

REVIEW

The Impact of Gender on the Landing Error Scoring System: A Systematic Review and Meta-Analysis

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Received: 29 August 2025 | **Revised:** 30 April 2026 | **Accepted:** 7 May 2026

Keywords: ACL | anterior cruciate ligament | landing error scoring system | LESS | sex differences

ABSTRACT

Background: Women are more likely than men to experience injuries to the anterior cruciate ligament (ACL). Biomechanical differences, assessed using tools such as the Landing Error Scoring System (LESS), may contribute to this risk. The LESS does not directly influence ACL injury risk but helps identify individuals who might be at higher risk. However, conflicting findings in the literature prevent clear conclusions about sex-based differences in LESS scores. This study systematically reviews and meta-analyzes research examining the influence of sex on LESS scores.

Methods: Four databases (ScienceDirect, PubMed, Web of Science, and Scopus) were searched from 2009 (when LESS was introduced) to May 21, 2024. Only studies evaluating the impact of sex on LESS scores were included. Studies were screened for bias risk and critically appraised. A meta-analysis was performed utilizing a random-effects model, where sex served as the independent variable and LESS scores represented the dependent variable. The quality of evidence was assessed with the GRADE criteria. This study was registered with PROSPERO.

Results: Sixteen studies met the inclusion criteria. Females showed significantly higher LESS scores than males ($p < 0.0001$), with a mean difference of 0.62 errors. However, substantial heterogeneity was observed across studies, and the overall quality of evidence was rated as very low according to GRADE.

Conclusions: Although a statistically significant difference between sexes was identified, the mean difference of 0.62 errors is not clinically meaningful. The findings should be interpreted with caution due to their high heterogeneity and very low-quality evidence. Furthermore, sex differences in LESS scores may be context-dependent and influenced by population characteristics and study conditions.

Trial Registration: PROSPERO (CRD 42023470540, October 19, 2023)

1 | Introduction

Injuries to the Anterior Cruciate Ligament (ACL) are frequent among athletes, accounting for approximately 26% of all knee-related injuries (Akbari et al. 2019; Hootman et al. 2007). In the USA, treating an ACL injury costs around \$17,000 (Parkkari et al. 2008), and over 25% of individuals cannot return to their

previous activity levels post-surgery (Brophy et al. 2012). ACL injuries can lead to lost training time, reduced performance, early knee osteoarthritis, and decreased knee function (Krosshaug et al. 2016). Females are 2–8 times more likely to suffer from ACL injuries than males (Prodromos et al. 2007), with non-contact incidents, such as improper jump-landing, being the primary

Abbreviations: ACL, Anterior Cruciate Ligament; LESS, Landing Error Scoring System; NOS, Newcastle–Ottawa Assessment Scale; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ROBINS-I, Risk Of Bias in Non-randomized Studies—of Interventions.

cause (Onate et al. 2010). Understanding the mechanisms and risk factors of ACL injuries is crucial for prevention (Hewett and Johnson 2010). While both sexes are vulnerable during sports movements, females face higher risks due to anatomical, hormonal, and neuromuscular factors (Hewett et al. 2009). Of these, neuromuscular deficits are modifiable, making them the primary focus for reducing injury risk (Jagadeesh et al. 2021).

The Landing Error Scoring System (LESS) is a commonly utilized clinical tool designed to assess an individual's movement mechanics during a jump-landing activity (Hagstrom et al. 2021; Kuenze et al. 2018; Lisman et al. 2021). It has proven especially useful in detecting abnormal movement patterns that could increase the risk of lower limb injuries in athletes, such as tears in the anterior cruciate ligament (ACL) (Kuenze et al. 2018; Lisman et al. 2021). Several studies have reported significant differences in LESS scores between men and women, with women generally exhibiting greater total landing errors (Kuenze et al. 2018; Sangjan et al. 2017). Errors that seem to occur more frequently in females include greater trunk flexion at the moment of initial contact, inward knee alignment at initial contact, and increased knee movement in the frontal plane (Kuenze et al. 2018). LESS analyzes a double-leg jump-landing task captured by two video cameras from the front and side views. Clinicians evaluate the footage to identify abnormal lower body and trunk movements during landing. They score 17 items based on the presence of movement errors, with a maximum possible score of 19, though the practical maximum is 17 (Padua et al. 2015, 2012). A higher LESS score reflects an increased number of landing errors, indicating suboptimal landing biomechanics and a greater likelihood of non-contact lower extremity injuries, including ACL injuries. The LESS is valued for its simplicity and effectiveness in early injury detection, aiding in preventing ACL injuries through targeted interventions (Padua et al. 2009).

