Journal of Physical Education and Sport ® (JPES), Vol. 24 (issue 3), Art 71, pp. 597 - 604, March 2024
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Kinetic insights into unipodal landings: A detailed study with gender differences

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Published online: March 31, 2024
(Accepted for publication March 15, 2024
DOI:10.7752/jpes.2024.03071

Abstract:
Knee injuries represent a predominant reality in sports practice. Kinetic factors or gender seem to be determining aspects for the onset of a knee injury. Currently, numerous studies have identified injury mechanisms suggesting an increased risk of suffering an injury, with landings being a fundamental element for evaluation. However, contributions regarding the analysis of kinetic factors during single-leg landings in non-professional athletes are scarce. This study investigates the kinetic factors associated with non-traumatic knee injuries during unipodal landings, focusing on gender differences and analyzing their disparities. A sample of 162 non-professional participants engaged in physical activity underwent unipodal landings from a height of 30 cm, evaluating forces and accelerations using a triaxial force platform and accelerometers. The analysis revealed nuanced findings regarding ground reaction forces (GRF), mediolateral (ML), and anteroposterior (AP) forces. While no significant differences were observed between men and women in vertical forces, women exhibited higher ML force, which could indicate neuromuscular control issues or associations with knee varus and valgus. Acceleration analysis highlighted comparable knee and ankle responses between genders, with women demonstrating slightly higher knee acceleration. The study underscores the role of GRF, ML, and AP forces in knee injury risk during landing, providing a comprehensive view of biomechanical aspects that may contribute to increased injury incidence. Gender-specific dynamics and potential implications for injury prevention strategies are analyzed. Further exploration is conducted on the kinetic differences found based on gender. This research enhances our understanding of knee injury mechanisms and aids in adapting preventive measures for athletic populations.
Key Words*:* **Risk, men, women, biomechanics, knee injury.**

Introduction

Non-traumatic knee injuries are associated with specific mechanisms and sports-related actions. Jump-landing actions are triggering events for injuries commonly documented in the literature (Chia et al., 2022; Tait et al., 2022). Individuals engaged in physical activity frequently perform various landing actions, including those executed unilaterally. Some authors, such as Weinhandl et al. (2010), have identified these actions as having a higher risk of injury, primarily due to specific kinetic characteristics described during single-leg jumps and landings (Weinhandl et al., 2010).

In recent years, literature has highlighted the particular biomechanics during the landing phase, from the initial ground contact to the moment of maximum force exerted against the ground, as moments of great relevance for triggering knee injuries (Bencke & Zebis, 2011; Hewett et al., 2005). Authors such as (Awad et al., 2021) reflected that landing with only one foot can determine the increased risk of knee injury, due to the relationship that the force generated in the lower limb just at the moment of landing has with the varao or valgus angle generated in the frontal plane. However, these authors did not relate the force generated against the ground during landings. For their part, (Marotta et al., 2020) found a positive correlation between dynamic valgus and activation of the anterior thigh musculature while subjects were dropped from a platform. Despite responding to this positive correlation, the kinetic explanation of the injury mechanism could not be reflected.

To assess the risk of injury in landings, different heights have been identified as reliable methods for analyzing injury risk. These heights have varied from 20 cm to 60 cm (Ali et al., 2014; Ford et al., 2003; Hanzlíková & Hébert-Losier, 2020; Hébert-Losier et al., 2023; Kristianslund & Krosshaug, 2013; Saadat et al., 2022). During these assessments, a number of kinetic outcomes must be integrated to better define the risk of knee injuries during unipodal landings (Van Der Harst et al., 2007), including variables such as force at initial contact or Vertical Ground Reaction Force (VGRF) (Chappell et al., 2002; Hewett et al., 2006; Ismail et al., 2016; Yamazaki et al., 2010). However, other kinetic variables, such as forces in the mediolateral ($Force_{ML}$) and anteroposterior (F_{AP}) axes or acceleration, are scarce, even in comparisons between sexes.

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In this context, sex differences have been reported as a key element in the analysis of knee injury risk during landings (Butler et al., 2013; Gehring et al., 2009; Holden et al., 2016; Lee & Shin, 2022; Nagano et al., 2007; Zhang et al., 2023). Recently, a study unveiled the kinetic response in jump landings applied to specific gestures such as the tennis serve (Mouritzio et al., 2024). Specifically, GRF was analyzed in the three axes, comparing the results between men and women. However, the study exclusively contemplated the maximum peak force, biasing the information on the peak force generated at the first contact with the ground (platform).

