Does Fatigue impact upon Static and Dynamic Balance Variables in Athletes with Previously Reported Ankle Injury?

MICHELLE LACEY* and BERNARD DONNE‡

Human Performance Laboratory, Departments of Anatomy and Physiology, School of Medicine, Trinity College Dublin, IRELAND.

*Denotes postgraduate student author, ‡Denotes professional author

ABSTRACT

Injury, resulting in deficits in static and dynamic balance, can result in significant time loss to sport, affect daily activities and potentially place athletes at greater risk of re-injury. In order to identify athletes at risk of ankle injury accurate and reliable balance assessment tools are required. The purpose of the current study was to quantify reliability and reproducibility of balance variables in currently healthy, previously injured, games players (n=19) and assess the impact of an intense intermittent zig-zag running protocol to volitional exhaustion, rated by RPE, on balance variables. A test re-test design assessed short-term reliability and reproducibility (ICC and 95% LoA) of static and dynamic variables The Y balance test was deemed a reliable measuring tool for assessing dynamic balance (composite score data; ICC = 0.96, 95%LoA from -95.7 to 105.8%). Assessing static balance variables (HurLabs iBalance platform) sway velocity ($mm.s^{-1}$) recorded the strongest reliability (ICC=0.79). Significant post-exercise increases ($P<0.001$) were detected in single-leg static balance for C90area (mm^2) and sway velocity ($mm.s^{-1}$) assessed on stable and unstable surfaces (stable: 227±84 vs. 366±146 mm^2 and 18.6±4.2 vs. 22.9±5.3 $mm.s^{-1}$: unstable; 275±128 vs. 370±140 mm^2 and 19.3±4.3 vs. 21.5±4.0 $mm.s^{-1}$). Non-significant differences ($P>0.05$) were detected in dynamic balance measures of anterior, posteromedial, posterolateral and composite reach scores measured at 4-min post-exercise. Further research should investigate the effects of fatigue on dynamic balance variables immediately post-exercise and, thereby, determine if differences exist when comparing previously injured and un-injured limbs.

KEY WORDS: Gaelic games players, sway velocity, C90 area, balance assessment, balance platform.

INTRODUCTION

Adequate movement, strength, and static and dynamic balance of the ankle are essential to human movement and especially in the sporting environment. Intrinsic factors; namely, physical fatigue, and extrinsic factors; namely, playing surface, may place the ankle complex at risk of injury. These factors can subsequently have significant consequences for individuals during daily activity, and within a sporting context.

Ankle sprain injuries are among the most commonly reported injuries in team sports, with a general incidence reported as high as 4.2 per 1000 person-hour in team sports (15). Ankle sprains affecting the lateral ligament complex are the most commonly reported (11) and the literature has reported ranges from 40% to over 70% of ankle sprains leading to the development of chronic ankle instability (CAI) (10, 23). Symptoms of CAI include weakness, pain, swelling, the feeling of 'giving way' and loss of ankle function. In multidirectional sports and field games that require speed, strength and agility, for example; Gaelic football, lateral ankle sprain injuries may account for 3.6% of all injuries and can result in over a week off from sport (25). This may lead to decreased sensorimotor control, proprioception, balance and overall performance for an individual and their team, which may result in re-injury.

Within sport patterns have been detected assessing the timing of injury within the game (13, 14, 25) which may implicate fatigue as a contributing factor to injury, in general the majority of injuries occur in the latter stages of the game. Whole-body and local muscle fatigue may hinder ankle balance, potentially placing athletes at further risk of injury. In addition, re-injury can result in a longer absence from play compared to first time injury (14).

Injury prevention strategies, including adequate screening and pre-habilitation, may have an influence on injury rates, particularly at the elite level (13, 25). Athletes displayed fewer ankle and musculoskeletal injuries following participation in a balance training programme (7), this may imply that decreased balance scores can be a suitable predictor of future ankle injuries. Dynamic balance may be used as an indicator of increased risk of lower limb injury (28), and, consequently, identification of poor balance, in a fatigued state, at the beginning of the season may highlight a player at risk of injury who could potentially benefit from a bespoke balance programme to offset injury occurrence or recurrence.

The effect of fatigue on balance has been investigated extensively in the literature (1, 5, 16, 21, 32, 33, 35, 36) with mixed results. This may be a consequence of different fatiguing protocols and balance assessments in the literature making external validity questionable. Different tools to assess dynamic and static balance are widely available (30), more recently expensive balance platforms have been utilised; however, for some teams these may be difficult to gain access to. Consequently, portable inexpensive devices, such as the Y Balance test (YBT) have been favoured among sports medicine professionals. Whilst the Star Excursion Balance Test (SEBT) has been used extensively to measure dynamic balance, test execution can be time consuming.

