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Does Fatigue Impact Static and Dynamic Balance Variables in Athletes with a Previous Ankle Injury?

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ABSTRACT

International Journal of Exercise Science 12(3): 1121-1137, 2019. Ankle 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 of static and dynamic balance variables in currently healthy, previously injured, athletes (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 measurement error by computing ICC and 95% limits of agreement (LoA). The Y balance test was deemed a reliable measuring tool for assessing dynamic balance, recording strong reliability (ICC = 0.96, 95% LoA from -95.7 to 105.8%). A HURlabs iBalance force platform assessed the static balance variables sway velocity and C90area; sway velocity ($mm \cdot s^{-1}$) recorded strong reliability (ICC = 0.79). Significant post-fatiguing protocol increases ($p < 0.001$) were detected in single-leg static balance for both C90area (mm^2) and sway velocity ($mm \cdot s^{-1}$) assessed on stable and unstable surfaces (stable: 227 ± 84 vs. 366 ± 146 mm^2 and 18.6 ± 4.2 vs. 22.9 ± 5.3 $mm \cdot s^{-1}$: unstable; 275 ± 128 vs. 370 ± 140 mm^2 and 19.3 ± 4.3 vs. 21.5 ± 4.0 $mm \cdot s^{-1}$). Non-significant post-fatiguing protocol differences ($p > 0.05$) were detected in dynamic balance variables (anterior, posteromedial, posterolateral and composite reach scores) measured at 4-min after completing the protocol. Further research should investigate the effects of fatigue on dynamic YBT variables immediately post-exercise and determine if differences exist when comparing previously injured and un-injured limbs.

KEY WORDS: Sway velocity, C90 area, balance assessment, balance platform, field-based team sports

INTRODUCTION

Adequate movement, strength, and static and dynamic balance of the ankle are essential to human movement and in the sporting environment. Intrinsic factors (physical fatigue) and extrinsic factors (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 (18). Ankle sprains affecting the lateral ligament complex are the most commonly reported (14) and the literature has reported ranges from 40 to over 70% of ankle sprains leading to the development of chronic ankle instability (CAI) (13, 26). Chronic ankle instability has been described as multifactorial and a term used to define mechanical and functional insufficiencies of the ankle (22). Static and dynamic balance deficiencies can be the results of one or many sprains. Other symptoms of CAI can include weakness, pain, swelling, the feeling of 'giving way' and loss of ankle function. In multidirectional sports and field-based games requiring speed, strength and agility (Gaelic football), lateral ankle sprain injuries may account for 3.6% of all injuries and can result in over a week off from sport (28). Sprain may also lead to ankle insufficiencies associated with CAI, such as decreased balance, sensorimotor control, proprioception, and overall performance, and may result in re-injury.

Within sport patterns have been detected assessing the timing of injury within the game (16, 17, 28) 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 and potentially place athletes at further risk of injury. In addition, re-injury can result in a longer absence from play compared to first time injury (17).

Fatigue differs according to the muscular group, actions involved, and exercise intensity and duration. The effect of fatigue on balance has been investigated extensively in the published literature (1, 7, 19, 24, 37, 38, 40, 41) with mixed results. This may be a consequence of different fatiguing protocols; namely whole-body fatigue, local muscle fatigue, and depending on the participant population, sport-specific fatigue. There are also differences in balance assessments used in the literature which further makes external validity questionable.

Different tools to assess dynamic and static balance are widely available (34) and more recently expensive balance platforms have been utilised to assess both static and dynamic balance. One such platform designed to assess static balance variables is the HURlabs iBalance platform (HURlabs, Tampere, Finland). The iBalance software uses output data from four force plates to assess static posturography, the performance of the postural control system in a static position based on body sway assessment through observation of the centre of pressure (CoP) trajectory. A displacement by time CoP variable (mean sway velocity in $mm \cdot s^{-1}$) and a displacement CoP variable (smallest ellipse that will include 90% of the CoP points; C90area) have been reported to be the most commonly assessed (36). For some teams designated balance platforms may be difficult to gain access to. Consequently, portable, inexpensive tests have been favoured among sports medicine professionals. The Star Excursion Balance Test (SEBT) has been used extensively to measure dynamic balance; however, as execution of SEBT can be time consuming a modified version, the Y Balance Test (YBT) was developed (33). The YBT uses three directions, namely, anterior (ANT), posteromedial (PM) and posterolateral (PL), and a combined composite score to assess dynamic balance (33).

