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Kinetic and kinematic differences between first and second landings of a drop vertical jump task: Implications for injury risk assessments☆

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ABSTRACT

Background: Though the first landing of drop vertical jump task is commonly used to assess biomechanical performance measures that are associated with anterior cruciate ligament injury risk in athletes, the implications of the second landing in this task have largely been ignored. We examined the first and second landings of a drop vertical jump for differences in kinetic and kinematic behaviors at the hip and knee.

Methods: A cohort of 239 adolescent female basketball athletes (age = 13.6 (1.6) years) completed drop vertical jump tasks from an initial height of 31 cm. A three dimensional motion capture system recorded positional data while dual force platforms recorded ground reaction forces for each trial.

Findings: The first landing demonstrated greater hip adduction angle, knee abduction angle, and knee abduction moment than the second landing (P-values < 0.028). The second landing demonstrated smaller flexion angles and moments at the hip and knee than the first landing (P-values < 0.035). The second landing also demonstrated greater side-to-side asymmetry in hip and knee kinematics and kinetics for both the frontal and sagittal planes (P-values < 0.044).

Interpretation: The results have important implications for the future use of the drop vertical jump as an assessment tool for anterior cruciate ligament injury risk behaviors in adolescent female athletes. The second landing may be a more rigorous task and provides a superior tool to evaluate sagittal plane risk factors than the first landing, which may be better suited to evaluate frontal plane risk factors.

1. Introduction

Each year in the United States over 120,000 people suffer an anterior cruciate ligament (ACL) injury (Huston et al., 2000). Female athletes are 4 to 6 times more likely to sustain ACL tears than their male counterparts playing similar high risk landing and pivoting sports (Hewett et al., 2005). These injuries are costly and debilitating, as up to 90% of ACL rupture patients exhibit symptoms of early onset arthritis within 10 years of injury (Lohmander and Roos, 1994; Lohmander et al., 2007). Most athletes who sustain ACL ruptures also experience a decrease in quality of life with knee symptoms within 15 years post-injury (Lohmander et al., 2004; von Porat et al., 2004). As costly reconstructive surgeries exhibit no long term benefits towards the reduction of osteoarthritis at the knee (Lohmander and Roos, 1994), injury prevention is likely the best method to reduce the negative consequences of an ACL rupture.

Approximately 70% of ACL injuries occur in non-contact situations as the result of a rapid deceleration or change in direction (Krosshaug et al., 2007; McNair et al., 1990; Myklebust et al., 1998). In regards to basketball, the most commonly reported mechanism of ACL rupture is

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rebounding, a task that involves a rapid, and often unstable, deceleration as athletes land from a maximal vertical jump (Powell and Barber-Foss, 2000). Jump landings produce high, sudden ground reaction forces that translate into large external torques at the knee that can rupture the ACL (Boden et al., 2000; Hewett et al., 1999). Research with three-dimensional motion capture systems has identified a number of mechanical factors that contribute to ACL injury risk during athletic tasks such as excessive knee abduction (Ford et al., 2003; Hewett et al., 2005), knee compression forces (Fleming et al., 2001; Meyer and Haut, 2008), internal tibial rotation (Meyer and Haut, 2008; Shin et al., 2011), and insufficient hip and knee flexion (Chappell and Limpisvasti, 2008; Pollard et al., 2010). The prevalence of these mechanical variables during athletic tasks can be attributed to an athlete's level of neuromuscular control (Hewett et al., 2005). Therefore, training protocols designed to enhance neuromuscular control and target injury risk deficits are effective in altering biomechanics and reducing the incidence of ACL injury within an athletic population (Chappell and Limpisvasti, 2008; Hewett et al., 1999; Pollard et al., 2006).

One task commonly used to evaluate injury risk biomechanics is the drop vertical jump (DVJ), which simulates the mechanics of rebounding a basketball (Ford et al., 2011; Hewett et al., 2005; Kernozek et al., 2005; Myer et al., 2011; Paterno et al., 2007). The DVJ requires an athlete to drop off a static box, land, immediately execute a maximal vertical jump toward a target, and finish with a second landing. Based on kinematic and kinetic performance traits and anatomical variables, an algorithm has been designed using the DVJ to evaluate an individual's cumulative risk of sustaining an ACL rupture (Myer et al., 2011). This algorithm is designed around the evaluation of a subject's first landing. However, during rebounding tasks, ACL injuries are most often endured as athletes land following a maximal vertical jump to secure the basketball (Powell and Barber-Foss, 2000). Accordingly, the second landing of a DVJ may provide a better simulation of injury risk mechanics.

