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Biomechanical Assessment of Single-Leg Drop Vertical Jump Landings: A Comparative Analysis of First and Second Landings

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Biomechanical Assessment of Single-Leg Drop Vertical Jump Landings: A Comparative Analysis of First and Second Landings

by

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Report

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Abstract

Biomechanical Assessment of Single-Leg Drop Vertical Jump Landings: A Comparative Analysis of First and Second Landings

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The drop vertical jump is commonly used to assess the biomechanical performance of athletes, both for screening for injury risk and for assessing return-to-play readiness. These assessments rely only on the performance of the first landing and the implications of the second landing have been largely ignored. The second landing, however, better simulates the mechanics of rebounding tasks which are most often associated with greater ACL injury risk. The purpose of this study is to analyze the differences in kinetic and kinematic metrics at the knee joint during the first and second landings of the single-leg drop vertical jump. The results of this study have implications for the future assessment of ACL injury risk and return-to-sport readiness. Greater peak vGRF and knee adduction and smaller knee flexion angle indicate that the second landing of the single-leg drop vertical jump may exhibit greater perturbation and better represents the mechanics associated with ACL injury risk. Moreover, the second landing is a more

rigorous task and presents a more challenging evaluation scenario and serves as a more reliable evaluation of risk factors in the sagittal and frontal plane, than the first landing.

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Chapter 1: Introduction

The Drop Vertical Jump (DVJ) exercise is a recognized method for detecting the increased susceptibility to Anterior Cruciate Ligament (ACL) injuries (Beyer et al., 2020; Khan et al., 2019). On an annual basis, this debilitating injury affects approximately 200,000 individuals (Beard et al., 2022), often significantly impairing the stability of the knee joint, a critical element in athletic performance (Khan et al., 2019). Strikingly, non-contact circumstances, precipitated by abrupt deceleration or directional shifts, account for approximately 70% of ACL injuries (Griffin et al., 2000; Krosshaug et al., 2007). These non-contact ACL injuries are commonly observed during single-leg jump landing situations (Kotsifaki et al., 2022).

One primary indicative feature of potential ACL injury is increased knee stiffness during landing. Evidence suggests that diminished knee flexion combined with a greater vertical ground reaction force (vGRF) correlates with a higher incidence of ACL injuries among adolescent athletes (Leppänen et al., 2017). In addition, certain mechanical factors have been pinpointed as contributory to ACL injury risk during athletic maneuvers, such as excessive knee abduction and insufficient knee flexion (Hewett et al., 2005; Pollard et al., 2010).

The DVJ task is a typical method employed to gauge knee injury risk, owing to its apt simulation of rebounding biomechanics prevalent in various sports (Hewett et al., 2005). Earlier research posits that athletes exhibit distinct changes in kinetic and kinematic patterns, as well as neuromuscular control, between the initial and subsequent landing during a drop landing task (Bates et al., 2013). Furthermore, recent studies suggest that the single-leg jump task may be a superior tool in evaluating knee function (Kotsifaki et al., 2022). Despite this, there remains a significant gap in research pertaining to the biomechanical behaviors exhibited during the second landing of the single-leg jump landing task, a task that aptly mimics the mechanics of jumping and rebounding in sports like basketball.

The objectives of this study were to examine the kinetic and kinematic differences between the first and second landing in the single-leg DVJ task. We hypothesized that the vertical center of mass (CoM) and knee flexion angle will be smaller in the second landing, while the knee abduction angle and vGRF will be greater in the second landing.

Chapter 2: Methods

PARTICIPANTS

Seven healthy young adults participated in this experiment (4 females and 3 males, the mean age was 25 ± 6 years). Participants were evaluated for anatomical measures prior to motion testing. Height was measured with metric tape while the subject stood barefoot (height = 169 ± 0.09 m). The participants' body mass was assessed by having them stand barefoot on a physical scale, yielding an average weight of 64.97 ± 9.88 kg. Before the experiment began, they completed a questionnaire regarding their dominant leg and received instructions for the task. All participants used their dominant leg in the experiments. Participants were free of ankle and or knee pain and no prior surgeries that would affect their mobility. The Institutional Review Board University of

Texas at Austin approved this experiment. All participants signed informed consent forms prior to participating.

