COMPARISONS OF PRE-LANDING AND EARLY LANDING KNEE FLEXION ANGLES BETWEEN SEXES AND LANDING TASKS

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The purpose was to compare pre-landing and early landing knee biomechanics between males and females and between double-leg and single-leg landings. Sixteen males and sixteen females participated in this study. The single-leg landings generally resulted in less time to minimal knee flexion angles prior to initial landing, decreased minimal knee flexion angles and average knee flexion velocities prior to initial landing, knee flexion angles at initial landing. The sex difference was only observed for knee flexion angles 50ms after initial landing in single-leg landings. These differences in the timing of minimal flexion angle and minimal knee angle prior to landing might be related to a small knee flexion angle at initial contact. Preparing for landing with greater knee flexion help mitigate the ACL injury risk in single-leg landings and women.

KEYWORDS: ACL, Biomechanics, Kinematics, Injury Risk, Kinetics.

INTRODUCTION: The Anterior cruciate ligament (ACL) injury is one of the most common and severe injuries during sports. Landing on a single leg with small knee flexion angles could result in a higher risk for ACL injuries (Dai et al., 2014). Single-leg landings are considered more dangerous than double-leg landings because the greater strength required limits the knee flexion angle at initial contact to perform a standing posture in single-leg tasks (Li et al., 2020). Compared with males, females have a higher incidence of ACL injuries in most sports events (Prodromos et al., 2007). Sex differences in landing biomechanics such as a lower knee flexion angle, great quadriceps muscle force, and greater impact forces during landing were reported in females compared with males (Chappell et al., 2007; Salci et al., 2004).
Although there is a wealth of information regarding the differences in landing mechanisms associated with ACL injuries between sexes and landing tasks, most studies have focused on the landing phase after ground contact (Landry et al., 2019). It is because ACL injuries commonly occur within 50 milliseconds after initial contact (Dai et al., 2015; Koga et al., 2010). Some studies have investigated the biomechanics of the knee joint motion during the pre-landing phase. Landing on an extended knee was probably associated with the muscle activation patterns for landing preparation (Chappell et al., 2007). The lowest knee flexion with peak ACL strain was observed approximately 55 ms prior to initial ground contact during a single-legged jump-landing (Englander et al., 2019). The knee motion pattern during the pre-landing phase is likely to affect the knee flexion angle at initial contact. However, the potential differences in pre-landing knee flexion angles between sexes and landing tasks are unclear. The findings might provide information to understand sex disparity in ACL injuries and the high risk associated with single-leg landings.
The purpose of this study was to compare pre-landing and landing knee kinematics between men and women and between double-leg and single-leg landings. It was hypothesized that women and single-leg landings would demonstrate less minimal knee flexion angles, later timing of minimal knee flexion angles, and knee flexion angular velocities during pre-landing compared to men and double-leg landings.

METHODS: Sixteen male and female recreational athletes participated in this study. (females, age: 20.8 ± 2.4 years; mass: 64.1 ± 9.0 kg; height: 1.71 ± 0.05; males, age: 23.2 ± 2.9 years, mass: 75.7 ± 8.5kg; height: 1.79 ± 0.05 m). Inclusion and exclusion criteria were previously described (Davis et al., 2019). Sixteen retro-reflective markers were placed on the trunk and the testing leg (preferred jumping leg for distances). Kinematic data were recorded using eight cameras at 160 Hz (Vicon Motion Systems Ltd, Oxford, UK). Ground reaction forces (GRF) were collected using one force platform at 1600 Hz (Bertec Corporation, Columbus, OH, USA).

Participants performed a minimum of three practice trials and three recorded trials of a forward landing task with the testing leg or both legs. The landing task required participants to jump forward from a 30 cm box placed half of the participant's body height from the force platform, and land with either the testing leg or both legs (Figure 1).
Kinematic variables included the minimal knee flexion angle in pre-landing, timing of minimal knee flexion angles in pre-landing, and average knee flexion angular velocity between this time and initial contact with the ground during pre-landing and between initial contact and 50 ms after landing during landing phases. Knee flexion angles at initial contact and 50 ms after initial contact were also extracted (Englander et al., 2019). Kinetic variables included peak vertical and posterior ground reaction forces (GRF) within 50ms after landing. Dependent variables were compared between the two landing conditions (double-leg and single-leg) and between sex (males and females) using two-way mixed ANOVA, followed by independent or paired t-tests. A type-I error rate of 0.05 was used for statistical significance.