The YBT uses three directions, namely, anterior (ANT), posteromedial (PM) and posterolateral (PL), and a combined composite score to assess dynamic balance (29). Fatigue induced by a modified Wingate test has been shown to negatively impact on normalised reach score in the YBT (21); however, participants did not have a history of ankle injury. Increases in sway velocity and dynamic postural control, measured by the SEBT, have been observed in athletes with a history of lateral ankle sprain following a fatiguing protocol executed on a treadmill (32, 33). However, the fatiguing protocol used in these studies (32, 33) did not replicate a game scenario; namely, lasting for 60+ minute and requiring variations in running velocity and changes of direction.

To the authors knowledge no study, to date, has assessed the effects of whole-body and local muscular fatigue on balance variables in a healthy game playing population with previously reported ankle injury. In order to accurately assess static and dynamic balance, reliable tools are needed. Therefore, the aims of the current study were to quantify reliability of the YBT and iBalance platform and identify any deficits in injured and un-injured limbs immediately post exercise. We hypothesized that the YBT and iBalance platform test re-test reliability data would be high. We also hypothesised that the fatiguing protocol used would induce deficits in static and dynamic balance variables, and that the magnitude of change observed would be greater in previously injured compared to un-injured limbs.

METHODS

Participants

A healthy, currently un-injured, cohort of male and female games players (n=19, aged 18-35 yr) were recruited from local clubs. All participants were involved in sport for a minimum of two sessions per week including a match. Athletes, with a previously reported injury (sustained 6-24 months prior to the study) were included. Exclusion criteria included athletes who sustained an injury within the last 6 months, athletes with balance disorders, cardiac abnormality, respiratory disease or symptoms of colds/influenza on the day of testing. Athletes with an acute or chronic musculoskeletal or neurological injury that could limit exercise capacity were also excluded.

An observational repeated measures study design assessed short-term reliability and reproducibility of investigated balance variables. In addition, an interventional study design assessed the effect of whole-body and local ankle muscle fatigue on single-leg static and dynamic balance to investigate if fatigue resulted in greater deficit in postural control variables in previously reported injured in comparison with un-injured limbs. Ethics approval was received from the Faculty of Health Sciences Ethics Committee at Trinity College Dublin and all procedures and measurements performed complied with the declaration of Helsinki guidelines.

All participants received an information leaflet outlining study details, and completed consent form, medical questionnaire and self-reported disability questionnaire (Cumberland ankle instability tool) prior to their first visit. Participants also completed a food and drink diary for the day prior to, and the day of testing. Participants were instructed not to undertake strenuous exercise 24-h prior to the day of testing, not to consume large amounts of food 2-h prior to attending and to ensure they were well-hydrated prior to arrival. All testing was completed within the same 2 hour window to minimise circadian variability. The current study required two testing sessions; namely Session 1, initial screening, familiarisation and balance assessment and Session 2, repeat balance assessment, fatiguing protocol and post –fatigue balance assessment.

Protocol

During session 1 participants were introduced to the laboratory and equipment, testing procedures and protocols were explained, and they viewed a video (more2perfrom) outlining how the Y Balance test was performed, Vestibular function was checked by taking a detailed subjective history (4) and leg length was assessed by measuring from the anterior superior iliac spine to the centre aspect of the ipsilateral medial malleolus using a standard measuring tape (Coral, Essex, UK). Measurements of body mass in kilogram (Seca, Hamburg, Germany) and height in metre (Holtain, Dyfed, UK) were performed; body mass index ($kg.m^{-2}$) was computed and skinfold thickness was assessed using a Harpenden caliper (Baty International, West Sussex, UK) and percentage body fat interpolated (12) from cumulative skinfold thickness data. Blood pressure and heart rate were measured using an automatic sphygmomanometer (Omron, Kyoto, Japan). Female participants were questioned if there was a possibility they may be pregnant. A mid-stream urine sample was collected and urine specific gravity assessed using a handheld refractometer (Eclipse, Bellingham & Stanley, Kent, UK) to ensure participants were euhydrated. As an initial balance familarisation session participants performed 4 trails on each leg and in each direction of the YBT, and 1 trial on each leg on stable and unstable surfaces on a balance platform (HURLabs, Helsinki, Finland).

