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Running title: Acute ankle sprain alters postural control strategies during single limb stance.

ABSTRACT

Background: Single-limb stance is maintained via the integration of visual, vestibular and somatosensory afferents. Musculoskeletal injury challenges the somatosensory system to reweight distorted sensory afferents. This investigation supplements kinetic analysis of eyes-open and eyes-closed single-limb stance tasks with a kinematic profile of lower limb postural orientation in an acute ankle sprain group to assess the adaptive capacity of the sensorimotor system to injury.

Methods: Sixty-six participants with acute ankle sprain completed eyes-open single-limb stance on their injured and non-injured limbs. Twenty-three of these participants successfully completed single-limb stance with their eyes closed. A non-injured control group of nineteen participants completed eyes open single-limb stance, with 16 completing eyes closed single-limb stance. 3-dimensional kinematics of the hip, knee and ankle joints as well as associated fractal dimension of the center-of-pressure path were determined for each limb during these tasks.

Findings: Between trial analyses revealed significant differences in stance limb kinematics and fractal dimension of the center-of-pressure path for eyes closed single-limb stance. The control group bilaterally assumed a position of greater hip flexion compared to ankle sprain participants on their side-matched “involved” (7.41 +/-6.1° vs 1.44 +/-4.8°; $\eta^2 = .34$) and “uninvolved” (9.59 +/-8.5° vs 2.16 +/-5.6°; $\eta^2 = .31$) limbs, with a greater fractal dimension of the center-of-pressure path (involved limb = 1.39 +/-0.16° vs 1.25 +/-0.14°; uninvolved limb = 1.37 +/-0.21° vs 1.23 +/-0.14°).

Interpretation: Acute ankle sprain causes bilateral impairment in postural control strategies.

Key words: ankle joint [MEsH]; biomechanics [MEsH]; kinematics [MEsH]; kinetics [MEsH]; postural balance [MEsH]

Introduction

Balance is a generic term describing the dynamics of body posture to prevent falling (Winter, 1995). Information about body posture in single-limb stance (SLS) with respect to the force of gravity is provided to the central nervous system by vestibular, visual and somatosensory afferents (McCollum G, 1996). The vestibular system acts to detect linear and angular accelerations, vision is the afferent primarily involved in planning movement while the somatosensory system is composed of a multitude of sensors that detect the position and velocity of all body segments, their contact with external objects, and the orientation of gravity (Winter, 1995). The ability of the structurally different sensory afferents (otherwise known as ‘degeneracies’(Glazier, 2009)) to combine and produce similar efferent motor responses allows the sensorimotor system to simplify a task within a limited number of movement strategies (Nashner, 1979). Selective reweighting of these degeneracies by the central nervous system is then based on the availability of reliable information (McKeon PO, 2012). As a result, it is possible for the functioning somatosensory system to produce a motor output contingent with maintaining balance in the presence of altered visual, vestibular and/or somatosensory signals (McCollum G, 1996). Despite this, some deterioration in the efferent response may become evident in simple postural control tasks (Winter, 1995).

Kinematic (Liu et al., 2012) and centre of pressure (COP) (Prieto, 1996) analyses have been previously used to quantify the motor response associated with distorted sensory environments during single limb stance in a variety of populations. A number of measures are currently available with which to characterise the COP path trajectory. However, traditional measures such as those that determine the area, length and velocity of the COP path have often yielded inconsistent or contradictory findings (McKeon and Hertel, 2006b) and have questionable reliability (Doyle TL, 2005). Furthermore, a newly developed measure of COP excursion called time-to-boundary (TTB) has shown potential in a number of studies (Hertel and Olmsted-Kramer, 2007, McKeon and Hertel, 2006a), but is limited by the requirement that participants must assume a foot placement contingent with assumptions required to calculate the value, which may restrict the observation of natural balance strategies and postural orientations. In contrast, fractal dimension (FD) is a technique which has previously been used in COP analyses (Doyle TL, 2005, Cimolin, 2011, Prieto, 1996, Błaszczyk, 2001, Manabe et al., 2001) to provide an indication of the complexity of the COP signal by describing its shape. Briefly, a straight line would have a fractal dimension equal to 1; a line so convoluted as to completely fill a plane has a dimension approaching the dimension of the plane (i.e. equal to 2; the standard dimension of a plane), and a line that ‘piles up in the plane’ by repeatedly crossing and re-crossing itself can have a fractal dimension of >2 (Katz and George, 1985). FD has previously been utilized successfully in COP analysis to characterise a degeneration in stability of the postural control system (Błaszczyk, 2001).

Musculoskeletal injury has the potential to challenge postural stability via a direct disturbance of somatosensory afferents, consequently challenging the system to reweight information to produce a suitable efferent response, and has been shown to manifest in bilateral balance deficits following acute lateral ankle sprain (LAS) (Wikstrom EA, 2010). LAS has previously been shown to be a significant injury risk in a wide variety of activity types (Doherty, 2014) and despite a number of studies presenting COP analyses of participants with acute LAS injury during SLS (Evans T, 2004, Hertel J, 2001, Leanderson et al., 1996, Holme et al., 1999, Fridén T, 1989), no current investigation has supplemented these analyses with a kinematic profile of postural orientation. Furthermore, no previous research has explored the capacity of the somatosensory system to cope in the absence of vision during the same task, in this group.

