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The Effects of Drop Vertical Jump Task Variation on Landing Mechanics: Implications for Evaluating Limb Asymmetry

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Abstract: Limb asymmetry is an important consideration when evaluating rehabilitation progress or re-injury risk. The drop vertical jump (DVJ) task is commonly used to assess landing mechanics; however, the extent to which task setup influences limb asymmetry is unknown. Our purpose was to examine limb asymmetries across DVJ variations. We hypothesized that more demanding variations involving greater jump distance and target use would elicit greater landing asymmetries. Participants performed six DVJ variations while lower extremity joint kinematics and kinetics were collected. Joint angles and internal moments of the hip, knee and ankle were computed at initial contact and over the decent phase of the initial landing. The horizontal jump distance and the verbal instructions provided on how to jump off the box influenced limb asymmetries. The DVJ variation without a horizontal jump distance resulted in significant differences at the hip and knee; specifically, greater hip and knee flexion asymmetry (7.0° and 15.2° differences, respectively) were observed between limbs at initial contact. Instructions restricting take-off and landing strategies reduced asymmetry; this indicates that verbal instructions are critical to avoid altering natural landing mechanics. To best utilize DVJ as a tool, study protocols should be standardized to allow for more generalizable research and clinical findings.

Keywords: kinematics; kinetics; anterior cruciate ligament (ACL); injury prevention; sports medicine; physical therapy; movement assessment; motion analysis; biomechanics

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1. Introduction

Biomechanical assessments of kinematics and kinetics are a critical tool for evaluating rehabilitation progress after injury, as they provide insight into movement patterns in a naturalistic setting. Such assessments are often used to help decide when an athlete is ready to return to sports or full activity following an anterior cruciate ligament injury, one of the most common non-contact lower extremity injuries in youth athletes [1,2]. Nearly 80% of all anterior cruciate ligament injuries are due to a non-contact mechanism, highlighting the importance of rehabilitation and injury prevention research to predict and identify biomechanical risk factors [3]. Specifically, non-contact anterior cruciate ligament injuries can occur when an athlete decelerates, plants with one leg and changes directions or lands from a jump. The drop vertical jump (DVJ) task is a dynamic, game-like movement that is commonly used during biomechanical assessments in order to evaluate return-to-play readiness and to identify biomechanical risk factors for re-injury. Furthermore, the DVJ task has been shown to be a strong predictor of injury, as it can be utilized to evaluate lower extremity risk factors [1]. While several studies have examined the DVJ task in athletes following anterior cruciate ligament injuries, there is limited research that evaluates the effect of different DVJ task protocols on asymmetry between limbs.

The functional movement pattern performed during the DVJ has been reported to identify poor landing mechanics indicating deficiencies in neuromuscular control, which is thought to contribute to a greater risk of injury or re-injury. Prior studies have indicated that athletes who exhibited stiff landing mechanics during the DVJ, specifically landing with reduced hip and knee flexion, along with dynamic knee valgus (multiplanar movement pattern including femoral adduction and internal rotation, anterior tibial translation, external tibial rotation, ankle eversion, and knee abduction) were at an increased risk for anterior cruciate ligament injuries [1,4]. Advanced motion capture technology has been widely used to assess landing mechanics in this population and has been shown to accurately measure three-dimensional joint motion more accurately compared to two-dimensional assessments. Poor neuromuscular control during landing, including increased knee abduction angle and moment along with reduced knee flexion and shock absorption, have also been shown to be predictors of subsequent anterior cruciate ligament injury [1,5]. Deficiencies in biomechanical movement patterns are most commonly evaluated using a measure of symmetry of the injured or non-dominant limb compared to the contralateral uninjured or dominant limb. Paterno et al. investigated limb asymmetries in athletes who had previously undergone anterior cruciate ligament reconstruction and found that the involved limb demonstrated compensations during the DVJ task, specifically greater vertical ground reaction forces and loading on the uninjured limb [6]. In performing such limb symmetry assessments, it is critical that dynamic tasks, such as the DVJ, reliably measure the intended biomechanical asymmetry so that appropriate clinical judgements can be made, such as permitting an athlete to return to their sport. It is important, therefore, to elicit “natural” asymmetry (e.g., that stemming from the injury or the individual), rather than asymmetry imposed by extrinsic factors (e.g., a sport-specific task design), while maintaining enough demand to induce risk factors such as asymmetry.

