Physical Therapy in Sport xxx (2013) 1–7

Contents lists available at SciVerse ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

The reliability and validity of the measurement of lateral trunk motion in two-dimensional video analysis during unipodal functional screening tests in elite female athletes

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ARTICLE INFO

Article history:
Received 8 January 2013
Received in revised form
7 May 2013
Accepted 21 May 2013

Keywords:
Trunk
Female athletes
Functional tests
Two-dimensional video analysis

ABSTRACT

Objective: To investigate the reliability and validity of the measurement of lateral trunk motion (LTM) in two-dimensional (2D) video analysis of unipodal functional screening tests.
Design: Observational study.
Setting: Research laboratory.
Participants: Forty-three injury-free female athletes.
Main outcome measures: Knee valgus (KV) and lateral trunk motion (LTM) angles were measured with a standard digital camera during the single leg squat and the single leg drop vertical jump (SLDVJ). Three-dimensional motion analysis was used during the SLDVJ to measure peak external knee abduction moment (pKAM). Intraclass correlation coefficients were calculated to assess the intra- and intertester reliability of the LTM angle. Correlations between 2D angles and pKAM were calculated for the SLDVJ.
Results: Excellent intraclass correlation coefficients for the LTM angle were found within (0.99–1.00) and between testers (0.98–0.99). The sum of KV and LTM was significantly correlated with the pKAM during the SLDVJ for the dominant ($r = -0.36$; $p = 0.017$) and non-dominant leg ($r = -0.32$; $p = 0.034$), while either angle alone was not.
Conclusions: LTM can be measured with excellent intra- and intertester reliability. The combination of KV and LTM was moderately associated with pKAM and thus including LTM may aid assessment of movement quality and injury risk.

1. Introduction

Female athletes are at increased risk for acute and overuse knee injuries, such as anterior cruciate ligament (ACL) injuries and patellofemoral pain syndrome (PFPS) (Agel, Arendt, & Bershadsky, 2005; Boling, Padua, Marshall, Guskiewicz, Pyne & Beutler, 2010). The underlying mechanisms of these injuries are multifactorial in nature. From an injury prevention perspective, biomechanical and neuromuscular factors are most important, as these can be modified by training (Hewett, Myer, Ford, Paterno, & Quatman, 2012).

Prospective studies have shown that increased knee abduction angles and moments are associated with an increased risk to sustain ACL (re-)injuries and PFPS (Hewett et al., 2005; Myer et al., 2010; Paterno et al., 2010). High risk knee loading may be the result of decreased whole body movement control, rather than a dysfunction of the knee itself, as it is recognized that the knee acts as an intermediate joint within a linked system of interdependent segments (Hewett & Myer, 2011; Mendiguchia, Ford, Quatman, Alentorn-Geli, & Hewett, 2011). Indeed, increasing evidence indicates that trunk control may have a large effect on knee injury risk (Hewett & Myer, 2011; Jamison, Pan, & Chaudhari, 2012; Mendiguchia et al., 2011; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). Movements of the trunk in the direction of the stance limb during unipodal tests may increase the external knee abduction moment (Jamison et al., 2012). Furthermore, increased lateral trunk motion (LTM) has been associated with the ACL injury mechanism in female athletes (Hewett, Torg, & Boden, 2009), and has been reported as a maladaptive movement strategy in subjects with PFPS (Nakagawa, Moriya, Maciel, & Serrao, 2012).

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http://dx.doi.org/10.1016/j.ptsp.2013.05.001

Assessment of movement quality during functional screening tests has been advocated to be important to evaluate (re-)injury risk (Chmielewski, Hodges, Horodyski, Bishop, Conrad & Tillman, 2007; Mottram & Comerford, 2008; Ortiz & Micheo, 2011; Sahrmann, 2011; Whatman, Hing, & Hume, 2011; Whatman, Hing, & Hume, 2012; Whatman, Hume, & Hing, 2012). Three-dimensional (3D) motion analysis is considered as the gold standard to identify poor biomechanical control of the lower extremity (McLean, Walker, Ford, Myer, Hewett & van den Bogert, 2005). However, due to the practical, temporal and spatial constraints of these methods, it is difficult to use in clinical settings and on larger scales. As a more time- and cost-effective alternative method, two-dimensional (2D) video analysis has been introduced. Despite the limitation that transverse movements cannot be measured (Ageberg, Bennell, Hunt, Simic, Roos & Creaby, 2010; Willson & Davis, 2008), 2D video analysis is considered as a useful method for measuring knee valgus (KV) angles during functional screening tests (Herrington & Munro, 2010; McLean et al., 2005; Miller & Callister, 2009; Mizner, Chmielewski, Toepke, & Tofte, 2012; Munro, Herrington, & Carolan, 2012; Stensrud, Myklebust, Kristianslund, Bahr, & Krosshaug, 2011; Willson & Davis, 2008).

However, focusing only on this angle and neglecting trunk motion may be too limited and may lead to misinterpretations when assessing knee injury risk, as it is recognized that LTM may play an important role in acute and overuse knee injury mechanisms by increasing the external knee abduction moment. In contrast with current practice where LTM is assessed during functional screening tests with visual observation (Chmielewski et al., 2007; Crossley, Zhang, Schache, Bryant, & Cowan, 2011; Whatman, Hing, et al., 2012) and 3D motion analysis (Jamison et al., 2012; Nakagawa et al., 2012; Whatman et al., 2011), LTM has not yet been measured with 2D video analysis.