Despite literature contributions on the analysis of knee injury risk during landings, there is limited evidence on the evaluation of knee injury risk during unipodal landings, including kinetic variables such as forces in axes other than the vertical (FML and FAP), acceleration, and in relation to sex. Therefore, the aim of this study was to assess kinetic factors as a key element in the risk of knee injuries during unipodal landings based on sex.

Material & methods

Participants

The participants comprising the sample in this study were 162 voluntary individuals, including 40 women (Table 1). All subjects engaged in physical exercise for at least 30 minutes per day, a minimum of 3 hours per week. To be eligible for participation, individuals were excluded if they had experienced a lower limb injury within the 6 months preceding the assessment. The study adhered to the principles of the Declaration of Helsinki and received approval from the Ethics Committee of the University of Seville.

Table 1. Descriptive analysis

VARIABLES	N = 162	Men	Women	*p*
Sex		122	40	
Age (years)	24 (±3)	25 (±2)	22 (±1)	.110
Body Mass (Kg)	72.84 (±12.76)	76.92 (±8.12)	65.36 (±4.52)	.103
Height (m)	1.74 (±0.07)	1.80 (±0.09)	1.63 (±0.06)	.071
Body Mass Index (Kg/m^2)	23.78 (±2.86)	24.75 (±1.12)	21.34 (±2.12)	.096
Hours of physical activity per week (h/week)	8.38 (±4.01)	8.79 (±3.96)	7.91 (±2.34)	.101

Data expressed as mean and SD
*$p \leq 0.05$.

Procedure

Each subject performed a unipodal landing with their dominant foot from a height of 30 cm. Participants placed their hands on their hips and, without further instructions, were instructed to fall forward. Prior to this, a standardized warm-up was conducted, comprising 5 minutes of joint mobility exercises, and including 10 landings for familiarization with unipodal landings. After the warm-up, a 2-minute interval elapsed before the valid attempt for assessment was completed.

Measure: Kinetics

Kinetics

A triaxial force platform operating at a sampling rate of 1000 Hz (Kistler 9260 AA6, Winterthur, Switzerland) was employed to assess unipodal landings. Specifically, the platform measured the Ground Reaction Forces (GRF) in all three axes. PF1 was defined as the first Vertical Ground Reaction Force (VGRF), while PF2 was defined as the VGRF. Additionally, mediolateral forces ($Force_{ML}$) were assessed as anteroposterior forces ($Force_{AP}$). In terms of acceleration, knee and ankle acceleration were evaluated using a triaxial accelerometer (xyzPLUX; PLUX—Wireless Biosignals, Lisbon, Portugal), with two accelerometers placed. Both accelerations were assessed in the vertical axis ($ACC_{KNEE}Z$ and $ACC_{ANKLE}Z$), mediolateral axis ($ACC_{KNEE}ML$ and $ACC_{ANKLE}ML$), and anteroposterior axis ($ACC_{KNEE}AP$ and $ACC_{ANKLE}AP$). The first accelerometer was positioned on the lateral condyle of the knee, and the second on the lateral malleolus of the ankle. Tape was used to secure the accelerometers to the skin. All signals underwent processing to eliminate gravitational forces exerted on the accelerometer.

Statistical analysis

For the statistical analysis, jamovi software (www.jamovi.org) was employed. Firstly, the parametricity of the variables was assessed using a Kolmogorov-Smirnov test. Each variable was represented by its mean and standard deviation (SD), and statistical significance was set at $p \leq 0.05$. Differences between genders were assessed using an independent samples t-test. Subsequently, the effect size was evaluated using Cohen's d (Cohen, 1988), calculated by dividing the difference of means between groups by the pooled standard deviation of both groups, taking into account the sample size. Effect sizes of 0.2 were considered small, 0.5 moderate, and 0.8 large.

Results

The force during landings was assessed by first analyzing the total force exerted by participants, measured in Newtons, and subsequently normalized by body weight (Table 2). In absolute terms, PF1 was 1306.14 (±204.69 N), while PF2 was 3310.43 N (±829.54).

The Mediolateral Force (ForceML) exhibited a value of 706.81 (±204.69 N), while the Anteroposterior Force (ForceAP) recorded a value of 234.28 (±97.36 N).