Presently, there is considerable variability in the protocols of administration for the DVJ task across motion capture labs. With this task, participants are asked to jump off a box and, upon landing, perform a maximum vertical jump. Inconsistencies in task setup yield study results that are difficult to generalize [7–12]. Slight variations in the setup for jump landing tasks have been shown to influence landing biomechanics [12], highlighting the importance of task selection when evaluating the implications of limb symmetry in return to sport decision making. Some studies report varying the jump distance incrementally to increase participant demand when landing, whereas others manipulate the jump distance as a function of the participant’s height. Others use a ‘drop jump’ in which the athlete drops from a platform onto a landing area immediately in front of the elevated platform [7,10,12–14]. Additionally, there is task variability in the verbal instructions given to athletes regarding specifically how to leave the jump platform, how to land, or how to perform the maximal jump. Furthermore, an overhead target may or may not be used, which can influence jump performance and biomechanics [10,15–17]. Almonroeder et al., identified that increased cognitive demands such as the inclusion of an unanticipated vertical jump component or the requirement to reach or grab for an object resulted in differences in lower extremity landing mechanics when compared to the performance of a DVJ without additional cognitive demands [10].

Individual performance and limb asymmetry elicited by the DVJ are considered by providers to identify movement deficiencies and to gather a better understanding of injury risk and rehabilitation progression [18]. Differences in landing biomechanics between limbs are used clinically to determine whether an athlete is ready to return to sports or activity. The extent to which task variation influences limb asymmetry is not currently known. Since asymmetry is key to the clinical interpretation of DVJ results, the purpose of the present study was to examine the effects of DVJ task variation on the asymmetry of lower extremity kinematics and kinetics between limbs in a healthy cohort, in which prior injury would not be a contributing factor. The task variations differed by horizontal jump distance, verbal instructions, and use of a jump target. We hypothesized that the DVJ variations that use a greater horizontal jump distance and overhead target would be more demanding and therefore elicit greater lower extremity kinematic and kinetic asymmetries, specifically at the hip and knee, while the addition of verbal instructions would reduce limb asymmetry.

2. Materials and Methods

2.1. Study Design and Participants

A single-group repeated measures design was followed for this study in order to determine the extent to which variations in the DVJ task setup influence kinematic and kinetic limb-to-limb asymmetries. Variations of the DVJ task differed based on the horizontal jump distance, the verbal instructions, and the use of a jump target. A convenience sample of twenty participants were recruited from the local community and seen for a single visit in a motion analysis laboratory. Participants with a history of orthopedic conditions or prior injury (within the past six months) that would limit their ability to perform the DVJ protocol were excluded. This study was approved by the University of Texas Southwestern Institutional Review Board (Approval ID #082010-134), and all participants provided informed written consent prior to initiating testing procedures. Participants wore their personal athletic footwear and comfortable clothing for testing.