Following a 10-min rest each participant executed 3 trials on the YBT (randomised direction) for dominant and non-dominant limbs followed by 2 trials on balance platform, each of 20-s duration, in the following sequence; namely, dominant and non-dominant limb single-leg stance on a stable surface followed by dominant and non-dominant limb single-leg stance on an unstable surface. Data for mean sway velocity ($mm.s^{-1}$) and C90area (mm^2) were computed from recorded posturograms for each assessed condition. To account for leg length differences across participants recorded YBT reach distances were normalised by dividing by leg length and expressed in percentage format (29). In addition, each individual's composite reach score was computed by summating normalised reach data across anterior, posteromedial and posterolateral directions and dividing by three times limb length (29).

During the second visit, participants executed the same battery of tests which facilitated control (pre-fatigue) data for the intervention aspect and re-test data for the reliability and reproducibility aspect of the current study. Immediately following this participants undertook a 10min warm-up and which included running at a variety of intensities and stretches of all major muscle groups. They then executed a sprint lap of the cones (Figure 1), this was performed by running through the timing gates at the start line, in a zig-zag pattern around the cones before returning to the timing gates. Once a participant's fastest lap time was recorded, calculations were made computing their individualised running protocol which consisted of a running exercise at various individualised intensities; one completed cycle equated to:

- Walking a straight line to the end cone (12-m) and walking a straight line back to the timing gates at a comfortable walking velocity.
- Two laps running at 55% of the participants sprint time.
- One lap running at 95% of the participants sprint time.

Participants completed the above cycle for 30-min, during which they were provided with feedback on their timings and encouraged to increase or decrease running velocity accordingly. At 10-min intervals participants completed the following cycle in triplicate; a straight sprint to the last cone and back, followed by a straight walk to the last cone and back. Rate of perceived excursion (RPE) was assessed at regular intervals throughout the protocol and water was provided during the walking aspect of the protocol. Upon completion, RPE ratings exceeded 18 for all participants, indicating exercise was executed to volitional exhaustion. Upon completion of the running protocol, participants once again executed the static single-leg iBalance testing protocol immediately, followed by the YBT. Both the above tests took 4-min each to complete and thus were completed within 8-min of finishing the running protocol. Assessed data from pre- and post-time points were used to assess changes, if any, in balance variables induced following fatiguing exercise. Participants were encouraged to keep well-hydrated during testing and post-assessment participant's body mass was again assessed, to ensure no participant was dehydrated. Finally participants completed a full warm-down including stretches prior to departure.

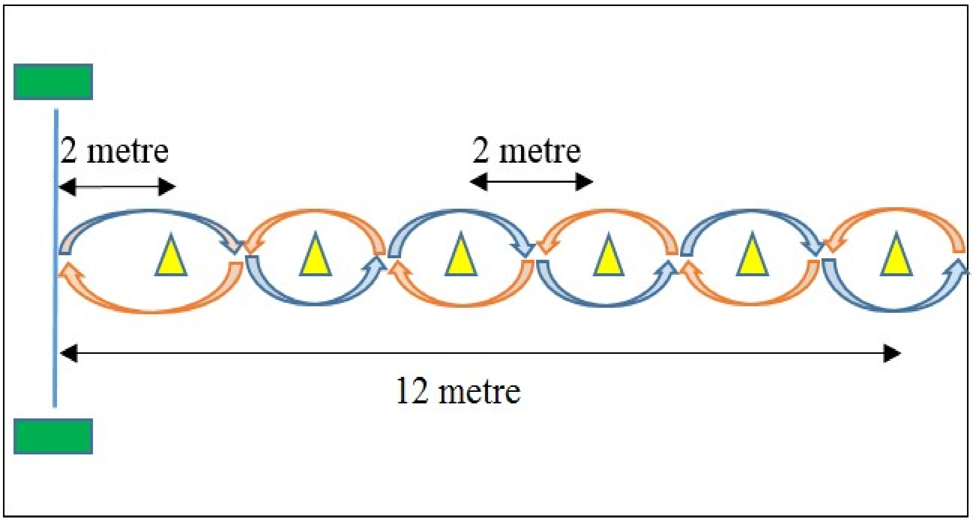

Figure 1: Diagram of running protocol; the yellow triangle denotes a cone and green rectangle denotes IR timing gates.

