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**Research article**

# Reliability of Single-Leg Balance and Landing Tests in Rugby Union; Prospect of Using Postural Control to Monitor Fatigue

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**Abstract**
The present study examined the inter-trial (within test) and inter-test (between test) reliability of single-leg balance and single-leg landing measures performed on a force plate in professional rugby union players using commercially available software (SpartaMARS, Menlo Park, USA). Twenty-four players undertook test – re-test measures on two occasions (7 days apart) on the first training day of two respective pre-season weeks following 48h rest and similar weekly training loads. Two 20s single-leg balance trials were performed on a force plate with eyes closed. Three single-leg landing trials were performed by jumping off two feet and landing on one foot in the middle of a force plate 1m from the starting position. Single-leg balance results demonstrated acceptable inter-trial reliability (ICC = 0.60-0.81, CV = 11-13%) for sway velocity, anterior-posterior sway velocity, and mediolateral sway velocity variables. Acceptable inter-test reliability (ICC = 0.61-0.89, CV = 7-13%) was evident for all variables except mediolateral sway velocity on the dominant leg (ICC = 0.41, CV = 15%). Single-leg landing results only demonstrated acceptable inter-trial reliability for force based measures of relative peak landing force and impulse (ICC = 0.54-0.72, CV = 9-15%). Inter-test results indicate improved reliability through the averaging of three trials with force based measures again demonstrating acceptable reliability (ICC = 0.58-0.71, CV = 7-14%). Of the variables investigated here, total sway velocity and relative landing impulse are the most reliable measures of single-leg balance and landing performance, respectively. These measures should be considered for monitoring potential changes in postural control in professional rugby union.

**Key words:** Time to stabilization, sway velocity, peak force, relative impulse, sensorimotor control.

## Introduction

Postural control is defined as the ability to control the centre of mass and incorporates synergistic performance of the neuromuscular and sensorimotor systems (Paillard, 2012). While many non-instrumented and instrumented assessments of postural control are available, static single-leg balance tests and dynamic single-leg landing tests performed on a force plate are commonly used in elite athletic populations. Single-leg balance and landing tasks are suggested to be associated with performance and injury occurrence in a variety of athletes (Munn et al., 2010). For example, postural control can successfully identify differences between healthy and injured populations with functional ankle instability (Wikstrom et al., 2005a) and anterior cruciate ligament reconstruction (Harrison et al., 1994). More recently, research has suggested the potential of postural control tests for monitoring neuromuscular fatigue (NMF) status in athletes (Clarke et al., 2015; Pau et al., 2016). However, understanding of the smallest worthwhile change and variability in measures is required to further use these measures in the monitoring of fatigue.

While countermovement jump (CMJ) testing is the most common tool to assess NMF in team-sport settings (Taylor et al., 2012), there are several limitations to its effectiveness. The CMJ is a maximal attempt to produce lower-body power, and athletes may be capable of adopting different movement strategies to accomplish similar total output and mask the presence of NMF (Gathercole et al., 2015). Secondly, CMJ may not account for more subtle central (neural drive) and peripheral (efferent feedback through mechanoreceptors) nervous system factors that are interrelated with NMF (Paillard, 2012). The value of postural control tests for athlete monitoring is their potential insight into underlying NMF during the critical post-match window when the practicality and athlete compliance of maximal power tests are limited, especially in collision sports like rugby union (Clarke et al., 2015).

As evidence of their criterion validity, postural control tests have demonstrated sensitivity to local, general, and sport-induced fatigue. Isokinetic exercise-induced fatigue has produced 12 – 49% decrements in balance performance and 5 – 17% decrements in landing performance (Bizid et al., 2009, Salavati et al., 2007, Wikstrom et al., 2004). General fatigue protocols consisting of running or mixed activity conditioning have resulted in 16 – 32% reductions in single-leg balance and 4-35% reductions in single-leg landing measures ( Brazen et al., 2010; Steib et al., 2013; Zech et al., 2012). Meanwhile, 65% and 28% reductions in balance and landing performance have been demonstrated following a simulated Canadian Football game and youth soccer match respectively (Clarke et al., 2015; Pau et al., 2016). Thus, there is evidence to suggest the robustness of static and dynamic postural measures to be applied to an ongoing NMF monitoring context in high-performance rugby.

