ASSOCIATION BETWEEN JUMP PERFORMANCE AND ACL INJURY KINEMATIC RISK FACTORS

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This study aimed to provide further insights into unclear aspects in the existing literature concerning the association between ACL injury kinematic risk factors and jump performance, as they might conflict. Fifty-four physically active females executed drop jumps with a maximal CMJ. A motion capture system provided knee and hip kinematics. Jump height, contact time, reactive strength index, initial speed, and power were obtained using a contact platform. Spearman's correlations between first and second landing kinematics and jump indicators were evaluated. The results showed how highly performing participants were also able to land safely, plausibly reducing ACL injury risk factors. These findings regarding the relationship between ACL injury risk factors and performance, may help the development of preventive training programs without compromising performance.

KEYWORDS: biomechanics, drop jump, jump parameters.

INTRODUCTION: The anterior cruciate ligament (ACL) injury is one of the most debilitating non-contact injuries in sports (Pulici et al., 2022). Although different mechanisms may lead to an ACL injury, common biomechanical features often include increased knee abduction and hip adduction combined with reduced lower limb flexion when the foot is planted on the ground, which may exacerbate the shear forces at the level of the proximal tibia (Dai et al., 2014; Grassi et al., 2017). Consequently, most preventive training programs for ACL injuries primarily aim to improve lower limb flexion and frontal plane alignment in sports gestures, such as landings (Lopes et al., 2018). However, suggesting athletes to focus on the landing phase might compromise jump performance (Dai et al., 2015). While some studies investigating the effect of a 'safe' landing on jump performance found that a preventive training program specialized for ACL injury may reduce biomechanical risk factors and improve jump performance simultaneously (Asgari et al., 2022), other studies found that a deeper lower limb flexion is associated with a lower jump height and a longer contact time, indicating less efficient jump execution (Dai et al., 2015; Fox, 2019).
The study aimed to investigate whether players who obtained better jump performance indicators, such as higher jump, also demonstrated a 'safe' landing technique in drop jumps. Based on the literature results, it was hypothesized that improved performance comes at the expense of landing kinematics, resulting in knee abduction and hip adduction, and decreasing knee and hip flexion, considered risk factors for ACL injuries.

METHODS: Fifty-four physically active females (23.7 ± 3.6 years) participated in this study, approved by the local Ethics Committee. Participants were 18-35 years old, engaged in amateur-level sports, participating in at least two weekly workouts, did not suffer any lower limb injury in the 6 months preceding the testing session, or participated in preventive training programs for ACL injuries.
After a 5-minute warm-up on a stationary bike and a specific warm-up including squats, jumps, and drop jumps, participants executed a double-leg 40-cm drop jump. Although the drop jump may not be strictly representative of the in-game ACL injury mechanism, it is widely used for assessing both biomechanical injury risk factors and athlete performance (de Britto et al., 2017; Stearns & Powers, 2014; Struzik et al., 2016). Participants were asked to drop off the box (initiating the movement with their preferred foot or both feet), land simultaneously with both

feet on a contact platform (placed 20 cm away from the box anterior edge), and suddenly perform a maximal countermovement jump, landing again on the contact platform without arm swing. After familiarizing themselves with the task, three valid trials were recorded. A trial was defined as valid when participants correctly landed with both feet on the platform, performed a smooth movement between the drop and the countermovement jump, and maintained balance for one second at the end of the task.
The trajectories of 36 reflective markers placed on participants' body on anatomical landmarks (Figure 1) were obtained using a 9-camera optoelectronic motion capture system (BTS S.p.A, Garbagnate Milanese, Italy). Before task execution, the participants' orthostatic position was recorded for 10 s to build a subject-specific model in data processing. Smart Tracker (BTS S.p.A, Garbagnate Milanese, Italy) and Visual3D (C-Motion, Inc., Germantown, USA) were used to process collected data (marker trajectory reconstruction, filtering and interpolation) and obtain first and second landing hip adduction and flexion and knee abduction and flexion, previously identified as kinematic risk factors for ACL injuries (only the right limb was analysed as the study does not focus on possible asymmetries between limbs). A custom Matlab code (Matlab, R2021a, The MathWorks, Inc., Natick, Massachusetts, USA) provided the peak values of the selected variables from the initial ground contact to the maximum knee flexion.

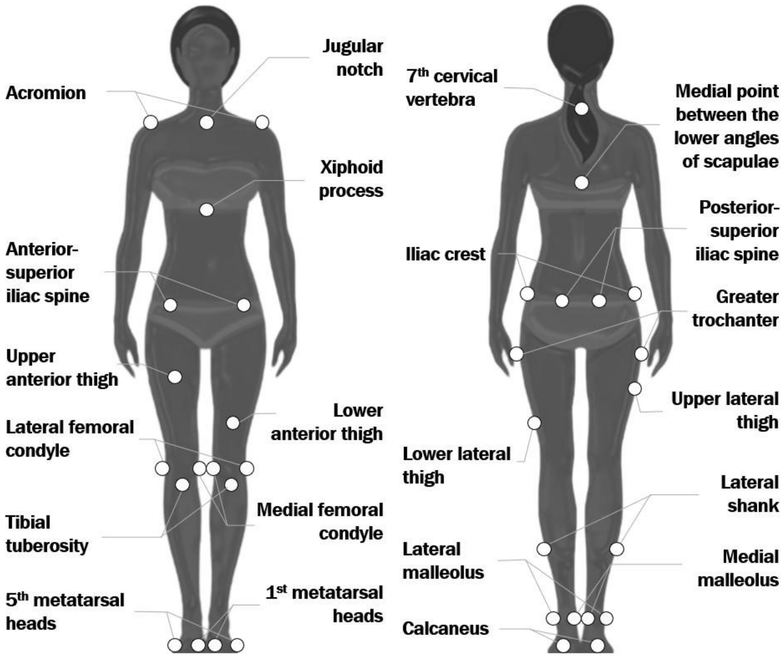

Figure 1: Anatomical landmarks used for marker placement.