Therefore, the purpose of the current investigation was to assess the effects of acute LAS on balance using kinematic and COP analyses in the presence and absence of visual afferents (i.e. eyes-open and eyes-closed SLS). We hypothesized that acute LAS would result in a reduction in participant self-reported function and would cause bilateral modification of postural kinematic orientation strategies when compared to control subjects, which would be reflected by COP trajectory measures sensitive to eyes-open and eyes-closed SLS. Such an analysis may serve to elucidate the strategies used by a somatosensory system challenged not only in organising distorted somatosensory afferents secondary to injury, but also in coping without previously available visual degeneracies (Overstall PW, 1977).

Methods

Participants

Sixty-six participants (forty-three males and twenty-three females; age 23.2 +/- 5 years; body mass 75.8 +/- 14.5 kg; height 1.73 +/- 0.1 m) were recruited from a University-affiliated hospital Emergency Department within 2 weeks of sustaining a first-time LAS for the current investigation. The following inclusion criteria were applied to all potential participants: (1) no previous history of ankle sprain injury (excluding the recent acute episode for the injured group); (2) no other lower extremity injury in the last 6 months; (3) no history of ankle fracture; (4) no previous history of major lower limb surgery; (5) no history of neurological disease, vestibular or visual disturbance or any other pathology that would impair their motor performance. An additional group of nineteen uninjured participants (fifteen males and four females; age 22.5 +/- 1.7 years; body mass 71.55 +/- 11.3 kg; height 1.74 +/- 0.1 m) with no prior history of LAS were recruited from the hospital catchment area population using posters and flyers to act as a control group. Participants were required to sign an informed consent form approved by the University Human Research Ethics Committee on arrival to the University biomechanics laboratory.

Questionnaires

Self-reported function, patient reported symptoms and functional ability as measures of LAS severity were assessed using the activities of daily living and sports subscales of the Foot and Ankle Ability Measure (FAAMadl and FAAMsport) (Carcia, 2008). Overall ankle joint function and symptoms were evaluated using the Cumberland Ankle Instability Tool (CAIT) (Hiller, 2006).

Procedures

Prior to completion of the SLS task, participants were instrumented with the Codamotion bilateral lower limb gait set-up (Charnwood Dynamics Ltd, Leicestershire, UK). Following collection of specific anthropometric measures required for the calculation of internal joint centres at the hip, knee and ankle joints, lower limb markers and wands were attached, as described by Monaghan et al. (Monaghan, 2006, Monaghan, 2007). A neutral stance trial was used to align the subject with the laboratory coordinate system and to function as a reference position for subsequent kinematic analysis as recommended in previously published literature (McLean, 2007). Kinematic data acquisition was made at 1000 Hz using 3 Codamtion CX1 units and kinetic data at 100 Hz using 2 AMTI (Watertown, MA) walkway embedded force-plates. The Codamotion CX1 units were time synchronized with the force-plates.

Single-leg stance trials

Participants performed three, 20 second trials of quiet SLS barefoot on a force- plate with their eyes open on both limbs, each separated by a 30 second break period. Following another 2 minute rest period, these participants then attempted to complete the SLS task with their eyes closed. Participants were required to complete a minimum of three practice trials on each limb for each condition prior to data acquisition. Participants who were unable to complete a full trial of SLS in the eyes closed condition after five attempts on both limbs were not included in this part of the analysis. The test order between legs was randomized. For both conditions of SLS, subjects were instructed to stand as still as possible with their hands resting on their iliac crests while adopting a postural orientation most natural to them; the position of the non-stance limb was not dictated as part of experimental procedures. Trials were deemed invalid if the subject lifted their hands off their iliac crests, placed their non-stance limb on the support surface, moved their non-stance hip into a position > 30 degrees abduction or lifted their forefoot/heel. A trial was deemed as failed in the eyes closed condition if the subject opened their eyes at any point.

Data Processing of Kinematics and COP measures

Kinematic data were calculated by comparing the angular orientations of the coordinate systems of adjacent limb segments using the angular coupling set ‘‘Euler angles’’ to represent clinical rotations in three dimensions. Marker positions within a Cartesian frame were processed into rotation angles using vector algebra and trigonometry. Discrete whole-trial averaged joint angular position values were calculated for the hip, knee and ankle joints in the sagittal, transverse and frontal planes of motion, producing nine ‘joint position’ dependent variables of interest for each limb.

Kinetic data acquired from the trials of SLS were used to compute the FD of the COP path. The COP is a bivariate distribution, jointly defined by the antero-posterior (AP) and medio-lateral (ML) coordinates which in a time series define its path relative to the origin of the force platform (Prieto, 1996). The AP and ML time series were passed through a fourth-order zero phase Butterworth low-pass digital filter with a 5-Hz cut-off frequency. We have adopted an algorithm previously published and described in the seminal paper by Prieto et al (Prieto, 1996) to calculate FD of the combined AP and ML COP paths. FD was calculated based on the 20 second interval for each SLS trial, and averaged across the three trials for each participant on each limb.