However, prior to the use of postural control tests as a NMF monitoring tool, the reliability of such tests must be clearly understood. By determining reliability, practitioners can also understand thresholds for meaningful change based on the typical error of the test to allow better interpretation of outcomes. Numerous measures have been used to describe balance performance based on the displacement, velocity, amplitude, area, frequency, predictability, and complexity of centre of pressure (COP) measures on a force plate (Duarte and Freitas, 2010). While many vari-

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ables demonstrate good reliability across a variety of testing methods related to trial length, stance, and visual conditions, mean sway velocity (SV) is identified as one of the generally more reliable variables (r = 0.32 – 0.94) (Ruhe et al., 2010). Dynamic postural control has been previously studied through a variety of landing protocols on a force plate (Tran et al., 2013). There is some disagreement in the literature about the key kinetic variables to measure, with time to stabilization (TTS) being the most common; alongside relative peak force, relative impulse, and customised calculations of stability index (Wikstrom et al., 2005b). There are also conflicting results on the reliability of dynamic postural control measures. Reliability ranges from moderate (ICC = 0.40) for youth soccer players performing a drop landing from a box (Fransz et al., 2014) to excellent (ICC = 0.96) for healthy participants landing from 50% of maximal jump height (Wikstrom et al., 2005b).

Given postural control tests have the potential to be applied as a NMF monitoring tool in elite sport, practical methods of data collection and analysis using commercially available software should be investigated. The inter-trial and inter-test reliability of single-leg balance and single-leg landing tests in athletes is necessary to understand typical error and the subsequent thresholds for meaningful change inherent to these tests. Therefore, the aim of this study was to examine the inter-trial and inter-test reliability of single-leg balance and single-leg landing tests performed on a force plate in professional rugby union players.

## Methods

### Experimental approach to the problem

Static balance and dynamic landing tasks were performed on a calibrated force plate in a test- re-test experiment to determine inter-trial and inter-test reliability. Testing sessions were identical and occurred on two training days separated by 7 days. Both testing days were preceded by 48 h of rest and performed at a standardised time (8:00 - 10:00) on the first training day of the week. All participants had extensive prior familiarity with the testing protocols, having undertaken testing procedures on at least six occasions prior to the testing weeks. Testing days were selected to follow weeks with similar prior training loads. Participants reported to the testing location in a secluded corner of the gym wearing normal training attire. Testing was performed barefoot and athletes had not participated in any physical activity prior to testing.

### Subjects

Twenty-four professional male rugby union players (age: 25.4 ±3.7 yr, height: 1.86 ± 0.06 m, mass: 105.7 ± = 13.7 Kg), including 14 forwards and 10 backs, volunteered to participate in this study. All participants were a part of the pre-season training roster for a professional rugby franchise (first-team matches: 63 ± 47). All participants were currently participating in full training and free of injury during the 3 months prior to the investigation. Full time training required participation in 4-5 conditioning and skill sessions, along with 4 strength training sessions in a weekly micro cycle. Prior to testing, all participants were provided written and verbal instructions and signed an informed consent form following approval by the University Ethics Committee. However, testing was performed as a part of normal sports science and medical screening practices at the club.

