Gait & Posture 61 (2018) 453–458

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Single leg squat ratings by clinicians are reliable and predict excessive hip internal rotation moment

Robert M. Barker-Davies[a,b,*], Andrew Roberts[a], Alexander N. Bennett[a,c], Daniel T.P. Fong[b], Patrick Wheeler[b], Mark P. Lewis[b]

[a] Academic Department of Military Rehabilitation, Defence Medical Rehabilitation Centre Headley Court, London, UK
[b] National Centre for Sport and Exercise Medicine, School of Sport Exercise and Health Sciences, Loughborough University, UK
[c] National Heart and Lung Institute, Faculty of Medicine, Imperial College, London, UK

ARTICLE INFO

Keywords:
Small knee bend
Kinematics
Kinetics
Military personnel
Rehabilitation
Sports medicine

ABSTRACT

Background: Single leg squats are commonly used subjective assessments of general biomechanical function, injury risk, as a predictor for recovery and as an outcome measure of rehabilitation. While 3D motion capture is a useful tool for elite sports performance and research it is impractical for routine clinical use.

Research question: This cross-sectional study aims to: assess reliability and validity of clinicians' subjective ratings of single leg squats compared to 3D motion capture, and to identify whether performance predicts joint moments.

Methods: 22 healthy military volunteers were simultaneously recorded on video and 3D motion capture performing single leg squats. Videos were reviewed twice by 5 physiotherapists rating performance on a 0–5 scale assessing squat depth, hip adduction, pelvic obliquity, pelvic tilt and trunk flexion summated into a composite score.

Results: Hip adduction and trunk flexion exhibited moderate to substantial inter- and intra-rater reliability (range $\kappa = 0.408–0.699$) other individual criteria were mostly fair ($\kappa \leq 0.4$). Composite scores for inter-rater reliability were $ICC_{(1,1)} = 0.419$ and $ICC_{(1,\kappa)} = 0.783$ and intra-rater reliability were $ICC_{(1,1)} = 0.672$ and $\kappa(w) = 0.526$. Validity against 3D kinematics was poor with only 6/75 individually rated criteria reaching $\kappa > 0.40$. Correlation was found between composite scores and hip internal rotation moment ($r_s = 0.571$, $p = 0.009$).

Significance: Repeated use of single leg squats by a single practitioner is supported. Comparisons between clinicians are unreliable but improved by average measures from multiple raters. Heterogeneous reliability across scoring components suggests a qualitative description of the criteria scored is less ambiguous than using composite scores in a clinical setting. Composite scores may be more useful for analysis at a population level. Poor validity against kinematic data suggests clinicians use additional information upon which they find agreement such as estimating kinetics. Correlation between hip internal rotation moment and subjective ratings may be such an example of clinicians trying to identify excessive abnormal loading.

1. Introduction

A commonly used clinical assessment of lower limb function is the single leg squat. This test is favoured by clinicians as it has relevance as a surrogate for higher functional activities such as running and jumping which are impractical to test either because of limitations of clinic space/facilities or due to the presence of pain in a patient population [1]. The single leg squat is used to give an idea of general biomechanical function and therefore as a potential risk factor for injury [2], a predictor for recovery and as an outcome measure of rehabilitation [3]. Whilst 3D motion capture is a useful tool for elite sports performance and research the time required for data capture and processing makes it difficult to provide immediate clinical information [4].

Abnormal kinematics that are potentially identifiable on single leg squat have been associated with injury. Lumbar stress injury has been associated with excessive knee valgus [2] and patellofemoral pain syndrome (PFPS) has been associated with excessive hip adduction, knee valgus, pelvic obliquity and ipsilateral trunk lean [5,6]. Kinematic single leg squat performance deficits have also been linked to other risk factors for injury. Females who have a greater risk of PFPS and anterior

* Corresponding author at: Academic Department of Military Rehabilitation, Defence Medical Rehabilitation Centre Headley Court, London, UK.
E-mail address: R.Barker-Davies@lboro.ac.uk (R.M. Barker-Davies).

https://doi.org/10.1016/j.gaitpost.2018.02.016
Received 6 September 2017; Received in revised form 7 February 2018; Accepted 14 February 2018

Table 1
Rating criteria for the Small Knee Bend (SKB) [22],Single Leg Squat (SLS) and Single Leg Decline Squat (SLDS) with kinematic interpretation for objective comparison. PFPS = patellofemoral pain syndrome.

Clinical Rating Criteria	Kinematic Interpretation for objective comparison	Reasoning for kinematic threshold describing poor or excessive movement
SKB: "Does the knee move inward from the 2nd toe?" SLS/SLDS: "Is there excessive Hip adduction?"	Is the peak hip adduction greater than 10°?	Hip adduction easier to spot than interpreting knee valgus 6° v 2.3° mean difference with a higher likelihood of clinically meaningful difference 94% v 74% [20]. Excessive hip adduction defined as 10.6–11.4° when single leg squatting with data extracted at 45° [42].
SKS: "Does the pelvis drop (hitch) on the weight bearing side?" SLS/SLDS: "Is there excessive pelvic obliquity?"	Is peak pelvic obliquity greater than 10°?	11.8° mean difference between those rated good and poor by expert consensus [20].
SKB: "Does the knee fail to move 2 cm past the second toes?" SLS/SLDS: "Do they fail to squat to 60°?"	Is the peak knee flexion angle less than 40° (SKB)/60° (SLS/SLDS)?	SKB: 40° consensus opinion from our panel of experienced physiotherapists SLS/SLDS: 60° consensus [6,7,12,13].
SKB: "Does the trunk lean forward (flex)?" SLS/SLDS: "Is there excessive trunk flexion?"	Is the peak trunk flexion angle greater than 10°?	No compelling evidence from literature. Consensus opinion from our panel of experienced physiotherapists. Also simplicity across criteria.
SKB: "Does the pelvis tilt forwards (anteriorly)?" SLS/SLDS: "Is there excessive anterior pelvic tilt?"	Is the peak anterior pelvic tilt angle greater than 10°?	