2.2. Procedures

Participants were instrumented with retroreflective markers according to a modified Cleveland Clinic marker set which included trunk and lower extremity markers, including lateral thigh clusters, anterior shank clusters, and a marker on the 5th metatarsal head [18,19]. A 14-camera motion capture system (Vicon Motion Systems Ltd., Denver, CO, USA) along with two force plates (Advanced Mechanical Technology Inc., Watertown, MA, USA) were used to capture marker trajectory and force data sampling at 240 Hz and 2880 Hz, respectively. Biomechanical data were collected while participants were asked to perform six variations of a drop vertical jump task, and three variations differed by horizontal jump distance, one variation provided additional verbal instructions on how to leave the box and two variations incorporated the use of an overhead jump target. For all six DVJ variations, a 31 cm tall plyometric box was used, and the landing area was designated by two 60 cm $\times$ 60 cm square force plates. Variations in the horizontal jump distance included a zero distance (Drop Jump) in which the front of the box was positioned adjacent to the force plates [20], as well as distances one-third of the participant's height (Third Height) [21] and one-half (Half Height) [22] of the participant's height from the front of the box to the center of the force plates (Figure 1). Participants stood on top of the box and were given verbal instructions to "Jump horizontally (not vertically) off of the box, landing simultaneously with one foot in each square, and then immediately perform a maximal vertical jump landing back with one foot in each square".

An additional variation of the Drop Jump was completed which only differed in verbal instructions provided to the participant. Specifically, for the Drop Jump, participants were first asked to "Drop off the box, landing with one foot in each square, and then perform a maximal vertical jump landing back with one foot in each square". For the Pop Off variation, participants were then instructed to "Slightly bend [their] knees to 'pop-off' the box with both feet at the same time, and then perform a maximal vertical jump landing back with one foot in each square" (Pop Off) (Figure 2). The Pop Off instructions were developed based on feedback from biomechanists and physical therapists that work in motion capture laboratories across the United States, who shared that participants commonly struggled to interpret how to 'drop' off the box, leading to an inconsistency in movement strategy, mainly leading or leaving the box with one foot rather than both feet. Lastly, a vertical jump target (Vertec by Jump USA, Sunnyvale, CA, USA) was added to the Half Height and Pop

Off variations (Target—Half Height and Target—Pop Off, Figure 2) in order to investigate the effect of reaching for a target. The jump target was set up on the opposite side of the force plates relative to the participant such that the participants jumped straight up to reach with both hands for the target overhead (Figure 2). Specifically, the participants were asked to "Jump horizontally (not vertically) off of the box, landing simultaneously with one foot in each square, and then immediately perform a maximal vertical jump, reaching for the overhead target with both hands, then landing back with one foot in each square". Three successful trials were collected for each DVJ variation. Trials in which the participant did not land with one foot in each force plate or failed to perform the subsequent maximal vertical jump and were deemed unsuccessful and repeated.

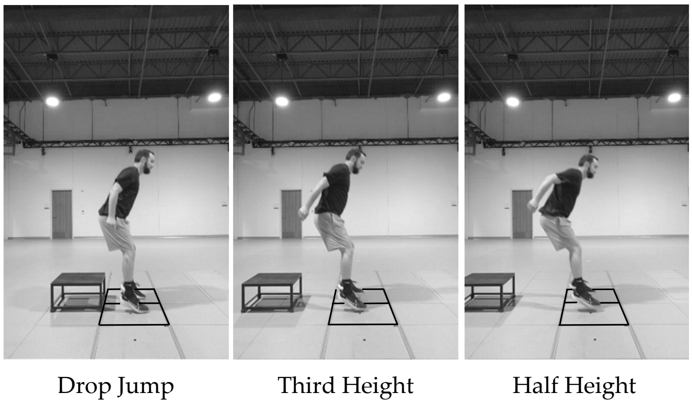

Figure 1. Drop vertical jump variations by distance.

