Test–Retest Reliability of Single-Leg Time to Stabilization Following a Drop-Landing Task in Healthy Individuals

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Context: Single-leg stability has been associated with injury risk and is a key component of many injury prevention interventions. Methods of measuring single-leg stability are varied yet often unreliable. **Objective:** To establish within- and between-day test–retest reliability for single-leg time to stabilization (SL-TTS) following a drop-landing maneuver of 20 cm in height among a healthy cohort. **Design:** Test–retest reliability study. **Setting:** Healthy cohort from a third-level educational institution. **Participants:** Nineteen (11 females and 8 males) healthy individuals. **Main Outcome Measures:** The SL-TTS in the vertical plane. **Results:** The SL-TTS showed good within-day (intraclass correlation coefficient = .715) and excellent between-day (intraclass correlation coefficient = .83) test–retest reliability. The minimal detectable change was calculated as 171.6 ms for within-day contexts and 123.8 ms for between-day contexts. **Conclusions:** This method of measuring SL-TTS is reliable and could be used to detect changes over time in a healthy cohort. This could be of value to clinicians in injury risk factor identification or assessing the effectiveness of single-leg stability training. However, further research is needed to investigate its reliability in pathological populations.

Keywords: force plate, outcome measure, protocol, dynamic stability

Deficits in landing stability have been identified as a risk factor for the incidence of ankle sprains and knee ligament sprains,¹ along with a plethora of other lower-limb injuries.² Landing stability has been a focus of many injury prevention programs, such as the FIFA 11 and FIFA 11+,³ which are recognized worldwide. Measuring landing stability has been aided by technological advancements and increased accessibility to force platforms, meaning clinicians can now quantify ground reaction forces (GRFs) and their translation across multiple planes during landing tasks. This information may be of value to rehabilitation clinicians, as previous research has identified that deficits in landing stability are a risk factor for lower-extremity injuries.¹ Traditionally, motion capture and 3-dimensional kinematic analyses have been utilized to measure landing stability; however, these methods are often more expensive, time consuming, and financially exhaustive when compared with force plate–derived outcome measures.

Time to stabilization (TTS) is a frequently reported metric which measures the time taken to stabilize to within a preset stability threshold after landing.⁴ However, TTS has been shown to be an unreliable outcome, with its variability attributed to factors such as lack of consistency in the propulsive jump prior to landing, lack of control for arm swing during jumping tasks used, or the complex demands placed on participants through reaching for the Vertec vertical jump apparatus (Gill Athletics, Champaign, IL), before placing hands back on the hips prior to landing.⁵

The aim of this study was to design a new protocol to reliably assess single-leg TTS (SL-TTS), while addressing the previously highlighted limitations in existing procedures (with the use of a protocol which attempts to control many of the aforementioned limitations). This proposed protocol measured single-leg TTS,

following a drop from a fixed 20 cm height, in a healthy cohort using a custom excel calculation spreadsheet.

Methods

Participants

A sample of 19 (11 females and 8 males) physically active third-level students (aged 22.4 [2.2] y) were voluntarily recruited through convenience sampling from the Department of Science and Health and Sports Department of the Institute of Technology Carlow (Table 1). Subjects were deemed eligible if they participated, for more than 2 hours per week, in a field sport. Subjects were excluded if they reported any incidence of back or lower-limb injury in the past 6 months. An injury was defined as any injury which prevented them from participating at full capacity in their chosen sport for more than 24 hours after the injury occurred.⁶ Participants were informed of the potential risks and benefits associated with their participation in the study. Informed consent and medical screening forms were obtained, as approved by the ethics in research committee of the Institute of Technology Carlow, Ireland. Subjects were informed that they were free to withdraw from the study at any time. The single tester, a Certified Athletic Therapist, with 3 years of experience, was blinded to all outcomes as all data were retrospectively analyzed after study completion.

Procedures

All measurements were performed by a single tester, a Certified Athletic Therapist, over 2 testing sessions, 3 days apart, in the Physiology Laboratory at Institute of Technology Carlow. Both testing sessions occurred at the same time on each of the days with subjects requested to abstain from high-intensity exercise for 24 hours prior to testing. All measurements were performed on the participants' self-reported preferred jumping leg (leg which they would prefer to jump off when jumping for a ball).

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The SL-TTS was recorded using the HUR labs Force Platform 8 (FP8; HUR labs Oy, Tampere, FI) in “General Acquisition of Data” mode, with all 4 sensors recording vertical GRFs at a refresh rate of 1000 Hz, taking sum of all sensor values as the final output measure. Individual body mass was measured in newtons by the force platform. Participants stood barefoot on the 28-cm-high box with toes at the edge. Subjects kept their hands on their hips at all times and were instructed to “step forward from a straight back leg, land and stick that landing position for a total of seven seconds” as counted aloud by the tester. As the FP8 stood at 8 cm high, the total drop height was 20 cm from box to the landing zone, which was 81×61 cm in dimension. Trials were repeated if they removed their hands, added a hop in order to stabilize, or put their second foot down before the 7 seconds had elapsed (Figure 1).

Five trials were performed as familiarization on each testing day to allow subjects to become comfortable with the test. Four recorded trials were then performed with raw data retrospectively exported for posttesting analysis. A 30-second rest period was adhered to during all familiarization and recorded trials.