Injury prevention strategies, including adequate screening and pre-habilitation, may have an influence on injury rates particularly at the elite level (16, 28). Athletes displayed fewer ankle and musculoskeletal injuries following participation in a balance training programme (10). This may imply that a poor balance score is a suitable predictor of future injuries. Both static and dynamic balance may be used as an indicator of increased risk of lower limb injury (32, 39). Consequently, identification of poor static and/or dynamic 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.

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. Further to the authors knowledge no study has used a 60-min intense intermittent zig-zag running to volatile exhaustion protocol. In order to accurately assess static and dynamic balance, reliable tools are needed and it is recommended that a number of statistical methods are used to assess the reliability of these tools (3), namely; the interclass correlation coefficient (ICC) to assess reliability and the level of agreement statistical approach (3) to quantify measurement error.

Therefore, this study had two objectives; firstly, quantify reliability of assessed dynamic and static balance variables, and secondly, identify any deficits in injured and un-injured limbs immediately after a fatiguing protocol designed to replicate a game scenario. 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 (mean sway velocity and C90 area) and dynamic (YBT; ANT, PM, PL, composite reach score) balance variables, and that the magnitude of change observed would be greater in previously injured compared to un-injured limbs.

METHODS

An observational repeated measures study design assessed short-term reliability 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 International Journal of Exercise Science guideline statements (29).

Participants

A healthy, currently un-injured, cohort of male and female athletes from field-based team sports (n = 19, aged 18 to 35 yr) were recruited from local sports clubs. Inclusion criteria required participants to be involved in a field-based team sport (Gaelic football, hurling / camogie (women's hurling), soccer or rugby) for a minimum of two sessions per week including a match. At the time of recruitment, participants reported to the research team a history of at least one ankle injury (sustained 6 to 24 months prior to the study) that had resulted in seven days lost to sport. Exclusion criteria included athletes who sustained any lower limb injury that had resulted in time lost in sport (minimum one day) 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 a history of surgery to either leg or a neurological injury that could limit exercise capacity were also excluded.

A 6 to 24 month injury timeframe was selected as six months has been advocated as sufficient time to return to sports activity beyond the risk of re-injury (37, 38) and 24 months as published research (2) has reported ankle symptoms for up to two years post-ankle sprain despite returning to full sporting activities. Athletes were not required to have sought the attention of a healthcare professional as it is estimated that 55% of patients who sustain an ankle sprain do not seek evaluation or treatment from a healthcare professional (22). As recommended by Gribble et al. (22) athletes were recruited based on the consequence of their ankle sprain, that being time lost in sport.

Static balance was measured using an 80 by 60 cm HURlabs iBalance platform (HURlabs, Tampere, Finland). Sensor specific data from four force transducers quantified the X and Y vertical co-ordinates of postrurogram (CoP) data on a laptop computer (Dell Inspiron, Dell, Texas, USA) using HURlabs iBalance software (iBalance premium Ver 2.4 HURlabs, Tampere, Finland). The iBalance platform was connected to, and powered by, the laptop via a direct USB connection. Two different static balance variables were subsequently computed from recorded CoP data, namely; mean sway velocity and C90 area.

Mean sway velocity ($mm \cdot s^{-1}$) is the summated distance divided by time and was calculated by dividing total trace length by test duration (20-s). Trace length on the posturogram was computed under software control by summing the length of the straight-line segments connecting successive CoP points separated in time by 200 ms (5 Hz), see Equation 1. Computation of this variable contains information about a person's ability to control their sway and to correct their balance; higher magnitude indicates decreased balance.