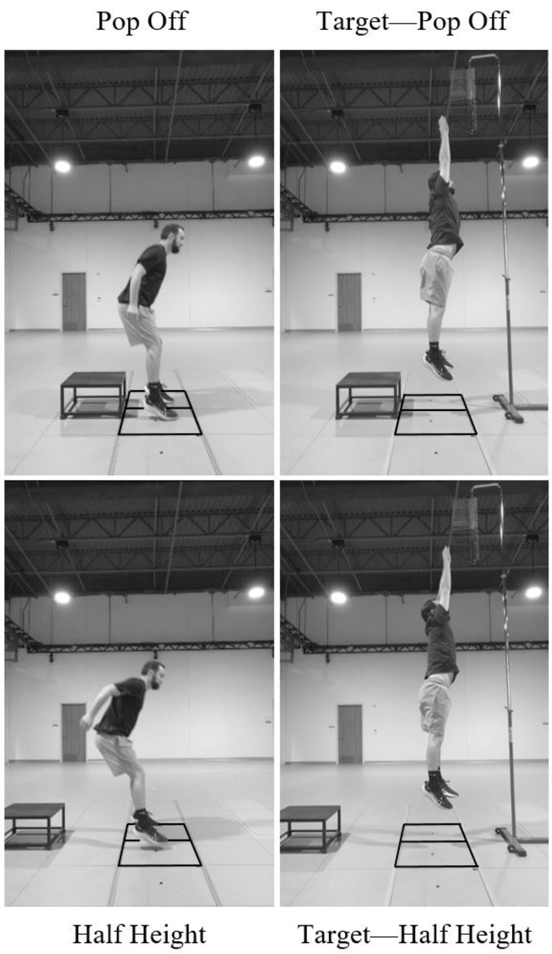

Figure 2. Drop vertical jump variations with instructions and target.

2.3. Data Processing and Analysis

The trials were processed via Vicon Nexus (OMG plc, Oxford, UK). Marker trajectories were filtered using a Woltring filter with a predicted mean square error of 10 mm^2, and force plate data were filtered using a 4th-order low-pass Butterworth filter with a cut-off frequency of 16 Hz [23]. Joint angles and internal moments for the hip, knee, and ankle in the sagittal, coronal and transverse planes were computed for each limb using a custom 6-degree-of-freedom MATLAB (MATLAB 2022a, Natick, MA, USA) model with a rotation order of flexion–extension, abduction–adduction, and internal–external rotation. Specifically, inverse dynamics was used to compute internal lower extremity joint kinetics that were normalized to body mass (in kilograms). A custom MATLAB code was also used to place identifiers at time points of interest, including the time of initial contact (time point in which the normalized vertical ground reaction force in the force plate exceeded 0 N/kg), maximum descent of the initial landing (lowest vertical position of the hip joint center), and take-off from the force plates for the vertical jump (time point before ground reaction force equaled 0).

The jump height was computed by subtracting the vertical height of the sacrum marker during standing from the highest vertical position of the sacrum marker recorded during the flight phase of the vertical jump (take-off through initial contact of the second landing in the force plates) and then converted into a percentage of body height. The trial with the greatest jump height for each DVJ variation was used for subsequent analysis. Lower extremity joint angles and moments were calculated and extracted at initial contact and across the descent phase of the DVJ (initial contact to maximum decent). Across the descent phase, maximum values were computed for the sagittal (flexion/extension) and coronal (adduction/abduction) planes, while mean values were analyzed for transverse (internal/external) plane angles. Specifically, mean values were computed for hip and knee rotation angles and rotational moments, since the trajectories across the decent phase remained relatively flat. Additionally, the maximum ground reaction force across the landing phase (initial contact to take-off) was computed and normalized to body mass (N/kg). Limb asymmetry was calculated as the absolute value of the difference between left and right legs for all biomechanical variables for each DVJ variation. Given the lack of normality, non-parametric statistical analyses were conducted. Specifically, Wilcoxon signed-rank tests were performed to determine differences in asymmetry across the six DVJ variations. Statistical significance was concluded when $p < 0.05$, except when comparing the three horizontal jump distances, in which a Bonferroni correction adjusted the significance level to $p < 0.017$.