### Procedures

### Balance

Static balance testing was performed using a commercially available piezoelectric force plate with a sampling frequency of 1000 Hz (9260AA6, Kistler Instruments, Winterthur, Switzerland). Force plate data was collected and analysed using commercially available software (SpartaMARS, Sparta Performance Science, Menlo Park, USA). Prior to testing the force plate was calibrated according to manufacturer's specifications, and prior to each test was zeroed before data collection. Participants were instructed to stand on two feet with hands on hips and eyes closed to establish baseline force. A subsequent beep indicated they should lift one leg and maintain a stable position for 20 seconds. A second beep indicated the end of the 20 second trial at which point participants were instructed to rest. A ten second interval was provided between trials with the second trial occurring on the opposite leg. In total, four trials (two per limb) were completed in alternating fashion. During each balance trial, COP displacement was measured, and commercially available software provided measures of total sway velocity ($m \cdot s^{-1}$), sway velocity anterior-posterior ($m \cdot s^{-1}$), and sway velocity medial-lateral ($m \cdot s^{-1}$) as based on previous evidence (Prieto et al., 1996).

### Landing

Following static balance testing, participants completed dynamic stability testing consisting of a jump and single-leg landing on the same force plate and data acquisition software. The force plate was re-zeroed, and participants stood still on the plate for 3 seconds to re-establish baseline force. Participants then stepped back to a starting mark 1 m from the centre of the force plate. Upon hearing an auditory signal, participants jumped off two legs and landed on the dominant (kicking) leg in the centre of the force plate. Participants were instructed to jump as high as possible and hold the landing on one leg. A second auditory signal indicated completion of the trial when the participant's ground reaction force had equalized within 5% of baseline force in accordance with established processing methods for time to stabilization (Colby et al., 1999). Subsequent trials were completed on alternating legs with a total of three trials performed on each side. Testing procedures were similar to those previously established (Wikstrom et al., 2005b). During each landing trial, relative peak landing force(rPF) ($N \cdot Kg^{-1}$), relative landing force impulse(rIMP) ($N \cdot Kg^{-1}s^{-1}$), and total time to stabilization (TTS) (s) were collected using commercially available software for dominant and non-dominant legs.

### Training loads

Given training induced fatigue may influence any measure of NMF or postural control, testing sessions were preceded by 48h recovery and training loads were recorded for the week prior to each testing session. Internal load was determined using the rating of perceived exertion (sRPE) method (Foster et al., 2001) within 15 minutes of each session on a modified 10 point Borg scale for all gym and field sessions. Training Load (TL) was calculated as sRPE x duration, resulting in an arbitrary unit (AU) value for each (gym, conditioning, on-field rugby and conditioning) session. Data was entered, calculated, and stored in data management software (Smartabase, Fusion Sports, Sumner Park, AUS). External load was determined for all field sessions with wearable integrated 15 Hz global positioning system (GPS) and 100 Hz accelerometer devices (SPI-HPU; GPSports, Canberra, Australia). Units were worn against the spine, just above the shoulder blades in manufacturer provided vests. Data was downloaded and analysed using Team AMS software and SPIIQ web applications (GPSports, Canberra, Australia) and reported here as total distance.

## Statistical analyses

Data was collated and categorized based on trial, test day, and dominant (D) or non-dominant (ND) leg determined by preferred kicking leg (Pau et al., 2015). Customised spreadsheets (Hopkins, 2002) were used to determine reliability via intraclass correlation coefficient (ICC), typical error (TE), and coefficient of variation (CV). Mean and standard deviation was also determined, and paired t-test used to identify between test differences. Significance was set at $p \leq 0.05$. Calculations were performed for comparison of trials within a test (inter-trial) for each variable collected as well as comparison of the mean values of trials from the two test dates (inter-test) (Hopkins et al., 2009). ICC provides a measure of relative reliability (Hopkins et al., 2009), and was interpreted based on the thresholds: < 0.49 (small), 0.50-0.69 (moderate), 0.70-0.89 (large), and 0.90-1.00 (very large) (Munro, 1986). Coefficient of variation provides a measure of absolute variability of the test and is calculated as: mean / TE *100, with CV ≤ 10% indicative of good reliability and CV ≤ 15% indicative of acceptable reliability (Hopkins, 2000).

# Results

## Training load

No significant differences ($p > 0.05$) were evident in any marker of internal or external training load in the week prior to either testing session (Table 1).