Equation 1: Sway velocity ($mm \cdot s^{-1}$) = $\Sigma d/t$, where $d = [(x_i - x_j)^2 + (y_i - y_j)^2]^{0.5}$ and t = time

The C90area (mm^2) is the area of the 90-percent confidence ellipse, and generally the bigger the area the bigger the sway. The C90 area is defined as the area of the smallest ellipse containing 90-percent of the CoP-points sampled at 100 Hz (10 ms intervals) during the 20-s trace recorded. The C90 ellipse is computed using the assumption that CoP co-ordinates will be approximately Gaussian distributed around their mean using Equation 2.

$$\text{Equation 2: C90area } (mm^2) = 4.605 * \Pi * [C_{xx} * C_{yy} - (C_{xy})^2]^{0.5}$$
$$\text{where } C_{xx} = [\Sigma(x_i - x_m)^2]/n-1,\ C_{yy} = [\Sigma(y_i - y_m)^2]/n-1 \text{ and } C_{xy} = [\Sigma(x_i - x_m)*(y_i - y_m)]/n-1$$

During assessment participants stood barefoot in single-leg stance at the centre of the platform with their non-stance leg held at 30° of hip flexion and 30° of knee flexion, hands on their hips and looking directly forward. A large 'X' was placed one metre in front of the participant to focus on during assessment, and they were requested to stand as still as possible. They were informed that the test would be disregarded if they had to touch the platform with their non-stance leg; however, athletes recruited had a level of balance such that this situation did not arise.

Dynamic balance was measured using the Y Balance test (YBT) which consists of a stance platform to which three pieces of PVC pipe are attached in the anterior, posteromedial, and posterolateral reach directions. The participant pushed a target (reach indicator) along the pipe, tape measured at 5 mm increments, and the target remained over the tape measure after performance of the test, making the determination of reach distance more precise. All participants were tested barefoot and standing with one leg on the centre piece, they were assessed while reaching with their free limb in each of the three assessed reach directions: anterior, posteromedial, and posterolateral directions in relation to their stance foot. The trial was discarded and repeated if the participant; failed to maintain unilateral stance on the platform (namely, touched down to the floor with the reach foot or fell off the stance platform), failed to maintain reach foot contact with the reach indicator on the target area while in motion (namely, kicked the reach indicator), used the reach indicator for stance support (namely, placed their foot on top of reach indicator), or failed to return the reach foot to the starting position under control or lifted the heel of the stance limb. To account for leg length differences across participants recorded YBT reach distances were normalised by dividing by leg length and expressed in percentage format (30). 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 (33).

All participants received a participant information leaflet outlining study details, and completed a consent form and medical questionnaire prior to their first visit. Participants also completed a self-reported disability questionnaire (Cumberland ankle instability tool [CAIT]) as a demographic descriptor; and 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-h 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 (more2perform) outlining how the YBT was performed. Vestibular function was checked by taking a detailed subjective history (6) 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 ($kg \cdot m^{-2}$) was computed and skinfold thickness was assessed using a Harpenden caliper (Baty International, West Sussex, UK) and percentage body fat interpolated (15) from cumulative skinfold thickness data. Resting 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 familiarization 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. Following a 10-min rest each participant executed 3 trials on the YBT (randomized 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.

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 aspect of the current study. Immediately following this participants undertook a directed 10-min warm-up that included running at a variety of RPE 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 infra-red timing gates (Brower Timing Systems, UT, USA) 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 60-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. 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.