The LESS is widely used in clinical practice and research due to its simplicity and minimal resource requirements, making it ideal for screening large groups of athletes (DiStefano et al. 2018; Welling et al. 2016). Understanding the factors influencing LESS scores is crucial for accurate interpretation, particularly when comparing male and female athletes. Some research indicates that there is no notable variation in LESS scores between genders (Bell et al. 2016; Boshi et al. 2024; Garbenyté-Apolinskienė et al. 2018; Jacobs et al. 2018; Marques et al. 2023; Smith et al. 2012; Welling et al. 2016; Wesley et al. 2015; Zhang et al. 2024), others report higher scores in females, leading to conflicting results (Beutler et al. 2009; de la Motte et al. 2016; DiStefano et al. 2018; Kuenze et al. 2018; Lam and McLeod 2014; Ogul and Ercan 2022; Padua et al. 2009; Theiss et al. 2014). The findings of prior studies on this topic have been inconsistent. However, given the surge in new studies and the growing emphasis on sex differences in sports injuries, particularly Anterior Cruciate Ligament (ACL) injuries, there is a compelling need to re-examine the impact of sex on LESS scores. Understanding sex differences in LESS scores can significantly contribute to the design of more targeted preventive programs to reduce injury risk in women. This meta-analysis and systematic review sought to comprehensively examine the literature on the role of sex as a factor influencing LESS.

2 | Methods

This systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al. 2009) to ensure a thorough and transparent synthesis of research findings. The review was officially registered in the PROSPERO database on October 19, 2023, under the registration number CRD 42023470540.

2.1 | Search Strategy

A thorough review of the literature was performed to locate pertinent articles available up to May 21, 2024, using four primary academic databases: ScienceDirect, PubMed, Web of Science, and Scopus. The investigation centered on research employing the Landing Error Scoring System (LESS) and incorporated keywords such as "Landing Error Scoring System" or "LESS" in combination with phrases related to gender differences. The search start date was adjusted to the earliest year of LESS usage in literature (2009) to ensure relevance, based on reviewer feedback.

To maximize the coverage, we performed a thorough manual review of reference lists from selected articles, identifying additional studies not indexed in the databases. This combination of database searching and reference list review was implemented to capture a comprehensive and relevant selection of studies addressing the influence of sex on LESS.

2.2 | Eligibility Criteria

A study was considered for inclusion in this systematic review if it met the following conditions:

- Type of study: Cross-sectional studies, prospective cohort studies, and randomized controlled trials (RCTs).
- Type of participants: Studies comparing sexes, with samples comprising both male and female athletes as well as military personnel.
- Competitional levels: Studies involving recreational, university, and team athletes.
- Language: The articles included in the analysis were published in either English or Chinese.
- Data Criteria: Studies qualified for statistical analysis if they provided separate means and standard deviations (SD) for males and females regarding the Landing Error Scoring System (LESS) and included information about the number of participants.

The following criteria were used to exclude studies:

- Samples composed solely of non-athletes.
- Studies focused exclusively on one gender.
- Qualitative, survey-based research or studies lacking critical data.

2.3 | Data Collection Process

Two researchers (MSA and HA) conducted independent systematic searches across several databases to locate relevant titles and abstracts. The results were carefully organized using EndNote (version X21 for Windows), which was employed to detect and

eliminate duplicate entries from different sources. Following this, both researchers evaluated the titles and abstracts to determine their suitability for inclusion in the study, prior to moving on to a full-text review. Additionally, the reference lists of eligible studies were examined to identify further studies that met the inclusion criteria. Following the initial screening, both authors, MSA and HA, independently examined the complete versions of the selected studies. They compared these studies against the predefined inclusion and exclusion criteria to ensure consistency and accuracy in the selection process. MSA and HA thoroughly discussed any disagreements regarding the inclusion of specific articles. In cases where a consensus could not be reached, the issue was referred to a third author (AEA) for resolution, and a final decision was made collectively. Furthermore, the authors registered the mean values for the LESS and extracted the corresponding standard deviations (SD) for both male and female participants.