Table 2. *Descriptive analysis of force during landings.*

VARIABLES	Mean	SD
PF1 (N/Kg)	18.14	5.92
PF2 (N/Kg)	45.72	8.69
$Force_{AP}$ (N/Kg)	3.23	1.19
$Force_{ML}$ (N/Kg)	9.84	2.68

Data expressed as mean and SD
PF1 (N/Kg) = Initial ground reaction force. PF2 (N) = Maximal Ground reaction force. $Force_{ML}$ (N/Kg) = Force in medio-lateral axe with respect to body mass. $Force_{AP}$ (N/Kg)= Force in antero-posterior axe with respect to body mass.

Subsequently, data on landing force were obtained according to gender (Table 3). There were no significant differences in the forces exerted in the vertical axis (PF1 and PF2) or ForceAP (p>0.05). However, the effect size indicated a moderate gender-based effect in PF2 (d=0.604). Additionally, in ForceML, women exhibited a significantly higher force compared to men (p=0.015).

Table 3. *Descriptive analysis of force during landings according to sex.*

VARIABLES	Men	Women	*p*	*d-Cohen*
PF1 (N/Kg)	17.50 (5.72)	20.08 (6.19)	0.426	0.442 (0.082-0.802)
PF2 (N/Kg)	44.48 (8.29)	49.58 (8.88)	0.830	0.604 (0.241-0.968)
$Fuerza_{AP}$ (N/Kg)	3.28 (1.27)	3.06 (0.87)	0.139	-0.186 (-0.543 – 0.172)
$Fuerza_{ML}$ (N/Kg)	9.63 (2.80)	10.50 (2.17)	0.015*	0.591 (-0.032 – 0.686)

Data expressed as mean and SD
*p ≤ 0.05. d-Cohen = the effect size.
PF1 (N/Kg) = Initial ground reaction force. PF2 (N) = Maximal Ground reaction force. $Force_{ML}$ (N/Kg) = Force in medio-lateral axe with respect to body mass. $Force_{AP}$ (N/Kg)= Force in antero-posterior axe with respect to body mass.

The acceleration during landings is depicted in Table 4. Concerning the knee, the highest partial acceleration was found in ACCKNEEML (2.34 ± 1.51 g), while those in ACCKNEEAP (1.94 ± 1.55 g) and ACCKNEEZ (1.99 ± 1.46 g) were very similar.

At the ankle, the highest partial acceleration found was ACCANKLEZ (3.95 ± 0.81 g), while the lowest was in ACCANKLEML (3.72 ± 1.17 g). In the AP axis, a value of ACCANKLEAP was found to be 3.91 (± 1.08 g).

Table 4. Descriptive analysis of 3-axis acceleration during landings.

VARIABLES	Mean	SD
$ACC_{KNEE}ML$ (g)	2.34	1.51
$ACC_{KNEE}AP$ (g)	1.94	1.55
$ACC_{KNEE}Z$ (g)	1.99	1.46
$ACC_{TANKLE}ML$ (g)	3.72	1.17
$ACC_{ANKLE}AP$ (g)	3.91	1.08
$ACC_{TANKLE}Z$ (g)	3.95	0.81

Data expressed as mean and SD. $ACC_{KNEE}ML$ (g) = Acceleration in medio-lateral axe in knee. $ACC_{ANKLE}AP$ (g) = Acceleration in antero-posterior axe in knee. $ACC_{ANKLE}Z$ (g) = Acceleration in vertical axe in knee. $ACC_{ANKLE}ML$ (g) = Acceleration in medio-lateral axe in ankle. $ACC_{ANKLE}AP$ (g) = Acceleration in antero-posterior axe in ankle. $ACC_{ANKLE}Z$ (g) = Acceleration in vertical axe in ankle.

The analysis of acceleration based on gender did not reveal significant differences between men and women regarding partial acceleration in the knee or ankle during landings (Table 5).

Nevertheless, knee partial acceleration was slightly higher in women across all axes, particularly noteworthy in $ACC_{KNEE}AP$, where a gender difference with a trend towards significance was observed (p=0.051); meanwhile, in the ankle, only $ACC_{ANKLE}ML$ was higher in women (3.85 ± 1.22 g).

Table 5. Descriptive analysis of acceleration in the 3 axes during landings according to sex.

