THE EFFECT OF JUMP DIRECTION AND PLANNING ON DROP LANDING MECHANICS IN FEMALE ATHLETES

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The purpose of this study was to assess differences in landing and jump kinematics during a drop landing task in female athletes. Participants (n=18) with previous athletic experience (i.e., jumping sports) volunteered for the study and performed planned and unplanned jumps in three different directions (left, straight, right). Kinematic and kinetic data were analyzed from initial ground contact and toe off. Preferential weight distribution toward the right side was found during the bilateral drop landing task which was supported by larger peak ground reaction forces (GRF_{Peak}) on the right limb. Jump direction significantly altered total plate time ($p<0.05$), GRF_{Peak} ($p<0.001$), mean GRF symmetry ($p< 0.01$), and knee path distance ($p<0.05$). Based on these findings, off-center jumps, but not anticipation, altered landing and jumping kinematics in a manner that may relate to knee injury risk.

KEYWORDS: decision making, landing mechanics, anterior cruciate ligament, females.

INTRODUCTION: With the growing popularity of intramural and collegiate athletic participation sport-based injuries have been on the rise (Hootman et al., 2007). One of the prevalent recurring injuries is an anterior cruciate ligament (ACL) tear and often occurs in a noncontact sport situation that involves either landing or cutting maneuvers. Also, females are 4 to 6 times more likely than males to experience an ACL rupture (Shultz 2015). Previously, researchers have investigated the anatomical, hormonal, and neuromuscular differences between sexes (Hewett et al., 2005, Hewett et al., 2010), yet no independent or combination of these characteristics adequately explain this phenomena.

The degree of injury risk for a noncontact ACL tear has been assessed using either a bilateral or single leg drop vertical jump test, searching for excessive knee abduction motion (Earl et al., 2007). A limitation with such tests relates to the amount of movement planning allowed for in controlled environments. In an attempt to achieve a more game like situation, Brown et al. (2009) used a cut maneuver task with anticipated and unanticipated conditions. The unanticipated cutting resulted in greater hip and knee internal rotation moments when compared with the anticipated condition (Brown et al., 2009). Thus, the decision making process involved with unanticipated cutting maneuvers appears to better reflect the demands of competition and underscores the necessity of understanding adaptable motor responses that may be associated with ACL injury risk. This study aims to examine the potential differences in hip, knee, and ankle landing and jump mechanics of women athletes when performing a drop jump task and includes a component of decision making with the use of anticipated and unanticipated jumps to three different directions.

METHODS: Eighteen college-aged women with sport experience in either soccer, basketball, volleyball, or tennis participated in this study. Participants were injury free in their lower extremity for at least 6 months prior to the study and had no history of an ACL tear. Before testing, research approval was granted by the Institutional Review Board and a written informed consent was signed by all participants.

Data were collected using a Vicon Nexus 3D Motion Analysis System with 10 cameras (200 Hz). Two Bertec force plates were used to collect ground reaction force data (1000 Hz). A lower extremity model comprised of markers placed bilaterally at the ASIS, PSIS, middle thigh, knee, middle shank, ankle, heel, and second metatarsal was used.

Each participant performed a set of drop landing jumps. Jumps began on a box at a height of 41 cm, upon stepping off, the athlete dropped to force plates 70 cm away, with one foot on each plate. Then, the individual immediately jumped one meter in a direction of either 45 degrees left, 45 degrees right, or straight ahead. In the anticipated trial, participants jumped in the order of: right, forward, left, left, forward, right for a total of 6 jumps. The unanticipated jump directions were randomized, with the participant receiving a direction jump arrow via a visual representation after leaving the box. Participants performed unanticipated trials until three good trials of each direction were collected. Rest between trails was determined by each participant. Data were filtered (Woltring) and then imported into Visual 3D.

In order to determine whether jump direction and stimulus altered how individuals approached the task, a general landing characteristic was defined by the total plate time (determined from ground reaction force (GRF) from initial contact (IC) to toe off (TO)). Peak ground reaction forces (GRF_{Peak}) for left and right limbs were identified from the kinetic data and normalized to the body mass of each participant. Joint angle changes from IC to TO were calculated for left and right ankle, knee, and hip joints. Also, a GRF symmetry index (GRF-SI) was calculated between the left and right limbs and was defined by the mean GRF-SI from IC to TO. An index equal to 1.0 indicated equal distribution, greater than 1.0 indicated greater right side loading, and less than 1.0 indicated greater left side loading. Lastly, a knee path distance for both knees was calculated from frontal plane displacements from IC to TO to index knee stability.

