

A Biomechanical Analysis of a Vertical Jump and Landing:

Performance Efficiency, Safety, and Injury Risk

1. Introduction

The vertical jump is a fundamental compound movement widely used in sport and exercise science to assess lower limb power, neuromuscular coordination, and athletic performance. It is integral to many sports, including basketball, volleyball, football, and rugby, in which athletes repeatedly generate high vertical forces and tolerate substantial landing impacts (Markovic and Mikulic, 2010). While jump height is often prioritised as a performance outcome, the landing phase places considerable mechanical demands on the musculoskeletal system. It is strongly associated with injury risk, particularly at the knee joint (Hewett et al., 2005). Consequently, analysing both the jump and landing phases provides a comprehensive evaluation of performance efficiency and movement safety. From a biomechanical perspective, the vertical jump involves coordinated extension of the hip, knee, and ankle joints, commonly referred to as triple extension. Efficient performance depends on kinematic variables such as joint range of motion, sequencing of joint extension, and trunk posture, alongside kinetic factors including impulse generation and force application (McGinnis, 2021). The stretch shortening cycle plays a crucial role during the countermovement phase by enhancing force production through elastic energy storage and neuromuscular preactivation (Komi, 2000).

In contrast, the landing phase is characterised by rapid deceleration and high impact forces. Suboptimal landing mechanics, such as reduced knee flexion, excessive trunk flexion, and medial knee displacement (dynamic knee valgus), have been linked to increased joint loading and elevated risk of anterior cruciate ligament (ACL) and patella femoral injuries (Hewett et al., 2005; Schmitz et al., 2007). As such, landing technique is a key focus in injury prevention and rehabilitation programmes.

Applying fundamental biomechanical principles, including Newton's laws of motion, the impulse-momentum relationship, and lever systems at the lower-limb joints, allows for detailed evaluation of movement efficiency and safety. Video-based biomechanical analysis offers a practical and accessible method for examining these principles in applied sport settings (Lees, 2002). When combined with anthropometric and body composition assessment, this approach enables interpretation of movement strategy alongside physical capacity.

The aim of this report is to investigate the biomechanics of a vertical jump and landing using video-based analysis supported by body composition data. Mechanical efficiency,

performance demands, and injury risk are examined, and evidence based recommendations are provided to enhance performance and reduce injury risk.

2 Methods: Participants

Biomechanical and anthropometric data were collected from an anonymised male participant (age 21 years and height 177cm body mass 78.0kg) body composition was assessed using bioelectrical impedance analysis (inBody 380 inBody Co., Seoul Korea) providing measures of skeletal muscle mass and fat mass, percentage body fat, phase angle and segmental lean mass distribution. The data were used to contextualise biomechanical performance and injury risk.

Movement task:

The participant performed a countermovement vertical jump with two foot take off and two foot landing. They performed this 3 times, each time beginning from an upright stance, followed by a rapid countermovement maximal vertical jump and a controlled landing. Arm swing was permitted to reflect a natural sport specific jumping technique. Three tries were completed with adequate rest between attempts to minimise fatigue

Data collection and analysis:

Movement data were collected using two dimensional video analysis a digital camera was positioned perpendicular to the sagittal plane at approximately hip height and at a fixed distance from the participant to minimise parallax error. Video footage was analysed frame by frame using motion analysis software

Key kinematic variables included hip, knee, and ankle joint angles during peak countermovement take off, initial landing, contact, and peak landing flexion. Trunk orientation and lower limbs alignment were visually assessed particularly during the landing phase. Screenshot were used to illustrate joint positions at key phases of the movement

Methodological limitations:

Two dimensional analysis limits accurate assessment of frontal and transverse plane motion, particularly knee valgus (McGinnis, 2021). Additionally, the absence of force plate data prevented direct quantification of ground reaction forces. Despite these limitations, video based analysis provides meaningful insight into movement patterns relevant to performance and injury risk.

3 results

During the countermovement phase, flexion was observed at the hip, knee, and ankle joints, followed by coordinated extension during take-off (Table 1). Peak knee flexion during the countermovement indicated effective utilisation of range of motion prior to propulsion. A proximal to distal extension sequence was evident at take-off, consistent with efficient triple extension mechanics (Figure 1). Trunk posture remained relatively upright throughout the propulsive phase.

Table 1. Sagittal plane joint angles (°) during key phases of the vertical jump.

Phase	Hip Flexion (°)	Knee Flexion (°)	Ankle Angle (°)
Peak Countermovement	60	85	25
Take-off	10	15	-20 (plantarflexion)

Landing Phase Kinematics

Initial ground contact during landing occurred using a forefoot to flat foot strategy. Progressive ankle dorsiflexion and knee and hip flexion were observed to absorb impact forces. However, variation was evident across trials, with one trial demonstrating reduced knee flexion at initial contact, indicative of a stiffer landing strategy (Table 2). Increased forward trunk lean was observed during landing compared to take-off (Figure 2).