VARIABLES	Hombres	Mujeres	*p*	*d*
$ACC_{KNEE}ML$ (g)	2.28 (1.46)	2.54 (1.67)	0.155	0.172 (-0.186 – 0.529)
$ACC_{KNEE}AP$ (g)	1.78 (1.46)	2.44 (1.73)	0.051	0.431 (0.071 – 0.791)
$ACC_{KNEE}Z$ (g)	1.90 (1.42)	2.30 (1.58)	0.150	0.274 (-0.084 – 0.632)
$ACC_{TANKLE}ML$ (g)	3.67 (1.16)	3.85 (1.22)	0.642	0.543 (-0.204 – 0.511)
$ACC_{ANKLE}AP$ (g)	3.94 (1.07)	3.81 (1.10)	0.950	-0.121 (-0.478 – 0.237)
$ACC_{TANKLE}Z$ (g)	3.99 (0.79)	3.81 (0.89)	0.363	-0.221 (-0.579 – 0.137)

Data expressed as mean and SD.
*p ≤ 0.05. d-Cohen = the effect size.
$ACC_{KNEE}ML$ (g) = Acceleration in medio-lateral axe in knee. $ACC_{ANKLE}AP$ (g) = Acceleration in antero-posterior axe in knee. $ACC_{ANKLE}Z$ (g) = Acceleration in vertical axe in knee. $ACC_{ANKLE}ML$ (g) = Acceleration in medio-lateral axe in ankle. $ACC_{ANKLE}AP$ (g) = Acceleration in antero-posterior axe in ankle. $ACC_{ANKLE}Z$ (g) = Acceleration in vertical axe in ankle.

Dicussion

Analyzing the forces that the knee withstands during jump landings provides crucial information about the load the joint must absorb. Kinetics has been a key aspect in knee injury analysis, with GRF being a frequently associated factor in triggering injuries to this joint (Sun et al., 2023; Zebis et al., 2008). According to Nigg (2001), VGRF will trigger a series of circumstances that favor the injury process, such as a decrease in control of the joint at the moment of ground contact (Nigg, 2001). Regardless of the accompanying variable, VGRF has undoubtedly been the most reported in the literature as a kinetic component related to the triggering of lower limb injuries (Abián et al., 2008; Dai et al., 2019; Ueno et al., 2020; Zahradnik et al., 2014).

In this study, this force was evaluated along with the forces exerted in the ML and AP axes. While it seems that higher values of ML force are related to an increase in knee valgus or varus (Chen et al., 2022), higher values in the AP force could be related to an increase in tibial translation and, therefore, a greater risk of ACL injury (Wang et al., 2022) (Wang et al, 2022).

Furthermore, kinetics during landings has also been studied in the literature as a risk factor for knee injury. It has been described that the greatest risk after landing from a jump or fall is described by PF1 and PF2. Thus, Pflum et al. (2004) described that during the first 25% of the amortization time is when the risk of knee injury increases, and during this period, both PF1 and PF2 appear (Pflum et al., 2004). This makes it essential to know both variables to study knee behavior during landings. As reflected by Abián et al. (2008), when normalizing VGRF by body weight, one of the threshold values for the risk of knee injury is above 10 times body weight (BW) during landings (Abián et al., 2008). Our results do not exceed this reference value during the descriptive phase (4.67BW ± 0.88). However, these values can be affected depending on the type of landing described. Thus, focusing on unipodal landings, our results are similar to those found by Blackburn and Padua (2008), who found average values of 5.1BW in monopodal landings from a height of 60 cm (Blackburn & Padua, 2008). The slight differences from our results could be due to protocol differences, hand position, or differences in the height from which the fall was initiated.

During landings, gender differences suggested that women exhibited a higher vertical force, although not significant, in both PF1 (12.85%) and PF2 (10.29%) after landing. These data align with findings by James et al. (2004) and Hewett et al. (2005) (Hewett et al., 2005; James et al., 2004). These authors indicated that the vertical component of force was higher in women, which may be related to an increased risk of injury in females. One possible explanation for this phenomenon could be that women do not exhibit good landing technique, maintaining a more upright position during descent (Blackburn & Padua, 2008), and making direct contact with the entire surface of the foot instead of landing first with the forefoot and then with the hindfoot. During this movement, the most critical moment for the ACL in landing coincides with PF2, and it is during this period that the ligament bears the greatest load (Pflum et al., 2004). Additionally, although not significant, our study reflected that women reported greater knee extension (and therefore straightening) than men during landings, supporting the previous explanation and potentially influencing a higher risk of injury for women.

