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Reliability of knee biomechanics during a vertical drop jump in elite female athletes

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ABSTRACT

The purpose of the study was to assess the within-session and between-session reliability of knee kinematics and kinetics in a vertical drop jump task among elite female handball and football athletes. Specifically, we aimed to quantify the within-session waveform consistency and between-session consistency of the subject ranking for a variety of knee kinematics and kinetics.

Forty-one elite female handball and football (soccer) athletes were tested in two sessions. The reliability of three-dimensional knee biomechanical measurements was quantified by the intra-class correlation, Spearman's rank correlation, and typical error. All the selected discrete variables achieved excellent within-session reliability (ICC > 0.87). The typical error of valgus angles, internal rotation angles, and internal rotation moment was constant throughout the whole stance phase. For between-session reliability, the selected discrete variables achieved good to excellent reliability (ICC > 0.69), except peak internal rotation moment (ICC = 0.40). All between-session rank correlation coefficients ranged from 0.56 to 0.90. Most of the discrete variables achieved good to excellent reliability in both within-session and between-session analysis. Moreover, moderate to strong between-session consistency of subject rankings was found, implying that the measurements assessed during the vertical drop jump demonstrate sufficient reliability to be used in both single-session and multiple-session studies.

1. Introduction

Vertical drop jump tasks have been widely used in anterior cruciate ligament (ACL) injury-related research in the last decade. Three-dimensional knee kinematics and kinetics, quantified using marker-based motion analysis systems, have been used to identify potential risk factors for ACL injuries [1,2]. Furthermore, knee kinematics and kinetics in vertical drop jumps are utilized for ACL injury risk assessment [2,3] and evaluation of training interventions [4,5].

Previous research has investigated both within-session and between-session reliability of various knee biomechanical variables in vertical drop jump tasks [6,7]. Ford et al. [6] utilized the intra-class correlation coefficient (ICC) and typical error of various discrete biomechanical variables to quantify the between-session reliability. The majority of the knee kinematic and kinetic variables were shown to have fair to excellent reliability within- (ICC from 0.67 to 0.99) and between-sessions (ICC from 0.59 to 0.92) in young female high school athletes [6]. Malfait et al. [7] assessed the within-session reliability of the knee kinematics variables, and showed that the variability ranged from 1.1° to 3.8°.

The ICC is commonly used to describe reliability, however, there is considerable confusion concerning both the calculation and interpretation of the ICC [8]. The ICC will give high reliability when the subject range is large, even if trial-to-trial variability is large [8,9]. Spearman's rank correlation will be unaffected by the range in the variable as it transforms the measurements to the ranking domain for the correlation calculation thus is less sensitive to between-subject variability. Spearman's rank correlation coefficient can theoretically provide additional information on reliability, in particular on subject rankings.

The coefficient of multiple correlations (CMC) has been used to assess the waveform reliability [6]. However, CMC coefficient measures are underestimating the reliability for small motions [10] and are generally insensitive to systematic error [11]. An alternative to the CMC, the waveform reliability can be quantified as the typical error of every time point. With this temporal

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presentation, the movement variability can be further described in a specific region such as initial contact or mid-stance. Using this approach, we could detect variation between sessions and attribute them to a specific phase of the movement. For example, a previous study found that most of the variability of the kinetics measurements were around impact (0–20% of contact phase) [7]. The current study would use this approach to present waveform reliability.

The low number of participants in the previous reliability studies is a major concern [12]. Methodology studies of reliability in sports medicine suggest that such studies should contain a minimum of 40 subjects [13]. The reliability of vertical drop jump tasks have, up until now, only been investigated in very limited populations, i.e. one study on 8 recreational athletes [7] and one on 11 high school athletes [6]. Likewise, the reliability of medial knee displacement was only reported from a study with five subjects [14].

Furthermore, previous studies have not investigated the reliability of vertical drop jump task in homogenous elite populations. Elite female handball and football cohorts are of particular interest, knowing that the risk of sustaining ACL injuries is higher, compared with other groups of athletes [15,16].

The aim of the present study was to assess the within-session and between-session reliability of knee kinematics and kinetics in a vertical drop jump task among elite female handball and football athletes. Specifically, we aimed to quantify the within-session waveform error of measurements and between-session consistency of the subject measurements and rankings.

2. Methods

2.1. Subjects

Forty-one elite female handball and football (soccer) athletes (mean ± SD: 22 ± 4 years old, 168 ± 5 cm, 66 ± 8 kg) performed vertical drop jumps in our biomechanics laboratory. The Regional Ethics Committee approved the study and all subjects provided signed informed consent forms.