2.4 | Risk of Bias

Prior to conducting the risk of bias assessment, two reviewers (MSA and HA) familiarized themselves with various evaluation tools. These included the Newcastle–Ottawa Assessment Scale (NOS) modified for cross-sectional studies (Modesti et al. 2016), the revised Risk of Bias tool for randomized trials (RoB 2.0) (Sterne et al. 2019), and the Risk Of Bias in Non-randomized Studies of Interventions (ROBINS-I) (Sterne et al. 2016). This preparation enabled both reviewers to thoroughly understand each tool's criteria and methodology, ensuring an accurate assessment of the quality and potential biases in the included studies.

To minimize assessment bias, a third party anonymized each article by removing identifiable information, such as authors' names, affiliations, countries, and publication sources. The potential for bias in each study was assessed with a particular focus on the LESS outcome score, following the recommendations outlined in the guidelines (Büttner et al. 2020). In cases of discrepancies in the risk of bias assessment scores, reviewers engaged in discussions to reach a consensus. The agreed-upon scores are summarized in the review (Table 1).

To evaluate the overall evidence quality, the GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) framework was utilized in accordance with the protocols for systematic reviews and meta-analyses. We assessed the quality of evidence using the GRADE approach, considering factors such as bias risk, inconsistency, indirectness, imprecision, and potential publication bias. Each study was rated as having high, moderate, low, or very low confidence in the estimated effect. The final GRADE scores reflect the certainty of evidence supporting the main outcomes, which are reported in this article.

2.5 | Demographic Characteristics

The PRISMA Flow Diagram provides a visual representation of the information flow during the process, outlining the inclusion of studies in the systematic review and meta-analysis (Figure 1). The review focused on LESS scores during jump-landing in both males and females. Out of these, 16 articles progressed to the meta-analysis stage (Bell et al. 2016; Beutler et al. 2009; Boshi

et al. 2024; de la Motte et al. 2016; DiStefano et al. 2009; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Kuenze et al. 2018; Lam and McLeod 2014; Marques et al. 2023; Ogul and Ercan 2022; Smith et al. 2012; Theiss et al. 2014; Welling et al. 2016; Wesley et al. 2015; Zhang et al. 2024).

2.6 | Synthesis of Results

The researchers conducted a random effects meta-analysis to account for differences among studies, using Microsoft Excel and Review Manager Version 5.4 from The Cochrane Collaboration in Denmark. This model was particularly applied when the I^2 statistic exceeded 50%, indicating high heterogeneity (Maher et al. 2003). To strengthen our findings, we performed subgroup and sensitivity analyses based on participant type and competition level. Furthermore, the evaluation of publication bias through funnel plots and Egger's test revealed no significant evidence of bias.

3 | Results

A total of 402 articles were identified from the databases based on our search keywords. After removing 243 duplicates, 159 articles remained for screening by title and abstract, from which 117 were excluded. We reviewed 42 full-text articles, excluding 23 based on the inclusion and exclusion criteria. Ultimately, only 16 studies advanced to the systematic review and meta-analysis (Bell et al. 2016; Beutler et al. 2009; Boshi et al. 2024; de la Motte et al. 2016; DiStefano et al. 2009; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Kuenze et al. 2018; Lam and McLeod 2014; Marques et al. 2023; Ogul and Ercan 2022; Smith et al. 2012; Theiss et al. 2014; Welling et al. 2016; Wesley et al. 2015; Zhang et al. 2024), following several exclusions: two studies (DiStefano et al. 2018; Padua et al. 2009) lacked sufficient quantitative data, and one study (Pryor et al. 2022) employed a different methodology and types of exercises (Figure 1). Detailed demographics and characteristics of these studies are summarized in Table 2.