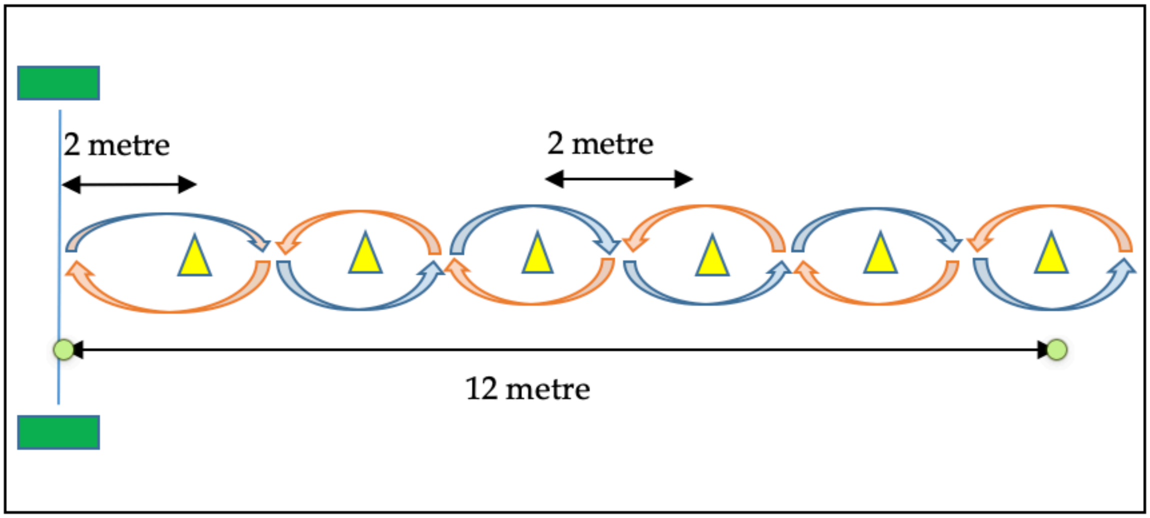

Figure 1. Diagram of running protocol; yellow triangles denote a cone and green rectangles denote Brower infra-red timing gates.

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. Reliability of test and re-test static and dynamic balance using combined data from both limbs were assessed using interclass correlation coefficient (ICC) and by computing upper and lower 95% limits of agreement (95% LoA). Given the potential limitations of using correlation analysis alone, we combined this with the level of agreement statistical approach (3) to compare test and re-test data, thereby computing reliability and quantifying measurement error. 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 by computing Cohen's d (mean exercise induced difference / pooled standard deviation) to quantify the effect size (9); accepted demarcations are < 0.2 trivial, from 0.2 to 0.5 poor to moderate, from 0.5 to 0.8 moderate to good and from 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, athletes. 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.

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).

	Age (yr)	Mass (kg)	Height (cm)	BMI ($kg \cdot m^{-2}$)	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)

(yr) – Year, (kg) - kilogram, (cm) – centimetre, ($kg \cdot m^2$) – kilogram divided by metre squared

Table 2. Test re-test reliability 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
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 $mm \cdot s^{-1}$	-5.2 $mm \cdot s^{-1}$
Mean sway velocity (unstable)	0.740	5.3 $mm \cdot s^{-1}$	-6.2 $mm \cdot s^{-1}$

(ICC) – Inter-class correlation coefficient, (LoA) – limits of agreement

Table 3. Test re-test reliability 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 reliability, ICC data for anterior, posteromedial and composite scores infer excellent 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 %

(YBT) – Y balance test, (ICC) – Inter-class correlation coefficient, (LoA) – limits of agreement

Mean sway velocity on a stable surface recorded the highest reliability. 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.