A similar relationship can be found in the AP axis since these values have shown a strong relationship with the risk of injuries during landings, as they have been strongly associated with tibial translation and, therefore, an increase in the force that the ACL bears (Nagano et al., 2007; Yeow et al., 2011). Based on our results, it could be observed that men present higher values than women, although these differences were not significant (p=0.139). Our data align with the results of authors as Sell et al. (2007) Sell, Ferris, Abt, Tsai, Myers, Fu et al. (2007), who also reflected that men exhibited higher AP force than women, even though in their study, the landing was preceded by a two-footed jump (Sell et al., 2007). These differences in this axis could be precisely due to greater knee flexion by men, which increases the force in the sagittal axis, and this is related to a reduction in the risk of injury compared to women (Vanmeerhaeghe et al., 2008). Although it will be discussed later, our results also showed that women landed with a greater extension angle than men, which is in line with what Vanmeerhaeghe et al. (2008) described, supporting the theory of an increased risk of injury in women based on these evaluated parameters.

Furthermore, our data shows that ML force in women was significantly higher than in men (p=0.015) during landings. Although in studies like those of van der Harst et al. (2007) (Van Der Harst et al., 2007), it was argued that it is difficult to find relevant studies comparing ML force between men and women after a jump landing, the differences found could be preceded by a lack of neuromuscular control in the frontal plane, causing an increase in ML force and knee valgus (Vanmeerhaeghe et al., 2008).

While force variables have been studied in the literature as indicators of increased risk of knee injury during landings, an innovative element of this study is providing data on the partial acceleration variable in all three spatial axes for both the knee and ankle. In recent years, triaxial acceleration has been classified as an innovative element that could provide researchers with relevant information in the preventive role of injuries (Zaffagnini et al., 2014). The benefits of this technology probably lie in its price (much cheaper than force platforms) and its size, allowing it to adhere to the ankle and knee without bothering the athlete and ensuring the ecological validity of the analysis.

Regarding landings, the results presented in this study are similar to those reported in a previous study by our group (Sañudo et al., 2012), where an AP knee acceleration of 1.5-1.7g was found. However, they showed a lower ML knee acceleration than in the present study (1.3-1.5g). This difference may be because the study provided subjects with instructions on landing technique, which was not the case in this protocol. As Tillman et al. (2004) indicate, depending on the landing technique, biomechanical values will be different, so standardizing the protocol completely should be taken into account in future interventions (Tillman et al., 2004).

Finally, literature has reflected the partial knee acceleration and compare the dominant foot with the non-dominant foot in subjects with ACL reconstruction and others injured in the same structure who have not been operated on (Setuain et al., 2015). These authors suggest that subjects who were injured and underwent ACL surgery have a greater vertical partial knee acceleration than those who were not operated on during landing. The authors indicate that this could be due to functional and biomechanical alterations in the operated group compared to the non-operated group, associating these alterations with asymmetries between limbs. In our study, biomechanical variables were not studied between the two limbs of each subject. However, in the gender comparison, women showed a higher but not significant AP knee acceleration than men during landing, with values similar to those of the previously mentioned study. This could indicate that women in the present study, with values higher than those of men (17.39%), present biomechanical alterations that predispose them to knee injuries during landings.

Conclusions

In conclusion, the analysis of forces exerted on the knee during jump landings provides valuable insights into the potential risks and mechanisms associated with knee injuries. GGRF play a pivotal role, triggering circumstances that favor injury processes, such as a loss of joint control during ground contact. Despite the variability in accompanying factors, VGRF consistently stands out in the literature as a key kinetic component linked to lower limb injuries.

The evaluation of forces in the ML and AP axes adds a nuanced perspective. Higher ML forces seem associated with increased knee valgus or varus, while elevated AP forces may imply a greater risk of knee injury through increased tibial translation.

Kinetics during landings, specifically focusing on PF1 and PF2, emerges as a critical factor influencing the risk of knee injury. Gender differences in landing dynamics highlight potential vulnerability in women, who exhibit higher vertical forces and greater knee extension during landings. This may be attributed to suboptimal landing techniques, characterized by a more upright posture and direct whole-foot contact, potentially increasing the risk of knee injuries.

In summary, this study contributes significant insights into the multifaceted biomechanical aspects of knee injuries during jump landings, emphasizing the importance of comprehensive kinetic and acceleration analyses. Understanding gender-specific differences and the impact of previous ACL interventions enhances our ability to develop targeted preventive strategies for knee injuries in athletic populations.

Conflicts of interest: Not applicable.

References

Abián, J., Alegre, L. M., Lara, A. J., Rubio, J. A., & Aguado, X. (2008). Landing differences between men and women in a maximal vertical jump aptitude test. *The Journal of Sports Medicine and Physical Fitness*, *48*(3), 305-310.

