

## ALTERING ENTRY ANGLES IN A JUMP LANDING TASK MODIFIES BIOMECHANICAL RISK FACTORS OF ACL INJURY

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This study investigated the effects of changing the entry-angle of a jump landing movement on ACL injury risk factors. Eight female recreational athletes performed 21 trials of a jump landing task. The direction of the first jump varied from -90° to 90° from the anterior axis in 30-degree increments. As the entry angle increased to the left, peak knee flexion and valgus angles as well as external valgus moments remained the same. In conditions where participants jumped more to their right, knee flexion angles were smaller and knee external valgus moments were greater. It can be concluded that kinematic analyses of frontal plane motion alone may not provide sufficient information for risk assessment on the field, as it may not reflect parallel changes in kinetics. These results can be used to further understand ACL injury risk factors in asymmetric jumping conditions.

**KEYWORDS:** lower extremity, asymmetric jumps, joint moments.

**INTRODUCTION:** Non-contact anterior cruciate ligament (ACL) injuries occur often among young athletes. This injury rate has been increasing over the past years (Beck, Lawrence, Nordin, DeFor, & Tompkins, 2017). Cutting and landing movements that involve sudden changes of direction and rapid deceleration have been observed as the types of movement that lead to ACL injury. Further investigations have proposed that having the foot rapidly planted with the knee close to full extension and a dynamic valgus collapse are common mechanisms for ACL injuries (Hewett, Myer, & Ford, 2006; Hewett, Torg, & Boden, 2009; Yu & Garrett, 2007).

There have been some studies looking specifically at the effects of sudden change of direction in running and cutting movements. Schreurs, Benjaminse, & Lemmink (2017a) indicated that, for female participants, knee flexion angles decreased, and knee valgus moments increased when cutting 90, 135 or 180 degrees compared to cutting 45 degrees. Furthermore, Sigward, Cesar, & Havens (2015) concluded that females had greater knee valgus moments when cutting 110 degrees compared to cutting 45 degrees. These studies investigated how changing the exit angle while performing a cutting movement affects ACL injury risk factors.

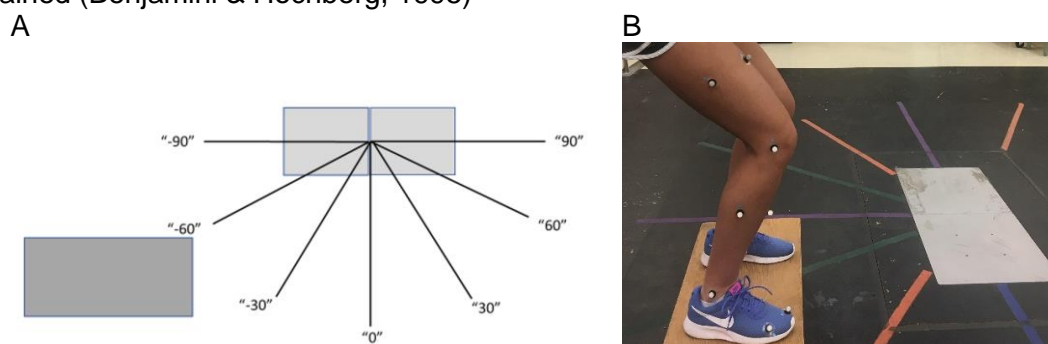
However, no previous studies have investigated the specific lower extremity biomechanical effects of landing from different entry angles in jump-land-jump movements. As such, the purpose of the current study was to investigate the effects of jumping *from* different directions on landing mechanics and ACL injury risk factors in jump-land-jump movements. Based on previous studies, we hypothesized as the angle of the jump was increased from the anterior, the landing characteristics would increase ACL injury, meaning smaller knee flexion angles, larger knee valgus angles, and larger knee valgus moments.

