Center of pressure, fractal dimension	X	63	X	47
Eyes open					
Kinematic	1. ACMD hip (flexion/extension)–ankle (inversion/eversion) "coupling"	✓	6	✓	3
Kinetic	2. Center of pressure, fractal dimension	✓	6	✓	3
SEBT: kinematic					
ANT	3. Knee flexion	✓	6	✓	3
	4. Ankle dorsiflexion	✓	6	✓	3
PL	5. Hip flexion	✓	6	✓	3
	6. Knee flexion	✓	6	✓	3
	7. Ankle dorsiflexion	✓	6	✓	3
	8. Knee flexion[b]	✓	4	✓	3
PM	9. Hip flexion	✓	6	✓	3
	10. Knee flexion	✓	6	✓	3
	11. Ankle dorsiflexion	✓	6	✓	3
	12. Knee flexion[b]	✓	4	✓	3
SEBT: kinetic					
PL	13. Center of pressure, fractal dimension	✓	6	✓	3
Single-leg drop landing					
Kinematic	14. Hip flexion (maximum before initial contact)	X	73	✓	24
	15. Hip flexion (maximum before initial contact)[b]	X	50	✓	24
Kinetic	16. Hip flexion moment (maximum after initial contact)	X	73	✓	24
Drop vertical jump: part 1					
Kinematic	17. Hip flexion (maximum before initial contact)	X	54	✓	27
Drop vertical jump: part 2					
Kinetic	18. Hip flexion moment (maximum after initial contact)[b]	X	54	✓	27
	19. Hip flexion moment (maximum after initial contact)[b]	X	54	✓	27
Gait					
Kinematic	20. Hip extension (maximum before toe off)	✓	6	✓	3
	21. Ankle inversion (maximum before toe off)	✓	6	✓	3

[a]Distribution of data completeness is also depicted in the table. If variables were not eligible for imputation for either time point 1 or 2 (eg, the eyes-closed SLS variables), they were not assigned a number. A checkmark indicates eligible for multiple imputation (≥40% data unavailability), whereas an "X" indicates not eligible for multiple imputation (≥40% data unavailability). ACMD, adjusted coefficient of multiple determination; ANT, anterior reach direction of the Star Excursion Balance Test; max, maximum PL, posterolateral reach direction of the Star Excursion Balance Test; PM, posteromedial reach direction of the Star Excursion Balance Test ; SEBT, Star Excursion Balance Test; SLS, single-limb stance.
[b]Relates to the uninvolved limb.

plus 3 independent salient outcomes), in addition to the questionnaire and performance groups of dependent variables, were then subjected to preliminary univariate statistical analysis (Pearson *r*) to evaluate their association with final outcome (CAI vs LAS coper). Variables were entered into a direct logistic model provided their correlation to outcome was significant at the level of $P < .05$.

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

RESULTS

Follow-up and Rehabilitation

Of the original 82 injured participants, 71 completed the 6-month follow-up, with 70 participants completing the 1-year follow-up; these final 70 were included in the prospective analysis. Of the final 70 participants, 28 (40%) were designated as having CAI and 42 (60%) were designated as LAS copers (see Appendix Figure A1, available online). Twenty-eight of these participants (40%) did not seek rehabilitative medical services, whereas 42 (60%) did.

A chi-square test for independence indicated no significant association between rehabilitation and outcome (CAI/coper) (χ^2(1, n = 80) = 1.21; P = .27; phi = 0.17).

Preliminary Univariate Statistics and Regression

After preliminary correlation analysis, no potential predictors at the 2-week time point were identified. However, because of the large amount of missing data secondary to participants being unwilling or unable to attempt some or all of the movement tasks, an exploratory analysis was conducted to evaluate the relationship between task completion at this time point and final outcome. First, a chi-square test for independence was utilized to evaluate any association between outcome (CAI vs LAS coper) and task completion on the involved limb (where appropriate) for the movement

TABLE 4
Results of the Logistic Regression Analysis for the Input Variables at the 2-Week Time Point[a]

Variable	$\hat{b}$	SE $\hat{b}$	$\hat{\beta}$	Wald *t*	*P* Value	OR (95% CI)
Drop landing (involved limb)	−0.98	0.94	−0.06	1.08	.30	0.38 (0.06-2.39)
Drop vertical jump	−1.30	0.68	−0.10	3.63	.06	0.27 (0.07-1.04)
Constant	4.21	1.61	—	6.87	.01	67.08 (0.00-0.00)