Ali, N., Robertson, D. G. E., & Rouhi, G. (2014). Sagittal plane body kinematics and kinetics during single-leg landing from increasing vertical heights and horizontal distances: Implications for risk of non-contact ACL injury. *The Knee*, *21*(1), 38-46. https://doi.org/10.1016/j.knee.2012.12.003

Awad, S., Muaidi, Q., & Ashan, M. (2021). Single-leg landing: Determining the risk of knee joint injuries in relation to frontal plane projection angles and lower leg muscle strength among recreational athletes. *Journal of Physical Education and Sport*, *21*(3).

Bencke, J., & Zebis, M. K. (2011). The influence of gender on neuromuscular pre-activity during side-cutting. *Journal of Electromyography and Kinesiology*, *21*(2), 371-375. https://doi.org/10.1016/j.jelekin.2010.10.008

Blackburn, J. T., & Padua, D. A. (2008). Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clinical Biomechanics*, *23*(3), 313-319. https://doi.org/10.1016/j.clinbiomech.2007.10.003

Butler, R. J., Willson, J. D., Fowler, D., & Queen, R. M. (2013). Gender Differences in Landing Mechanics Vary Depending on the Type of Landing. *Clinical Journal of Sport Medicine*, *23*(1), 52-57. https://doi.org/10.1097/JSM.0b013e318259efa0

Chappell, J. D., Yu, B., Kirkendall, D. T., & Garrett, W. E. (2002). A Comparison of Knee Kinetics between Male and Female Recreational Athletes in Stop-Jump Tasks. *The American Journal of Sports Medicine*, *30*(2), 261-267. https://doi.org/10.1177/03635465020300021901

Chen, T. L., Lam, W., Wong, D. W., & Zhang, M. (2022). A half marathon shifts the mediolateral force distribution at the tibiofemoral joint. *European Journal of Sport Science*, *22*(7), 1017-1024. https://doi.org/10.1080/17461391.2021.1938690

Chia, L., De Oliveira Silva, D., Whalan, M., McKay, M. J., Sullivan, J., Fuller, C. W., & Pappas, E. (2022). Non-contact Anterior Cruciate Ligament Injury Epidemiology in Team-Ball Sports: A Systematic Review with Meta-analysis by Sex, Age, Sport, Participation Level, and Exposure Type. *Sports Medicine*, *52*(10), 2447-2467. https://doi.org/10.1007/s40279-022-01697-w

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed). L. Erlbaum Associates.

Dai, B., Garrett, W. E., Gross, M. T., Padua, D. A., Queen, R. M., & Yu, B. (2019). The effect of performance demands on lower extremity biomechanics during landing and cutting tasks. *Journal of Sport and Health Science*, *8*(3), 228-234. https://doi.org/10.1016/j.jshs.2016.11.004

Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus Knee Motion during Landing in High School Female and Male Basketball Players: *Medicine & Science in Sports & Exercise*, *35*(10), 1745-1750. https://doi.org/10.1249/01.MSS.0000089346.85744.D9

Gehring, D., Melnyk, M., & Gollhofer, A. (2009). Gender and fatigue have influence on knee joint control strategies during landing. *Clinical Biomechanics*, *24*(1), 82-87. https://doi.org/10.1016/j.clinbiomech.2008.07.005

Hanzlíková, I., & Hébert-Losier, K. (2020). Clinical Implications of Jump Distance on Landing Error Scoring System Scores. *Journal of Athletic Training*. https://doi.org/10.4085/68-20

Hébert-Losier, K., Boswell-Smith, C., & Hanzlíková, I. (2023). Effect of Footwear Versus Barefoot on Double-Leg Jump-Landing and Jump Height Measures: A Randomized Cross-Over Study. *International Journal of Sports Physical Therapy*, *18*(4), 845-855. https://doi.org/10.26603/001c.81107

Hewett, T. E., Ford, K. R., & Myer, G. D. (2006). Anterior Cruciate Ligament Injuries in Female Athletes: Part 2, A Meta-analysis of Neuromuscular Interventions Aimed at Injury Prevention. *The American Journal of Sports Medicine*, *34*(3), 490-498. https://doi.org/10.1177/0363546505282619

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., Van Den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. *The American Journal of Sports Medicine*, *33*(4), 492-501. https://doi.org/10.1177/0363546504269591

Holden, S., Boreham, C., & Delahunt, E. (2016). Sex Differences in Landing Biomechanics and Postural Stability During Adolescence: A Systematic Review with Meta-Analyses. *Sports Medicine*, *46*(2), 241-253. https://doi.org/10.1007/s40279-015-0416-6