## Inter-trial reliability

Inter-trial reliability, representing variability between trials within the same single-leg balance testing session, are presented in Table 2. ICC's for all reported variables were deemed large (ICC > 0.70), except for anterior-posterior sway velocity on the dominant leg which was classified as moderate (ICC = 0.60). CV's for all reported variables ranged from 11-13%, indicating moderate within-testing variability for measures of static postural control. Additionally, typical error (TE) exceeded smallest worthwhile change (SWC) for all measures, and significant differences ($p < 0.05$) were evident between trials for all variables on the dominant leg.

**Table 1. Mean (±SD) training load and distance for weeks prior to reliability testing day1 and day 2.**

| | Week 1 | Week 2 |
|---|---|---|
| **Number of session (field, gym)** | 6, 4 | 6, 4 |
| **Daily total training load (au)** | 538 (146) | 744 (139) |
| **Daily total distance (m)** | 4652 (709) | 4767 (675) |
| **Weekly total training load (au)** | 3667 (641) | 3393 (534) |
| **Weekly total distance (m)** | 17699 (3952) | 18662 (3096) |

au=arbitrary units, m=metres, No significant differences between weeks

Inter-trial reliability, representing variability between trials within the same single-leg landing testing session is presented in Table 3. ICC's for the force-based landing variables of relative peak force and relative impulse were moderate to large (ICC = 0.54 – 0.72) and CV's between 9 - 15% indicate moderate variability of force based measures of dynamic postural control. In contrast time to stabilization resulted in small ICC's (0.22 – 0.27) and CV's between 25 - 29%, indicating high variability in stability-based measures of dynamic postural control. TE exceeded SWC for all measures, and significant differences ($p = 0.01$) were evident between trials for relative impulse on the dominant leg.

## Inter-test reliability

Inter-test reliability, representing the variability between single-leg balance testing sessions performed 7 days apart is presented in Table 4. ICC's for all reported variables were deemed moderate to very large (ICC = 0.61 – 0.90), except for medial-lateral sway velocity on the dominant leg which was classified as small (ICC = 0.41). CV's for all reported variables ranged from 7 - 15% indicating moderate between test variability for measures of static postural control. TE exceeded SWC for all measures, and no significant differences ($p > 0.05$) were observed between any reported variables for testing sessions performed 7 days apart.

Inter-test reliability, representing the variability between single-leg landing sessions performed 7 days apart is presented in Table 5. ICC's for the force-based variables of relative peak force and relative impulse are moderate to

**Table 2. Mean (± SD) inter-trial reliability of single-leg balance test performed with eyes closed on a force plate**

| | Trial 1 | Trial 2 | TE | ICC | %CV | SWC | *P* value |
|---|---|---|---|---|---|---|---|
| **Sway Velocity – ND (m/s)** | .085 (.019) | .084 (.020) | .010 | .75 | 12 | .004 | .17 |
| **Sway Velocity – D (m/s)** | .089 (.018) | .085 (.020) | .010 | .73 | 12 | .004 | .02* |
| **Sway Velocity AP – ND (m/s)** | .060 (.014) | .060 (.016) | .008 | .75 | 13 | .003 | .21 |
| **Sway Velocity AP – D (m/s)** | .065 (.013) | .058 (.012) | .008 | .60 | 13 | .003 | .01* |
| **Sway Velocity ML – ND (m/s)** | .048 (.012) | .046 (.011) | .006 | .71 | 13 | .002 | .22 |
| **Sway Velocity ML – D (m/s)** | .049 (.013) | .047 (.012) | .005 | .81 | 11 | .002 | .01* |

ND = Non-Dominant, D = Dominant, AP = Anterior / Posterior, ML = Medial / Lateral, TE = Typical Error, ICC = Intraclass Correlation Coefficient, %CV = % Coefficient of Variation, SWC = Smallest Worthwhile Change, *= significantly different between Trial 1 and 2 (p ≤ 0.05).