3. Results

Twenty participants completed the testing protocol. However, two participants were excluded from the original sample due to poor data quality (i.e., marker dropout). Therefore, eighteen participants (eight males; age: 21.4 $\pm$ 4.2 years; height: 169.7 $\pm$ 9.9 cm; weight: 69.3 $\pm$ 15.0 kg) were included for analysis. Notably, all participants reported right leg dominance based on which leg they would use to kick a ball. Significant differences in asymmetry represented as the absolute value difference between sides are highlighted in Table 1. There were no differences in the asymmetry of the maximum vertical ground reaction force across the landing phase for any DVJ variation comparison. The vertical jump height was found to be significantly higher with the addition of a jump target during the Half Height variation (Target—Half Height: 140.8% body height; Half height 138.4% body height).

When comparing the DVJ variations by distance, there were no significant differences in limb asymmetry between the Half Height and Third Height variations. At initial contact, the Drop Jump elicited greater asymmetry in hip flexion (7.0°) and knee flexion joint angles (15.2°) compared to both the Half Height (hip flexion: 2.2°; knee flexion: 3.7°) and Third Height (hip flexion: 1.7°; knee flexion: 4.9°) jump distances. Additionally, there was slightly greater asymmetry in the knee abduction angle with Drop Jump compared to the Half

Height variation only (3.6° versus 2.4°, respectively). The only significant asymmetry found in joint moments when comparing by distance was increased asymmetry over the descent phase in the transverse knee moment for Drop Jump compared to Half Height (0.065 Nm/kg versus 0.042 Nm/kg, respectively). There were no significant findings in joint kinetics at initial contact when comparing across the three jump distances.

Table 1. Limb asymmetry for joint angles (°) and moments (Nm/kg) at initial contact and over the decent phase by DVJ variation.

	Initial Contact	**Half Height**	**Third Height**	**Drop Jump**	**Pop Off**	**Target-Half Height**	**Target-Pop Off**
Kinematic Angles (°)	Hip flexion	2.2 (2.0)	1.7 (1.7)	**7.0 (3.9)** ^{H,T}	**2.8 (2.0)** ^{D}	2.5 (1.7)	2.9 (2.6)
	Knee flexion	3.7 (2.6)	4.9 (3.5)	**15.2 (9.3)** ^{H,T}	**4.9 (2.9)** ^{D}	5.3 (2.5)	5.8 (5.5)
	Hip adduction	6.0 (3.5)	4.1 (3.0)	4.9 (4.4)	4.2 (3.1)	4.1 (2.0)	3.9 (3.6)
	Knee abduction	2.4 (1.8)	2.6 (2.1)	**3.6 (2.5)** ^{H}	**2.1 (1.2)** ^{D}	2.6 (1.9)	2.1 (1.9)
	Hip rotation	5.1 (3.7)	5.7 (5.0)	7.1 (5.8)	5.1 (4.6)	5.9 (5.7)	5.4 (3.7)
	Knee rotation	6.2 (4.9)	5.3 (3.5)	5.7 (4.96)	4.9 (3.7)	6.1 (3.4)	6.2 (3.9)
Kinetics **Moment (Nm/kg)**	Sagittal hip	0.22 (0.25)	0.23 (0.22)	0.29 (0.19)	**0.16 (0.13)** ^{D}	0.20 (0.20)	0.18 (0.16)
	Sagittal knee	0.10 (0.13)	0.12 (0.11)	0.13 (0.08)	**0.07 (0.05)** ^{D}	0.08 (0.09)	0.08 (0.06)
	Coronal hip	0.17 (0.12)	0.13 (0.08)	0.13 (0.11)	0.13 (0.09)	0.13 (0.07)	**0.09 (0.07)** ^{P}
	Coronal knee	0.09 (0.07)	0.08 (0.05)	0.08 (0.05)	0.09 (0.05)	0.10 (0.08)	0.10 (0.05)
	Transverse hip	0.03 (0.02)	0.04 (0.02)	0.04 (0.03)	0.03 (0.02)	**0.03 (0.02)** ^{H}	0.03 (0.02)
	Transverse knee	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.00)	**0.01 (0.01)** ^{H}	0.01 (0.01)
	Descent phase	**Half Height**	**Third Height**	**Drop Jump**	**Pop Off**	**Target-Half Height**	**Target-Pop Off**
Kinematic Angles (°)	Hip flexion	2.7 (2.2)	2.5 (2.8)	2.5 (1.6)	2.7 (1.9)	2.7 (1.7)	2.5 (2.5)
	Knee flexion	3.1 (2.7)	3.1 (2.4)	2.6 (2.1)	2.8 (1.8)	2.8 (2.0)	3.1 (3.1)
	Hip adduction	5.5 (4.7)	4.5 (3.5)	4.1 (3.4)	3.8 (3.9)	4.8 (4.9)	4.3 (3.9)
	Knee abduction	2.6 (1.9)	2.6 (2.0)	3.4 (2.5)	**2.2 (1.4)** ^{D}	2.6 (1.8)	2.3 (1.8)
	Hip rotation	5.7 (4.1)	7.4 (5.3)	6.9 (4.9)	4.7 (3.2)	6.6 (4.6)	6.9 (7.3)
	Knee rotation	5.0 (4.2)	5.3 (4.3)	5.8 (3.9)	5.0 (4.0)	5.6 (4.6)	6.3 (5.2)
Kinetics **Moment (Nm/kg)**	Sagittal hip	0.36 (0.21)	0.65 (0.99)	0.36 (0.32)	0.22 (0.18)	0.24 (0.23)	0.36 (0.37)
	Knee extensor	0.30 (0.23)	0.27 (0.15)	0.28 (0.21)	0.29 (0.20)	0.34 (0.29)	0.33 (0.16)
	Coronal hip	0.28 (0.25)	0.37 (0.34)	0.278 (0.17)	0.21 (0.16)	0.26 (0.25)	0.39 (0.37)
	Coronal knee	0.23 (0.18)	0.20 (0.16)	0.18 (0.16)	0.21 (0.17)	0.24 (0.16)	0.23 (0.20)
	Transverse hip	0.08 (0.08)	0.10 (0.08)	0.09 (0.08)	0.07 (0.08)	0.10 (0.07)	0.08 (0.10)
	Transverse knee	0.04 (0.03)	0.05 (0.03)	**0.06 (0.04)** ^{H}	0.05 (0.05)	0.04 (0.04)	0.06 (0.05)