The objective of this study was to examine the kinetic and kinematic differences between the first and second landings in a DVJ. Anecdotal evidence indicates that athletes display greater lower extremity neuromuscular control deficits during the second landing. Therefore, the hypothesis tested was that lower extremity biomechanical deficits associated with increased ACL injury risk would be greater in the second landing than the first landing. Specifically, we evaluated whether study participants demonstrated greater knee abduction, greater hip adduction, reduced knee and hip flexion and increased side-to-side asymmetry in the second landing relative to the first landing of a DVJ.

2. Methods

This study examined middle ($n = 162$; age = 12.6 (0.9) years) and high school ($n = 77$; age = 15.6 (0.9) years) female basketball players from a cohort in a prospective, longitudinal study. Study participants were tested immediately preceding their upcoming season. Procedures were approved by the institutional review board and informed written consent was obtained from the parent or legal guardian of each subject prior to testing. Each subject assented to participation prior to testing.

Participants were evaluated for anatomical measures and maximal vertical jump height prior to motion testing. Height was measured with a stadiometer while the subject stood barefoot (height = 1.60 (0.09) m). To evaluate body mass, participants stood barefoot on a calibrated physician scale (mass = 55.4 (13.2) kg). Shoe size and maximal countermovement vertical jump height were also measured individually for each subject.

For 3-D biomechanical motion analysis, participants wore athletic shorts and tee shirts that were taped in a manner that exposed skin around the greater trochanter of the hip the lower lumbar and abdominal regions and were instrumented with 43 retroreflective markers for 3-D biomechanical analysis. Markers were arranged in a modified Helen Hayes marker set with a backpack (Skeeter CamelBak, Petluma, CA) to define the superior torso and previously marked shoes (Supernova, Adidas, Herzogenaurach, Germany) to standardize footwear (Bates et al., 2013). A static trial was captured to anatomically define each body segment and determine neutral alignment for each subject. 3D motion was collected with a 10-camera motion capture system (Eagle cameras, Motion Analysis Corporation, Santa Rosa, CA) that sampled at 240 Hz. vertical ground reaction force (vGRF) was sampled at 1200 Hz and collected by dual, in-ground, multi-axis force platforms (AMTI, BP600900 Watertown, MA) such that each platform corresponded with a single leg of each subject.

Participants each performed three trials of the DVJ task (Ford et al., 2007). The DVJ began with each subject standing on top of a 31 cm box with feet positioned 35 cm apart and arms held at their sides. The box was aligned such that when a subject dropped straight down from the box, they would land with each foot on a separate force platform. Participants proceeded to drop straight down from the box and complete a first landing on the force platforms. Upon landing, participants immediately transitioned into a maximal vertical jump toward a provided target, which was followed by a second landing. The provided target was a basketball suspended at the maximal vertical jump height recorded previously for each subject. Prior to execution of the DVJ, participants were instructed to drop straight down from the box without any vertical launch, execute a maximal vertical jump upon contact with the force platforms, and attempt to reach for and bring down the provided target. No specific instructions were provided for the execution of the second landing. If participants failed to land with both feet contained in separate force platforms on the first landing then the trial was repeated. If participants failed to land with both feet contained in separated force platforms on the second landing then the trial was excluded from analysis. Of the 239 participants, 33 failed to complete a successful trial and were excluded.

3-D biomechanical motion data were processed through Visual3D (version 4.0, C-Motion, Inc., Germantown, MD) with custom MATLAB (version 2010b, The Mathworks, Inc., Natick, MA) code for both the first and second landing phases of the DVJ. Landing phase was defined as the moment of initial contact (IC) with the force platform, where the vGRF first exceeded 10 N, through the lowest point of center of gravity during stance (Bates et al., 2013). vGRF data were filtered through a fourth-order, low-pass, digital filter with a cutoff frequency of 100 Hz for vGRF calculations, while marker trajectories and vGRFs were filtered at a cutoff frequency of 12 Hz for kinetic and kinematic calculations (Ford et al., 2010b). For data analysis, each individual subject was represented by the mean of all of her successful trials. All moments were reported as external joint moments derived from the GRFs created during contact with the force platforms.

A 2-by-2 analysis of variance (side: right versus left and landing type: first versus second) examined the relationships between each kinetic and kinematic variable. Post-hoc Student's *t*-tests assessed statistical differences in peak values between the first and the second landing when warranted. *t*-tests were also used to evaluate between landing differences at initial contact and the time point corresponding to the maximal vGRF. Side-to-side asymmetry was assessed through absolute differences in peak values for each kinetic and kinematic variable. Statistical analyses were performed in MATLAB and statistical significance was established a priori at $P < 0.05$.

3. Results

3.1. Sagittal plane

Comparison of sagittal plane kinetic and kinematic values revealed significant side versus landing type interactions at the hip for maximum flexion angle and maximum extension moment (P-values < 0.035). Between landing differences were present in sagittal plane kinetics and kinematics for both the hip and knee. Specifically, the study participants demonstrated reduced peak flexion angles at both joints during