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Research Article

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Reliability of Hop Distance and Frontal-Plane Dynamic Knee Valgus Angle during Single-leg Horizontal Hop Test

Hussain Ghulam*, **Lee Herrington, Paul Comfort and Richard Jones**

Abstract

Context: Single-leg hop for distance (SHD) performance and two-dimensional (2-D) video assessment of frontal-plane knee valgus, during the single-leg landings, have been reported to identify the risk of knee injuries such as patellofemoral pain syndrome and/or anterior cruciate ligament tears. There are limited studies investigating the reliability and measurement error in single-leg hop for distance test and the 2-D video analysis of knee valgus angle on landing from this maximal forward hop.

Objective: To evaluate the reliability and measurement error of hop distance and 2-D video assessment of lower limb frontal-plane dynamic knee valgus on landing during the SHD task.

Design*:* Repeated measures reliability study.

Participants: 12 recreationally active university students (8 men and 4 women 34.2 ± 3.1 y, height 170.8 ± 6.5 cm; mass 82.1 ± 15.9 kg).

Main outcome measurement: Within and between-days reliability and measurement error values of hop performance and 2-D frontal-plane projection angle (FPPA) during SHD test.

Methods: For hop and 2-D tests: participants performed maximal SHD with standard 2-D digital video recording of the landing for assessment of FPPA.

Results: For hop test distance: the within-day ICCs showed good to excellent reliability (0.89-0.93), and between-days ICCs were good, (0.85-0.90). Standard error of measurement for SHD value ranged from 6.52-9.83 cm. FPPA on landing: the within-day ICCs showed good reliability (0.87 to 0.90), and between-days ICCs were good, (0.81-0.88). Standard error of measurement for 2-D values ranged from 1.33-1.61°.

Conclusions: Hop distance and 2-D FPPA on landing during SHD were shown to be a reliable measure of lower extremity performance and dynamic knee valgus. Using the measurement error values existing along with previously published normative data, clinicians can now make informed decisions about individual performance and variations in performance/injury risk following interventions.

Keywords

Measurement error; Single-leg hop tests; Frontal-plane projection angle; Outcome measures

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Introduction

In many sports, players are required to jump and land horizontally along a playing surface in a very quick and efficient manner, and for this reason, athletes often take part in training programs that improve their ability to jump horizontally with hop distance therefore being related to various performance parameters [1]. There are a number of studies which have also demonstrated that hop tests can identify differences between lower extremities in injured participants [2-6], and are commonly used tests with injured participants to identify patient function during rehabilitation [7]. Hop tests can also be used in healthy populations to determine limb symmetry and predict muscle strength and power [8].

The reliability of single leg hop test performance (in terms of distance) in both injured and uninjured participants has been evaluated and shown to be high [1,6,9-14]. However, different methodologies have been used, for example only two of the studies [1,9] provided information on the participants' activity levels; which is important because results from an athletic population cannot necessarily be applied to a non-athletic population and vice versa [7], due to differences in the familiarity with such movements and overall conditioning.

Injury to the knee joint are one of the most frequently occurring injuries in a number of sports [15,16]. Most injuries to the knee joint such as anterior cruciate ligament (ACL) tears and patellofemoral pain syndrome happen in noncontact manner or through overuse mechanisms [17,16]. However, the main cause of the noncontact and overuse injuries is multifactorial [18]. During physical activity, abnormal lower limb biomechanics has been commonly postulated as a cause in the etiology of both overuse and traumatic knee injury [17,19]. Changes in a combination of altered hip, knee and ankle kinematics have been associated with the term dynamic knee valgus [18], and this has been reported to be related to knee injury [17-19].

The use of the two-dimensional 2-D analysis from frontal-plane projection angle (FPPA) of the knee joint has been introduced to measure dynamic knee valgus motion during different screening tasks [18,20,21]. The first study [18] was applied to assess the reliability and associated error measurement of lower limb dynamic knee valgus during single-leg squat (SLS), drop jump (land with one foot) from a 30 cm high step, and single-leg landing (step forward) from a 30 cm high step using 2-D video analysis. They found that women demonstrated significantly higher FPPA in all tests apart from the left single-leg squat. Within-day ICCs ranged from 0.59 to 0.88, with between-days ICCs showing good to excellent reliability (0.72 to 0.91). Standard error of measurement and smallest detectable difference ranged from 2.72-3.01° and 7.54-8.93°, respectively. Another study assessing the influence of gender and exercise on lower limb control during the drop-jump test found that the majority of untrained female and male athletes demonstrated knee valgus alignment appearance on the video analysis [20]. After neuromuscular training, both male and female athletes improved knee separation distances and a more neutral lower extremity alignment on landing and takeoff. Another investigation was performed to assess the core strength and lower extremity alignment in single leg squats using 2-D video analysis [21]. Females were found to have greater FPPA in landing and generally

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decreased trunk, hip, and knee isometric torque, while the strength of hip external rotation was most closely associated with the FPPA.