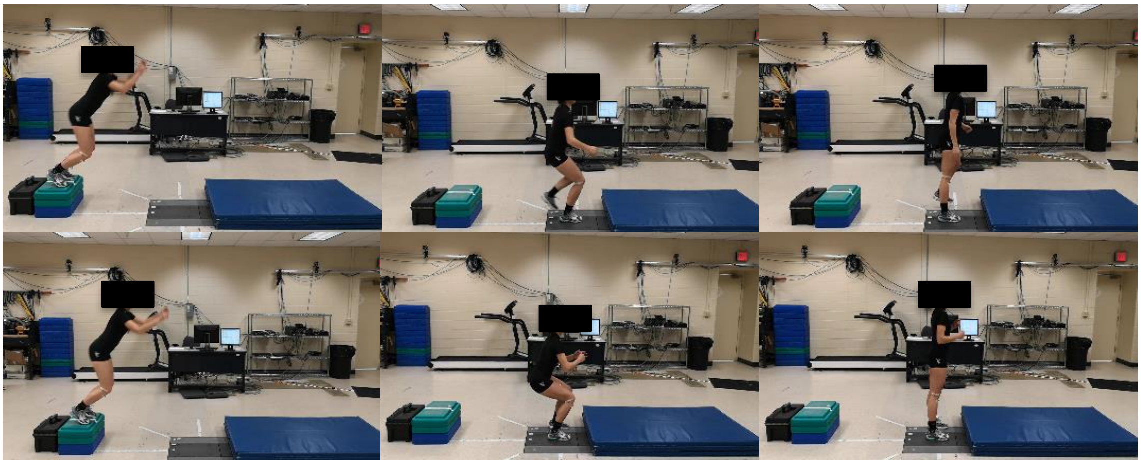

Figure1. The jump landing with the single-leg landing (top) and double-leg landing (bottom)

RESULTS: The single-leg landings generally resulted in less time to minimal knee flexion angles prior to initial landing, decreased minimal knee flexion angles and average knee flexion velocities prior to initial landing, knee flexion angles at initial landing, knee flexion angles and average knee flexion velocity 50 ms after initial landing, and increased peak vertical and posterior forces compared to the double-leg landings (Table 1). The sex difference was only observed for knee flexion angles 50ms after initial landing in single-leg landings. Knee flexion angles 50 ms prior to and after initial contact were graphically presented in Figure 2.