[a]95% CI, 95% confidence interval; $\hat{b}$, standardized beta weight; $\hat{\beta}$, semistandardized beta weight using the mean predicted probability of 0.636 as a reference value; OR, odds ratio; SE = standard error.

tasks responsible for the greatest majority of missing data: the eyes-closed SLS, DL, and DVJ tasks. A significant association was noted between outcome and task completion for the DL ($\chi^2(1, n = 80) = 4.9$; $P = .02$; phi = −0.31) and DVJ ($\chi^2(1, n = 80) = 7.9$; $P < .01$; phi = −0.37) tasks. Based on this, DVJ and DL task completion were entered into a direct logistic regression model. The dependent variable was outcome. This model was statistically significant ($\chi^2(2, n = 68) = 10.96$; $P = .004$), explained between 14.9% (Cox and Snell R^2) and 20.0% (Nagelkerke R^2) of the variance in outcome, and correctly classified 67.6% of cases. The sensitivity and specificity of the final model was 83.3% and 55.3%, respectively (Table 4).

Six potential predictors were identified at the 6-month time point (CAIT and FAAMadl scores; reach distances in the ANT and PL directions of the SEBT [involved limb]; factor 1, which related to joint kinematics during the SEBT; and salient parameter 16, which related to joint kinetics during the DL task). Results of preliminary correlation analyses for time points 1 and 2 are presented in Appendix Table A3 and Appendix Table A4, respectively. Descriptive statistics for the 6 potential predictors at time point 2 are presented in Table 5.

These potential predictors were entered into a direct logistic regression model in 1 block. CAIT score, ANT reach distance, and salient DL parameter 16 were then removed using a backward elimination technique in the optimization of the predictive capacity of the model. The regression analysis was then repeated.

The model was statistically significant ($\chi^2(2, N = 68) = 28.99$; $P < .001$), explaining between 34.7% (Cox and Snell R^2) and 47.5% (Nagelkerke R^2) of the variance in outcome and correctly classifying 84.8% of cases. The sensitivity and specificity of the final model was 75% and 91%, respectively (Table 6). Reflection of the structure and pattern coefficients for factor 1 revealed that it represented salient biomechanical parameters 3 to 12 inclusive for the SEBT (involved limb: sagittal plane joint positions at the hip, knee and ankle in the PL and PM directions, and at the knee and ankle for the ANT direction; uninvolved limb: sagittal plane joint positions at the knee in the PL and PM directions) (see Appendix 4, available online).

The results from the preliminary correlation and subsequent regression analyses with multiple imputation were largely consistent with those from a complete case analysis (Appendix Results and Appendix Tables A5 and A6, available online).

TABLE 5
Descriptive Statistics of the Variables Selected for Regression Analysis[a]

	6-Month Time Point	
	CAI	LAS Coper
CAIT score, of 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
Variable 16, N·m/kg[b]	0.55 ± 1.10	0.12 ± 0.55

[a]Data are reported as the mean ± SD. %LL, percentage of limb length; ACMD, adjusted coefficient of multiple determination; ANT, anterior reach direction of the Star Excursion Balance Test; CAIT, Cumberland Ankle Instability Tool; FAAMadl, activities of daily living subscale of the Foot and Ankle Ability Measure; PL, posterolateral reach direction of the Star Excursion Balance Test; PM, posteromedial reach direction of the Star Excursion Balance Test; SEBT, Star Excursion Balance Test.

[b]Salient biomechanical variable 16 relates to hip flexion moment after ground contact during the single-leg drop landing task.

DISCUSSION

Findings from this study reveal that a number of salient variables identified at the 6-month time point after a first-time LAS injury are directly predictive of 12-month outcome (CAI vs LAS coper). PCA was utilized to reduce the dimensionality of the salient biomechanical outcomes in this study: factor 1 represented sagittal plane joint positions for both the involved (ANT: knee, ankle; PL/PM: hip, knee, and ankle) and uninvolved (PL/PM: knee) limbs. Because of the positive correlation of factor 1 to the aforementioned sagittal plane motions during the SEBT (see Appendix 4, available online), and in light of the negative mean value for the CAI group for this outcome (Table 5), we can deduce that participants who exhibited deficits in these movement patterns during the specified reach directions at the 6-month time point had over twice the odds of developing CAI as part of the final prediction equation[40] (Table 6).