**Table 3.** Mean (±SD) inter-trial reliability of single-leg landing test performed onto a force plate from 1 meter away with a self-selected jump height.

| | Trial 1 | Trial 2 | TE | ICC | %CV | SWC | *P* value |
|---|---|---|---|---|---|---|---|
| Relative Peak Force – ND (N/Kg) | 4.58 (1.01) | 4.93 (1.199 | .62 | .69 | 13 | .22 | .17 |
| Relative Peak Force – D (N/Kg) | 4.62 (1.22) | 5.14 (1.45) | .71 | .72 | 15 | .27 | .30 |
| Relative Impulse – ND (N*s/Kg) | 2.16 (.30) | 2.23 (.37) | .23 | .54 | 11 | .07 | .32 |
| Relative Impulse – D (N*s/Kg) | 2.08 (.28) | 2.25 (.33) | .18 | .65 | 9 | .06 | .01* |
| Time to Stabilization – ND (s) | .61 (.16) | .64 (.19) | .15 | .27 | 25 | .04 | .43 |
| Time to Stabilization – D (s) | .71 (.25) | .61 (.19) | .19 | .22 | 29 | .04 | .09 |

ND = Non-Dominant, D = Dominant, TE = Typical Error, ICC = Intraclass Correlation Coefficient, %CV = % Coefficient of Variation, SWC = Smallest Worthwhile Change, *= significantly different between Trial 1 and 2 ($p \leq 0.05$).

**Table 4.** Mean (±SD) inter-test reliability of single-leg balance test performed with eyes closed on a force plate.

| | Test 1 | Test 2 | TE | ICC | %CV | SWC | *P* value |
|---|---|---|---|---|---|---|---|
| Sway Velocity – ND (m/s) | .086 (.020) | .085 (.020) | .010 | .67 | 12 | .003 | .78 |
| Sway Velocity – D (m/s) | .091 (.018) | .089 (.018) | .008 | .79 | 9 | .003 | .63 |
| Sway Velocity AP – ND (m/s) | .060 (.015) | .060 (.014) | .008 | .61 | 13 | .003 | .79 |
| Sway Velocity AP – D (m/s) | .061 (.012) | .062 (.013) | .004 | .89 | 7 | .003 | .47 |
| Sway velocity ML – ND (m/s) | .048 (.012) | .048 (.011) | .005 | .78 | 11 | .002 | .75 |
| Sway Velocity ML – D (m/s) | .052 (.012) | .049 (.012) | .008 | .41 | 15 | .002 | .32 |

ND = Non-Dominant, D = Dominant, AP = Anterior / Posterior, ML = Medial / Lateral, TE = Typical Error, ICC = Intraclass Correlation Coefficient, %CV = % Coefficient of Variation, SWC = Smallest Worthwhile Change, *= significantly different between Trial 1 and 2 ($p \leq 0.05$).

**Table 5.** Mean (±SD) inter-test reliability of single-leg landing test performed onto a force plate from 1 meter away with a self-selected jump height.

| | Test 1 | Test 2 | TE | ICC | %CV | SWC | *P* value |
|---|---|---|---|---|---|---|---|
| Relative Peak Force – ND (N/Kg) | 4.58 (1.00) | 4.89 (1.05) | .67 | .58 | 14 | .21 | .13 |
| Relative Peak Force – D (N/Kg) | 4.76 (.90) | 5.05 (1.15) | .57 | .71 | 12 | .21 | .10 |
| Relative Impulse – ND (N*s/Kg) | 2.18 (.31) | 2.27 (.24) | .17 | .64 | 8 | .05 | .09 |
| Relative Impulse – D (N*s/Kg) | 2.22 (.27) | 2.31 (.26) | .15 | .68 | 7 | .05 | .05* |
| Time to Stabilization – ND (s) | .63 (.12) | .62 (.13) | .08 | .60 | 13 | .03 | .82 |
| Time to Stabilization – D (s) | .66 (.17) | .60 (.14) | .13 | .28 | 21 | .03 | .10 |