cruciate ligament injury than males, exhibit excessive hip adduction, hip internal rotation and knee valgus [7–9]. Localised muscular fatigue has been associated with increased trunk flexion, pelvic obliquity, pelvic tilt, pelvic rotation and hip adduction [10].

There is limited research linking these kinematic abnormalities to the excessive loads they imply. A reduction in peak knee valgus (ES = 0.5 p = 0.051) has been associated with a larger reduction in valgus abduction moment (ES = 0.71, P = 0.03) after four weeks neuromuscular training [11]. Knee valgus alignment on single leg squats has also been associated with other trainable deficits such as reduced flexibility [12] and strength [13]. These modifiable risk factors are amenable to physical therapy that could result in improved outcomes. Correcting excessive knee valgus on the single leg squat in PFPS has associated decreases in pelvic obliquity, hip adduction and internal rotation and pain [14]. Improvements in single leg squat deficits effected by neuromuscular training have been maintained at 3 months follow up and associated with improved pain and function [15].

The reliability with which these biomechanical abnormalities can be identified from clinical examination of the single leg squat as opposed to more objective technologies such as 3D motion capture is uncertain [16]. Analysis of processed 2D video images has shown good intra-rater reliability (Intra-class correlation coefficients (ICC) > 0.59) [17], inter-rater reliability (ICC > 0.96) and validity (r = 0.81) when assessing knee valgus and hip adduction angles [4]. Annotation of still video pictures whilst more practical than 3D motion capture is still removed from immediate dynamic assessment in vivo. Using a 3-point qualitative scale (good, fair or poor technique) on viewing 2D full speed video 3 clinicians demonstrated good intra and inter-rater reliability (*Kappas* > 0.6*)* [18]. Such subjective measures however cannot be directly validated against 3D kinematics though increased hip adduction and decreased knee flexion have been associated with 'poor' ratings [19]. Frontal plane video ratings from 66 physiotherapists assessing binary questions for the presence of knee valgus and pelvic obliquity showed good inter/intra-rater reliability and validity against 3D kinematics [20]. This study aims to build upon this by adding knee flexion, pelvic tilt and trunk flexion to form a 5-point scale as well as including video analysis in the sagittal plane. The hypotheses to be tested are that 5 components of clinical single leg squat ratings, hip adduction, knee flexion, pelvic tilt, pelvic obliquity and trunk flexion are reliable and valid compared to 3D motion capture. It is also hypothesised that kinematic performance will predict lower limb joint moments associated with injury.

2. Methods

Based on a power of 80% (β-level = 0.8) and an α-level of 0.05 anticipating substantial reliability (P_0 > 0.6–P_1 = 0.8), the calculations of Walter [21] estimate the requirement for at least 5 raters (n) of 20 subjects (k).

A total of 25 healthy military volunteers were screened. The inclusion criteria were males aged 18–55 and exclusion criteria musculoskeletal injury in the preceding 6 months or associated occupational restrictions concerning physical activity. Participants in a range of military roles (Table 2) were invited to take part by the chief investigator (RBD). The Ministry of Defence Research Ethics Committee approved the study (684/MODREC/15) and all participants gave written informed consent. Each participant was invited to the biomechanics laboratory at the Defence Medical Rehabilitation Centre at a convenient time between September 2016 and February 2017. Participants undertook the following movements described below.

For the small knee bend (SKB) verbal instruction was given as follows:

> *"Stand on one leg with your foot pointing forward. Place the unsupported foot behind you by bending your knee 90°. While keeping your body upright, keeping your pelvis and heel in position, bend your knee so that your knee is in line with your 2nd toe and moves past it until you can no longer see the tape line."* [22].

5 repetitions were tested [12] allowing 2–3 practice repetitions immediately prior to testing [5,7]. There was one minute of rest between trials [6,7]. Individual SKB scoring items [22] were interpreted as per Table 1.

Squat movements were standardised and 2 further tests the single leg squat (SLS) and with the addition of a 25° decline board [23] the

Table 2
Demographics of participants.

N = 20	Mean (Range) ± SD
Age (years)	34.3 (23–52) ± 6.7
Height (m)	1.79 (1.69–1.89) ± 0.05
Weight (kg)	85.6 (73.3–99.7) ± 9.1
BMI	26.7 (20.5–30.6) ± 2.8
Leg Dominance	Right n = 18 Left n = 2
Role	Administrative Officers n = 5, Aircraft Technicians n = 4, Doctors n = 2, Nurses n = 6, Physical Training Instructors n = 3