2.2. Sample size calculation

Sample size calculation was performed using the formula of Shoukri et al. [17]. The formula is specifically designed for reliability studies by setting the limit of the confidence interval width of the reliability coefficient. The width of the confidence interval was set to be 0.2 based on the reliability coefficient reported by Ford and colleagues [6]. Based on this, with three repeated trials and mean reliability coefficient value of 0.8, the formula gave a minimum sample size requirement of 37 subjects.

2.3. Design and protocol

Subjects were tested during pre-season in two separate sessions, on average separated by two weeks. We instructed subjects to drop off a 30 cm box and perform a maximal jump upon landing with their feet on separate force platforms (AMTI LG6-4-1, Watertown, Massachusetts, USA). They were allowed to have three practice trials and at least three valid trials were collected for each player. At least two test operators observed the execution of the jump. If sub-maximal effort was suspected, or when jumping instead of dropping off the box (i.e. increasing the vertical center of mass position at take-off from the box), we asked the subject to repeat the jump. Players were encouraged to jump with maximal effort for every jump.

Subjects wore indoor sport shoes, shorts and a sports bra. Thirty-seven reflective markers were attached over anatomical landmarks on the legs, arms and torso [18]. One experienced physiotherapist, with several years practice for marker placement, was employed for skin marker placement in both sessions.

We used a 480 Hz 16-camera system (Oqus 4, Qualisys, Gothenburg, Sweden) to capture motion, while we recorded ground reaction forces using two force platforms collecting at 960 Hz (AMTI LG6-4-1, Watertown, Massachusetts, USA). We calibrated the motion analysis system according to guidelines from the manufacturer, and calculated and tracked marker trajectories using the Qualisys Track Manager (Qualisys, Gothenburg, Sweden).

We defined the contact phase as the period where the unfiltered vertical ground reaction force exceeded 20 N. Marker trajectories and force data were filtered and interpolated using Woltring's smoothing spline in the cubic mode [19], using a 15 Hz cut-off [18]. We calculated the hip joint center using the method proposed by Bell et al. [20], with the anterior-posterior position of the hip joint decided by the anterior-posterior position of the marker over the greater trochanter. Furthermore, we defined the knee joint center according to Davis [21], and the ankle joint center according to Eng and Winter [22]. Anatomical coordinate systems of the thigh and shank were determined from the static calibration trials. We defined the vertical axis in the direction from the distal to the proximal joint center, while the anterio-posterior axis was defined perpendicular to the vertical axis with no mediolateral component. The third axis was the cross product of the vertical and antero-posterior axes. Consequently, all segments had neutral internal/external rotation in the static calibration trial. We obtained technical, dynamic thigh and shank segment coordinate systems using an optimization procedure involving singular value decomposition [23].

We estimated inertia parameters based on 46 measures of segment heights, perimeters and widths using a modified Yeadon's method [24], with hand and foot parameters calculated with the method of Zatsiorsky and Seluyanov [25]. We calculated hip and knee joint moments with inverse dynamics using recursive Newton-Euler equations of motion as described by Davis et al. [21] and projected onto the three rotational axes of the joint according to the joint coordinate system standard [26].

We used the Grood and Suntay [26] convention for calculating joint angles from the marker-based motion analysis. Medial knee displacement was introduced to quantify the valgus lower limb alignment which is believed to increase the risk of ACL rupture [1,3]. We calculated medial knee position as the perpendicular distance between the knee joint center and the line joining the ankle and hip joint centers, projected on the frontal plane. The difference between the perpendicular position at the initial foot contact and the peak value was defined as the medial knee displacement. An advantage of this convention compared with a pure knee separation measure is that we can assess knee control individually for the left and right leg. Furthermore, this measure is simpler than skin marker based 3D valgus measurements, which is useful in applied clinical settings [27]. We ran all calculations using custom Matlab scripts (MathWorks Inc., Natick, Massachusetts, USA).

2.4. Statistical analysis

For simplicity, only the measurements from the right leg were used for analyses. Each trial was time-normalized from 0% to 100% of the stance phase. For every time point, we calculated the typical error based on three trials from each subject. The typical error was calculated from the standard deviation of inter-trial differences divided by the square root of 2 [28]. The typical error represented 52% of test–retest differences of a subject in the sample group [28]. The between-session typical error was calculated based on the mean value of three trials in each session. Moreover, the mean