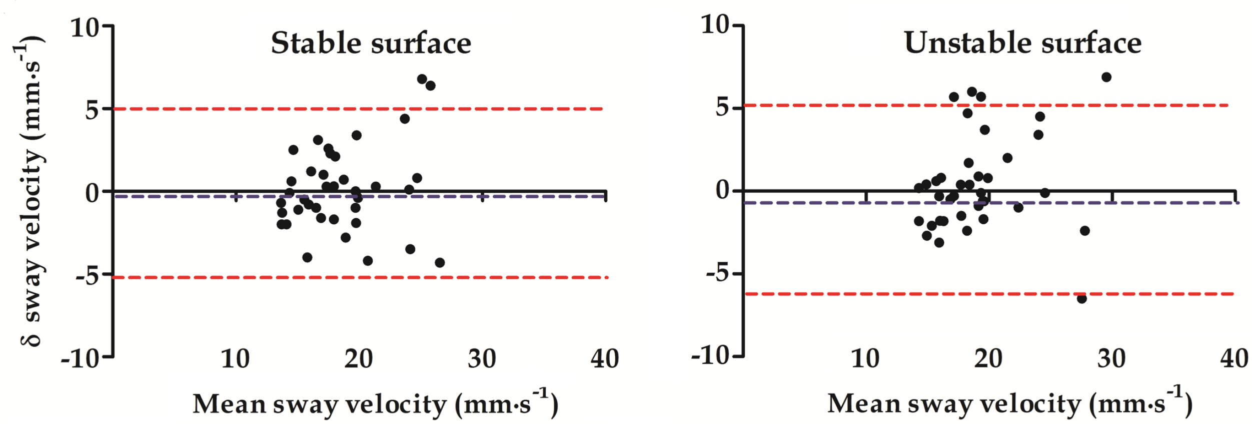

Figure 2. Bland Altman plots of sway velocity (mm·s^{-1}) data on stable (left) and unstable (right) surfaces. Dashed blue line infers mean bias, dashed red lines indicate upper and lower 95% LoA.

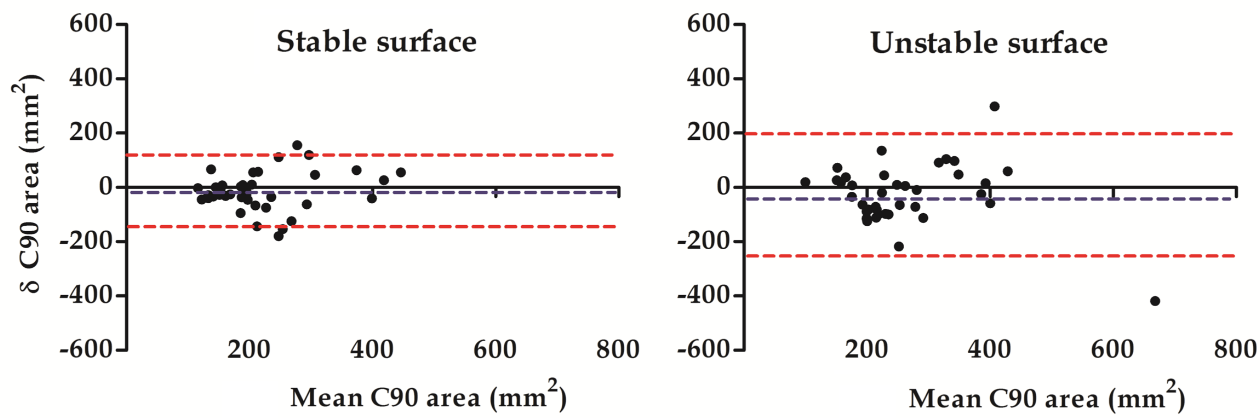

Figure 3. Bland-Altman plots of C90 area (mm^2) data on stable (left) and unstable (right) surfaces. Dashed blue line infers mean bias, dashed red lines indicate upper and lower 95% LoA.

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 (Figure 4) 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; 160, 95% CI 94 to 226 and 119, 95% CI 54 to 185 mm^2, $p < 0.001$; unstable; 108, 95% CI 37 to 178 and 96, 95% CI 26 to 166 mm^2, $p < 0.01$) in both injured and un-injured limbs. Analysis of mean sway velocity (mm·s^{-1}) on stable and unstable surfaces (Figure 5) 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 (4.4, 95% CI 1.9 to 7.0 and 4.3, 95% CI 1.7 to 6.8 mm·s^{-1}, $p < 0.001$) in previously injured and un-injured limbs on a stable surface and in previously injured (2.5, 95% CI 0.7 to 4.3 mm·s^{-1}, $p < 0.01$) and un-injured limbs (2.0, 95% CI 0.2 to 3.9 mm·s^{-1}, $p < 0.05$) on an unstable surface. Analysis of normalised YBT data (anterior, posteromedial, posterolateral and composite reach) failed to detect any significant differences (Table 4).