Statistical analysis

Data are presented as mean and standard deviation and were analysed using GraphPad Prism Ver. 7 software (GraphPad Prism, CA, USA). Data normality was confirmed using the Pearson D'Agostino omnibus normality test. Reproducibility and reliability of pre-intervention test and re-test static and dynamic balance of combined data from both ankles were assessed using interclass correlation coefficient (ICC) and upper and lower 95% limits of agreement (95% LoA). Scedasticity of difference data were assessed by computing Pearson product moment correlation coefficient of test re-test difference versus mean. Intervention data were analysed using a 2 factor (injury history by time) ANOVA with time (pre- and post-exercise data) as a repeated measure, detected differences were subsequently quantified using *post-hoc* Bonferroni testing. Meaningfulness of the detected difference were quantified using Cohen's D; < 0.2 poor, 0.2 to 0.5 trivial to moderate, 0.5 to 0.8 moderate to good and 0.8 to ≥ 1.0 good to excellent. For all statistical tests $P < 0.05$ inferred significance.

RESULTS

Baseline anthropometric data are presented in Table 1. Enlisted participants, male (n= 11) and female (n=8) were healthy, currently un-injured, games players. Reproducibility and reliability variables for static balance are presented in Table 2 and for dynamic balance variables in Table 3. Computed ICC data were interpreted as recommended (6); < 0.4 poor reliability; between 0.40 and 0.59 fair reliability; between 0.60 and 0.74 good reliability and > 0.75 excellent reliability.

	Age (yr)	Mass (kg)	Height (cm)	BMI ($kg.m^{-2}$)	Body fat (%)	Cumberland Score
Female	28 (4)	63.1 (8.0)	165 (7)	22.9 (1.7)	24.0 (3.0)	26 (4)
Male	24 (4)	85.0 (13.9)	181 (5)	26.0 (3.6)	16.0 (4.2)	22 (6)

Table 1: Mean data with standard deviation in parentheses for female (n=8) and male (n=11) participants. A Cumberland ankle instability score of <24 (n=9) was classified as unstable and a score >24 (n=10) was classified as stable (19).

	ICC	Upper 95%LoA	Lower 95%LoA
C90area (stable)	0.680	127 mm^2	-156 mm^2
C90area (unstable)	0.536	197 mm^2	-249 mm^2
Mean sway velocity (stable)	0.786	5.0 $mm.s^{-1}$	-5.2 $mm.s^{-1}$
Mean sway velocity (unstable)	0.740	5.3 $mm.s^{-1}$	-6.2 $mm.s^{-1}$

Table 2: Test re-test reliability and reproducibility data for static balance variables assessed using the HURlabs iBalance platform. The ICC data for C90area (stable) infers good reliability; C90area (unstable) fair reliability; mean sway velocity (stable) excellent reliability; mean sway velocity (unstable) good reliability.

	ICC	Upper 95%LoA	Lower 95%LoA
Anterior	0.930	4.6 %	-4.7 %
Posteromedial	0.867	6.9 %	-7.4 %
Posterolateral	0.711	7.9 %	-11.6 %
Composite score	0.925	6.6 %	-7.1 %

Table 3: Test re-test reliability and reproducibility data for dynamic balance using the YBT. Upper and lower 95% LoA are expressed in % format as reach distances were normalised to % of individual leg length. The ICC data for posterolateral infers good reproducibility, ICC data for anterior, posteromedial and composite scores infer excellent reproducibility.

Mean sway velocity on a stable surface recorded the highest reproducibility. Mean differences between repeat tests and the upper and lower 95%LoA for stable and unstable surfaces for sway velocity and C90 area are presented in Bland Altman format in Figures 2 and 3, all assessed data sets were homoscedastically distributed.

