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Clinical assessment of countermovement jump landing kinematics in early adolescence: Sex differences and normative values

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ABSTRACT

Background: Adolescent females have been reported to have a higher risk of non-contact knee joint injuries compared to their male counterparts, with deficiencies in neuromuscular control being purported to be the primary differentiating factor. As such, assessment of movement quality during functional screening tests in this population is warranted. Widespread implementation of such screening requires clinically accessible screening measures and normative data. Therefore, the aim of the present study was to provide normative data for clinical analysis of landing kinematics in early adolescent male and female athletes, with a corollary of determining whether a difference between the sexes is evident with such screening.
Methods: Ninety seven male and 84 female athletes (mean age = 13 ± 1.41 years) in the first year of high school participated. Each participant performed 3 countermovement jump trials. Frontal and sagittal plane knee joint angles were recorded by video cameras for both dominant and non-dominant limbs. A multivariate analysis of variance (MANOVA) was used to determine the effect of sex on the dependent variables.
Findings: Males displayed significantly greater knee flexion prior to initial contact ($P < 0.001$) and knee varus displacement ($P < 0.001$). No differences were observed between males and females for max knee flexion ($P > 0.05$).
Interpretation: Early adolescent female athletes demonstrate less desirable landing biomechanics than their male peers. The first year in high school, when early adolescent females are first exposed to high school sports, may be an ideal time to assess movement quality during functional tasks and intervene with injury prevention programs if necessary.

1. Introduction

Female athletes are reported to have a higher incidence and prevalence of both acute and chronic non-contact knee joint injuries such as anterior cruciate ligament (ACL) injury (Walden et al., 2011) and patellofemoral pain (PFP) (Boling et al., 2010). They are 4 times more likely to sustain an ACL injury (Agel et al., 2005; Prodromos et al., 2007; Walden et al., 2011) and 2–3 times more likely to develop PFP (Boling et al., 2010) when compared to age and activity matched male athletes; with the etiology of both being linked to deficiencies in neuromuscular control (Myer et al., 2014). It has been consistently reported that adolescent and young adult female athletes display differences in lower limb neuromuscular control and associated lower limb biomechanical profiles compared to their age and activity matched male peers, thus putting them at an increased risk of lower limb musculoskeletal injury (Decker et al., 2003; Ford et al., 2003; Lephart et al., 2002; Malinzak et al., 2001; Pollard et al., 2004; Sigward and Powers, 2006). Specifically, biomechanical profiles characterized by decreased knee flexion, increased knee valgus angles and moments, and asymmetries in lower limb kinematics and kinetics during athletic tasks have been shown to be associated with an increased risk of developing PFP and of sustaining an ACL injury (Boling et al., 2009; Hewett et al., 2005; Myer et al., 2010; Paterno et al., 2010). Even though the incidence of PFP and ACL injury is particularly high in adolescent females (Ireland, 1999; Myer et al., 2010; Shea et al., 2004; Tenforde et al., 2011), it has yet to be comprehensively determined when the aforementioned differences in landing biomechanics between males and females begin to manifest and whether or not they are present in early adolescence. The increased risk of lower limb musculoskeletal injury and in particular non-contact ACL injury has been purported to coincide with the rapid growth of the skeletal system (Caine et al., 2008; Quatman et al., 2006; Stracciolini et al., 2013). This may predispose maturing female athletes to an increased risk of injury in the absence of neuromuscular adaptation to control the long levers of the body and the associated elevated center of mass (Hewett et al., 2004; Myer et al., 2009; Quatman et al., 2006).

Lower limb neuromuscular training programs have previously been shown to be effective in reducing rates of non-contact knee injuries, as well as altering 'high risk' lower limb movement patterns during athletic tasks (Gilchrist et al., 2008; Hewett, 1999; Myer

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et al., 2013; Myklebust et al., 2003; Myklebust et al., 2007; Petersen et al., 2005). The effectiveness of these programs could potentially be improved if they are targeted towards "high risk" populations (Myer et al., 2013). Consequently, assessment of movement quality during functional screening tests in adolescent female athletes is prudent. However, it is imperative that inexpensive, valid and reliable clinical assessment tools to identify athletes with aberrant lower limb biomechanical profiles during athletic tasks are available in order to implement interventions in this population. Although three dimensional (3D) motion analysis is considered the gold standard to evaluate movement quality, it requires expensive equipment and significant expertise and is time intensive. This makes 3D analysis impractical for screening adolescents in high school and team sports settings. Measurement of neuromuscular control by two dimensional (2D) video analysis has previously been validated (Eltoukhy et al., 2012; McLean et al., 2005; Norris and Olson, 2011) and may present a more time and cost effective screening methodology. Widespread implementation of such screening requires objective criteria and normative data during functional performance tasks that can be used to identify deficits and monitor progress and response to interventions in athletes.