ND = Non-Dominant, D = Dominant, TE = Typical Error, ICC = Intraclass Correlation Coefficient, %CV = % Coefficient of Variation, SWC = Smallest Worthwhile Change, *= significantly different between Trial 1 and 2 ($p \leq 0.05$).

large (ICC = 0.58 – 0.71), and CV's between 7 - 14% indicate moderate between test variability of force-based measures of dynamic postural control. Time to stabilization resulted in a moderate ICC on the non-dominant leg (ICC = 0.60) and small ICC on the dominant leg (0.28). CV's ranged from 13 - 21% indicating large between test variability of stability-based measures of dynamic postural control. TE exceeded for all measures, and significant differences ($p < 0.05$) between testing sessions 7 days apart were evident only for relative impulse on the dominant leg.

## Discussion

The objectives of this study were to determine the inter-trial and inter-test reliability of specific static and dynamic postural control protocols performed on a force plate, with a view understanding their variability when measuring NMF in professional rugby union players. Our results indicate generally better reliability of balance measures than landing measures, with sway velocity and relative impulse being the most reliable of the measures investigated for balance and landing respectively. An understanding of the variability (biological and technological) and sensitivity of the tests will establish thresholds for meaningful change that can be used to identify potential NMF and thus inform decisions related to performance optimisation.

### Single-leg balance

Sway velocity measures showed moderate (ICC > 0.50) to good (ICC > 0.70) inter-trial (within test) and inter-test (between test) reliability for all vectors and limbs, except for inter-test reliability of medial-lateral (ML) sway velocity on the dominant leg (ICC = 0.41). Yamanaka et al. (2012) and Hertel et al. (2006) use a similar single-leg stance protocol and COP mean velocity processing methods, reporting ICC's of 0.64 and 0.72 for respective measures. Such findings are comparable to the present results, though these studies did not include CV values to compare to the present findings of 7-13%. Other existing research spans a broad range of populations, testing protocols and processing methods and thus direct comparison is difficult. For example, Meshkati et al. (2011) investigated the reliability of mean velocity of double leg stance on a force plate in athletes with results of ICC's from 0.45 – 0.89 and CV's from 7.2 – 11.7%. Salavati et al. (2009) reported good reliability of mean sway velocity in double leg stance for a group of healthy controls with eyes open (ICC = 0.91 and CV = 7.3%), and Clarke et al. (2015) reported ICC = 0.71 – 0.99 for sway area in a tandem stance protocol among Canadian Football players. Whilst this collection of research provides an overview of the expected reliability and sensitivity of mean velocity measures, the variety of methods justifies the need for evidence in specific populations and protocols in order for thresholds for meaningful change to be understood.

Exploring sway velocity as a marker of postural control in more detail, our results indicate that participants performed better (lower sway velocity) on the ND leg than the D leg in 11 out of 12 tests. This performance bias is supported by existing research suggesting lower sway velocity on the ND leg (Hertel et al., 2006). In addition, all ML measures show good reliability except for inter-test measures on the D leg (ICC = 0.41). The ML direction is the smallest base of support, and is perceived as the most challenging direction of single-leg stability despite previous reports of acceptable reliability for ML sway (ICC = 0.64 – 0.65) (Hertel et al., 2006, Yamanaka et al., 2012). Of further note, inter-trial measures showed significant improvements between trial 1 and trial 2 on the dominant leg indicating a systematic bias between trials. Thus, the addition of practice trials to the testing protocol could further improve reliability. Regardless, inter-test reliability suggests that total sway velocity and anterior-posterior sway velocity are the most reliable (ICC = 0.79, 0.90 respectively) and sensitive (CV = 9%, 7% respectively) measures of single-leg balance investigated in the current study.