The CAI literature is replete with studies that have sought to identify the movement patterns that characterize CAI.[2,4,5,8] To our knowledge, this is the first prospective analysis of individuals recruited after they incurred a first-time LAS and it is the first study that has tracked

TABLE 6
Results of the Logistic Regression Analysis for the Input Variables at the 6-Month Time Point[a]

Variable	$\hat{b}$	SE$\hat{b}$	$\hat{\beta}$	Wald t	P Value	OR (95% CI)
FAAMadl	0.18	0.06	0.29	8.52	.004	1.19 (1.06-1.34)
PL	0.02	0.03	0.06	0.40	.525	1.02 (0.96-1.09)
Factor 1	0.91	0.40	0.21	5.07	.024	2.48 (1.13-5.49)
Constant	−17.94	6.16	—	8.48	.004	0.00 (0.00-0.00)

[a]95% CI, 95% confidence interval; $\hat{b}$, standardized beta weight; $\hat{\beta}$, semistandardized beta weight using the mean predicted probability of 0.636 as a reference value; FAAMadl, activities of daily living subscale of the Foot and Ankle Ability Measure; PL, posterolateral reach direction of the Star Excursion Balance Test; OR, odds ratio.

this 12-month divergence across a range of movement tasks and identified the post-LAS risk factors for CAI development. It is important to note that although the CAI subgroup was classified in accordance with recently published guidelines, it may be representative of a population early in the disease process; it is plausible that the CAI paradigm worsens with time, wherein deteriorations in functional ability may yet continue outside the time period we evaluated.[35]

Inconsistencies in the literature concerning the principal CAI-defining movement deficits[38] compelled us to use a series of descriptive analyses of this LAS cohort[6-20] to inform our choice of dependent variables for the regression analyses detailed in this article. Our hypothesis was that the salient biomechanical outcomes identified via this process would represent a conglomeration of deficits across a spectrum of human movement in the CAI group.[31] The finding that the deficits exhibited by the CAI group were generally isolated to only one part of this spectrum (the SEBT task) contradicted our primary hypothesis.

Differences in both reach distance performance and its underlying movement during the SEBT are well documented in CAI populations relative to both noninjured controls[29,32,41] and LAS copers.[41] Our findings in relation to factor 1 not only contradict the notion that the limb contralateral to the side of injury is “uninvolved,” but they also implicate proximal joints (hip/knee) in the coping mechanisms of LAS.

Whether these deficits in ROM at the hip and knee joints originate from restrictions at the distal ankle magnifying proximally or from central motor control mechanisms deserves consideration. Deficits in ankle dorsiflexion ROM as determined using the knee to wall test have been shown to impair reach performance in the ANT direction of the SEBT[34]; however, in the current study, this performance measure (the knee to wall test) yielded no significant correlation to outcome at any of the time points. Therefore, it is likely that the observed sagittal plane ROM deficits are a manifestation not of current structural or morphological “blocks” at the ankle but of spinal and/or supraspinal alterations in motor control mechanisms after the initial LAS.[22,31] It is also possible that the cascade of motor control alterations that led to CAI began with the acute injury, wherein morphological restrictions were present but have since subsided.[44] The presence of static and dynamic postural control deficits in LAS participants both within 2 weeks[9,13,19] and 6 months[7,18] after injury occurrence is in agreement with this.[31] In the current study, CAI participants exhibited bilateral deficits in dynamic postural control compared with LAS copers (as factor 1 represented sagittal plane knee motion during the SEBT on the uninvolved limb). This is of clinical importance, because rehabilitation programs must be thus designed with the bilateral nature of these deficits in mind.

Although the salient outcomes from the dynamic tasks (the DL and DVJ) did not contribute to the prediction equation, it is worth noting that the outcome relating to hip flexion moment after ground contact during the DL would have had some predictive value if it were entered into the regression equation independently. We were surprised by this “redundancy” and the lack of significant independent contributors for outcome for the variables from the dynamic movement tasks. However, their lack of contribution to prediction is partly elucidated in lieu of the fact that as part of the data imputation procedures, some of the salient biomechanical outcomes relating to these tasks were removed entirely due to excessive data “missingness.” Indeed, the variables relating to the eyes-closed variant of the SLS task could not even be considered at either time point for regression due to missingness of data, with the DL and DVJ tasks similarly oriented at time point 1. This prompted an exploratory evaluation, which revealed that whether an individual can actually complete certain jumping and/or landing movement tasks within 2 weeks of incurring a first-time LAS has some predictive value; the odds ratios in the combined prediction model for task completion revealed that inability or unwillingness to complete the DL and DVJ tasks increased the odds of developing CAI by 2 to 3 times. This is an interesting finding and is likely predicated by underlying injury severity. However, although this model had good sensitivity (80%), its specificity was moderate (55%) and therefore likely to produce a large number of false-negative results. The specificity of the model was potentially belied by the fact that no distinction was made between an inability (wherein a participant attempted the task but was unable to complete it due to its difficulty) and an unwillingness (wherein a participant did not attempt the task, citing an associated fear of injury exacerbation) to complete the task during test protocol; this was a post hoc exploratory analysis and not part of the a priori study design.