Data Analysis and Statistics

For the LAS group, limbs were labelled as ‘‘involved’’ and ‘‘uninvolved’’ based on FAAM and CAIT results. For all outcomes, we calculated mean (SD) scores for the involved and uninvolved limbs in the LAS group, and mean (SD) scores for the left and right limbs in the control group. Participant characteristics were compared between the LAS and control groups using multivariate analysis of variance. The dependent variables were age, mass, sex and height. The independent variable was status (injured *vs* non-injured).

In order to test our hypothesis that acute LAS would cause bilateral changes in COP and kinematic measures of postural orientation, we undertook a series of independent samples t-tests for each outcome comparing: involved limb *vs* control, and uninvolved limb *vs* control. In all cases the limbs in the control group were side matched to the injured group. The significance level for analyses were adjusted for multiple tests using the Benjamini-Hochberg method for false discovery rate (<5%) (Benjamini, 1995). All data were analyzed using Predictive Analytics Software (Version 18, SPSS Inc., Chicago, IL, USA).

Results

Regarding participant characteristics there was no statistically significant difference between the LAS and control groups on the combined dependent variables, F (4, 80) = 1.75, p = 0.14; Wilk's Lambda = 0.91; partial eta squared = 0.08. Regarding function the CAIT score for the ankle sprain group was 11.85 +/-7.91. The FAAMadl score for the ankle sprain group was 68.50 +/-18.65%. The FAAMsport score for the ankle sprain group was 32.11 +/-23.85%. Participant characteristics and questionnaire score are detailed in Table 1.

All participants completed the eyes-open SLS task on both limbs. Of the sixty-six participants in the LAS group, twenty-three completed the SLS task with their eyes-closed on both their involved and uninvolved limbs. Of the nineteen participants in the control group, sixteen completed the SLS task with their eyes-closed on both limbs.

There was no significant difference in eyes-open SLS kinematics between the LAS and control groups for the involved and uninvolved limbs. There was no significant difference in eyes-open SLS FD scores for the LAS and control groups involved and uninvolved limbs.

There was a significant difference in eyes-closed SLS kinematics between the LAS and control groups for the involved and uninvolved limbs. Multiple testing with a false discovery rate of less than 5% revealed that control group exhibited increased hip flexion compared to LAS group on both the involved (control group: 7.41 +/-6.1º, LAS group: 1.44 +/-4.8º; t (1, 38) = -3.42, p = 0.001, two tailed) and uninvolved (control group: 9.59 +/-8.5º, ankle sprain group: 2.16 +/-5.6º; t(1, 38) = -3.30, p = 0.002, two tailed) limbs. The magnitude of the differences in the means for the involved limb was -5.96º (95% CI: -9.49 to -2.43º) and -7.4º

(95% CI: -11.98 to -2.87º) for the uninvolved limb. Means +/-SD for each joint in each plane of motion, with corresponding t-test statistics are detailed in Table 2. Between-groups comparisons of the kinematic profile for the involved and uninvolved limbs are detailed in Figures 1 and 2 (‘k-flake graph’).

There was a significant difference in eyes-closed SLS FD scores between the LAS and control groups for the involved and uninvolved limbs. Multiple testing with a false discovery rate of less than 5% revealed that the LAS group displayed reduced FD of the COP path trajectory compared to the control group on both their involved (LAS group: 1.25 +/-0.14, control group: 1.39 +/-0.16; t(1, 38) = -3.09, p = 0.00, two tailed) and uninvolved limbs (LAS group: 1.23 +/-0.14,control group: 1.37 +/-0.21; t (1,38) = -2.53, p = 0.01, two tailed).

Discussion

Our results demonstrate a significant difference between the postural orientation utilized by participants with acute LAS compared to non-injured controls, during eyes-closed SLS. Specifically, these injured participants, who reported significant functional impairment, assumed a position of reduced hip flexion compared to non-injured participants with no functional impairment. This difference was observed bilaterally and the effect size was large for both limbs. The position of reduced hip flexion was associated with reduced complexity of the COP path, as illustrated by the smaller FD of the LAS group on both their involved and uninvolved limbs. There was no difference between postural orientation as depicted by the kinematic variables and associated complexity of the COP path trajectory of the LAS group compared to the control group in the eyes-open condition.