The RoB 2.0 Risk of Bias for Randomized Trials was utilized in 6 studies (42.1%) (Bell et al. 2016; Boshi et al. 2024; DiStefano et al. 2018; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Welling et al. 2016), with three studies demonstrating a low risk of bias (Bell et al. 2016; Welling et al. 2016), four studies showing a moderate risk of bias (Boshi et al. 2024; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Pryor et al. 2022), and one study identified as having a high potential for bias (DiStefano et al. 2009).

The ROBINS-I risk of bias tool was applied to 4 non-randomized studies (21.1%) (Beutler et al. 2009; de la Motte et al. 2016; Smith et al. 2012; Zhang et al. 2024), all of which exhibited a moderate risk of bias (Beutler et al. 2009; de la Motte et al. 2016; Smith et al. 2012; Zhang et al. 2024) (Table 1).

For the meta-analysis, we used data from 16 studies, encompassing 2960 male and 1801 female participants (Bell et al. 2016; Beutler et al. 2009; Boshi et al. 2024; de la Motte et al. 2016; DiStefano et al. 2009; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Kuenze et al. 2018; Lam and McLeod 2014; Marques et al. 2023; Ogul and Ercan 2022; Smith et al. 2012; Theiss et al. 2014; Welling et al. 2016; Wesley et al. 2015; Zhang

TABLE 1 | Evaluation of bias risk utilizing RoB 2.0 for randomized controlled trials (RCTs), ROBINS-I for non-randomized studies, and NOS for cross-sectional studies.

Risk of bias	Study (year)	Type of study	Overall risk of bias
RoB 2.0 for RCTs	Garbenytė-Apolinskienė et al. (2018)	Randomized controlled trial	Moderate
	Jacobs et al. (2018)	Randomized controlled trial	Moderate
	Boshi et al. (2024)	Randomized controlled trial	Moderate
	Bell et al. (2016)	Randomized controlled trial	Low
	Welling et al. (2016)	Randomized controlled trial	Low
	DiStefano et al. (2009)	Cluster- randomized controlled trial	High
ROBINS-I for non-randomized	Smith et al. (2012)	Case-control study	Moderate
	de la Motte et al. (2016)	Prospective cohort study	Moderate
	Beutler et al. (2009)	Prospective cohort study	Moderate
	Zhang et al. (2024)	Prospective cohort study	Moderate
NOS for cross-sectional	Marques et al. (2023)	Cross-sectional study	Low
	Ogul and Ercan (2022)	Cross-sectional study	Moderate
	Kuenze et al. (2018)	Cross-sectional study	Moderate
	Wesley et al. (2015)	Cross-sectional study	Low
	Lam and McLeod (2014)	Cross-sectional study	Moderate
	Theiss et al. (2014)	Cross-sectional study	Low

Note: RoB 2.0: The RoB 2.0 tool for assessing the risk of bias in randomized trials. ROBINS-I: The ROBINS-I Risk of Bias tool was applied fore Non-Randomized Study. NOS: The Newcastle–Ottawa Assessment Scale (NOS) was employed for Cross-Sectional Study.

et al. 2024). Seven studies (Beutler et al. 2009; de la Motte et al. 2016; DiStefano et al. 2009; Kuenze et al. 2018; Lam and McLeod 2014; Ogul and Ercan 2022; Theiss et al. 2014) found that females had significantly higher LESS scores than males, indicating a greater frequency of landing errors. In contrast, nine studies (Bell et al. 2016; Boshi et al. 2024; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Marques et al. 2023; Smith et al. 2012; Welling et al. 2016; Wesley et al. 2015; Zhang et al. 2024) reported no significant difference in LESS scores between sexes. Given the substantial heterogeneity ($I^2 = 55\%$, $p = 0.004$), a random-effects model was applied (Hanzlíková et al. 2021). The meta-analysis findings revealed that females had significantly higher LESS scores than males ($p < 0.0001$). However, the mean difference of $-0.62 [-0.81, -0.43]$ errors was considered clinically insignificant, as it amounted to less than one error (Figure 2).

We utilized the GRADE framework to evaluate the quality of evidence, considering aspects such as risk of bias, inconsistency, indirectness, imprecision, and potential publication bias. The studies were rated across confidence levels from high to very low, with findings incorporated into the overall evaluation presented in this article.

