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The reliability of biomechanical variables collected during single leg squat and landing tasks

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ABSTRACT

Introduction: The aim of this study was to determine the within- and between-day reliability of lower limb biomechanical variables collected during single leg squat (SLS) and single leg landing (SLL) tasks.
Methods: 15 recreational athletes took part in three testing sessions, two sessions on the same day and another session one week later. Kinematic and kinetic data was gathered using a ten-camera movement analysis system (Qualisys) and a force platform (AMTI) embedded into the floor.
Results: The combined averages of within-day ICC values ($ICC_{SLS} = 0.87$; $ICC_{SLL} = 0.90$) were higher than between-days ($ICC_{SLS} = 0.81$; $ICC_{SLL} = 0.78$). Vertical GRF values ($ICC_{SLS} = 0.90$; $ICC_{SLL} = 0.98$) were more reliable than joint angles ($ICC_{SLS} = 0.85$; $ICC_{SLL} = 0.82$) and moments ($ICC_{SLS} = 0.83$; $ICC_{SLL} = 0.87$).
Discussion: This study demonstrates that all joint angles, moments, and vertical ground reaction force (GRF) variables obtained during both tasks showed good to excellent consistency with relatively low standard error of measurement values. These findings would be of relevance to practitioners who are using such measures for screening and prospective studies of rehabilitative techniques.

1. Introduction

The single-leg squat (SLS) and single leg landing (SLL) manoeuvres are frequently used tasks to assess lower alignment (Herrington, 2013; Nakagawa et al., 2014; Willy and Davis, 2011). Both have biomechanical and neuromuscular similarities to a wide range of athletic movements and thus are involved in rehabilitation programmes of different sports designed to prevent injuries and enhance athletic performance (Herrington, 2013; Willy and Davis, 2011; Willson et al., 2006; Myer et al., 2005). Given their widespread use, understanding the kinematic and kinetic variability of single leg squat and landing are essential to be able to discriminate between random error and real differences attributable to poor movement strategies or to interventions to change those movement strategies. Previous studies have undertaken assessments of reliability in SLS (Nakagawa et al., 2014; Whatman et al., 2011) and landings (Malfait et al., 2014; Milner et al., 2011; Ford et al., 2007). These previous studies have only investigated single elements of reliability (i.e. kinematics or kinetic data alone or within or between day reliability). In reviewing the literature, no study has looked at the within- and between-day reliability and associated measurement error of lower limb joint angles, moments and ground reaction force variables during SLS & SLL together in the same cohort. This information is important to evaluate previous and upcoming research, especially intervention studies, and also for practitioners who use these tasks to evaluate individual performance during training or rehabilitation. Without measurement error values, changes in performance cannot be evaluated properly as it is not known whether these changes may be attributed to the intervention or from measurement errors such as marker position, marker re-application, static alignment and tasks difficulty (Whatman et al., 2011; Malfait et al., 2014; Ford et al., 2007).

The purpose of this study was to investigate the within- and between-day absolute and relative reliability of lower limb kinematic and kinetic variables collected during SLS and SLL maneuverers.

2. Materials and methods

2.1. Subjects

Fifteen recreational athletes, 7 males (age 25 ± 6.4 years; height 171 ± 6.7 cm; mass 69.7 ± 10.7 kg) and 8 females (age 26 ± 3.5 years; height 163 ± 5.4 cm; mass 63 ± 8.0 kg) participated. Subjects

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were required to be free from lower limb injury for at least six months, and have no history of lower limb surgery. A recreational athlete was defined as participating in physical activity for at least 1 hour, three times a week. Ethical approval was given from the University Research and Governance committee and all participants gave informed consent.

2.2. Procedure

A ten-camera motion analysis system (Pro-Reflex, Qualisys, Sweden), sampling at 240 Hz, and a force platform embedded into the floor (AMTI, USA), sampling at 1200 Hz, were used to collect kinematic and kinetic variables during the support phase of single leg squat and landing tasks. Each participant underwent two sessions on the same day with an hour break between, and another session one week later.

Before testing, subjects were fitted with the standard training shoes (New Balance, UK) to control shoe-surface interface. Reflective markers (14 mm) were attached with self-adhesive tape to the participants' lower extremities over the following landmarks; anterior superior iliac spines, posterior superior iliac spines, iliac crest, greater trochanters, medial and lateral femoral condyles, medial and lateral malleoli, posterior calcanei, and the head of the first, second and fifth metatarsals. The tracking markers were mounted on technical clusters on the thigh and shank with elastic bands. The foot markers were placed on the shoes, and the same individual placed the markers for all participants. That individual had undertaken over 10 supervised (by an expert in the field) marker application sessions prior to undertaking the project. The calibration anatomical systems technique (CAST) was employed to determine the six-degree of freedom movement of each segment and anatomical significance during the movement trials (Ford et al., 2007). The static trial position was designated as the subjects' neutral (anatomical zero) alignment, and subsequent kinematic measures were related back to this position. The markers were removed and replaced for the within-session trials and obviously removed and replaced for the between-day trials.