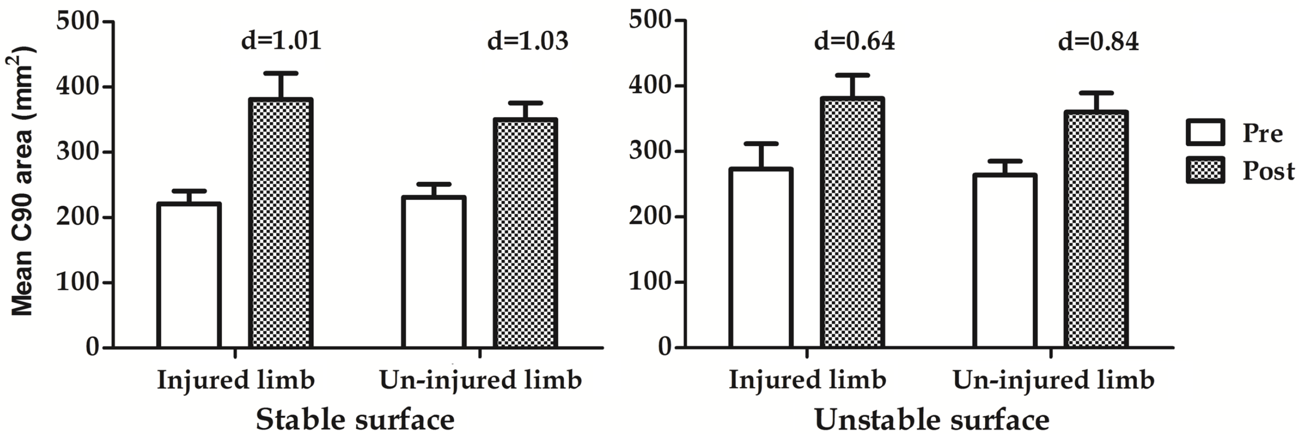

Figure 4. Bar graph of mean C90 area (mm²) for previously injured and un-injured limbs on stable and unstable surfaces pre- and post-exercise, bars denote SEM, (n = 19). Computed Cohen's d inferring the meaningfulness of the detected exercise induced differences is displayed above post-exercise data.