This is the first analysis to combine stabilometric and kinematic measures of angular displacement during SLS in a group with acute LAS, and the first to present an evaluation of the eyes-closed condition for this task in this group. Measurement of discrete characteristics of the COP path such as its length, area and velocity is a branch of stabilometry that has previously been used to explore the effects of acute ankle sprain on single-limb balance with relatively consistent findings: acute ankle sprain injury causes an increase in COP velocity, and by extension, a greater displacement of the COP in a specified time interval (Evans T, 2004, Hertel J, 2001, Holme et al., 1999, Fridén T, 1989). However, the statistical approach to analysis of the dependent variables applied in some of the aforementioned investigations is a source of concern, bringing the observed consistency of these measures in this population into question. Indeed, the absence of parametric analysis (Holme et al., 1999), and a lack of control for multiplicity of dependent variables (Evans T, 2004, Hertel et al., 2001, Fridén T, 1989) with adjusted alpha levels, thus increasing the probability of family-wise error, is cause for concern. Furthermore, the reliability of the traditional measures of COP used in these investigations has been shown to be questionable (Doyle TL, 2005), with contradictory findings having been previously reported in the literature (McKeon and Hertel, 2006b). Hence, we have chosen to utilise FD as a measure of COP analysis, and have adopted a Benjamini-Hochberg method for false discovery rate correction for multiple testing in the current investigation (<5%) for all variables in the avoidance of increasing family-wise error.

FD represents a reliable method of analyzing COP path trajectory (Doyle TL, 2005, Myklebust JB, 1995), whereby a change in FD may indicate a change in the postural control strategies for maintaining quiet stance (Doyle TL, 2005). Furthermore, FD has been shown to be a suitable means to characterise quite stance COP under a number of conditions as compared to more traditional measures (Doyle TL, 2005). Błaszczyk et al. (Błaszczyk, 2001) compared the COP path trajectory FD in healthy elderly participants in eyes-open bilateral stance to that of eyes-closed bilateral stance. The increase in FD that occurred with elimination of visual afferents led the authors to attribute a change in FD to a change in balance and postural stability. In pathological conditions, FD has been shown to be useful in evaluating postural instability in Parkinson and ataxia patients in bilateral stance in eyes open and eyes closed conditions (Manabe et al., 2001). Results from the research of Manabe et al. (Manabe et al., 2001) elucidated that the transition to eyes-closed stance corresponded with an increase in FD in pathological and control groups, with an associated higher FD in the pathological group. This was proportional to the severity of the condition in the pathological group. Cimolin et al. (Cimolin, 2011) observed an increase in FD in participants with Prader-Willi Syndrome compared to healthy controls during bilateral stance with their eyes-open. They theorized that higher FD values may be interpreted as an inability of pathological patients to synergistically modulate the three sources of afferent information (i.e., the visual, vestibular and somatosensory systems) involved in maintaining balance.

In contrast to the findings reported in these analyses, we have observed a decrease in FD associated with pathology (acute LAS), which was present in the eyes-closed condition only, for both the involved and uninvolved limbs of injured participants. We offer two explanations for the contrasting results: differences in subject sample and task type separate the current investigation from those previously discussed. Specifically, we have assessed participants with acute LAS injury (as opposed to participants with longstanding neurological impairment) during a task of single limb stance (in contrast to the bilateral stance task utilized in the investigations by Cimolin et al. (Cimolin, 2011) and Manabe et al. (Manabe et al., 2001). With regards to the results observed in the current analysis, we theorize that a linear relationship between COP path trajectory and its associated FD does not exist; there may be an ideal FD which is specific to the constraints of the task and those limiting the individual, but it does not place on a scale where more or less is better or worse. In losing some of the available degeneracies via the distortion of somatosensory afferents, the postural control system of the injured participants has fewer available strategies with which to complete the prescribed task. While an increase in FD has previously been associated with the loss of visual afferents (Błaszczyk, 2001, Doyle TL, 2005), the lower FD within the constraints of this condition in the injured group compared to the non-injured group in the current investigation may reflect a postural control system with fewer available strategies with which to complete the task. In essence the injured participants were less able to utilize the base of support available to them, as evidenced by a reduced FD. That there was no difference in the eyes-open condition between LAS and control participants reflects that the presence of visual afferents sufficed to allow the postural control system of this injured group to optimally organize the network of constraints and degeneracies in a manner similar to that of the control group; several investigations have demonstrated that in circumstances where one or two sensory afferents are deficient, sufficient compensatory information can be provided by remaining sources for equilibrium to be maintained (Horak et al., 1990, Nashner, 1971). The non-significance of the between-group findings for the eyes-open condition is however in contrast with previous research (Evans T, 2004, Hertel J, 2001, Leanderson et al., 1996, Holme et al., 1999, Fridén T, 1989) and may be due to these studies' previously discussed methodological differences.