4 | Discussion

This systematic review and meta-analysis examined sex differences in Landing Error Scoring System (LESS) scores, particularly focusing on disparities in jump-landing biomechanics between males and females. The LESS tool is a valuable standardized measure for assessing landing biomechanics, specifically movement patterns that may predispose individuals to injury, especially in high-risk groups such as athletes and military personnel (Padua et al. 2015, 2012). Anterior cruciate ligament (ACL) injuries, which are often linked to improper landing techniques, show a significantly higher

incidence in female athletes compared to males, emphasizing the importance of understanding sex-specific LESS differences for effective injury prevention (Kuenze et al. 2018; Wesley et al. 2015). Although our results showed statistically significant differences, with females typically having higher LESS scores than males, the mean difference of 0.62 errors is not clinically meaningful and should not be interpreted as indicative of a meaningful difference in injury risk. Our analysis revealed inconsistent findings across studies regarding the impact of sex on LESS scores. Of the 16 studies included, seven indicated significantly higher LESS scores among females, suggesting that females may experience more frequent errors in landing technique (Beutler et al. 2009; de la Motte et al. 2016; DiStefano et al. 2009; Kuenze et al. 2018; Lam and McLeod 2014; Ogul and Ercan 2022; Theiss et al. 2014).

On the other hand, nine studies found no substantial sex-based differences, suggesting that the relationship between sex and LESS scores may be complex and context-dependent (Bell et al. 2016; Boshi et al. 2024; Garbenytė-Apolinskienė et al. 2018; Jacobs et al. 2018; Marques et al. 2023; Smith et al. 2012; Welling et al. 2016; Wesley et al. 2015; Zhang et al. 2024). Studies that observed higher scores in females frequently attributed this trend to neuromuscular and biomechanical factors, such as increased trunk flexion and knee valgus, both of which are recognized as risk factors for ACL injury (Hewett et al. 2009; Kuenze et al. 2018). These findings underscore the importance of a multifactorial approach to studying landing biomechanics, taking into account anatomical, neuromuscular, and hormonal influences (Hewett et al. 2009).

The observed differences in LESS scores between males and females may arise from various biological and developmental factors. Literature suggests that females undergo pubertal changes, including increased joint laxity and altered muscle activation patterns, which can compromise neuromuscular control and