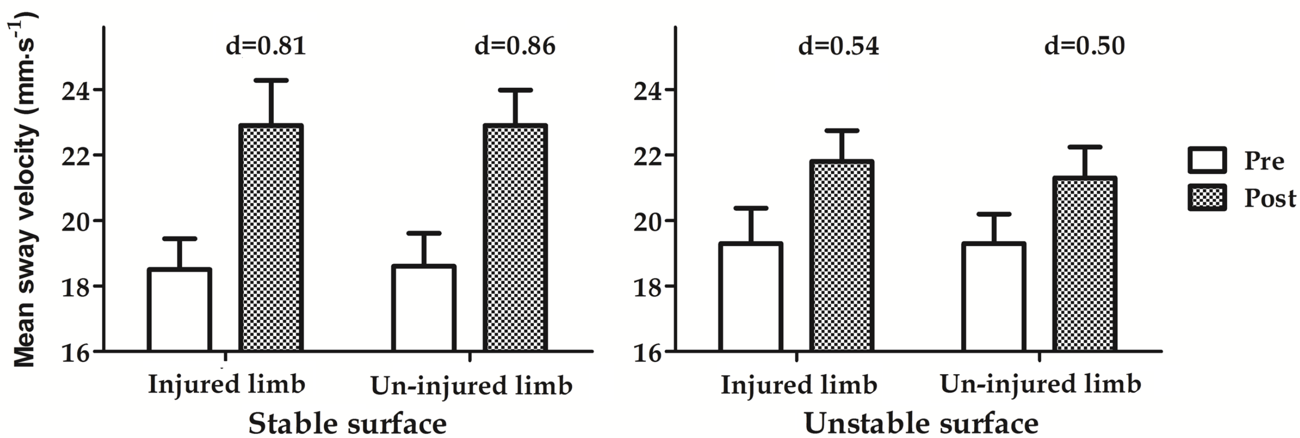

Figure 5: Bar graph of mean sway velocity (mm·s^{-1}) for previously injured and un-injured limbs on stable and unstable surfaces pre- and post-exercise, bars denote SEM, (n = 19). Computed Cohen's d inferring the meaningfulness of the detected exercise induced differences is displayed above post-exercise data.

Table 4. Mean and standard deviation (SD) for normalised YBT reach and composite score data pre- and post-exercise for injured and un-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
Un-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

(YBT) – Y balance test

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 the iBalance force platform used to assess static balance variables assessed; mean sway velocity ($mm \cdot s^{-1}$) recorded higher reliability than C90area (mm^2) on both stable and unstable surfaces. The second hypothesis; namely, impact of exercise induced fatigue, was partly accepted as data analysis demonstrated significant increases in mean sway velocity ($mm \cdot s^{-1}$) and C90area (mm^2) measured immediately following a 60-min intense intermittent zig-zag running protocol to volitional exhaustion in a cohort of healthy, currently un-injured athletes. However, there were no significant fatigue induced effects detected for any of the assessed YBT dynamic variables; namely, anterior, posteromedial and posterolateral reach directions normalised to leg length, or computed composite scores when assessed at 4-min post-exercise. Finally, there were no significant effects of fatigue detected comparing between injured and un-injured limbs.

The YBT results of the current study are comparable to previous research reporting fair to good (27) and excellent reproducibility (24, 33), however, only one of these studies (33) examined composite score data. There is continued debate concerning the optimal number (4 or 6) of practice trials in adults and athletic adolescents (27, 33, 35). 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. Of note, no athlete continued to improve their reach scores in any YBT directions assessed indicating plateauing by trial 1, consequently, we assumed that learning had stabilised by trial 1, a finding comparable with published data (35). Although the original protocol describing the YBT (33) 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 (27) and disallowed the stance foot from being lifted during reaches in order for study data to be comparable to others (21, 23) whose population included participants from soccer and hockey.

The current study demonstrated mean sway velocity data ($mm \cdot s^{-1}$) 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 (11) has also reported mean sway velocity ($cm \cdot s^{-1}$) 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 CoP variables that would equate to mean sway velocity and area (4, 30) 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. Research by da Silva et al. (11) 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 populations, 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 (5) which help stabilise the ankle complex. In sports that require multiple changes in direction; namely field-based team sports, local musculature of the ankle joint assists in maintaining joint integrity, stability and balance. Impaired muscle activation patterns or reflexive activity of these muscles (identified by measuring mean sway velocity) may reduce protective mechanisms needed in sport and thus may place the ankle at increased risk of injury. When assessing static balance variables, reliability data indicates mean sway velocity to be the CoP variable that should be used, however, considering the influence of individual anthropometric characteristics on CoP measures, future research should consider normalising CoP measurements to height, body mass and BMI which may further increase reliability (31).

To the authors' knowledge this is the first study to assess the effects of whole-body and local muscle fatigue on the CoP variables; namely, C90area (mm^2) and mean sway velocity ($mm \cdot s^{-1}$) on stable and unstable surfaces, in a cohort of healthy athletes (predominantly Gaelic football 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 (Cohen's d) ranging from excellent, as demonstrated in C90 area (mm^2) on a stable surface, and moderate to good, demonstrated in mean sway velocity ($mm \cdot s^{-1}$) on an unstable surface.