The raw data were then inserted into a custom-created excel spreadsheet containing formulae to calculate the time at which stability was reached. Stability was defined as the point at which vertical GRF reached a level within 5% of body weight and remained within 5% of body weight for a subsequent second (1000 data points).^{5,7} The time point which corresponded with the first point at which vertical GRF crossed 10 N was accepted as initial contact time and was subtracted from the onset of stability to calculate SL-TTS (see [Supplementary Material](#) [available online] for spreadsheet). The 3 best times (quickest) out of the

Table 1 Mean and SD for Subject Age, Body Mass, and Self-Selected Preferred Jumping Leg

Characteristic	Female (n = 11)		Male (n = 8)		Total (N = 19)	
Age, y	22.1 (2.7)		22.8 (1.4)		22.4 (2.2)	
Body mass, kg	67.7 (10.6)		83 (15)		74.1 (14.5)	
Preferred jumping leg	L = 7	R = 4	L = 5	R = 3	L = 12	R = 7

Abbreviations: L, left; R, right.

Figure 1 — Single-leg time to stabilization procedures.

4 test trials were used for analysis upon completion of testing procedures.

Statistical Analyses

All data were tabulated and analyzed using IBM Statistical Package for the Social Sciences (SPSS, version 23, Armonk, NY) and Microsoft Excel 2013 (Redmond, WA). Means, SDs, coefficients of variance in percentage, and intraclass correlation coefficients (ICCs), along with the respective 95% confidence intervals were calculated within SPSS with $\alpha = .05$ and $1 - \beta = 0.95$. ICC (3,1) was applied in within-day analyses, with ICC (3,*k*) applied in between-day analyses for intratester reliability.^{8–10} The ICC statistics were classified within the following ranges: poor (.0–.39), fair (.4–.59), good (.6–.74), or excellent (.75–1).⁸ The SEM and minimal detectable change (MDC⁹⁵) were calculated for both within- and between-day reliability analyses using the following formulae.^{8,9}

$$\text{SEM} = \text{SD} \times \sqrt{(1 - r)}$$

(with “*r*” being the ICC value calculated prior),

$$\text{MDC}^{95} = 1.96 \times \sqrt{(2) \times \text{SEM}}.$$

Results

Mean and SD SL-TTS scores for the 3 best trials recorded on day 1 and mean and SD scores for days 1 and 2 are represented in Table 2. Good within-day reliability (ICC = .715) was found across the trials for day 1 with ICC (3,1), 95% confidence intervals, coefficients of variance, SEM, and MDC⁹⁵ represented in Table 2. On comparison of days 1 and 2 average measures, excellent between-day reliability (ICC = .83) was found with ICC (3,*k*), 95% confidence intervals, coefficients of variance, SEM, and MDC⁹⁵ represented in Table 2. All participants successfully completed testing procedures with the maximum number of failed trials which required repetition being 1.

Discussion

The aim of this study was to establish the reliability of SL-TTS measurement after a standardized drop-landing task. Findings suggest that there is good within-day intratester reliability (ICC [3,1] = .715) and excellent between-day intratester reliability (ICC

[3,*k*] = .83) for the SL-TTS, which exceeds those reported previously (ICCs = .423 and .662, respectively).⁵ Furthermore, the reported MDC⁹⁵ values provide valuable information to practitioners that any change in SL-TTS greater than 124 ms means a true change in performance has occurred beyond that of measurement error alone.⁹

This degree of reliability may have been achieved by removing arm movement and visual demands which were present in previous procedures,⁵ while also replacing the propulsive jump with a step-down from a standardized height of 20 cm, although this may be a study limitation as the landing task may not reflect a situation which occurs in sporting contexts.⁵ Finally, through the use of a custom excel spreadsheet for SL-TTS calculations, this outcome can be cheaply and easily measured by any practitioner once their chosen force plate can measure and plot vertical GRF with its corresponding time data, as opposed to employing the labor of software developers to design a similar testing protocol.

This procedure allows clinicians to measure one's ability to stabilize following a single-leg landing in a reliable and economical manner.

Study Limitations

Although reliable, the adapted testing procedures may not replicate sporting demands as landings rarely occur in a controlled manner, like those in the outlined experimental procedure. Also, investigation into the task-specific learning effects and reliability of these procedures in pathological populations is necessary before it is widely accepted into clinical practice.

Future research should aim to investigate the intertester reliability and external validity of SL-TTS measurement using this protocol, comparison to a gold standard such as 3-dimensional kinematic data, its association with injury incidence, and its reliability among pathological populations and specific target populations (athletes, etc) to allow greater generalization of outcomes.

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Table 2 Within- and Between-Day Reliability Statistics

Within-day reliability statistics for SL-TTS							
Movement	Trial 1, $\bar{x}$ (SD)	Trial 2, $\bar{x}$ (SD)	Trial 3, $\bar{x}$ (SD)	ICC (3,1) (95% CI)	CV%	SEM	MDC ⁹⁵
SL-TTS	749.1 (296.7) ms	698.7 (283.6) ms	671.3 (234.2) ms	.715 (.498–.867)	14.7%	61.9 ms	171.6 ms
Between-day reliability statistics for SL-TTS							
Movement	Day 1, $\bar{x}$ (SD)	Day 2, $\bar{x}$ (SD)	ICC (3, <i>k</i>) (95% CI)	CV%	SEM	MDC ⁹⁵	
SL-TTS	706.4 (245.6) ms	616.4 (230.8) ms	.830 (.559–.935)	16.1%	44.7 ms	123.8 ms	

Abbreviations: $\bar{x}$, mean; CI, confidence interval; CV, coefficient of variance, expressed as a percentage; ICC (3,1), intraclass correlation coefficient—2-way mixed-effects, single measures; ICC (3,*k*), intraclass correlation coefficient—2-way mixed-effects, average measures; MDC⁹⁵, minimal detectable change at 95% CI; SL-TTS, single-leg time to stabilization.

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