EXPERIMENTAL PROCEDURES

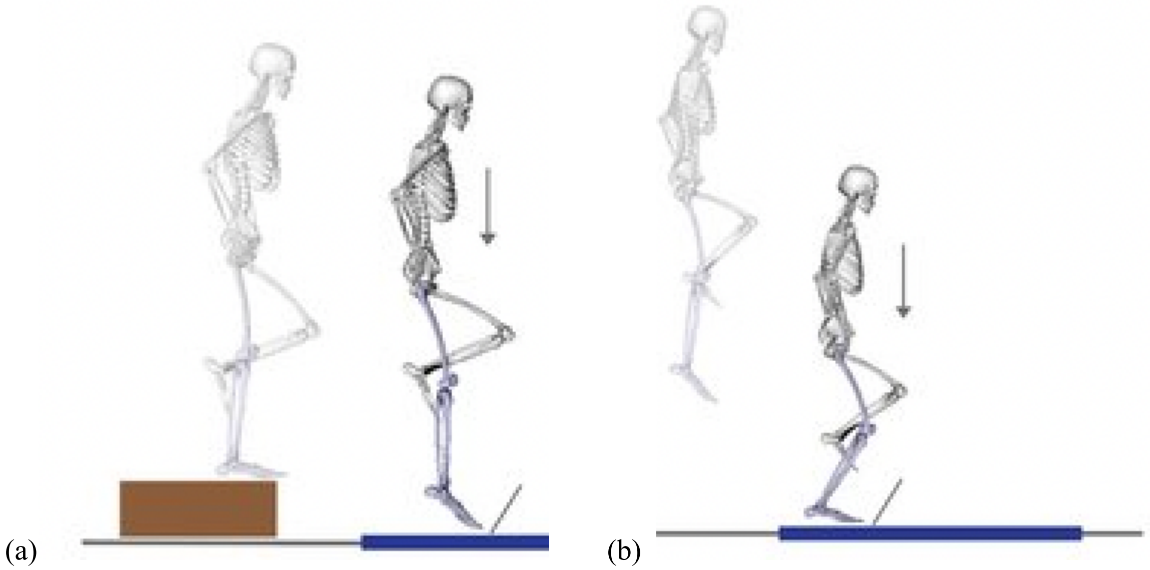

Figure 1: (a) First landing of vertical jump landing task (b) Second landing of vertical jump landing (Kotsifaki et al., 2022)

Participants began from a single leg standing position on a platform with a height of 0.25m in front of a force plate (Wang & Peng, 2013). Participants positioned their foot and arm in a neutral standing position first (feet positioned 35 cm apart and arms held at their sides.) Then the non-dominant leg was flexed and lifted to the position where the participant felt balanced and ready to perform a single-leg jump. The box was aligned such that when a participant dropped straight down from the box, they would land in the center of the force plate. Participants were instructed to jump off a static box, immediately execute a maximal vertical jump toward the target and land with the tested foot on the force plate, and then jump upward the send time as high as possible.

Positional data was recorded at a rate of 100 Hz using a three-dimensional motion capture system (VICON Motion System Ltd, Oxford, UK), paired with a standard full-body plug-in gait 39 marker-set. The placement of markers on the body is as follows: there's one marker placed on the front and back of the headband. For the torso, two markers are situated on the sternum, one on the xiphoid process, and another on the C7 vertebra. The shoulders host two markers on the acromion process each. Each upper arm carries two markers, one each on the lateral and medial sides. The elbows have a marker on the lateral epicondyle each, while both the forearms also have one marker each on their lateral and medial sides. For the wrists, one marker each is placed on the radial and ulnar styloid. The second metacarpal of each hand has one marker. On the pelvis, there's a marker on the anterior superior iliac spine (ASIS) and another on the posterior superior iliac spine (PSIS) of each hip. Each thigh has one marker on both its lateral and medial sides. The knees feature a marker on the lateral epicondyle each. Each shank has one marker on its lateral and medial sides. The lateral malleolus of each ankle has one marker, and finally, each foot has a marker on the heel (calcaneus) and the head of the second metatarsal. Participants, dressed in athletic shorts and tee shirts, were carefully taped in such a way that the skin around the greater trochanter of the hip and the lower lumbar and abdominal regions was visible to the motion capture cameras. Each participant underwent a static trial to determine the anatomical definition of their body segments and establish their reference neutral alignment. Kinetic data was collected with a Bertec (Bertec Corporation, Columbus, OH, USA) force plate at a rate of 2000Hz.

DATA ANALYSIS

The subsequent processing and calculation of the three-dimensional biomechanical motion data were executed using Vicon Nexus 1.8.5 software (Vicon, Oxford Metrics, UK). This was performed during both the initial and secondary landing phases of the single-leg vertical jump landing task.

By employing the relative positions of the retro-reflective markers, the Vicon system conceptualized each bodily segment as a rigid body characterized by predefined length and volume. An internal biomechanical model was employed to allocate mass to each segment. These mass values were expressed as a percentage of the subject's total body weight. Throughout each frame of the single-leg vertical drop landing task, the Vicon system was utilized to estimate the subject's Center of Mass (CoM) location at every point. This estimation was based on the parameters and positioning of each rigid segment, as captured by the three-dimensional motion capture system.