**METHODS:** Eight adult female students that were right leg dominant (age:  $21.4 \pm 1.3$  years; mass:  $68.1 \pm 12.8$  kg; height:  $1.7 \pm 0.06$  m) participated in this ongoing study. Participants were required to be physically active and participate in sports that involved jump landing and directional changes. Participants didn't have any history of any major lower extremity injuries. The study was approved by the host university's human subjects Institutional Review Board. Participants were asked to perform jump-land-jump movements. For each trial, they stepped up onto a 28-cm high box, facing anteriorly, jumped horizontally 50% of their body height and landed with both feet on the two force platforms (Advanced Mechanical Technology Inc, Watertown, MA USA) mounted to the ground. Immediately after landing, participants performed a maximal-height vertical jump. The direction of the first jump was manipulated between seven different directions, from -90 to +90 degrees in 30-degree incremental blocks (Figure 1). Participants performed 21 jump-land-jump trials in total with 3 trials for each

direction. The order of trials was block randomized using the Durstenfeld shuffle algorithm (Durstenfeld, 1964). There was a 30-second rest interval between trials to prevent fatigue. Retroreflective markers were placed on the participants bony landmarks to define dominant limb foot, shank, thigh, and pelvis segments. Marker position data were recorded using 8 Vicon MX cameras (Vicon Motion Systems Ltd, Oxford, UK) at a sampling frequency of 160 Hz. In addition, ground reaction forces (GRFs) were recorded using the aforementioned force platforms at a sampling rate of 1600 Hz.

Kinematic and kinetic data of the dominant limb were low pass filtered at cutoff frequencies of 15 and 200 Hz, respectively, using a 4<sup>th</sup> order zero lag Butterworth filter (Yu, Gabriel, Noble, & An, 1999). Lower extremity joint angles were calculated using Cardan angles in a planar rotation order of sagittal, frontal and transverse (Grood & Suntay, 1983). For data analysis, peak knee flexion angle, valgus angle and external valgus joint moments during the first 100 milliseconds of landing were extracted. Previous research has shown the first 100 ms of contact to be most probable for ACL injury to happen (Dai, Mao, Garrett, & Yu, 2015). Knee joint moments were calculated using bottom-up inverse dynamics via de Leva's anthropometric model (de Leva, 1996). Moments were normalized to body mass.

Repeated measures ANOVA was utilized to test for the main effects of jumping direction. Mauchly's test was utilized to verify the assumption of sphericity. Greenhouse-Geisser corrections were applied for violation of sphericity assumption. Significant main effects were also explored using pairwise t-tests, and a study-wise false discovery rate of 5% was maintained (Benjamini & Hochberg, 1995)



**Figure 1:** A: A schematic view of the box placement and direction of the different jumps  
B: A participant getting ready to perform the 30° condition jump

**RESULTS:** Repeated measure ANOVAs indicated statistically significant main effects in knee flexion angle ( $p < 0.001$ ) and knee external valgus moments ( $p < 0.001$ ) during the first 100 ms of landing when jumping from different directions. No significant differences in the knee valgus angles were found ( $p = 0.38$ ). Table 1 illustrates mean  $\pm$  standard error of knee flexion angles, valgus angles, and external valgus moments respectively across all jumping directions. As it's shown in Table 1, when the participant is jumping to the right (-90°, -60° and -30° conditions), knee flexion angles were decreased, and knee joint external valgus moments increased.

**DISCUSSION:** The purpose of the current study was to investigate the effects of jumping from different directions on landing mechanics in performing a jump-land-jump task. The results partially supported the hypothesis that jumping from a sharper angle leads to a smaller knee flexion angle. The results revealed that jumping from a 90° angle to their right (the -90° condition) resulted in a significantly smaller knee flexion angles compared to all the other jump directions except for the -60° and -30° conditions (jumping from an angle to their right). Previous studies have demonstrated that a small knee flexion angle increases the anterior shear forces on the proximal end of the tibia and therefore loads the ACL (Yu & Garrett, 2007). Zahradnik, Jandacka, Farana, Uchytíl, & Hamill (2017) also suggested that in landings with smaller knee flexion angles, specifically those closer to 30° of knee flexion, the lower extremity is positioned in a way that absorb smaller portions of GRFs. Therefore, the passive tissues of the knee, including the ACL, may go through higher amounts of shock absorption due to stiffer

landing. The change in peak knee flexion angles in the current investigation are larger in magnitude compared to some previous research (Schreurs, Benjaminse, & Lemmink, 2017a), but participants were still able to maintain peak knee flexion angles beyond 75°. Nonetheless, these results still likely indicate increased ACL injury risk (Pollard, Sigward, & Powers, 2010). When participants jumped to their right, they exhibited smaller knee flexion angles compared to when they jumped to their left. These results may be suggesting that when participants are jumping to their right, their right leg is leading the movement and therefore experiences a stiffer landing to brake the jump, and as such has an increased ACL injury risk. This hypothesis is supported by the observation that, ground reaction forces were asymmetric and increased in the leading leg compared to the trailing.