Ismail, S. A., Button, K., Simic, M., Van Deursen, R., & Pappas, E. (2016). Three-dimensional kinematic and kinetic gait deviations in individuals with chronic anterior cruciate ligament deficient knee: A systematic review and meta-analysis. *Clinical Biomechanics (Bristol, Avon)*, *35*, 68-80. https://doi.org/10.1016/j.clinbiomech.2016.04.002

James, C. R., Sizer, P. S., Starch, D. W., Lockhart, T. E., & Slauterbeck, J. (2004). Gender Differences among Sagittal Plane Knee Kinematic and Ground Reaction Force Characteristics during a Rapid Sprint and Cut Maneuver. *Research Quarterly for Exercise and Sport*, *75*(1), 31-38. https://doi.org/10.1080/02701367.2004.10609131

Kristianslund, E., & Krosshaug, T. (2013). Comparison of Drop Jumps and Sport-Specific Sidestep Cutting: Implications for Anterior Cruciate Ligament Injury Risk Screening. *The American Journal of Sports Medicine*, *41*(3), 684-688. https://doi.org/10.1177/0363546512472043

Lee, J., & Shin, C. S. (2022). Sex difference in effect of ankle landing biomechanics in sagittal plane on knee valgus moment during single-leg landing. *Scientific Reports*, *12*(1), 18821. https://doi.org/10.1038/s41598-022-23675-y

Marotta, N., Demeco, A., Moggio, L., Isabello, L., Iona, T., & Ammendolia, A. (2020). Correlation between dynamic knee valgus and quadriceps activation time in female athletes. *Journal of Physical Education and Sport*, *2020*(05).

Mouritzio, C., Athannaildi, I., Arvanitido, V., & Kelli, E. (2024). Disparities in ground reaction forces between serve types in young male and female tennis athletes. *Journal of Physical Education and Sport*, *24*(1).

Nagano, Y., Ida, H., Akai, M., & Fukubayashi, T. (2007). Gender differences in knee kinematics and muscle activity during single limb drop landing. *The Knee*, *14*(3), 218-223. https://doi.org/10.1016/j.knee.2006.11.008

Nigg, B. M. (2001). The Role of Impact Forces and Foot Pronation: A New Paradigm: *Clinical Journal of Sport Medicine*, *11*(1), 2-9. https://doi.org/10.1097/00042752-200101000-00002

Pflum, M. A., Shelburne, K. B., Torry, M. R., Decker, M. J., & Pandy, M. G. (2004). Model Prediction of Anterior Cruciate Ligament Force during Drop-Landings: *Medicine & Science in Sports & Exercise*, *36*(11), 1949-1958. https://doi.org/10.1249/01.MSS.0000145467.79916.46

Saadat, S., Stephenson, M. L., & Gillette, J. C. (2022). Entry angle during jump landing changes biomechanical risk factors for ACL injury. *Sports Biomechanics*, 1-13. https://doi.org/10.1080/14763141.2022.2088399

Sañudo, B., Feria, A., Carrasco, L., De Hoyo, M., Santos, R., & Gamboa, H. (2012). Gender Differences in Knee Stability in Response to Whole-Body Vibration. *Journal of Strength and Conditioning Research*, *26*(8), 2156-2165. https://doi.org/10.1519/JSC.0b013e31823b0716

Sell, T. C., Ferris, C. M., Abt, J. P., Tsai, Y., Myers, J. B., Fu, F. H., & Lephart, S. M. (2007). Predictors of proximal tibia anterior shear force during a vertical stop-jump. *Journal of Orthopaedic Research*, *25*(12), 1589-1597. https://doi.org/10.1002/jor.20459

Setuain, I., Millor, N., González-Izal, M., Gorostiaga, E. M., Gómez, M., Alfaro-Adrián, J., Maffiuletti, N. A., & Izquierdo, M. (2015). Biomechanical jumping differences among elite female handball players with and without previous anterior cruciate ligament reconstruction: A novel inertial sensor unit study. *Sports Biomechanics*, *14*(3), 323-339. https://doi.org/10.1080/14763141.2015.1060253

Sun, T., Li, D., Fan, B., Tan, T., & Shull, P. B. (2023). Real-Time Ground Reaction Force and Knee Extension Moment Estimation During Drop Landings Via Modular LSTM Modeling and Wearable IMUs. *IEEE Journal of Biomedical and Health Informatics*, *27*(7), 3222-3233. https://doi.org/10.1109/JBHI.2023.3268239

Tait, D. B., Newman, P., Ball, N. B., & Spratford, W. (2022). What did the ankle say to the knee? Estimating knee dynamics during landing — A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *25*(2), 183-191. https://doi.org/10.1016/j.jsams.2021.08.007

Tillman, M. D., Hass, C. J., Brunt, D., & Bennett, G. R. (2004). Jumping and Landing Techniques in Elite Women's Volleyball. *Journal of Sports Science & Medicine*, *3*(1), 30-36.