The landing phase was demarcated as beginning at the point of initial contact (IC), characterized by the vertical ground reaction force (vGRF) first exceeding 10 N upon the subject's landing on the force plate. The phase continued until the moment when the center of mass (CoM) achieved its lowest position during the stance (Bates et al., 2013). The vGRF data was normalized to the participants' body mass (Alenezi et al., 2014) and was filtered through a 4th order low-pass Butterworth filter with a cut-off frequency of 12 Hz to compute the vGRF in Vicon (Ford et al., 2010). The vGRF data was obtained during the initial and subsequent landing phases, while the positions of the Center of Mass (CoM) were computed throughout the entirety of the drop landing task.

Furthermore, the knee abduction and knee flexion values were registered during the deceleration phase (ground contacting), coinciding with the maximum vGRF for both the first and second landing phases in Vicon.

STATISTICAL ANALYSIS

For statistical analysis, each individual subject was represented by the mean of all three successfully trials (Ford et al., 2007). Upon checking the normal distribution of the difference in each pair of parameters between first and second landing, we employed a paired t-test to identify any statistical variances in the kinetic and kinematic measurements between the initial and subsequent landings. Before commencing with the statistical examination, the peak vertical ground reaction force (vGRF) was adjusted relative to the body mass of each participant and displayed as absolute values. The degree of knee abduction and flexion were noted and reported in degrees. The threshold for determining statistical significance was predetermined to be a p-value smaller than 0.05.

Chapter 3: Results

Knee Joint Flexion and Knee Joint Abduction

No difference in knee joint flexion and abduction was found during the IC phase of first and second landing ($p < 0.05$). However, peak vGRF was significantly higher in the second landing (2.4 ± 0.2xBM vs 2.8 ± 0.4xBM, $p = 0.004$). Peak knee flexion was significantly smaller in the second landing than the first landing (44.04° ± 11.43° vs 36.80° ± 7.17°, $p = 0.03$). Knee abduction was significantly greater in the second landing than the first landing (9.11°± 5.4° vs 6.1°± 4.5°, p = 0.009) at the time of peak vGRF.

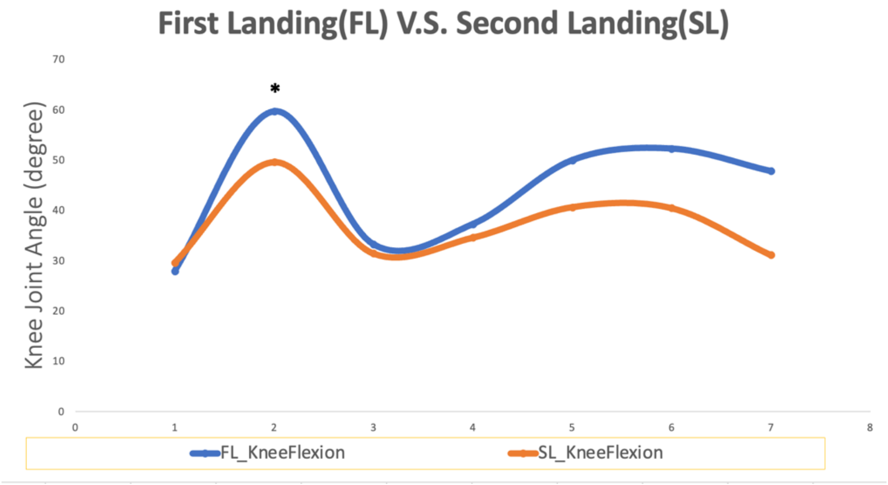

Figure 2: Shows the significant differences in knee flexion angle (degree) between first and second landing

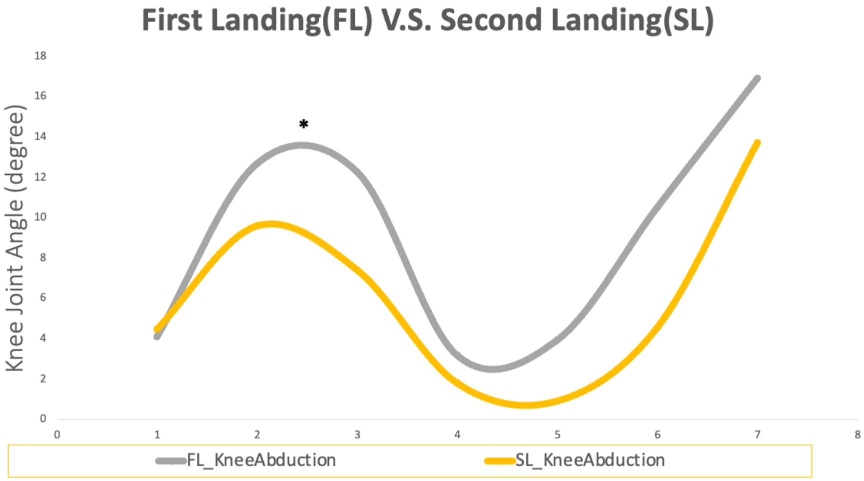

Figure 3: Shows the significant differences in knee abduction (degree) between first landing and second landing