Note: Statistically significant differences are presented in bold. Distance comparison was noted in the Drop Jump column ($p < 0.017$), superscripts H and T denote statistically significant differences compared to the Half Height and Third Height variations, respectively. Instruction comparison was noted in the Pop Off column ($p < 0.05$), superscript D denotes statistically significant differences compared to the Drop Jump variation. Target comparison was noted in the Target-Half Height and Target-Pop Off columns ($p < 0.05$), superscripts H and P denote statistically significant differences compared to the Half Height and Pop Off variations, respectively.

Furthermore, an adjustment in verbal instructions during the Pop Off resulted in significant findings compared to Drop Jump. Specifically, Pop Off resulted in less asymmetry at initial contact for hip flexion (2.8°), knee flexion (4.9°), and knee abduction (2.1°) angles compared to the Drop Jump variation. Similar to the joint angle findings at initial contact, sagittal hip moments (0.161 Nm/kg) and sagittal knee moments (0.069 Nm/kg) demonstrated reduced asymmetry with the Pop Off variation compared to Drop Jump (sagittal hip moment: 0.294 Nm/kg; sagittal knee moment: 0.129 Nm/kg). Over the descent phase, there was slightly greater asymmetry in knee abduction with Drop Jump compared to Pop Off (3.4° versus 2.2°, respectively). No significant differences were observed in joint kinetics over the descent phase when additional verbal instructions were provided.

The addition of a jump target yielded differences in transverse plane moments at initial contact for the hip and knee with greater hip rotation moment asymmetry but reduced knee rotation moment asymmetry with Target—Half Height (transverse hip moment: 0.034 Nm/kg; transverse knee moment: 0.006 Nm/kg) compared to the Half Height variation (transverse hip moment: 0.025 Nm/kg; transverse knee moment: 0.010 Nm/kg).