**Table 1:** Mean  $\pm$  standard error of peak knee flexion angle, valgus angle, and external valgus moments for all jump angle conditions. N = 8

		Flexion (°)	Valgus (°)	Valgus Moments (Nm/kg) *10 <sup>-2</sup>	
Jump Angle	Right				
	-90°	75.1 $\pm$ 3.5 C	9.3 $\pm$ 2.7	10.4 $\pm$ 1.4	ABC
	-60°	81.4 $\pm$ 5.9 ABC	10.4 $\pm$ 3.2	13.5 $\pm$ 1.0	A
	-30°	79.3 $\pm$ 3.9 BC	10.4 $\pm$ 3.0	11.2 $\pm$ 0.9	ABC
	0°	84.3 $\pm$ 4.6 A	11.0 $\pm$ 3.0	7.2 $\pm$ 0.7	BC
	Left				
	30°	82.6 $\pm$ 3.9 AB	10.2 $\pm$ 3.0	8.4 $\pm$ 1.3	ABC
60°	84.4 $\pm$ 3.7 A	9.9 $\pm$ 2.9	8.3 $\pm$ 1.3	BC	
90°	82.2 $\pm$ 3.3 AB	9.6 $\pm$ 2.8	9.0 $\pm$ 1.4	ABC	

Significant differences indicated above as A > B > C at a false discovery rate of no more than 5%.

Furthermore, the findings of the current study revealed that external knee valgus moments are significantly higher when jumping from the -60° condition compared to the 0° and 60° conditions. The knee external valgus moment in the -60° condition was nearly statistically larger compared to 90° and 30° conditions as well ( $p = 0.058$  and  $0.051$ , respectively). These results demonstrate smaller amounts of external knee valgus joint moments compared to other investigations which could possibly be due to the difference in the movements (Schreurs, Benjaminse, & Lemmink, 2017a; Sigward, Cesar, & Havens, 2015)

The results suggest that as the angle of the first jump increases, the medio-lateral GRFs increase and as a result, external valgus joint moments increase as well. In addition, participants demonstrated greater external valgus moments jumping to their right compared to jumping to their left. This may be due to latent trunk lean in the same direction as the jump, resulting in a knee valgus moment in the leading leg. These findings are in line with previous investigations in jump landing movements associating greater knee valgus moments with higher risks for ACL injury (Chappell, Yu, Kirkendall, & Garrett, 2002).

On the other hand, no significant differences were found in peak knee valgus angles, suggesting that considering solely frontal plane motion to assess ACL injury risk may not be adequate given the significant changes in frontal plane moments. Therefore, kinetic analyses should be evaluated as well as kinematic analyses for a more thorough injury risk assessment. However, the limited sample size may be one reason for these statistically insignificant differences. As this investigation is ongoing and guided by *a priori* power analyses, future results are expected to better illuminate this phenomenon. In addition, further analysis of current and future data will investigate the effects of altering entry angle on jump performance.

**CONCLUSION:** Performing a jump-land-jump movement, where the direction of the first jump is sharper and asymmetric, potentially increases biomechanical risk factors associated with ACL injury. Knee flexion angles are decreased, and knee valgus moments are increased for the right limb specifically when jumping to the right. It is recommended for athletes to avoid performing sharp jumps ipsilateral to a leg at increased risk for ACL injury. Only observing frontal plane kinematics doesn't provide sufficient information about risk factors, as moments increase without significant alterations in peak valgus angles. Kinetic measures should be considered as well, but this may be challenging to athletes and coaches on the field. It is

suggested that future investigations explore the effects of other modifiable and nonmodifiable risk factors and methodological designs, such as reactive movement components or ACL risk factors between the sexes, at these increased entry angles to enunciate potential effects.

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