Peak vGRF and CoM

While the lowest CoM in vertical position is significantly higher during the second landing than it is during first landing (957mm ± 57mm vs 919 mm ± 76 mm, $p < 0.05$), there was no difference in peak CoM between the first and second landing ($p > 0.05$). Peak vGRF was significantly higher in the second landing (2.4 ± 0.2xBM vs 2.8 ± 0.4xBM, p = 0.004).

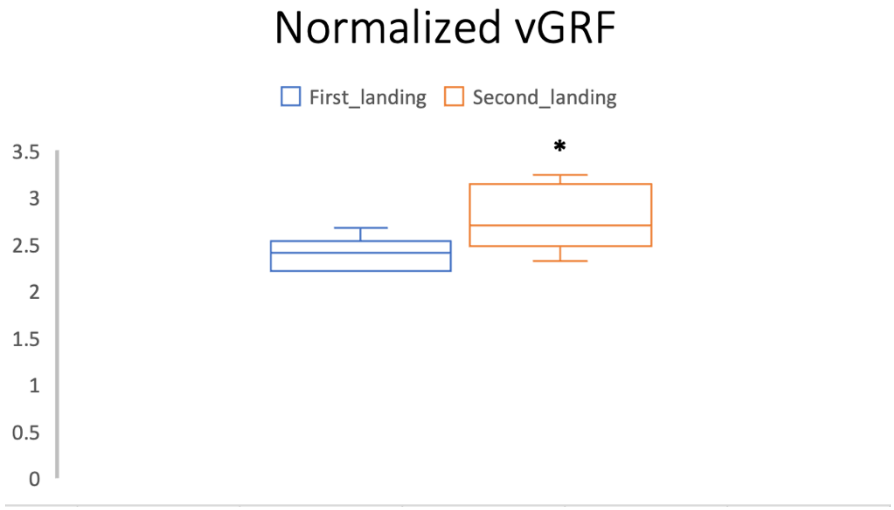

Figure 4: Shows the significant differences in peak vGRF (absolute value after normalization) between first landing and second landing

Chapter 4: Discussion

The primary objective of this research was to perform a comparative analysis of the kinetic and kinematic variables in the first and second landing of a single-leg drop vertical jump (DVJ). Specifically, the research explored whether the second landing elicits greater peak knee abduction, flexion, and vertical ground reaction force (vGRF). Previous research has identified knee abduction as a significant predictor of Anterior Cruciate Ligament (ACL) injury risk (Hewett et al., 2005). The observed increase in knee flexion in our study is associated with an elevated real-time risk of ACL injury due to a potential valgus collapse at the knee joint (Krosshaug et al., 2007).

This contradicts prior research that suggested increased jump height as the primary cause of heightened vGRF (Ford et al., 2011; Peng, 2011). However, our findings of a higher peak vGRF, increased knee adduction, and a reduced knee flexion angle indicate that the second landing of a single-leg DVJ may result in greater perturbations, more accurately representing the mechanics associated with the risk of ACL injury.

Furthermore, our results show no substantial differentiation in knee flexion and abduction during the initial contact point for the first and second landings, a finding consistent with prior studies that associate an increase in jump height with augmented knee flexion during initial contact (Yeow et al., 2009). The lack of significant knee kinematic variations between the two landings at the initial contact phase could be ascribed to similar jump heights for both landings. Our analysis also demonstrated no discernible difference in the peak vertical center of mass (CoM) between the two landings, thereby confirming that the drop heights in the single-leg DVJ task in this study were equivalent for the first and second landings. As a result, it can be concluded that the observed differences in kinetics and kinematics during the subsequent contact phase are likely due to altered neuromuscular control patterns rather than simply variations in jumping mechanics.

These findings bear important implications for future assessments of ACL injury risk and readiness for a return to sports. Single-leg DVJ, as a simulation of a rebounding task, may serve as a more suitable screening tool for ACL injury (Myer et al., 2011). Moreover, the second landing, being a more demanding task, offers a challenging evaluation scenario, providing a more reliable assessment of risk factors in the sagittal and frontal planes than the first landing.

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