Although the SLS balance task is intended to be static in nature, every participant displayed varying amounts of movement despite being asked to stand as still as possible. Consequently, the time series represent an internally generated perturbation, as well as the organization of a postural control system in which the resultant ground reaction forces differ to the displacement of the segments of the kinetic chain to which they are coupled (Winter, 1995, Myklebust JB, 1995). The current research tackles this issue by supplementing measures of the COP path trajectory with an averaged 3-dimensional kinematic profile of lower limb alignment to discern the differences in joint position that accompany COP FD. Furthermore, conceptualization of the postural orientation that produced the observed FD makes the current findings more accessible to clinicians. The kinematic profiles can be seen to reflect the FD of the COP path: similar to the FD in the eyes-open condition, there were no differences in the average position assumed by LAS participants at the hip, knee or ankle in the sagittal, frontal or transverse planes of motion compared to control participants for either the involved or uninvolved limbs. However, in the eyes-closed condition, the reduced FD of LAS participants compared to control participants on both the involved and uninvolved limbs was linked to a bilateral decrease in hip flexion. The presence of bilateral impairments in subjects with acute LAS is well documented in the literature (Wikstrom EA, 2010), supporting the hypothesis that LAS has the capacity to cause spinal-level inhibition through gamma motor neuron loop dysfunction resulting in postural control impairment (Khin-Myo-Hla, 1999). The conscious perception of swelling and pain associated with the acute ankle sprain in the current sample during the full weight-bearing SLS task had the capacity to cause this supraspinal inhibition, thus impairing postural control strategies when potential degeneracies became unavailable (i.e. in the eyes-closed condition). This is reflected in the bilaterally observed decrease in hip flexion and COP path trajectory FD in the injured group (with significant self-reported functional impairment) compared to the non-injured group (with no self-reported functional impairment).

The ankle joint has a central role for maintaining equilibrium in SLS. The elimination of visual afferents disrupts this equilibrium, and corrections in healthy populations are then made at the hip (Tropp and Odenrick, 1988). We hypothesize that the natural transition from an inverted pendulum model (where the ankle has a central role in postural corrections) to a multi-segmental chain model (where the hip has a central role in postural corrections) on removal of visual afferents did not occur in the injured group secondary to a change in the sensory environment due to injury (McCollum G, 1996). In the eyes-open task for both groups, the sensorimotor system had the ability to shift reliance away from the affected area toward other available receptors, hence no between-group differences were observed.

The consequences of these bilaterally observed impairments in postural control are of significant importance considering their role in increasing the risk of re-spraining the injured ankle (McGuine TA, 2000, Tropp et al., 1984), and particularly in view of the equality of the observed effects on the involved and uninvolved limbs; it has been estimated that at least 1 out of 3 individuals who incur an ankle sprain will go on to have recurrent issues (Gerber et al., 1998), indicating that current care and decisions for return to activity may be inadequate for ankle sprains (Medina McKeon JM, 2013). We encourage caution in returning athletes to play too quickly following acute LAS, and the completion of rehabilitation protocols bilaterally. The potential worth of a task of eyes-closed SLS as a simple yet challenging early-stage rehabilitation exercise should also be noted.

It is however important to note that the simplicity of the kinematic analysis technique used in the current investigation must be considered a potential limitation. We chose to quantify a surrogate of the motor output using COP and averaged kinematic measures to provide a simple and immediately accessible conceptualisation of the sensorimotor response to distorted sensory afferents. Future research may benefit from more advanced analyses of movement variability and between-joint coupling during SLS to further advance current understanding. Furthermore, future investigations would benefit from a follow-up period whereby participants with acute LAS are evaluated longitudinally in the determination of outcome; recovery or the onset of chronicity. Finally, static postural control testing may not be sensitive enough to identify all functional deficits associate with acute ankle sprain injury. Dynamic balance tests, such as the Star Excursion Balance Test may serve as a means to functionally assess patients with acute LAS. This test may be more sensitive in detecting functional deficits in the entire lower extremity during dynamic activities (Gribble et al., 2012). Further profiling of kinematic and kinetic variables in this area is warranted.

Conclusions

The postural control system of participants with acute LAS displays bilateral impairment when denied previously available sensory degeneracies, as evidenced by altered postural orientation strategies and reduced complexity of the COP path during eyes closed SLS. Future research is required to identify the variables that determine recovery or the onset of chronicity in patients with acute LAS injury.

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Figure legends

Figure 1: K-flake graph depicting average joint position for the hip, knee and ankle for the involved limb of injured and non-injured participants. Δ indicates statistically significant between groups difference. Movements are listed in order of positive and negative values, with neutral equating to a value of 0 (for example, hip adduction is the positive and hip abduction the negative value for hip frontal plane motion).

Figure 2: K-flake graph depicting average joint position for the hip, knee and ankle for the uninvolved limb of injured and non-injured participants. Δ indicates statistically significant between groups difference. Movements are listed in order of positive and negative values, with neutral equating to a value of 0 (for example, hip adduction is the positive and hip abduction the negative value for hip frontal plane motion).

Table 1

Table 1. Participant characteristics and questionnaire scores (mean +/- SD with 95% CIs) for the LAS and control groups. LAS = ankle sprain

Group	Age (years)	Mass (kg)	Height (m)	CAIT (/30)	FAAMadl (%)	FAAMadl (%)
AS	23.22 +/- 4.95; [95% CI: 22.01 to 24.45]	75.84 +/- 14.48; [95% CI: 72.28 to 79.40]	1.73 +/- 0.10; [95% CI: 1.71 to 1.76]	11.85 +/- 7.91; [95% CI: 9.61 to 13.55]	68.50 +/- 18.65; [95% CI: 63.77 to 73.16]	32.11 +/- 23.85; [95% CI: 32 to 45.22]
Control	22.53 +/- 1.68; [95% CI: 21.72 to 23.34]	71.55 +/- 11.31; [95% CI: 66.01 to 77.01]	1.75 +/- 0.08; [95% CI: 1.71 to 1.78]	30 +/- 0.00; [95% CI: 30 to 30]	100 +/- 0.00; [95% CI: 100 to 100]	100 +/- 0.00; [95% CI: 100 to 100]