### Single-leg landing

The single-leg landing measures investigated in the current study can be divided into two categories, including the force-based measures of relative peak force (rPF) and relative impulse (rIMP) and stability-based measure of time to stabilization (TTS). Inter-trial reliability of single-leg landing measures resulted in moderate ICC values (0.54 – 0.72) and CV's (9 – 15%) for force based measures rPF and rIMP, while TTS was less reliable (ICC 0.22 – 0.60; CV 13 – 29%). While a variety of testing protocols exist throughout the literature, similar protocols to our study demonstrate ICC's of 0.97 and 0.90 for TTS on the ND and D legs respectively (Colby et al., 1999) and an ICC of 0.78 and CV of 18% for TTS on the D leg (Wikstrom et al., 2005b). These studies demonstrate better reliability which could result from methods using submaximal jump heights and non-athlete populations. Given the current study instructed elite athletes to jump as high as possible, it is conceivable our study investigated greater landing forces which pose a greater challenge to stability (Wikstrom et al., 2005a). Modifications to the protocol for improving reliability could include further standardizing landing force by setting a submaximal target (Wikstrom et al., 2005a), barrier (Colby et al., 1999), or box height (Ross and Guskiewicz, 2004), though it may then lack ecological validity in an athletic environment.

The majority of research focuses on the stability-based measure of TTS with very few reporting rPF or rIMP. Previous research may have not reported these measures because of the focus on more direct measures of stability; however, absorption and stabilization are equally important aspects of the landing process (Wikstrom et al., 2006). Specifically, force based measures relate better than stability based measures to the dynamic nature of multi-directional movement demands and collisions inherent to rugby. Tran et al. (2013) reported rPF as a measure of attenuation of eccentric load in a study investigating single-leg landing performance among adolescent surfers. The ICC of 0.63 and CV 25% for rPF on the D leg reported in this study (Tran et al., 2013) is lower than those reported in our study, possibly due to investigation of a youth population.

Of practical relevance, using mean values from three trials resulted in generally improved reliability between tests for both force and stability measures over respective weeks. Further, inter-test analysis revealed that performance and reliability was better on the dominant leg for force-based measures and better on the non-dominant leg for stability-based measures. This could reinforce the idea of differing roles of the dominant and non-dominant legs as mobilizers and stabilizers (Grouios et al., 2009). That said, previous literature contradicts this hypothesis given that leg preference has been shown to be inconsistent between tasks (Huurnink et al., 2014). Regardless, force based measures appear to be the most reliable, while TTS on the non-dominant leg could also be an acceptable measure of dynamic postural control.

In summary, the use of various postural control tests in a real world context is based on the trade-off between time and effort required for testing and the relevance of determining an individual's ability to use the complex interaction of sensorimotor system elements (Paillard, 2012). Previous evidence demonstrates that static tests are more reliable than dynamic tests (Fransz et al., 2014) and several studies indicate that single-leg balance and landing tests measure different elements of postural control (Sell, 2012), though dynamic tests are more ecologically valid to the demands of athletes (Pau et al., 2015). This confirms our results which indicate more difficult testing protocols (single-leg balance with eyes closed and single-leg landing from maximal jump height) result in greater variability and as a result are less precise (higher CV's). However, more challenging tests are more likely to elicit large changes based on contributing factors of proprioception and neuromuscular control and thus still able to detect meaningful change (Meshkati et al., 2011).

## Conclusion

Of the measures identified for investigation in this study, sway velocity and relative impulse are the recommended measures of single-leg balance and landing performance based on their reliability and precision. Time to stabilization should be used with caution due to the differing reliability between dominant and non-dominant legs and higher variability. The variables in the current study represent measures included in commercially available force plate assessment software used by teams in elite sport settings, and other measures exist that may prove more or less effective, but require further investigation. Additionally, the current study can be used to determine the sensitivity of tests and form the foundation for further investigation into the relationship of postural control to fatigue and performance in rugby union populations.

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## Key points

- Single-leg balance demonstrated acceptable inter-trial and inter-test reliability.
- Single-leg landing demonstrated good inter-trial and inter-test reliability for measures of relative peak landing force and relative impulse, but not time to stabilization.
- Of the variables investigated, sway velocity and relative landing impulse are the most reliable measures of single-leg balance and landing respectively, and should considered for monitoring changes in postural control.

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