The 2-D analysis of FPPA can be used for large screening of training and intervention programs to minimise frontal-plane dynamic knee valgus [20]. Therefore, it would appear logical to use 2-D analysis for large scale screening of athletes. However, no study has yet investigated the knee dynamic valgus from FPPA whilst undertaking a maximal forward hop task, a task which is commonly used to measure functional performance. Therefore, the aims of this study were to assess the within and between-days reliability and associated measurement errors of the single-leg hop for distance test and FPPA after landing whilst carrying out the landing from the single-leg hop for distance task, and finally determine the reliability of a measure of limb symmetry index (LSI) based on single-leg hop distance.

Methods

Twelve recreationally active university students (8 men and 4 women 34.2 ± 3.1 years, height 170.8 ± 6.5 cm; mass 82.1 ± 15.9 kg), volunteered to participate in the study. Participants were required not to have lower extremity injury, for at least 6 months prior to testing and had no history of lower limb surgery. To be suitable as recreationally active, participants were required to attend a minimum of 30 minutes of physical activity three times per week; this included recreational and competitive sports. No participants were involved in professional or semi-professional sport, or engaged in more than 4 hours of strenuous physical activity per week. All participants were over 18 years old and provided written informed consent to participate. The study was approved by the university research and ethics committee.

Procedure

The procedure for undertaking SHD and the capturing of landing FPPA was based on previous work [1,7,22,23]. For each participant, the tests were individually performed on both legs. Participants were asked to wear the same training shoes each time they attended: with these shoes being the ones they wore the majority of the time for their training activities. Participants were asked to avoid any strenuous exercise for the 24 hours prior to the testing day. Participants removed the clothes covering their lower limbs such as socks, and were also been asked to wear loose shorts or underwear. Participants' shirts were held up by adhesive tape, male participants were asked to remove their shirts if they preferred.

Test

Before starting any of the following tests, participants warmed up on an exercise bicycle for 5 minutes with minimal resistance (75W) and then were asked to perform practice trials (maximum of three) for the test to get familiar with the procedure. Following this, three trials were collected of maximally single hop for distance for both legs. Participants participated in two experimental tests on one day (with one hour between each testing session), and another separated by 7 days.

Test protocol

Hop test performance was assessed using a normal metric tape measure. The start line was labelled by a 0.3 m strip of tape and was placed perpendicular to the 8 m strip of tape secured to the floor. After finishing the practice trials, three successful trials were collected for each leg. Successful attempts were defined as when the participants hopped and landed with complete stabilisation on one leg for three seconds. A rest period of 30 seconds was allowed between trials. There were no restrictions given to participants regarding the use of arm movement during hop test. Participants achieved three maximum hop attempts with complete stabilisation after landing. Each participant's leg lengths were measured on the first test occasion using a standard tape measure, and the measurement was from the anterior superior iliac spine (ASIS) to the distal tip of the medial malleolus while participants lay supine, leg length was used during data analysis to normalise excursion distances.

Single-leg horizontal hop for distance

Participants started by standing on one leg, with their toe on the marked starting line. Participants were then instructed to hop as far as they could horizontally and land on the same leg. The distance hopped from the starting point to the place where the participant's heel hit was taken. Hop data was normalised to limb length by dividing the distance covered by leg length then multiplying by 100 and resulted as a percentage value [7].