A univariate analysis was performed on all dependent variables (total plate time, GRF-SI, knee path distance) to determine whether landing mechanics were influenced by the reactive condition and jump direction. Mean and standard error measures are reported to reflect the accuracy of the data to population samples. Additionally, a covariate of foot orientation (straight versus altered) was identified and included in the ANCOVA to account for a change in foot placement on the force platform. An alpha level of 0.05 was used to denote statistical significance for all comparisons.

RESULTS: A significant effect of direction was found for total plate time ($p<0.05$) with right jumps (M:0.397 s, SE:0.011) being significantly longer than left (M:0.362 s, SE:0.011) and straight (M:0.363 s, SE:0.012) jumps. A significant effect of direction was found for left and right GRF_{Peak} ($p<0.001$), with all directions significantly different than each other.

Table 1: p-values for the change in hip, knee, and ankle joint angle from initial contact to max knee flexion for the left and right limbs. Jump direction resulted in significant different landing mechanics. No significant effect of condition or direction by condition.

		Left		Right	
		Foot Orientation	Direction	Foot Orientation	Direction
Hip	Sagittal	p<0.001	p<0.05	p<0.001	p<0.001
	Frontal	p<0.001	p<0.001	p<0.05	p=0.85
	Transverse	p<0.001	p<0.05	p<0.05	p=0.59
Knee	Sagittal	p<0.01	p<0.05	p=0.061	p=0.16
	Frontal	p=0.96	p=0.10	p=0.06	p<0.05
	Transverse	p<0.05	p<0.01	p<0.001	p<0.05
Ankle	Sagittal	p=0.96	p=0.46	p=0.85	p=0.08
	Frontal	p<0.001	p<0.001	p=0.08	p=0.14
	Transverse	p<0.001	p=0.25	p=0.86	p=0.80

A significant effect of direction was also found for mean GRF-SI ($p< 0.01$) with right jumps (M:1.763, SE:0.084) significantly higher than left (M:1.464, SE:0.086) and straight (M:1.350, SE:0.095) jumps. A significant interaction effect between direction and condition ($p<0.05$) was found with planned right jumps (M:1.963, SR:0.142) significantly higher than unplanned right jumps (M:1.564, SE:0.084).

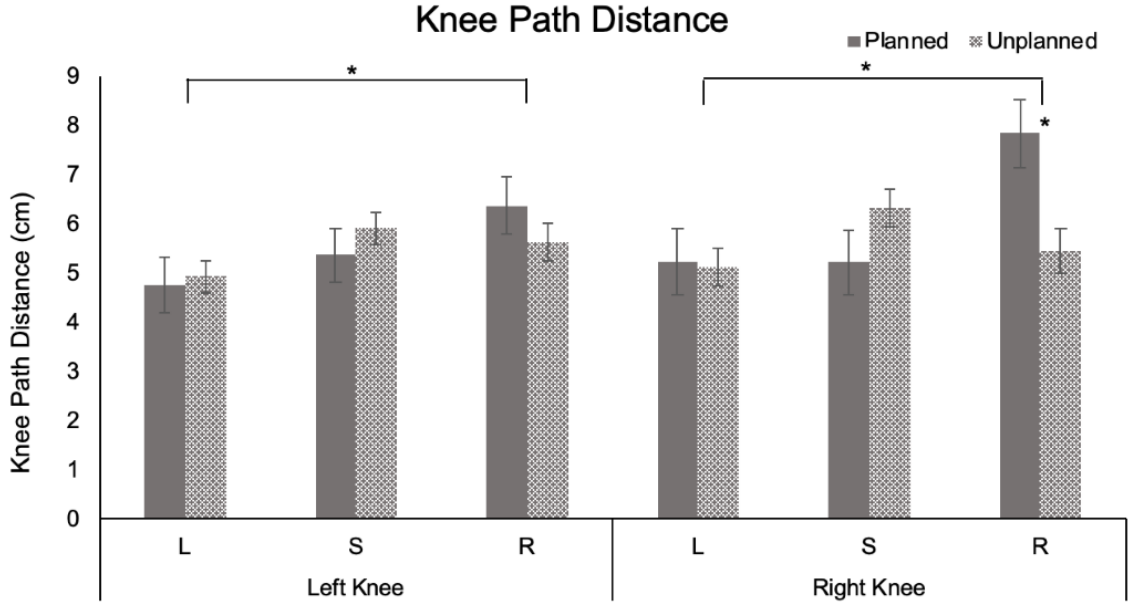

Figure 1. Mean (±SD) knee path distance for planned and unplanned jumps and as a function of direction (L=left; S=straight; R=right) for both limbs. A significant effect of direction was found for left and right path distance ($p<0.05$). Right ($p<0.01$) and left ($p<0.05$) knee paths were significantly higher for right jumps compared to straight and left jumps. A significant interaction effect between direction and condition was found at the right knee ($p<0.01$) where planned right jumps were significantly higher than unplanned right jumps.