Frontal plane observation revealed intermittent medial knee displacement during initial landing contact.

Table 2. Landing mechanics across three trials.

Variable	Try 1	Try 2	Try 3
Knee flexion at contact (°)	30	22	28
Trunk flexion at contact (°)	15	25	18
Observed knee valgus	Minimal	Moderate	Minimal

3.3 Body Composition Results

Body composition analysis revealed high skeletal muscle mass (41.7 kg) and low percentage body fat (7.6%), consistent with an athletic profile (Table 3). Segmental lean mass distribution was symmetrical between the lower limbs, suggesting balanced force-producing capacity. Phase angle was high (7.4°), indicating favourable cellular health and neuromuscular function.

Table 3. Participant body composition characteristics.

Variable	Value
Body Mass	78.0 kg
BMI	24.9 kg·m ⁻²
Skeletal Muscle Mass	41.7 kg
Percentage Body Fat	7.6%
Phase Angle	7.4°

4. Discussion

The aim of this study was to examine the biomechanics of a vertical jump and landing with respect to performance efficiency, safety, and injury risk by integrating video-based kinematic analysis with body composition data. The findings demonstrated efficient jump mechanics alongside landing characteristics associated with increased injury risk.

During the propulsive phase, the participant displayed coordinated triple extension and effective utilisation of the stretch shortening cycle, both of which are key determinants of vertical jump performance (Komi, 2000; Markovic and Mikulic, 2010). The observed proximal to distal sequencing aligns with previous research indicating that effective force summation enhances vertical impulse and jump height (McGinnis, 2021). An upright trunk position during take off likely facilitated efficient vertical force application.

Body composition data further contextualised these findings. High skeletal muscle mass and low body fat percentage improve the force-to-weight ratio, which is strongly associated with jump performance (Markovic and Mikulic, 2010). Symmetrical lower-limb lean mass may have contributed to balanced take-off mechanics, reducing asymmetrical loading during propulsion.

In contrast, the landing phase revealed biomechanical characteristics associated with elevated injury risk. Reduced knee flexion at initial contact, observed in Trial 2 (Table 2), reflects a stiffer landing strategy, which has been linked to increased vertical ground reaction forces and greater knee joint loading (Schmitz et al., 2007). Increased trunk flexion during landing may further increase knee extensor moments, placing additional stress on the knee joint (Hewett et al., 2005).

The presence of medial knee displacement during landing is particularly concerning, as dynamic knee valgus is a well established risk factor for non contact ACL injury (Hewett et al., 2005). Although precise quantification was limited by two dimensional analysis, visual evidence suggests frontal plane instability. Importantly, this occurred despite favourable muscular characteristics, highlighting that muscle mass alone does not guarantee safe movement patterns. Neuromuscular control and landing strategy are critical determinants of injury risk (Myer et al., 2011).

From a mechanical efficiency perspective, effective landing requires gradual deceleration and coordinated joint flexion to dissipate forces safely. The rapid transition from initial contact to peak knee flexion observed in this analysis suggests high loading rates, which may increase cumulative tissue stress during repeated jumping tasks (Schmitz et al., 2007).

Methodologically, combining video analysis with body composition assessment strengthened the investigation by contextualising movement mechanics alongside physical capacity. However, limitations include the absence of kinetic data and the use of a single participant, which restrict generalisability. Future research incorporating force plates and three dimensional motion capture would allow for more precise quantification of joint loading and frontal plane mechanics.

5. Conclusion and Recommendations

This study investigated the biomechanics of a vertical jump and landing using video-based analysis supported by body composition assessment. The participant demonstrated efficient jump mechanics characterised by coordinated triple extension, utilisation of the stretch–shortening cycle, and favourable physical characteristics, including high skeletal muscle mass and low body fat percentage. These factors support effective force production and jump performance.

However, analysis of the landing phase revealed potential injury risk factors, including reduced knee flexion, increased trunk lean, and intermittent medial knee displacement. These findings indicate that neuromuscular control and landing technique are critical determinants of movement safety, independent of muscular capacity.

To enhance performance, it is recommended that the participant maintains lower-limb strength and continues plyometric training emphasising optimal countermovement depth and proximal-to-distal sequencing. To reduce injury risk, landing technique training should prioritise increased knee and hip flexion, neutral knee alignment, and controlled trunk posture. Neuromuscular training programmes incorporating feedback-based jump-landing drills are recommended.

Integrating biomechanical analysis with body composition assessment provides a comprehensive framework for understanding both physical capacity and movement quality, supporting informed training and injury prevention strategies.

6. References (UWTSD Harvard)

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