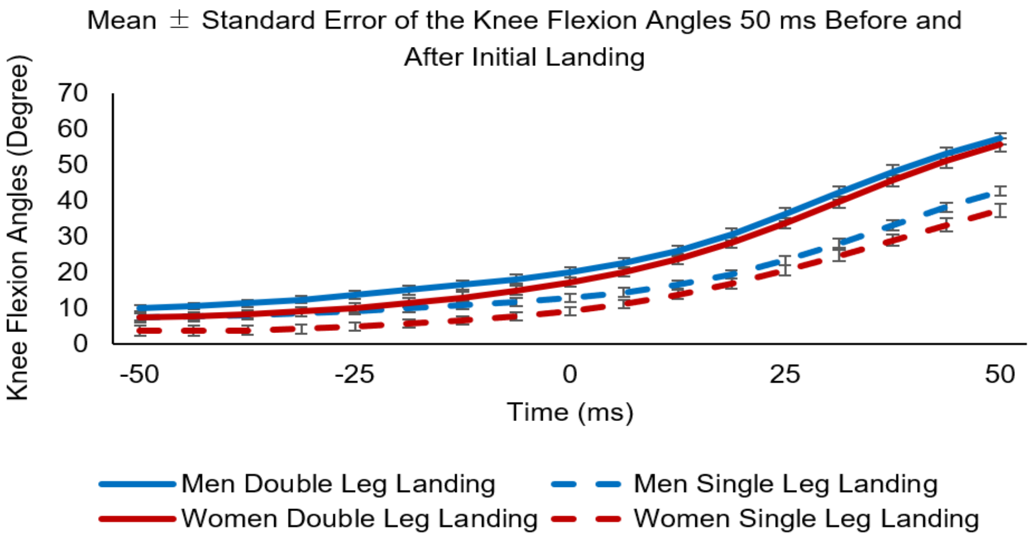

Figure 2. Pre-landing and early landing knee flexion angles

Table 1. Mean ± standard deviations of dependent variables

	Double-leg Landing		Single-Leg Landing		p values of ANOVA		
	Men	Women	Men	Women	Landing Condition	Sex	Interaction
Timing of Minimal Knee Flexion Angles Prior to Initial Landing (ms)	-62.8± 12.7 ^	-54.8 ± 17.5 ^	-45.7± 21.9 ^	-46.9 ± 14.5 ^	**0.001**	0.506	0.184
Minimal Knee Flexion Angles Prior to Initial Landing (deg)	8.6 ± 4.0 ^	6.4 ± 5.5 ^	6.4 ± 4.2 ^	2.8 ± 5.6 ^	**<0.001**	0.082	0.354
Average Knee Flexion Velocities Prior to Initial Landing (deg/s)	176.5±55.8 ^	194.2±45.8 ^	123.1±63.8 ^	130.5± 53.7 ^	**<0.001**	0.414	0.675
Knee Flexion Angles at Initial Landing (deg)	20.1 ± 5.6 ^	17.0 ± 6.0 ^	12.9 ± 4.7 ^	9.2 ± 4.4 ^	**<0.001**	0.059	0.633
Knee Flexion Angles 50 ms after Initial Landing (deg)	57.3 ± 6.3 ^	55.7 ± 6.8 ^	42.6 ± 5.2 ^*	37.3 ± 7.6 ^*	**<0.001**	0.121	**0.022**
Average Knee Flexion Velocity 50 ms after Initial Landing (deg/s)	744.4±54.5 ^	773.3±74.6 ^	594.0±76.2 ^	560.6±124.1 ^	**<0.001**	0.933	**0.042**
Peak Vertical Forces 50 ms after Initial Landing (Body Weight)	3.0 ± 0.7 ^	2.8 ± 0.7 ^	4.3 ± 0.7 ^	4.6 ± 0.6 ^	**<0.001**	0.819	0.121
Peak Posterior Forces 50 ms after Initial Landing (Body Weight)	-0.7 ± 0.2 ^	-0.8 ± 0.2 ^	-1.2 ± 0.2 ^	-1.2 ± 0.3 ^	**<0.001**	0.452	0.115

^: significant effects ($p < 0.05$) of landing conditions for each sex; *: significant effects ($p < 0.05$) of sex for each landing conditions.

DISCUSSION: The findings support the hypothesis that single-leg landings would demonstrate less minimal knee flexion angles, later timing of minimal knee flexion angles, and knee flexion angular velocities during pre-landing compared to double-leg landings. Consistent with a previous study (Pappas et al., 2007), the current findings showed that single-leg landings had lower knee flexion angles and greater peak GRF during landing than double-leg landings. During landings tasks, the ground reaction force imposes external joint moments on the knee. Compared to double-leg landings, only one leg was used to resist the external moment, so participants compensated the increased forces with decreased knee flexion angles to decrease the external moment arm. However, the small knee flexion angle, short flexion time, and slow angular velocity during pre-landing in single-leg landings indicated less flexion time and space to prepare for landing, which might contribute to the higher risk of ACL. When perturbation occurs, less timing to flex the knee might lead to a particularly dangerous landing posture.
The hypothesis related to sex difference was partially supported. Females had similar timing of minimum knee flexion angles and average knee flexion velocity during pre-landing but only tended to have a small knee flexion angle at initial contact compared to males. A decreased minimal knee flexion angle prior to initial landing in females could result in insufficient space to achieve a greater knee flexion angle at initial contact. Females had increased quadriceps activation, decreased hamstring activation, and decreased knee flexion angles during pre-landing (Chappell et al., 2007). Weak muscle strength and different muscle control patterns could contribute to the small knee flexion at initial contact in females, which might increase the vulnerability of the ACL in females. It should be noted that the sample size was relatively small for the sex comparisons, and a larger sample size would be needed for sufficient statistical power for between-subject comparisons.

CONCLUSION: The present study examined the knee biomechanics differences in pre-landing and early landing phases during double-leg and single-leg landings between males and females. Our results detailed different knee motion patterns between female and male subjects and between single-leg and double-leg landings. These differences in the timing of minimal flexion angle and minimal knee angle prior to landing may be related to small knee flexion angles at initial contact, which might contribute to a high risk of ACL injuries in single-leg landings and women. Increasing muscle strength and preparing for landing with greater knee flexion help mitigate the ACL injury risk in single-leg landings and women, especially when perturbations or unanticipated events occur during mid-flight.

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