LAS = ankle sprain

Table 2

Table 2. Discrete kinematic variable values for the hip, knee, ankle and foot for the involved and uninvolved limbs of the ankle sprain (injured) and side-matched limbs of the control (non-injured) groups during the performance of eyes open and eyes closed SLS. Add/abd = adduction (positive)/abduction (negative); flex/ext = flexion (positive)/extension (negative); int/ext = internal (positive) /external rotation (negative); var/val = varus (positive)/valgus(negative); inv/ev = inversion (positive) /eversion (negative) ; dor/pla = dorsiflexion (positive)/plantarflexion (negative). *indicates statistical significance.

		Involved			Uninvolved		
		Injured	Non-injured		Injured	Non-injured	
				Eyes open			
Hip	Add/Abd	4.05 +/- 4.38	4.18 +/- 4.43	t(83) = 0.11, p = 0.91, $\eta^2 = .00$	5.53 +/- 6.21	2.77 +/- 5.13	t(83) = 1.77, p = 0.08, $\eta^2 = .039$
	Flex/Ext	1.51 +/- 8.21	3.57 +/- 5.36	t(83) = -1.03, p = 0.31, $\eta^2 = .01$	4.96 +/- 3.91	3.91 +/- 5.94	t(22.7) = -.73, p = 0.48, $\eta^2 = .025$
	Int/Ext rot	1.82 +/- 4.84	5.03 +/- 9.1	t(21.02) = 1.48, p = 0.15, $\eta^2 = .11$	1.71 +/- 6.93	-0.09 +/- 5.57	t(83) = 83, p = 0.30, $\eta^2 = .013$
Knee	Var/Val	0.64 +/- 1.71	0.87 +/- 1.26	t(83) = 0.54, p = 0.59, $\eta^2 = .00$	1.15 +/- 5.50	-0.15 +/- 2.55	t(65.84) = 1.45, p = 0.15, $\eta^2 = .03$
	Flex/Ext	5.69 +/- 6.38	7.66 +/- 10.33	t(22.09) = 0.79, p = 0.44, $\eta^2 = .031$	1.33 +/- 1.02	6.90 +/- 8.49	t(18.15) = 2.85, p = 0.01, $\eta^2 = .50$
	Int/Ext rot	1.06 +/- 4.08	-0.95 +/- 7.62	t(21.05) = 1.10, p = 0.28, $\eta^2 = .06$	6.53 +/- 10.14	1.85 +/- 4.95	t(83) = 1.94, p = 0.05, $\eta^2 = .046$
Ankle	Inv/Ev	-0.19 +/- 4.24	-1.37 +/- 5.59	t(83) = 0.99, p = 0.32, $\eta^2 = .012$	1.39 +/- 3.56	-0.79 +/- 5.51	t(22.49) = 1.63, p = 0.12, $\eta^2 = .013$
	Dor/Pla	6.01 +/- 3.22	7.6 +/- 6.1	t(20.97) = 1.09, p = 0.28, $\eta^2 = 0.06$	3.93 +/- 3.43	5.99 +/- 5.33	t(22.45) = 1.6, p = 0.12, $\eta^2 = 0.13$
Foot	Abd/add	-4.36 +/- 4.78	-4.56 +/- 6.36	t(83) = 0.14, p = 0.88, $\eta^2 = 0.00$	0.79 +/- 4.75	-4.89 +/- 4.6	t(83) = 0.58, p = 0.56, $\eta^2 = 0.00$
				Eyes closed			
Hip	Add/Abd	4.96 +/- 3.5	4.85 +/- 2.98	t(37) = 0.10, p = 0.9, $\eta^2 = .00$	4.64 +/- 4.38	2.71 +/- 5.21	t(37) = 1.25, p = 0.22, $\eta^2 = .04$
	Flex/Ext*	**1.44** +/- **4.76**	**7.41** +/- **6.11**	**t(37) = -3.42, p = 0.001,** $\boldsymbol{\eta^2 = .34}$	**2.16** +/- **5.61**	**9.59** +/- **8.45**	**t(37) = -3.3, p = 0.002,** $\boldsymbol{\eta^2 = .31}$
	Int/Ext rot	0.58 +/- 5.08	4.96 +/- 11.41	t(19.17) = 1.44, p = 0.17, $\eta^2 = .12$	-0.54 +/- 6.9	-2.62 +/- 4.91	t(37) = 1.04, p = 0.31, $\eta^2 = .031$
Knee	Var/Val	0.26 +/- 1.6	0.32 +/- 1.95	t(37) = -0.09, p = 0.93, $\eta^2 = .00$	0.37 +/- 2.19	-0.11 +/- 2.45	t(37) = 0.64, p = 0.53, $\eta^2 = .01$
	Flex/Ext	9.11 +/- 8.25	11.77 +/- 9.29	t(37) = 0.94, p = 0.35, $\eta^2 = .025$	8.08 +/- 6.49	15.60 +/-16.19	t(18.39) = 1.76, p = 0.09, $\eta^2 = .19$
	Int/Ext rot	2.63 +/- 3.29	0.46 +/- 8.92	t(17.86) = 0.93, p = 0.37, $\eta^2 = .054$	2.61 +/- 5.51	3.78 +/- 5.72	t(37) = 0.64, p = 0.52, $\eta^2 = .01$
Ankle	Inv/Ev	-1.18 +/- 5.56	-0.42 +/- 6.6	t(37) = 0.39, p = 0.70, $\eta^2 = .00$	-2.2 +/- 4.27	-1.79 +/- 10.4	t(37) = -0.17, p = 0.87, $\eta^2 = .00$
	Dor/Pla	7.85 +/- 4.11	9.72 +/- 5.91	t(37) = -1.17, p = 0.25, $\eta^2 = 0.03$	8.04 +/- 4.64	10.4 +/- 9.23	t(37) = 1.05, p = 0.25, $\eta^2 = 0.04$
Foot	Abd/add	-4.01 +/- 4.77	-4.89 +/- 6.34	t(37) = 0.49, p = 0.63, $\eta^2 = 0.01$	-6.32 +/- 4.48	-5.62 +/- 4.7	t(37) = 0.47, p = 0.64, $\eta^2 = 0.00$