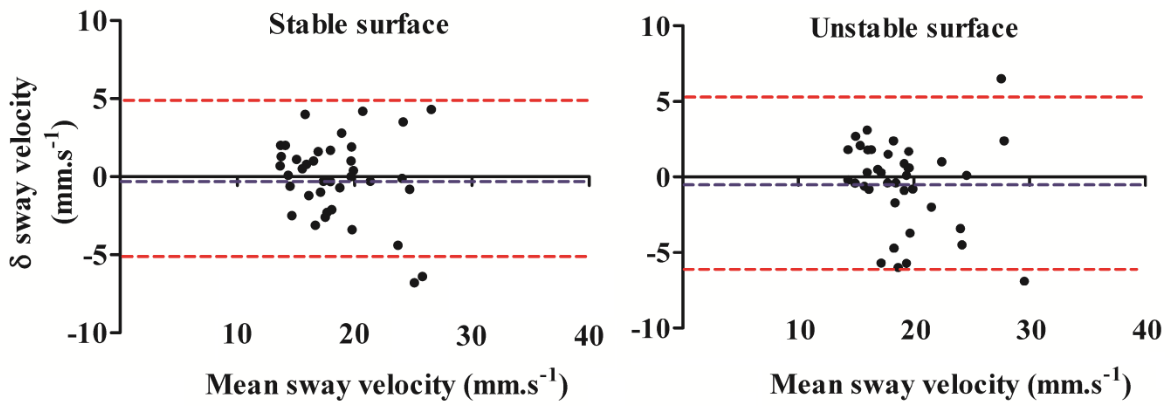

Figure 2: Bland Altman plots of sway velocity (mm.s^{-1}) data on stable (left) and unstable (right) surfaces. Dashed blue line infers mean bias, dashed red lines indicate upper and lower 95% LoA.

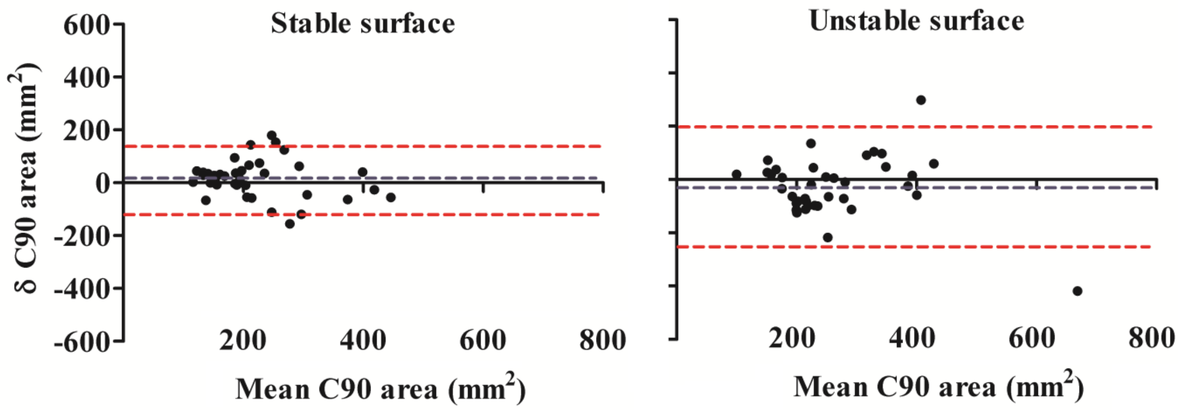

Figure 3: Bland Altman plots of C90 area (mm^2) data on stable (left) and unstable (right) surfaces. Dashed blue line infers mean bias, dashed red lines indicate upper and lower 95% LoA.

A 2 factor ANOVA with time as a repeated measure was performed on static balance data to assess if the effect of a previously reported injury impacted on the exercise induced changes recorded. Analysis compared mean differences in previously injured and un-injured limbs of participants (n=19) pre- and post-exercise on stable and unstable surfaces. Analysis of mean C90area (mm^2) on stable and unstable surfaces indicated that overall there were significant exercise ($P < 0.001$) induced effects but no previous injury or injury by exercise interactions. *Post-hoc* analysis indicated significant exercise induced differences (stable, $P < 0.001$; unstable, $P < 0.01$) in both injured and un-injured limbs. Analysis of mean sway velocity (mm.s^{-1}) on stable and unstable surfaces indicated significant exercise ($P < 0.001$) induced effects but no previous injury or injury by exercise interaction. *Post-hoc* analysis indicated significant exercise induced difference ($P < 0.001$) in previously injured and un-injured limbs on a stable surface and in previously injured ($P < 0.01$) and un-injured limbs ($P < 0.05$) on an unstable surface, see Table 5. Analysis of normalised YBT data (anterior, posteromedial, posterolateral and composite reach) failed to detect any significant differences, see Table 6.