Frontal plane projection angle

The frontal plane projection angle (FPPA) was assessed during hopping tasks using a single camera, Casio Exilim, EX-F1 (Casio Computer CO Limited, Japan) with a standard sampling frequency of 30 fps, that was placed on a tripod at a height of 80 cm from the floor to the middle of lens, 2.5 m away from an X-shaped marker which was placed as a reference for the central point on the floor. Participants were asked to hop to the X-shaped marker from a starting point based on their individual hop distance achieved during the practice trials, to ensure that the landing was at a point ±1 meter from the X-shaped marker, to accommodate the calibration. In order to examine the FPPA after the landing from the single-leg hop for distance test, three black markers were placed directly on the participants' skin before starting the test using a black marker on the following points:

Anterior superior iliac spine (ASIS).

Midpoint of the knee joint (midpoint of the medial and lateral femoral epicondyles).

The middle of the ankle mortise anatomical landmark.

All markers were placed by the same experimenter, and the midpoints were determined using a standard tape measure. These markers were used in order for FPPA of the knee to be determined. The analysis of the FPPA was undertaken in Quintic Biomechanics Software (v21, Quintic, Sutton Coldfield, UK) where FPPA was taken at the maximum knee flexion angle after landing (defined as the lowest point the pelvis reached) (see Figure 1), and the convention used for measurement was that 180 degree equals straight, angles <180 were considered valgus, and >180 considered varus.

Statistical Analysis

The mean value of the three measures (trials) for each session 1, 2, and 3 was calculated to find out the reliability between session 1 and 2 (within day) and between session 1 and 3 (between days). All statistical analyses were conducted using SPSS for Windows version 20.0 (SPSS Inc, Chicago, IL). All data was initially assessed for normality using a Shapiro-Wilk test, and demonstrated normal distribution of all results. Intraclass correlation coefficients (ICC) [24], using model

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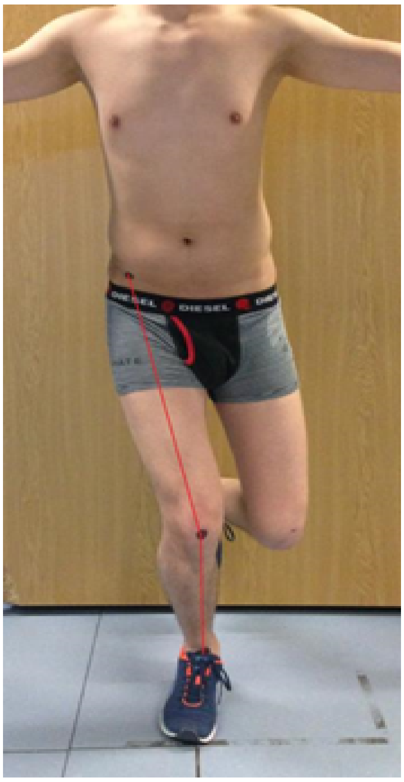

Figure 1: Anatomical marker placement.

3 with two-way mixed model was used to assess the within- and between-sessions reliability, from which 95% confidence intervals (CI), and standard error of measurement (SEM) were calculated to establish random error scores. ICC values were interpreted according to the following range [25]: poor <0.40, fair 0.40 to 0.70, good 0.70 to 0.90, and excellent >0.90.

SEM was calculated using the formula [4]: SD (pooled) × √1- ICC

Moreover, repeated measures ANOVA were performed to determine if significant differences occurred between testing sessions with Bonferroni post-hoc analysis used for pairwise comparisons. Effect sizes were also calculated using the Cohen *d* method:

Cohen's *d* was calculated using the formula:

Cohen's $d = M_1 - M_2 / \sigma_{pooled}$ Where $\sigma_{pooled} = \sqrt{[(\sigma_1^2 + \sigma_2^2) / 2]}$

Effect sizes for recreationally trained participants were interpreted based on the recommendation of Rhea [26] trivial < 0.35, small 0.35-0.80, moderate 0.80-1.50, large > 1.5.

Results

For the single-leg hop for distance test, the ICC range values for the within-day tests (0.89-0.93) were higher than the range of between-days (0.85-0.90). Similarly, the ICC range values for FPPA during landing aspect of the single-leg hop for distance task were higher in within-day tests (0.87-0.90) than the range of between-days (0.81-0.88). The within- and between-day SEM values for the single-leg hop for distance test were between 6.52-9.83 cm. The within- and between-day SEM values for the FPPA during the landing phase of the single-leg hop for distance task were ranged between 1.33 - 1.61°.