The goal of the present study was to investigate the reliability and validity of the measurement of LTM in 2D video analysis during unipodal functional screening tests. Therefore, the reliability of this 2D LTM angle was first examined. Further, the correlations between 2D angles and 3D peak external knee abduction moment were calculated to validate this 2D method.

2. Methods

2.1. Participants

A total of 43 elite female athletes (22 soccer, 11 handball and 10 volleyball) were tested (mean ± SD: age = 21.1 ± 3.4 years; height = 170.0 ± 8.3 cm; weight = 65.2 ± 8.0 kg). Athletes were recruited from one soccer, one handball and one volleyball team of the highest national level. Participants were injury and pain free, and above 16 years old. Appropriate ethical approval had been granted by the local ethical committee prior to the commencement of the study. Before participating in the study, all participants read and signed the informed consent form.

2.2. Procedure and measurements

All participants wore a sports bra, tight-fitting shorts and standardized neutral indoor shoes (Kelme Indoor Copa). If necessary, long hair was tied up to avoid marker occlusion. All participants completed the single leg squat (SLS) test, and the single leg drop vertical jump (SLDVJ) test. These unipodal screening tests were described in previous studies (Claiborne, Armstrong, Gandhi, & Pincivero, 2006; Crossley et al., 2011; Munro et al., 2012; Nakagawa et al., 2012; Stensrud et al., 2011; Willson, Ireland, & Davis, 2006) and were chosen in this study above bipodal screening tests because trunk compensations may be more obvious in the absence of the support of the contralateral leg. Before the start of the tests, all participants executed a standardized warm-up program, consisting of a series of bipodal squats (2 × 8) and bipodal jumps (2 × 5) (Stensrud et al., 2011).

During the SLS, participants were instructed to move from double-leg stance to single-leg stance during 2 s, to perform a squat movement on one leg to approximately 75° of knee flexion during 2 s, and to return to the double-leg standing starting position during 2 s. The amount of knee flexion (75°) was measured during the practice trials with a standardized goniometer (Gymna). During the tests itself, the researcher visually controlled the amount of knee flexion. Whatman et al. (2011) showed that participants are able to produce a consistent range of sagittal plane motion without the need for complicated and time consuming monitoring. The speed of movement was checked with a metronome. Participants were asked to look straight ahead, to keep the shoulders above the knees to standardize the amount of hip flexion, to keep the non-supporting knee parallel to the supporting knee, and to fold their arms across their chest to avoid marker occlusion and compensatory arm movements (Fig. 1A–D). A trial was not valid if these instructions were not followed, if the non-supporting leg touched the ground or if the participants clearly lost balance or fell during the test.

During the SLDVJ, participants were asked to drop off a box of 10 cm with one leg, followed by a maximum vertical jump on the same leg, moving their arms freely (Fig. 1E–H). Participants were instructed to attempt reaching an overhead goal with both hands. A trial was not valid if the participants jumped off the box instead of just dropping, if the non-supporting leg touched the ground, if the participants reached with only one hand, or if the participants clearly lost balance or fell during the test (Stensrud et al., 2011).

The same researcher provided all specific instructions to each participant. Participants were allowed to familiarize themselves with the tests by performing 3 practice repetitions before the start of the tests. The first three valid trials were selected based on the previously mentioned criteria and included for further analysis. For both tests, the dominant and the non-dominant leg were tested. The dominant leg was defined as the preferred leg to kick a ball. The order of the tests was determined randomly. Afterwards, body height and weight were measured.

To validate our 2D measurements, 3D motion analysis was used during the SLDVJ. Each participant was instrumented with 48 spherical reflective markers positioned according to a 6-degrees-of-freedom eight segment ‘Lower Limb and Trunk’ (LLT) model including feet, upper and lower legs, pelvis and trunk (Vanrenterghem, Gormley, Robinson, & Lees, 2010). Segmental coordinate systems were defined as in the Liverpool John Moores University model (Robinson & Vanrenterghem, 2012), using separate trials for anatomical calibration (Cappozzo, Catani, Della Croce, & Leardini, 1995) and for calculating functional hip joint centres (Schwartz & Rozumalski, 2005) and functional knee joint axes (Besier, Sturnieks, Alderson, & Lloyd, 2003). All modelling and analyses were undertaken in Visual 3D (v.4.83, C-motion, Germantown, MD, USA) using geometric volumes to represent segments based on cadaver segmental data (Dempster & Gaughran, 1967) and in a custom Matlab program.

Force plate data were sampled at 1000 Hz, on a 0.8 × 0.3 m^2 force plate (AMTI, MA, USA). Three-dimensional kinematic data were simultaneously (time synchronized) recorded with the force data in Nexus (Vicon, Oxford Metrics, UK) using 6 optoelectronic cameras, sampling at 100 Hz.

Marker trajectories and force data were both filtered using a 4th order low pass Butterworth filter with a cut off frequency of 20 Hz (Bisseling & Hof, 2006). Touch-down and take-off events were created when the vertical force crossed a 20 N threshold. The peak external knee abduction moment (pKAM) between touch-down and take-off was calculated using inverse dynamics. These

Please cite this article in press as: Dingenen, B., et al., The reliability and validity of the measurement of lateral trunk motion in two-dimensional video analysis during unipodal functional screening tests in elite female athletes, *Physical Therapy in Sport* (2013), http://dx.doi.org/10.1016/j.ptsp.2013.05.001