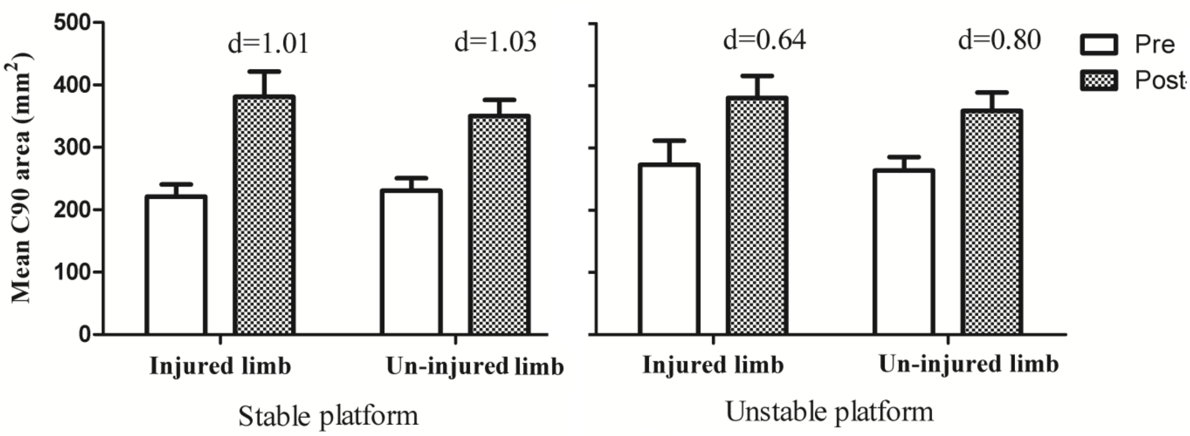

Figure 4: Bar graph of mean C90 area (mm²) for previously injured and un-injured limbs on stable and unstable platforms pre- and post-exercise, bars denote SD, n=19. Effect size data inferring the meaningfulness of the detected exercise induced difference are displayed above post-exercise data.

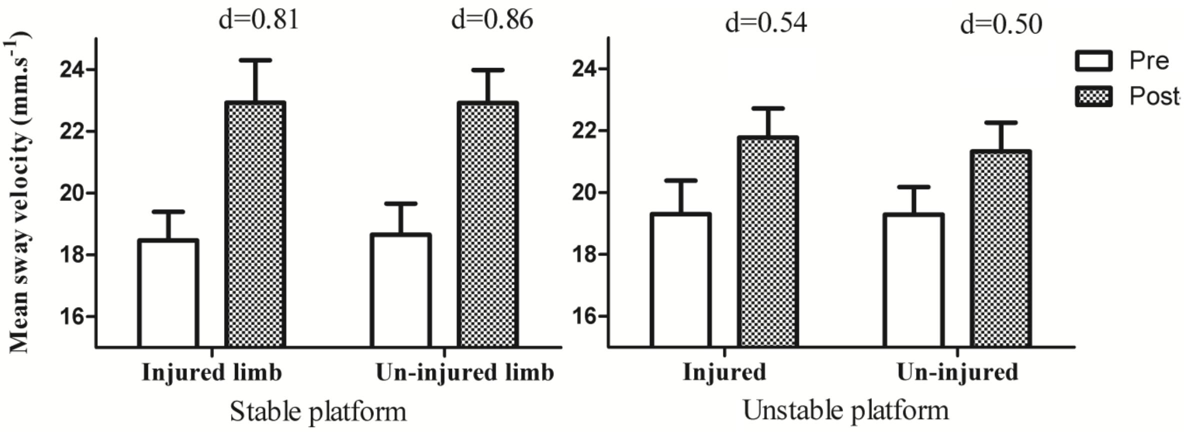

Figure 5: Bar graph of mean sway velocity ($mm{\cdot}s^{-1}$) for previously injured and un-injured limbs on stable and unstable platforms pre- and post-exercise, bars denote SD, n=19. Effect size data inferring the meaningfulness of the detected exercise induced difference are displayed above post-exercise data.

Variable	Pre-	Post-	95% CI of difference
Injured limb C90area (mm^2) stable	221±85	381±175	94 to 226
Un-injured limb C90area (mm^2) stable	231±87	350±112	54 to 185
Injured limb C90area (mm^2) unstable	273±169	381±154	37 to 178
Un-injured limb C90area (mm^2) unstable	264±93	360±128	26 to 166
Injured limb SV ($mm.s^{-1}$) stable	18.5±4.1	22.9±6.0	1.9 to 7.0
Un-injured limb SV ($mm.s^{-1}$) stable	18.6±4.4	22.9±4.7	1.7 to 6.8
Injured limb SV ($mm.s^{-1}$) unstable	19.3±4.7	21.8±4.1	0.7 to 4.3
Un-injured limb SV($mm.s^{-1}$) unstable	19.3±3.9	21.3±4.1	0.2 to 3.9

Table 5: Mean and standard deviation (SD) for C90area (mm^2) and sway velocity ($mm.s^{-1}$) on stable and unstable surfaces pre- and post-exercise for injured and non-injured limbs, n=19.