Jump performance was evaluated using a contact platform (Chronojump-Boscosystem, Barcelona, Spain), providing jump height (cm), contact time (s), reactive strength index (RSI, m/s), initial speed (m/s), and power (W), estimated as body mass·g·(drop height+1.226·flight time2)/contact time. Jump height was then normalized to the participants' height (cm/cm).
Spearman's correlation coefficient (r_S) was used to determine the correlation between kinematic variables and jump performance indicators, through a two-tailed test (α=0.05), using IBM SPSS Statistics v.27 (IBM Corporation, Armonk, NY, USA). The correlation between the first landing kinematic variables and all jump performance indicators has been evaluated, while the analysis concerning the second landing kinematics included jump height only, as contact time, RSI, initial speed and power exclusively referred to the first landing contact phase with the contact platform.

RESULTS: Kinematic variables and jump performance indicators descriptive statistics are reported in Table 1. Both first landing knee and hip flexion showed a positive correlation with contact time and negative correlation with jump power ($p<0.01$). First landing knee abduction was negatively correlated with the jump height, but through a poor correlation ($p=0.05$) (Chan, 2003). Jump height was also correlated with second landing knee flexion (fair correlation, positive r_S, p=0.03), knee abduction (fair correlation, negative r_S, p<0.01) and hip flexion (fair correlation, positive r_S, p=0.02). All results are reported in Table 2.

Table 1: Descriptive statistics of landing kinematic variables and jump performance indicators (mean ± SD).

Variables	1st landing	2nd landing
Knee flexion (°)	79.5 ± 18.6	74.5 ± 17.5
Knee abduction (°)	0.1 ± 4.7	0.8 ± 4.2
Hip adduction (°)	-0.2 ± 4.2	0.4 ± 4.1
Hip flexion (°)	73.3 ± 17.6	69.8 ± 19.5
Jump height (cm/cm)	0.14 ± 0.03	
Contact time (s)	0.493 ± 0.116	
RSI (m/s)	0.52 ± 0.23	
Initial speed (m/s)	2.13 ± 0.22	
Power (W)	854 ± 295	

Table 2: Correlations between first and second landing kinematics and jump performance indicators. Spearman's coefficients are reported. (*p<0.05)

Kinematic variables	Jump height	Contact time	RSI	Initial speed	Power
1st-knee flexion	0.24	0.55*	-0.24	0.22	-0.43*
1st-knee abduction	-0,27*	-0.18	-0.03	-0.24	0.18
1st-hip adduction	0.07	-0.15	0.10	0.08	0.13
1st-hip flexion	0.21	0.51*	-0.23	0.18	-0.51*
2nd-knee flexion	0.30*				
2nd-knee abduction	-0.38*				
2nd-hip adduction	-0.01				
2nd-hip flexion	0.31*				

DISCUSSION: In this study, we investigated the relation between drop jump kinematics and performance indicators, through the estimation of the correlation coefficient, presuming that to enhance jump performance, athletes may compromise the execution of the landing phase, thereby exposing themselves to a higher risk of ACL injuries.

Higher knee and hip flexion corresponded to increased contact time and decreased jump power. Although greater lower limb flexion is associated with a lower risk of injury as it may reduce knee loads while landing (Alentorn-Geli et al., 2009), the resulting increase in contact time could be considered disadvantageous to performance (Kobsar & Barden, 2011), as it may affect the movement speed required during in-game situations. In this study, however, participants were asked to focus on reaching the maximal jump height with a smooth movement between dropping and jumping, and not just to jump quickly. Considering how instructions may change jump biomechanics and performance (Khuu et al., 2015), we might suppose that participants exhibited an increased knee and hip flexion to better control the drop from the box and prepare for the second vertical jump, without affecting its execution (Ball & Zanetti, 2012). In support of this hypothesis, first landing knee and hip flexion were not negatively correlated to jump height or RSI.

Although the initial hypothesis based on past studies (Dai et al., 2015; Fox, 2019), jump height negatively correlated with first and second landing knee abduction and positively correlated with second landing knee and hip flexion. This finding demonstrates how participants who performed a higher jump could also implement a 'safer' landing technique, with reduced knee abduction and increased lower limb flexion, considered biomechanically protective measures for the integrity of the ACL (Grassi et al., 2017). Likely, participants achieving higher jump heights may be those who participate in sports where jump execution is more frequent, thereby demonstrating enhanced skill in landing safely from higher jumps. In this regard, it could be interesting to investigate homogeneous groups based on the sport practiced and level to understand whether the obtained results are confirmed or reversed.

CONCLUSION: Contrary to past studies and our initial hypothesis, this analysis demonstrated that a better drop jump performance was associated with a safer landing technique. It could be crucial to investigate further the relationship between ACL injury biomechanical risk factors and the effectiveness of sports gestures, such as jump height, cutting speed, or reactiveness. A better understanding of the trade-off between performance and injury risk factors would assist in developing ad-hoc prevention programs to protect players without affecting performance.

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