DISCUSSION: Larger GRF_{Peak} were found on the right compared to the left limb as well as a preferential weight distribution toward the right side (>1.0 GRF-SI) during the drop landing task. As the athlete decelerates upon initial ground contact, greater magnitudes of force can lead to an increased risk of injury. To reduce such risk, neuromuscular training programs emphasize teaching the athlete to have a "soft" landing whereby GRF_{Peak} are lessened compared to rigid landing strategies to reduce ACL injury risk. Here, the asymmetrical GRF_{Peak} and loading between the right and left limbs suggests that individuals used a landing strategy that potentially placed the right knee at a higher risk of injury. Furthermore, the high GRF-SI indicates a right limb preference for weight distribution not only during landing but throughout the entire sequence of landing and jumping.

The kinematic characteristics of the landing strategy provides information regarding the manner in which individuals absorb GRFs. For example, reduced sagittal plane joint motion may include larger forces acting at a single joint rather than proper force absorption throughout the lower extremity kinetic chain. The observed differences of joint changes from initial contact to max knee flex with direction jumps indicates landing strategies were dependent on whether individuals jumped forward compared to left and right directions. Such kinematic changes are likely necessary for the left and right jumps to induce a directional change of the GRF vector; however, additional analyses of the center-of-mass position relative to the GRF vector is needed to better understand the mechanisms used to execute the directional jumps as well as the relation to known injury risk factors. Lastly, the lack of kinematic differences for planned and unplanned jump may be related to a low degree of challenge associated with the visual stimuli and is supported by the low number of unsuccessful trials collected during the experiment.

The knee path distance measure indicated the amount of travel of the knee joint in the frontal plane from initial contact to toe-off. It was assumed that a lower knee path distance would indicated a more stable knee where as longer path lengths would suggest that the knee showed greater abduction/adduction motion. The observed increased displacement for both knees during rightward direction jumps was surprising given the functional demands of the directional jump. Specifically, it was expected that the contra-lateral limb (i.e., left leg for rightward jumps) would facilitate a directional change of the center-of-mass with increased knee abduction in that a rightward direction jump would have a greater GRF_{peak} for the left limb and an increased knee path distance in order to project the GRF vector toward the target direction; however, the findings did not support this prediction. Lastly, recent evidence has shown that single-leg, rather than double-leg, landings provide a better indication of knee injury risk (Ithurburn et al., 2015) and evaluating such landings with a decision-making components warrants further investigation.

The standard drop landing jump with either vertical or forward motion following the landing normally requires inter-limb symmetry; however, the findings were consistent with previous evidence that females tend to be one-limb dominant (Hewett et al., 2010). Individuals in the current study showed a right limb preference for all drop landing conditions that was further emphasized during rightward jumps. This increased loading on the right limb potentially increases injury risk as most ACL tears occur when the athlete is heavily loaded on a single limb (Brown et al., 2009). Also, the right limb dominance may be related to limb preference difference for a preferred plant leg versus a preferred kick or drive leg. Investigation of limb preference in motor tasks that do not demand symmetry may provide further insight for the prevention and rehabilitation of ACL injuries.

CONCLUSION: In this investigation jump direction altered lower extremity landing mechanics of the female population, but the anticipation manipulation did not have a significant effect on landing and jumping strategies except for the right knee path distance in the rightward direction. It is possible that the stimulus was not sufficiently challenging for the decision making process of the individual as previous evidence suggests that more game-realistic stimuli emphasize key perceptual components that could yield greater insight to evaluations of knee injury risk for females (Brown et. al., 2009). During dynamic sport activities, individuals must execute motor responses beyond highly controlled conditions and will encounter environment that demand unanticipated movements, which may lead to poor movement strategies that place the knee at risk of injury. Therefore, a training program with sufficiently challenging cognitive and physical demands that match game scenarios may potentially reduce the risk of ACL injury.

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