		Anterior	Posteromedial	Posterolateral	Composite
Injured	Pre-exercise	59.6 ± 7.0	109.5 ± 8.2	108.9 ± 7.3	101.1 ± 9.9
	Post-exercise	58.6 ± 6.6	109.1 ± 9.2	107.2 ± 9.2	100.0 ± 10.8
Non-injured	Pre-exercise	59.1 ± 6.5	108.3 ± 7.9	108.9 ± 6.1	99.9 ± 8.5
	Post-exercise	59.0 ± 6.2	110.4 ± 8.1	108.4 ± 7.3	101.0 ± 8.9

Table 6: Mean and standard deviation (SD) for normalised YBT reach data and composite score pre- and post-exercise for injured and non-injured limbs, n=19.

DISCUSSION

The first hypothesis was accepted; namely, the YBT is a reliable tool for measuring dynamic balance variables when normalised to leg length and expressed as a percentage; concerning static balance variables assessed, mean sway velocity ($mm.s^{1}$) recorded higher reliability than C90area (mm^2) on both stable and unstable surfaces. However, while the YBT demonstrated higher test-retest reliability when compared to static measures of balance; the YBT test was less sensitive to changes in balance as reflected by its inability to detect pre- to post-differences in balance associated with fatigue. The second hypothesis; namely, impact of exercise induced fatigue, was partly accepted as data analysis demonstrated significant increases in mean sway velocity ($mm.s^{-1}$) and C90area (mm^2) measured immediately after a 60-min intense intermittent zig-zag running protocol to volitional exhaustion in a cohort of healthy, currently un-injured games players. However, there were no significant fatigue induced effects detected for any YBT dynamic variables assessed; namely, anterior, posteromedial and posterolateral reach directions normalised to leg length, or computed composite scores when assessed at 4-min post-exercise.

The YBT results of the current study area comparable to previous research reporting fair to good (24) and excellent reproducibility (21, 29), however, only one of these studies (29) examined composite score data. There is continued debate concerning the optimal number (4 or 6) of practice trials in adults and athletic adolescents (24, 29, 31). As participants in the current study were completing static balance tests within the same testing session to offset any fatigue 4 practice trials were incorporated. Although the original protocol describing the YBT (29) permitted footwear, allowed the stance foot to be lifted and documented the greatest of 3 reaches. We prohibited footwear to eliminate bias, averaged 3 reach directions (24) and disallowed the stance foot from being lifted during reaches in order for study data to be comparable to others (18, 20) whose population included participants from soccer and hockey.

The current study demonstrated mean sway velocity data ($mm.s^{-1}$) to have superior reliability over C90area data(mm^2), this finding may implicate against C90area (mm^2) usage as this static variable exhibited the greatest variability on a day to day basis. Previous research (8) has also reported mean sway velocity ($cm.s^{-1}$) to be the more reliable measure when compared to C95area (cm^2) for assessing balance in older adults. Researchers have also assessed the reliability of centre of pressure (CoP) variables that would equate to mean sway velocity and area (2, 26) with varying results, however, these authors assessed bipedal stance and therefore data cannot be directly compared to the current study. When assessing static balance variables there are a wide variety of assessed static variables reported in the literature, along with variations in duration of test, number of practice trials, and number of trials used. The different protocols used makes comparison of results with the current cohort difficult. Of note considering the influence of individual anthropometric characteristics on CoP measures, normalising CoP measurements to height, body mass and BMI may increase reliability (27).

To the authors' knowledge this is the first study to assess the effects of whole-body and local muscle fatigue on the CoP variables C90area (mm^2) and mean sway velocity ($mm.s^{-1}$) on stable and unstable surfaces, in a cohort of healthy games players (predominantly Gaelic players) with a prior history of ankle injury utilising an intermittent zig-zag running protocol. Significant statistical differences were detected comparing post- with pre-exercise data, see Figures 4 and 5. With effect sizes ranging from excellent, as demonstrated in C90 area (mm^2) on a stable surface, and moderate to good, demonstrated in mean sway velocity ($mm.s^{-1}$) on an unstable surface. Whilst there are a wide variety of posturographic CoP variables are available and assessed in the literature, this makes direct comparison difficult.

Similar to the current study, previous literature has reported increases in static balance variables following fatigue; namely, mean sway velocity (32, 33) following whole-body fatigue induced using a treadmill running protocol; however, conflicting reports (1) of no effects on postural sway following local muscle fatigue also exist. Although the current study recorded large effect sizes comparing pre- and post-fatigue C90area (mm^2) data, this variable displayed inferior reliability compared to mean sway velocity data, therefore, perhaps mean sway velocity ($mm.s^{-1}$) should be considered as the static variable of choice. Research by da Silva et al. (8) concluded that CoP variables calculated from force platform data may be able to provide more accurate information relating to biomechanical and neuromuscular control strategies for sustained balance among different population, however, it is important to note that CoP variables originate from biological systems that may have intrinsic variability affecting reliability and validity. CoP alterations are proportional to ankle torque, a combination of descending motor commands, as well as mechanical properties of the surrounding musculature (3).