The countermovement jump (CMJ) is a versatile exercise which could be used to assess both performance and injury risk in many populations. For example, assessment of the vertical jump height an individual can attain during CMJ is often undertaken in various sports as an indication of lower limb explosive power and evaluation of movement quality (and in particular landing biomechanics) could provide supplemental information as to whether an athlete may be at risk of obtaining a non-contact lower limb musculoskeletal injury. Consequently, it is likely that assessment of CMJ performance as part of preseason screening could be beneficial to strength and conditioning specialists, coaches, athletic trainers, physical therapists and athletes.

Therefore, the objectives of the current investigation were to present normative kinematic and limb symmetry values for early adolescent high school male and female athletes during performance of CMJ trials, as well as determining whether a difference in lower limb landing kinematic movement profiles exists between the two groups. A corollary investigation was undertaken to determine the reliability of 2D analysis of CMJ landing kinematics.

2. Methods

2.1. Participants

Ninety seven male and 84 female athletes in their first year of high school from six schools within the University catchment area participated in the present study. Participant characteristics (age, height, and body mass) are displayed in Table 1. At the time of testing, all athletes were fully engaged in court or field-based sports, track and field athletics, or athletic dance (e.g. gymnastics) and free from lower limb injury (as assessed by a Chartered Physiotherapist at the time of testing). Written informed parental consent for each participant was obtained prior to testing with participant assent being obtained on the day of testing. All testing was undertaken in the relevant schools' gymnasium. Upon arrival for the testing session, each participant was informed and familiarized with the testing procedure. Height, body mass, date of birth and limb dominance were recorded prior to testing for all participants. For the purpose of the current study limb dominance was defined as the leg preferably used to kick a soccer ball as far as possible. The study was approved by the University Human Research Ethics Committee.

Table 1
Participant characteristics. All values are reported as mean (SD).

Sex	*n*	Age	Height (m)	Body Mass (kg)
Female	84	13 (1.15)	1.59 (0.06)	49.65 (8.62)
Male	97	13 (1.67)	1.59 (0.08)	47.94 (10.36)

2.2. Test protocol

Retro-reflective markers (Vicon Motion Systems Ltd; 20 mm) were placed on the greater trochanter, the upper border of the lateral knee joint line, and lateral malleolus of both legs of participants. Specifically the markers were placed onto to the most prominent points of the greater trochanter and lateral malleolus. On the lateral knee joint line the marker was placed perpendicular to the line connecting the lateral malleolus and the head of the fibula while the knee was flexed. Markers were placed directly onto the skin of participants and as such required participants to wear athletic shorts which were taped in a manner that exposed skin around the greater trochanter of the hip so the marker could be visually identified and digitized during the data processing. All markers were placed by the same researcher.

A demonstration of how to correctly perform a CMJ was then provided to each participant. Participants began standing upright with feet positioned shoulder width apart and hands positioned on the hips. Standardized instructions were to perform an unconstrained vertical jump for maximum jump height that included an initial countermovement to a self-selected depth. Participants were then allowed to practice the jump. When participants demonstrated proficient ability they then performed three CMJ test trials. Trials were not included if the participant removed their hands from their hips or lost their balance during landing.

Two-dimensional frontal and sagittal plane knee kinematic data were captured with three standard video cameras (Canon Legria HF R306) with an acquisition rate of 50 frames/second. Cameras were positioned at a height of 1.03 m in the frontal and sagittal planes. Two-dimensional analysis has previously been shown to be a valid method of quantifying and measuring lower limb kinematics (Bittencourt et al., 2012; McLean et al., 2005; Norris and Olson, 2011).

2.3. Data reduction

The sagittal plane video camcorder was used to capture knee flexion angles that are calculated from the video frame just prior to initial contact (pre-IC) and the video frame at maximum knee flexion (Myer et al., 2011). Initial contact was defined as the frame in which the participants' toes first came in contact with the force plate. This was visually identified by watching the video frame by frame. Knee flexion range of motion (RoM) was calculated as the difference in knee flexion between the two positions ($\theta 1 - \theta 2$; Fig. 1). Knee flexion angles were calculated for both the dominant and non-dominant limbs of each participant. All flexion angles were defined as degrees of flexion (positive) with 0° representing full knee extension.

In the frontal plane, knee valgus displacement was quantified from the frames pre-IC and maximum frontal plane knee joint motion. Pre-IC was defined as outlined above, while the point of maximum frontal plane knee motion was identified as the frame of the greatest displacement of the knee in the frontal plane during landing. The angle formed between the three markers was then quantified by digitizing the reflective markers on the hip, knee and ankle. Knee valgus displacement was then calculated as the difference in angle between the two time points ($\gamma 1 - \gamma 2$; Fig. 2). This was completed for both the dominant and non-dominant limbs of each participant. Knee valgus displacement was defined as degrees of valgus (positive) or varus (negative) knee motion, with 0° representing no knee motion in the frontal plane between the time point pre-IC and the time of max frontal plane knee motion during the descent phase of landing. Frontal and sagittal plane knee joint angles