With regard to the kinematics and energetics of these tasks, we offer that these components of the movement spectrum are likely to be useful in the assessment of LAS and CAI populations; however, because of problems with task completion and data missingness, this is not reflected in the current study. This is evidenced by the fact that findings from the exploratory reports, wherein findings were simply presented for the data that were available, identified deficits that were persistent across time points (namely, increased hip-ankle coupling during SLS[18-20] and increased hip flexion during the DL and DVJ tasks[6,14-17]).

That deficits in hip joint control seemed to be a continuous theme in both the descriptive reports[6-20] and in the final regression analysis of the current study is an interesting finding. Reflection of the forest plots used to extract the salient biomechanical outcomes illustrates this (see Appendix Figures A2 to A4, available online), whereby the hip was the predominant lower extremity joint at which biomechanical deficits manifested in the CAI group at the 12-month time point. It is plausible that the aforementioned alterations in central motor control mechanisms involved central control dissonance at the ankle joint with increased reliance on hip joint movement strategies to fulfill postural control (both static and dynamic)[8,9,13,18-20] and jumping/landing tasks.[6,14-17] We speculate that hip joint stability and the strength or activation of its supporting musculature is likely to be a central characteristic of the coping mechanisms exhibited by CAI or coper participants, directly affecting global movement mechanics and foot positioning.[24]

On the basis of these findings, we believe that rehabilitation after LAS should incorporate the full spectrum of human movement and should contextually encourage the appropriate use of hip-based and/or ankle-based static and dynamic movement strategies. The current research cannot confirm the potential efficacy of such an approach, however, but may inform future intervention studies of LAS populations. We believe that the efficacy of training programs for CAI treatment compared with controls would be potentiated using a structured approach that includes (1) the entire movement spectrum, (2) both the injured limb and the contralateral limb, and (3) hip- and ankle-based static and dynamic movement tasks, for the reasons we have alluded to above.

That our secondary hypothesis was confirmed by the results of the current study should be of particular interest to clinicians, because the self-report questionnaires relating to ankle joint function have the advantage of "clinical accessibility."

In fact, on the basis of the standardized beta weights for the variables in the combined prediction model at the 6-month time point, the FAAMadl contributed most to the prediction equation (Table 6). On the basis of these findings, we would encourage clinicians to incorporate this outcome in a goal-oriented rehabilitation program design, because it could be used to give an indication of the likelihood that a patient will (or will not) develop CAI.

It is unfortunate that no predictors from the salient outcomes emerged at the 2-week time point in the current study, because this is the time that clinicians are most likely to encounter their patients and have the ability to implement preventive measures, before the onset of chronic sequelae. It is likely that the 2-week window of eligibility for assessment undermined the homogeneity of our sample at this time point, thus increasing the chance of sampling error. This must be recognized as a limitation of the current study. However, because of the high prevalence of LAS in the general population, the difficulty in actually recruiting patients with a first-time LAS would have been compounded further if we were only able to assess them in a predetermined 24-hour interval, thus threatening the feasibility of the study. Another limitation of this research is that we did not have access to imaging techniques such as magnetic resonance imaging to quantify the extent or severity of the incurred injury in an objective manner. As previously noted, injury severity likely played a role in participants' ability to complete the prescribed tasks. Although this was not continuous with our experimental objectives, the importance of the mechanical insufficiencies (such as ligament damage and osteochondral defects) associated with acute LAS in the CAI paradigm remain unclear. This limitation is compounded by the fact that it was beyond our resources to quantify the type of rehabilitation protocols undertaken by the cohort. Finally, because the LAS cohort participants were recruited after the initial injury, it is unknown whether the deficits identified either in the descriptive research reports[6-20] or in this prospective analysis preceded or were caused by the first instance of LAS.

In conclusion, this analysis has identified several clinically accessible and biomechanical outcomes that have predictive capacity of long-term outcome 2 weeks and 6 months after a first-time LAS injury. These findings have implications for clinicians, who can use these simple outcomes in goal-oriented rehabilitation programs and to assess the risk a given patient has for developing CAI, and for researchers, who should attempt to develop rehabilitation programs on the basis of the biomechanical deficits identified.

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