While decreased postural sway measured using single-leg stance may indicate a higher risk for ankle sprains (34), it may be criticised for not being a true reflection of a sporting situation (9) and thus perhaps more dynamic measures should be utilised. The current study reported no significant differences in dynamic balance variables assessed using the YBT at 4-min post exercise. There have been numerous studies using the SEBT as an assessment tool for identifying balance deficits post-fatigue, however, both SEBT and YBT display differences in reach scores when directly compared (17), this therefore makes comparison difficult. The results of the current study are in contrast to previous literature (21) reporting negative effects of fatigue, following a 60-s Wingate test, on YBT reach scores in a competitive sports population. The cohort in the current study consisted mainly of Gaelic footballers, a sport requiring different demands to other sports; namely, a skill known as 'soloing'. Soloing involves the player stabilising on one leg whilst kicking the ball with the other leg back into their hands. This Gaelic football skill is performed while running at a wide range of velocities, being tackled and also whilst changing direction. In the cohort assessed in the current study this skill would be required bilaterally and to a high level. Perhaps the regular, low-intensity periods within a game situation have facilitated the current cohort to adapt to this recovery time and restore any sensorimotor impairment induced by exercise within this 4-min time interval.

There were no significant effects of previous injury detected comparing pre- and post-exercise data, and no interaction of injury history by exercise, in any CoP variables assessed. This is in contrast to previous research (32, 33) reporting greater static and dynamic balance scores following a whole-body fatigue induced protocol in participants with history of ankle sprain. However, participants of these (32, 33) and the current study had all returned to full participation in sport including demanding regular match play, which may be likely attributed to participation in appropriate rehabilitation. Decreases in bilaterally postural stability have recently been reported post-unilateral ankle sprain (10); possibly the opposite occurs during the rehabilitation phase and a central learning effect is induced bilaterally. Kapreli et al. (22) concluded that altered feed-forward mechanisms and altered afferent information may lead to adaptations in the organisation of the central nervous system which enhances bilaterally.

This study is not without limitations. In the observational aspect of the current study, prior to conducting balance tests a warm-up activity was not included; this may have contributed to decreased reach scores. However, the test-retest aspect of the current study not only facilitated reliability assessment but the assessed retest data acted as pre-fatigue control data, and, therefore, including a pre-assessment warm-up would have potentially induced bias in the intervention trial. The current study assessed ankle instability by completion of a self-reported disability tool, namely; the Cumberland Ankle Instability Tool, and not by performing a manual anterior drawer or talar tilt test for mechanical instability; therefore, it is difficult to judge if there was a true mechanical instability present, or if this was purely subjective. This may have led to heterogeneity in the measured outcomes. We also used a subjective measure (RPE) to rate fatigue, and, therefore without an objective measure to quantify muscular fatigue we cannot ascertain that all participants were completely exhausted. However, a previous study (33) of a similar nature reported RPE ≥ 17 and objective blood lactate data (~8 $mmol.L^{-1}$) at exhaustion using a treadmill protocol. Additionally, the current study enlisted a mixed gender population from a variety of field-sports (although mainly Gaelic players), consequently we cannot ascertain that all participants exercised to volitional exhaustion to implicate dynamic balance significantly. Finally, of note, the exercise protocol used was aimed to replicate the intensities of a sporting situation, but was not a true reflection of a game situation. The assessment of static and dynamic variables following a game situation was not achievable in the current study.

When assessing static and dynamic balance it is important that any apparatus used is valid, reliable and suit participant requirements. The YBT is an inexpensive reliable tool to assess dynamic balance in a healthy Gaelic games player's population and while the use of force platforms is becoming increasing popular, they have added expense. The physiological requirements of different sports vary, and, therefore, future studies should consider assessment of balance variables that directly imitate challenges within the sport. Therefore, dynamic balance (YBT data) should be assessed immediately following a fatigue inducing protocol simulating the unique challenges of a sport, rather than at 4 min post-exercise as dictated the current study protocol, in order to determine if differences exist when comparing previously injured and un-injured limbs. In addition, a detailed assessment of the temporal timeframe of the return to baseline of static balance variables post-fatigue should also be considered.

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