Ueno, R., Navacchia, A., DiCesare, C. A., Ford, K. R., Myer, G. D., Ishida, T., Tohyama, H., & Hewett, T. E. (2020). Knee abduction moment is predicted by lower gluteus medius force and larger vertical and lateral ground reaction forces during drop vertical jump in female athletes. *Journal of Biomechanics*, *103*, 109669. https://doi.org/10.1016/j.jbiomech.2020.109669

Van Der Harst, J. J., Gokeler, A., & Hof, A. L. (2007). Leg kinematics and kinetics in landing from a single-leg hop for distance. A comparison between dominant and non-dominant leg. *Clinical Biomechanics*, *22*(6), 674-680. https://doi.org/10.1016/j.clinbiomech.2007.02.007

Vanmeerhaeghe, A. F., Tutusaus, L. C., De Antolín Ruiz, P., & Massó I Ortigosa, N. (2008). Efectos de un entrenamiento propioceptivo sobre la extremidad inferior en jóvenes deportistas jugadores de voleibol. *Apunts. Medicina de l'Esport*, *43*(157), 5-13. https://doi.org/10.1016/S1886-6581(08)70063-X

Wang, C., Yang, G., Yang, H., Chen, C., Zhang, H., Wang, K., & Lu, A. (2022). Research on Knee Joint Load and Influencing Factors of Typical Tai Chi Movements. *Applied Bionics and Biomechanics*, *2022*, 1-11. https://doi.org/10.1155/2022/6774980

Weinhandl, J. T., Joshi, M., & O'Connor, K. M. (2010). Gender comparisons between unilateral and bilateral landings. *Journal of Applied Biomechanics*, *26*(4), 444-453. https://doi.org/10.1123/jab.26.4.444

Yamazaki, J., Muneta, T., Ju, Y. J., & Sekiya, I. (2010). Differences in kinematics of single leg squatting between anterior cruciate ligament-injured patients and healthy controls. *Knee Surgery, Sports Traumatology, Arthroscopy*, *18*(1), 56-63. https://doi.org/10.1007/s00167-009-0892-z

Yeow, C.-H., Kong, C.-Y., Lee, P. V.-S., & Goh, J. C.-H. (2011). Correlation of axial impact forces with knee joint forces and kinematics during simulated ski-landing. *Journal of Sports Sciences*, *29*(11), 1143-1151. https://doi.org/10.1080/02640414.2011.578146

Zaffagnini, S., Lopomo, N., Signorelli, C., Muccioli, G. M. M., Bonanzinga, T., Grassi, A., Raggi, F., Visani, A., & Marcacci, M. (2014). Inertial sensors to quantify the pivot shift test in the treatment of anterior cruciate ligament injury. *Joints*, *02*(03), 124-129. https://doi.org/10.11138/jts/2014.2.3.124

Zahradnik, D., Uchytil, J., Farana, R., & Jandacka, D. (2014). Ground Reaction Force and Valgus Knee Loading during Landing after a Block in Female Volleyball Players. *Journal of Human Kinetics*, *40*(1), 67-75. https://doi.org/10.2478/hukin-2014-0008

Zebis, M. K., Bencke, J., Andersen, L. L., Døssing, S., Alkjær, T., Magnusson, S. P., Kjær, M., & Aagaard, P. (2008). The Effects of Neuromuscular Training on Knee Joint Motor Control During Sidecutting in Female Elite Soccer and Handball Players. *Clinical Journal of Sport Medicine*, *18*(4), 329-337. https://doi.org/10.1097/JSM.0b013e31817f3e35

Zhang, Y., Hu, Z., Li, B., Qiu, X., Li, M., Meng, X., Kim, S., & Kim, Y. (2023). Gender Differences in Lower Extremity Stiffness during a Single-Leg Landing Motion in Badminton. *Bioengineering*, *10*(6), 631. https://doi.org/10.3390/bioengineering10060631