To orientate participants with the tasks, each subject was asked to perform 3–5 practice trials of each task before data collection. During SLS, subjects were instructed to stand on the right leg and hold the left leg in approximately of knee flexion without allowing the legs to contact each other, then start squatting down as far as they can (but no lower than a position of the thigh being parallel to the ground) and return to single leg stance without losing their balance. Consistent with the work of Zeller et al. Zeller et al. (2003), the squat depth was not controlled as this better represented a clinical setting in which normal inter-participant variability would exist. During practice trials, there was an acoustic counter for each participant over this 5-s period, in which the first count initiates the squat, the third indicates the deepest point of the squat and the fifth indicates the end (Herrington, 2013). This standardises the test for all participants, thereby reducing the effect of velocity on knee angles and movement pattern. In SLL, subjects landed down from a 30-cm step on their right leg onto a mark 10 cm from the bench. The effect of the arms was minimised by asking the subjects to keep their arms crossed against their chest. Participants were required to complete five successful trials for each task.

2.3. Data processing

Visual3D motion (Version 4.21, C-Motion Inc. USA) was used to calculate the joint kinematic and kinetic data. Motion and force plate data were filtered using a Butterworth 4th order bi-directional low-pass filter with cut-off frequencies of 12 Hz and 25 Hz, respectively, with the cut-off frequencies based on a residual analysis (Yu et al., 1999). All lower extremity segments were modelled as conical frustra, with inertial parameters estimated from anthropometric data (Dempster, 1959). Kinematic and kinetic data were normalised to of the right leg descend phase during squat and landing. Joint kinematic data was calculated using an X–Y–Z Euler rotation sequence. Joint kinetic data were calculated using three-dimensional inverse dynamics, and the joint moment data were normalised to body mass and presented as external moments referenced to the proximal segment. External moments were described in this study, for example, an external knee valgus load will lead to abduct the knee (valgus position), and an external knee flexion load will tend to flex the knee (Malfait et al., 2014). The following discrete variables were calculated for each trial: peaks of vertical ground reaction force (vGRF), hip flexion and adduction moments, knee flexion and abduction moments, ankle dorsiflexion moment, and peaks of lower limb joint angles at frontal, Sagittal, & transverse planes.

2.4. Statistical analysis

In order to assess the relative and absolute reliability, Intraclass correlation coefficients, model, was used in conjunction with Confidence Intervals and Standard error of measurement (SEM), with a significance value of $P < 0.05$. The ICC classification (less than 0.4 was poor, between 0.4 and 0.75 was fair to good, and greater than 0.75 is excellent) was used to describe the range of values (Fleiss, 1986). SEM was obtained by taking square root of the mean square error from the analysis of variance.

3. Results

Tables 1 and 2 contain ICCs with (95% CI), means, and SEM values for lower limb kinematic and kinetic variables collected from SLS and SLL trials. The combined averages of within-day ICC values ($ICC_{SLS} = 0.87$; $ICC_{SLL} = 0.90$) were higher as compared to the between-days ($ICC_{SLS} = 0.81$; $ICC_{SLL} = 0.78$).

Out of seven joint angles analysed in this study, within-day ICC values for all measures were excellent during both tasks ($ICC \geqslant 0.78$) apart from knee internal rotation during SLL which showed moderate reliability ($ICC \geqslant 0.53$). Between-day kinematic measures exhibited fair to excellent consistency with ICCs ranging from 0.48 to 0.96. Within- and between-day SEM values for joint angles ranged between (1.22°–4.16°) during SLS, while during SLL ranged between (1.00°–3.35°).

During both tasks, sagittal and frontal planes moments exhibited excellent ICCs during within- and between-day ($ICC \geqslant 0.75$) apart from hip adduction in SLS (Within $ICC = 0.63$; between $ICC = 0.73$) and between day knee valgus moment in SLL ($ICC = 0.69$). Within- and between-day SEM values for joint moments ranged between (0.5–0.13 N m kg) during both tasks. The ICC values of vertical GRF data ($ICC_{SLS} \geqslant 0.89$; $ICC_{SLL} \geqslant 0.97$) were higher than kinetic and kinematic variables.

4. Discussion

This study set out to assess the within- and between-day reliability of kinematic and kinetic variables during SLS and SLL tasks in recreational athletes. Previous studies have reported the reliability of only kinematic variables during similar but not identical tasks such squat and stepping (Nakagawa et al., 2014) drop vertical jump (Malfait et al., 2014), small knee bending (Whatman et al., 2011), & landing (Ford et al., 2007). With the single leg squat and landing being used in many screening programmes (Willy and Davis, 2011; Willson et al., 2006; Myer et al., 2005; Zeller et al., 2003; Dwyer et al., 2010), it is important to know how the variability in