Figure 1

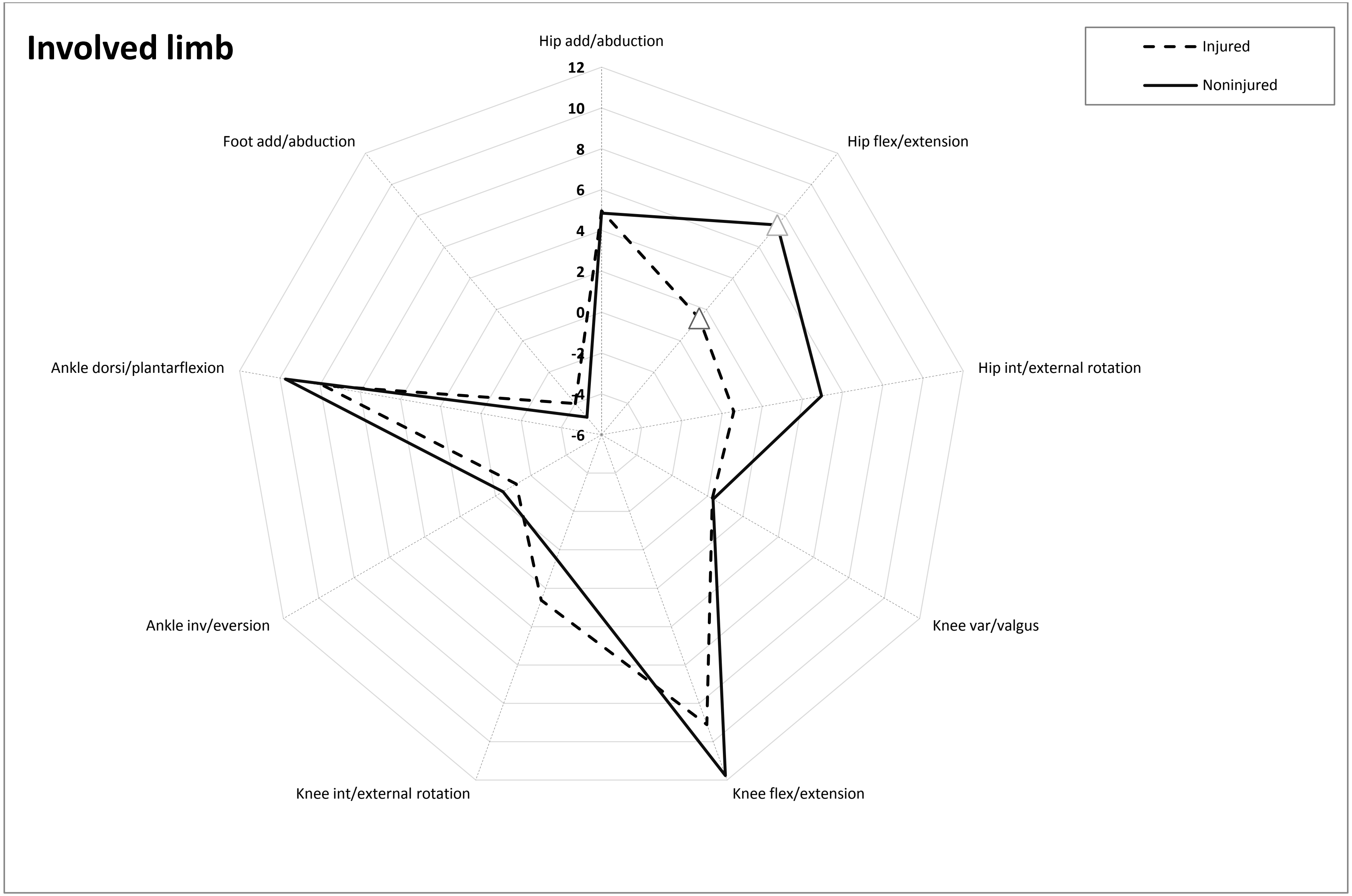
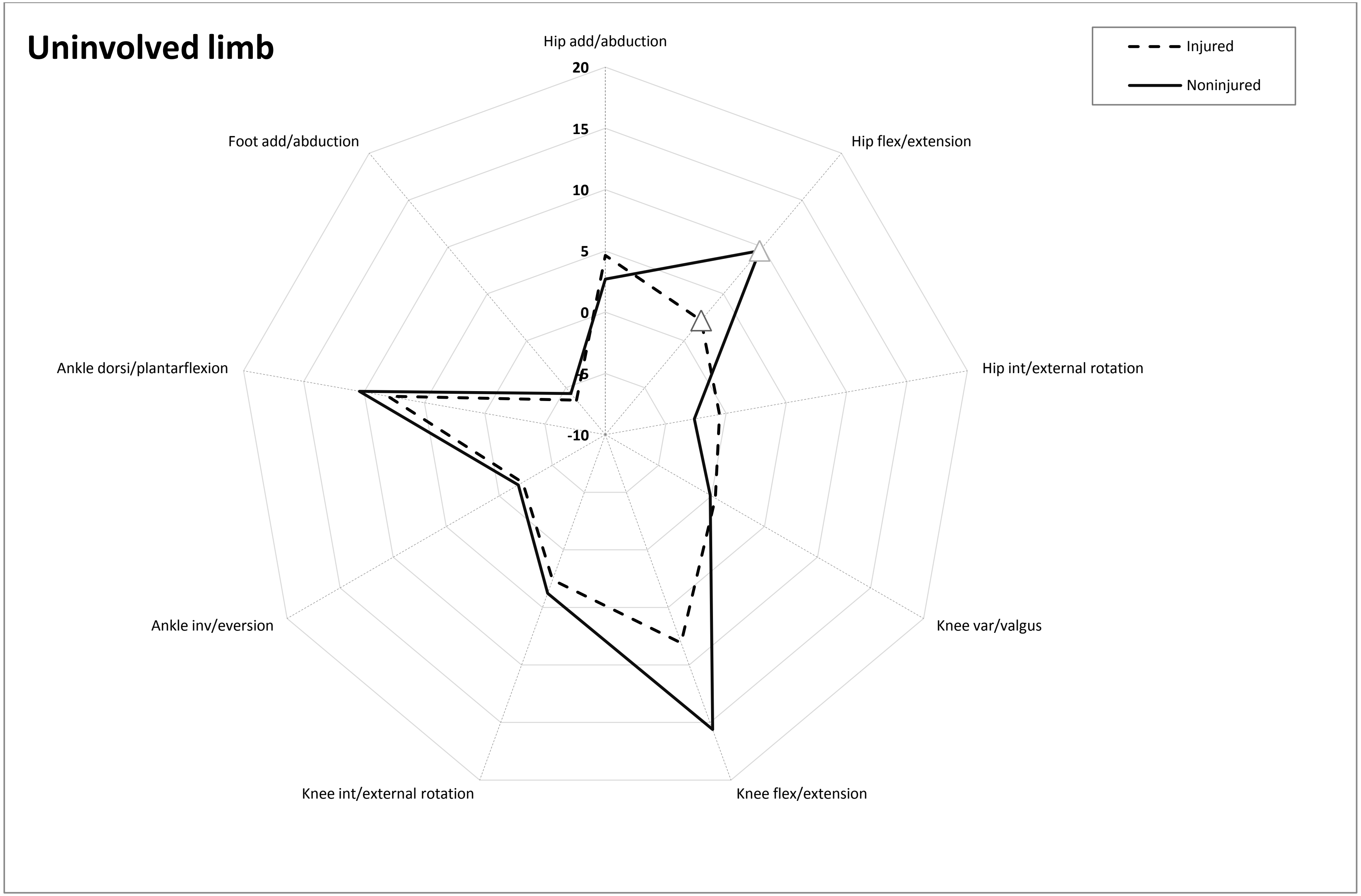

Involved limb
Injured
Noninjured
Hip add/abduction
Hip flex/extension
Hip int/external rotation
Knee var/valgus
Knee flex/extension
Knee int/external rotation
Ankle inv/eversion
Ankle dorsi/plantarflexion
Foot add/abduction
12
10
8
6
4
2
0
-2
-4
-6

Figure 2


Uninvolved limb
Injured
Noninjured
Hip add/abduction
20
15
10
5
0
-5
-10
Hip flex/extension
Hip int/external rotation
Knee var/valgus
Knee flex/extension
Knee int/external rotation
Ankle inv/eversion
Ankle dorsi/plantarflexion
Foot add/abduction