In addition, separate repeated measures ANOVAs showed no significant difference (p>0.05) in single hop distance or FPPA between trials for the both legs, with Bonferroni post hoc analysis showing no significant (p>0.05) difference between trials one and two, trials one and three and trials two and three (Tables 1 and 2). The ICC for LSI was high for both within day (0.81) and between day (0.88) performances. Repeated measures ANOVA showed no significant difference (p>0.05) in LSI for hop distance between trials, with Bonferroni post hoc analysis showing no significant difference between trials one and two (99.88 ± 12.27, 99.76 ± 12.16, p>0.05, Cohen's *d*=0.01) (Within day), trials one and three (99.88 ± 12.27, 99.92 ± 12.37, p>0.05, Cohen's *d*=0.003) and trials two and three (99.76 ± 12.16, 99.92 ± 12.37, p>0.05, Cohen's *d*=0.013) (Between days) (Figure 2).

Table 3 illustrates the percentage of participants achieving LSI for hop distance values of 85, 90 and 95% respectively.

Discussion

Single-leg hop for distance tests are commonly used tests undertaken with injured participants to identify their function level [7]. The individual hop distances and FPPA showed acceptable consistency, and good to excellent ICC values suggested that using this method is reliable in both within and between days. Furthermore, no learning effects were observed within (<1% variation) or between days (<3.5% variation) for single-leg hop distance. Similarly, no differences in LSI were observed between testing sessions.

Our results suggest that this protocol could be used in the future research when assessing lower extremity single-leg hop for distance performance and FPPA. Such results have been confirmed previously by Bolgla and Keskula [11] whom investigated the test- re-test reliability for single-leg hop for distance in 20 participants (5 males and 15 females). They reported ICC's of 0.96 for single-leg hop for distance with a resulting SEM of 4.56 cm while our study reported similar but slightly lower ICC's (0.93) and slightly larger SEM (6.52) cm. Their reliability and SEM results are better than ours and one of the potential reasons is that the test-retest intervals used in their study were 48 hours, while our test-retest session separation was 7 days which may take into account these differences. The time that separates the test-retest sessions could affect reliability [27], therefore, it is necessary to evaluate the single-leg hop for distance reliability with time intervals between testing sessions that are more closely replicated to the time frames that may be used in a clinical setting [27]. Moreover, in their study they did not provide information about participants' activity levels; which is an essential point because results from athletic group cannot be necessarily extrapolated to a sedentary group and vice versa [7].

Increased dynamic knee valgus during common sporting activities has been postulated as an injury risk factor for the knee-joint complex [17,19]. Dynamic knee valgus can be evaluated using a number of different screening tasks [28,29,18,21], but to date, most studies have used three-dimensional (3-D) analysis to evaluate lower limb kinematics. However, the use of 2-D video analysis has recently become increasingly popular because of its greater practicality [18], and value in large population screening. The validity of 2-D video analysis of FPPA compared with 3-D assessment has been established previously [30,31] and showed that 2-D method can be used to evaluate excessive knee valgus in elite athletes, particularly from FPPA. However, the reliability of the 2-D procedure is not that well established, especially with regard to test-retest repeatability and

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Table 1: Descriptive and reliability statistics within day.

Test		Trial 1	Trial 2					
		Mean ± Study		**CV (%)**	**SEM**	**ICC (95% CI)**	**P**	**Cohen's *d***
Hop Distance (cm)	Right	100.5 ± 26.5	100.3 ± 24.9	4.38	6.52	0.93 (0.87-0.99)	p>0.05	0.007
	Left	100.7 ± 24	100.6 ± 23.5	2.99	7.36	0.89 (0.81-0.98)	p>0.05	0.004
FPPA (°)	Right	7.6 ± 5	8.7 ± 5.2	14.25	1.33	0.90 (0.76-0.96)	p>0.05	0.216
	Left	7.2 ± 4	7.8 ± 4.3	21.39	1.49	0.87 (0.78-0.93)	p>0.05	0.072

Table 2: Descriptive and reliability statistics between days.