There was not any significant asymmetry noted in joint angles at either initial contact or over the descent phase when a target was included at the Half Height distance or in joint kinetics over the descent phase. Lastly, Target—Pop Off demonstrated reduced asymmetry compared to Pop-Off for the coronal hip moment at initial contact (0.086 Nm/kg versus 0.130 Nm/kg, respectively). Similar to the Target—Half Height comparison, there was no significant asymmetry found in joint angles at initial contact or any biomechanical variables over the descent phase with the addition of a jump target to the Pop Off variation.

4. Discussion

The purpose of this study was to determine whether kinematic and kinetic asymmetries vary across different DVJ variations. Specifically, we tested whether variations in jump distance, use of a jump target, or verbal instructions had an effect on limb symmetry during landing. Manipulating the jump distance elicited asymmetry in hip/knee flexion and knee abduction at initial contact with the Drop Jump variation. The use of a jump target elicited asymmetry in hip and knee moments in the transverse plane during the Target—Half Height and coronal hip moment during the Target—Pop Off variation. Adjustments to verbal instructions with the Pop Off variation yielded fewer asymmetries in hip and knee flexion at initial contact as well as knee abduction at both initial contact and over the decent phase compared to Drop Jump. Additionally, Pop Off resulted in less asymmetry in sagittal hip and knee moments.

These findings are consistent with previously identified limitations of the DVJ task. Namely, the protocol being employed matters greatly to the findings and therefore their interpretation. As discussed, previous studies have shown that manipulating the jump distance has a meaningful effect on study outcomes [7,8,12,24]. Our own findings support this, showing that varying the distance elicited both kinematic and kinetic changes at the hip and knee depending on the specific setup. Findings in a study conducted by Tsai et al. identified that a less stiff landing strategy with increased hip and knee flexion related to a reduction in tibiofemoral shear and compressive forces [24]. High tibiofemoral joint forces have been proposed to impact anterior cruciate ligament injury risk, specifically those that occur in a non-contact manner. In some of our previous work, we recommended the Third and Half Height conditions given that the more challenging jump distances elicited reduced knee flexion at initial contact compared to the Drop Jump [21]. Given that the Third and Half Height distances elicited reduced knee flexion at initial contact in our previous work, along with the conclusions from the Tsai et al. paper, the inclusion of a further horizontal jump distance is preferred when then goal is to assess biomechanical landing risk factors. Additionally, a previous study investigating landing strategies during a Drop Jump demonstrated a lack of association between biomechanical variables and increased injury risk, suggesting that a farther jump distance may result in higher tibial shear forces and coronal knee moments [7]. In the current study, the Drop Jump exhibited greater asymmetry with increased hip and knee flexion upon landing compared to the Half Height and Third Height which both required a more extended landing position. Anecdotally, participants tended to lead more with one leg when dismounting from the Drop Jump which might result in greater asymmetry upon landing, compared to a horizontal jump off the box in which the landing was more symmetrical while more demanding. Along with previous research that highlights reduced biomechanical risk factors with a flexed landing position, these findings suggest that while incorporating a horizontal jump distance would increase physical demand, greater asymmetry was observed with the Drop Jump.

Differences in verbal instructions have been shown to manipulate study results [7,8,14,21]. Again, these variations in our own study design exhibited significant differences. In our previous work, the Pop Off condition produced a more flexed hip and plantarflexed ankle upon landing when compared to a Drop Jump, as well as increased (internal) hip extensor and knee abductor moments which are indicative of a safer landing strategy [21]. Additionally, findings in a study conducted by Welling et al. identified that a safer landing technique was achieved in a drop vertical jump task when additional instructions were provided [14].