Similar to the current study, previous literature has reported increases in static balance variables indicating decreased balance ability (instability) following fatigue; namely, mean sway velocity (37, 38) 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 when compared to mean sway velocity data, therefore, perhaps mean sway velocity ($mm \cdot s^{-1}$) should be considered as the static variable of choice.

Single-leg balance may be criticised for not being a true reflection of a sporting situation (11) due to its static nature and as such dynamic balance assessment may better reflect the sensorimotor control mechanisms required in sport specific actions. However, poor balance measured using single-leg stance has been shown to predict a higher risk for ankle sprains (39) in a sporting population. Therefore, depending on resources available, perhaps sports teams should consider both static and dynamic measures when assessing single-leg balance as an indicator for increased risk of ankle injury.

While the current study reported no significant differences in dynamic balance variables assessed using YBT at 4-min post exercise, numerous factors need to be considered. One of the required kinematic components of the YBT is dorsiflexion of the ankle, especially when the stance foot is not allowed to be lifted, therefore limited dorsiflexion due to previous injury may not result in significant changes in scores. The results of previous studies (37, 38) which have used the SEBT as an assessment tool for identifying dynamic balance deficits post-fatigue are in contrast to the current study, however, both SEBT and YBT display differences in reach scores when directly compared (20), this therefore makes comparison difficult. The current study results are also in contrast to previous literature reporting negative effects of fatigue on YBT reach scores, in a completive sports population, following a 60-s Wingate test; a fatiguing protocol somewhat different to the current study. The aforementioned studies (37, 38) also used a different protocol to the current study, inducing fatigued by treadmill running to exhaustion. The fatiguing protocol used in these studies (24, 37, 38) did not replicate a game scenario; namely, lasting for 60+ minute and requiring variations in running velocity and multiple changes of direction. 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. The variety in running velocities and explosive efforts required during sprinting, landing, jumping and turning are important for most field-based team sports and consequently the lower limb injury patterns in Gaelic football are similar to other field-based team sports such as soccer, Australian rules football and rugby union (17, 28). Therefore the results of this study could be considered transferable to other field-based team sports. Future research should consider assessing dynamic balance immediately after a fatiguing protocol similar to the one used in the current study. Of note, Gaelic football requires a specific skill known as 'soloing' which 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 and may have contributed to non-significant differences in reach scores assessed 4-min post-exercise. However, as the authors are not aware of any literature that directly compares YBT measures between Gaelic football players and other sports, it is difficult to ascertain that the dynamic balances results of this study are due to the above named skill requirement in the sport.

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. The results of this study are in contrast to previous research (37, 38) 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 (37, 38) 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 (13); possibly the opposite occurs during the rehabilitation phase and a central learning effect is induced bilaterally. Kapreli et al. (25) 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. Athletes included in this study were required to have suffered one ankle sprain that resulted in at least 7 days lost to sport. To gain an indication of self-reported disability participants completed the CAIT; results did not indicate the enlisted cohort to be homogenous to either a stable or an unstable ankle group. As severity, symptoms and recovery from an ankle sprain can differ greatly between individuals, perhaps future research should include a homogenous groups of athletes with an unstable or stable ankle as classified by the CAIT (22) following ankle injury.

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, unpublished in-house data assessing the current intermittent zig-zag protocol in male games players documented post-exercise blood lactate and RPE data in excess of 10 $mmol \cdot L^{-1}$ and ≥ 18. In addition, a previous study (38) of a similar nature reported RPE ≥ 17 and objective blood lactate data (~8 $mmol \cdot L^{-1}$) at exhaustion using a treadmill protocol. The current study enlisted a mixed sex population from a variety of field-sports (although mainly Gaelic football players), but essentially from a variety of fitness levels and backgrounds, and, 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 football player 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.

In the current study fatigue did not affect dynamic balance according to the YBT data assessed 4-min post exercise, but did affect static balance variables recorded immediately post-exercise using the iBalance platform. 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 by 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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