Test		Trial 1	Trial 3					
		Mean ± Study		**CV (%)**	**SEM**	**ICC (95% CI)**	**P**	**Cohen's *d***
Hop Distance (cm)	Right	100.5 ± 26.5	103.9 ± 27.2	4.56	8.98	0.90 (0.83-0.98)	p>0.05	0.127
	Left	100.7 ± 24	103.1 ± 21.6	3.92	9.83	0.85 (0.78-0.96)	p>0.05	0.105
FPPA (°)	Right	7.6 ± 5	7.0 ± 4.3	17.71	1.46	0.88 (0.72-0.95)	p>0.05	0.129
	Left	7.2 ± 4	6.5 ± 3.3	21.13	1.61	0.81 (0.74-0.91)	p>0.05	0.191

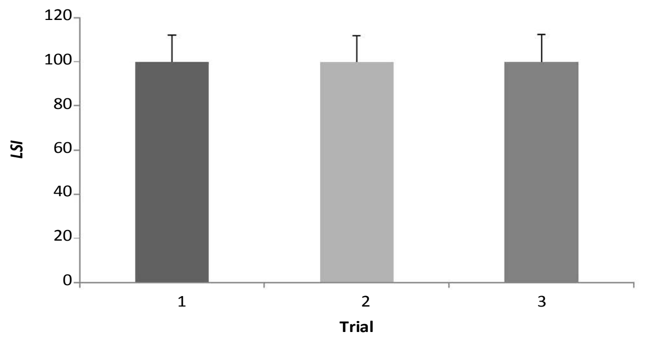

Figure 2: Comparison of LSI between trials.

Table 3: Percentage of participants achieving limb symmetry index values for hop distance.

LSI	≥ 85	≥ 90	≥ 95
Single-leg Hop Distance	100	83	75

during the landing of the single-leg hop for distance task has not been investigated. Therefore, one of the aims of the current study was to evaluate the reliability of 2-D video analysis of FPPA during the landing of the single-leg hop for distance task. The good ICC values in our study suggest that assessment of FPPA during this task is reliable in both within- and between-days. Our findings therefore suggest that this method could be used in future research with confidence, in clinical and large-scale screening projects to evaluate lower limb dynamic valgus. As no previous study has investigated the 2-D results found during single-leg hop for distance land further research is needed in this area, to confirm our findings though.

It is worth noting that the within-day reliability of the right and left leg values of both tests, single-leg hop for distance test and 2-D video analysis of FPPA during the landing, were higher than between-days, and this can confirm that repeating the tests in the same day (within-day) are more likely to limit the errors as the participants get used to the applied tests more than repeating them 1 week later, although no significant (p>0.05) learning effect was noted in either case. Moreover, placing the markers after 7 days for re-testing may differ than placing them during the within-day test.

The current study established an important finding, which is that all participants achieved an LSI for hop distance score of at least 85%, despite previous results that showing that 80% LSI is adequate [17]. Therefore, our recommendation during rehabilitation and conditioning for practitioners is to accept a minimum 85% LSI as a measure of symmetry between limbs. Importantly LSI was shown to be highly reliable both within (ICC=0.81) and between days (ICC=0.88).

One limitation of the current study is that the accuracy and magnitude of 3-D lower limb joint rotations during any activity cannot be fully replicated by 2-D FPPA measurements. However, in the absence of the 3-D measurements 2-D still can provide a reliable and valid measure of gross lower limb kinematics [18]. Another limitation of this study is that it is still unclear whether decreased knee-flexion angles (during initial contact) can affect the amount of dynamic knee valgus measured as we only measured FPPA at the maximum knee-flexion angle, and therefore, further investigation of this as a possible contributing factor is needed. Furthermore, the population included in our study were all healthy, recreationally active university students. However, it is still unclear whether 2-D FPPA testing may be influenced by age or by level of sporting activity, therefore these findings may not be valid for young and older age groups or highly athlete and injured populations which finally require further studies on other populations. It also has to be acknowledged that only the intrarater reliability of FPPA was measured, and therefore, further investigation looking at interrater reliability is required.

Practical Applications

Good to excellent ICC values allow practitioners to use the single-leg hop for distance test incorporating 2-D FPPA tests confidently to assess lower limb function during their rehabilitation or injury prevention programs. Our SEM results give practitioners values that allow them to make more clear decisions about changes in a participant's single-leg hop for distance test and 2-D FPPA evaluation. The SEM results illustrate the range of true score is likely to lie for each individual [32]. Meaning that a true score for the single-leg hop for distance test would lie within the range of 6.52 - 9.83 cm of the main score, whereas a true score for the 2-D FPPA test would lie within the range of 1.33 - 1.61° of the observed score. Researchers and clinicians should consider a change in hop distance > 9.83 cm and FPPA > 1.61° to be meaningful.

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