In the current study, less asymmetry was measured in hip flexion, knee flexion, and knee abduction during the Pop Off task, which provided additional instructions to the participants on specifically how to leave the box (i.e., with both feet simultaneously), compared to the Drop Jump instructions which did not specify the take-off strategy. Similar to the findings in the distance comparison, greater asymmetry with the Drop Jump can likely be attributed to the participant's takeoff strategy in which they are more likely to leave the box with one foot first rather than both feet simultaneously given the additional instructions with the Pop Off variation. Additionally, asymmetry was observed in the coronal hip moment at initial contact with Pop Off, which was not observed with the Target—Pop Off condition. These findings, along with the body of previous work, highlight the challenges researchers and clinicians face in utilizing complex movement tasks effectively. While each study individually has appropriate justifications for their own design, the collective effect is a body of work that is difficult to draw consistent or reliable conclusions from. The purpose of testing instruments like the DVJ is to ensure that they can be used confidently and correctly, and this study highlights the need for increased attention to DVJ protocols, specifically in the standardization of the instructions provided.

Prior work has investigated the use of a jump target and its implications on jump performance during the DVJ [10,12,15–17,25,26]. Specifically, Ford et al. reported that the use of an overhead target resulted in higher jump height and knee extensor moments during a drop jump [26]. Conversely, Almonroeder et al. did not find any influence as a result of a jump target in jump performance (jump height) during a DVJ set at a standard horizontal distance of 15.24 cm. However, the target condition resulted in greater peak vertical ground reaction forces and reduced peak knee flexion angles [10]. In our previous work, the inclusion of a jump target supported the findings of increased jump performance in the Half Height condition [21]. Additionally, we previously found increased hip and knee flexion angles during the Half Height condition when a target was introduced, which differs from Almonroeder's study which found decreased knee flexion with target use [10,21]. Almonroeder et al. investigated the DVJ in a cohort of female participants, who have been shown to exhibit stiffer landings compared to males [10], which could explain reduced knee flexion in their cohort. While symmetry between limbs was not considered in either study, Ulman et al. investigated the dominant limb, while Almonroeder analyzed the non-dominant limb [10,21]. Alternatively, in the current study we considered both limbs and found significant side-to-side differences in transverse plane hip moments. Greater asymmetry in knee rotation moments was observed at initial contact in the Half Height variation (0.010 Nm/kg) compared to Target—Half Height (0.006 Nm/kg). Conversely, the hip rotation moment demonstrated greater asymmetry at initial contact with the addition of a target (Target—Half Height 0.034 Nm/kg; Half Height 0.025 Nm/kg). Thus, while the asymmetries identified with target use were small, it is important to consider how the inclusion of a jump target contributes to asymmetry due to task demands and not inherent limb differences.

The present study is limited in a few ways. First, the inclusion of data from eighteen participants makes it challenging to generalize these findings beyond the relatively young, healthy group. Additional considerations should be made before interpreting these findings in a context beyond that which was studied. Additionally, the task order was not randomized, and while participants were given ample recovery time between trials, it nevertheless introduces possible fatigue throughout the DVJ progression. Data collection was limited to three repetitions per DVJ variation, and adequate rest was allowed in order to limit learning effects or fatigue. Lastly, for practical purposes, not every iteration of a DVJ test setup was studied. This limits the generalizability of findings to all DVJ protocols.

5. Conclusions

Variation in DVJ setup can introduce unanticipated limb-to-limb asymmetries in kinematic and kinetic studies. Given the findings of our study, when assessing biomechanical risk factors using a DVJ task, the horizontal jump distance and verbal instructions influenced limb asymmetry. Alternatively, the use of a jump target did not elicit asymmetries compared to variations without a jump target. Additionally, verbal restrictions on take-off and landing strategies (e.g., with both feet at the same time) reduced asymmetry; this indicates that standardized verbal instructions are critical to avoid altering natural mechanics. To best utilize DVJ as a tool, it is important to standardize study protocols to allow for more generalizable research and clinical findings.

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