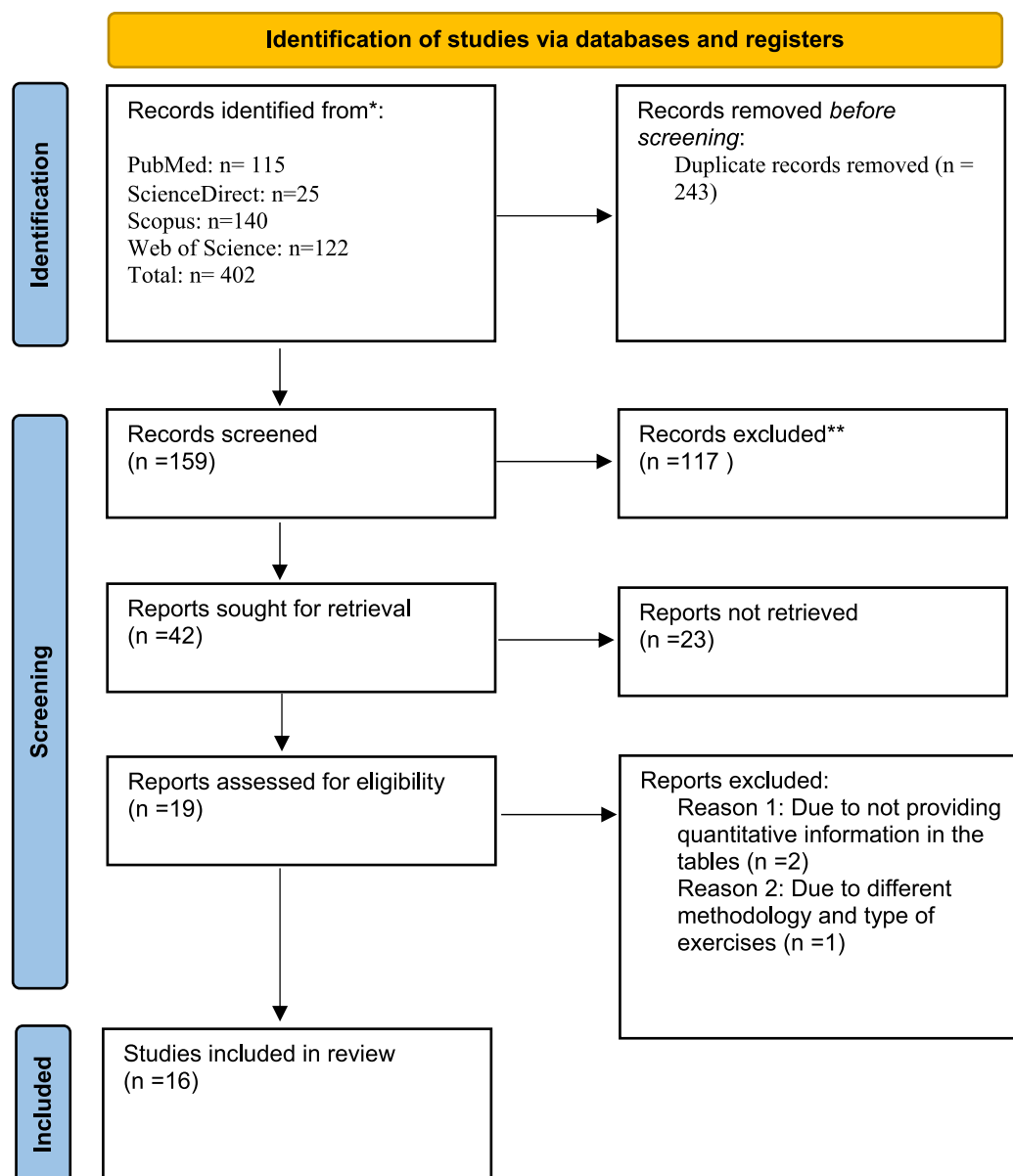


FIGURE 1 | PRISMA flow diagram illustrating the process of information flow during the inclusion of studies in the systematic review and meta-analysis.

contribute to less stable landings (Holden et al. 2016). This is particularly relevant given that puberty has been linked to heightened susceptibility to ACL injury among females. Consequently, intervention programs targeting adolescent females may play a critical role in reducing ACL injury risks by enhancing stability and neuromuscular control during landing maneuvers. Additionally, previous knee injuries in females are linked to heightened ACL risk, especially in those who do not engage in preventive programs (Voskanian 2013). In contrast, males generally maintain lower LESS scores across age groups, possibly due to differing neuromuscular development patterns (Hands et al. 2013).

Most studies included in this review focused on athletic and military populations, who typically exhibit higher physical demands and greater susceptibility to ACL injuries (Owens 2014).

Although these studies provide valuable insights, they may not adequately represent the general population. Future research should consider including more diverse samples to enhance the generalizability of findings across broader, non-athletic groups. Furthermore, variations in LESS scores have been observed based on activity level and competition intensity, with higher intensity athletes often demonstrating different movement patterns compared to recreational athletes or non-athletes. Such variability indicates that LESS scores may be influenced by the level of sport participation, further complicating the interpretation of results.

One significant challenge in synthesizing LESS data across studies is the variation in protocols and scoring methods, which can impact the reliability and comparability of findings. Differences in camera setup, sampling frequency, and the calculation

TABLE 2 | An overview of comparative research analyzing the differences in LESS scores between men and women.

Study (y)	Sample size (n)	Population	Age (y) ^a	Height (cm) ^a	Weight (kg) ^a	Body mass index ^a	Less score (errors) ^a	Comparison F versus M	Type of study
Boshi et al. (2024)	F: 16	Physical education students	F: 21.8 ± 1.5	F: 164.3 ± 4.8	F: 55.8 ± 7.2	F: 20.7	F: 6.8 ± 1.3	Females demonstrated significantly higher scores than males ($p < 0.001$).	RCT
	M: 19		M: 20.2 ± 2.0	M: 175.0 ± 4.7	M: 72.9 ± 10.4	M: 23.8	M: 6.3 ± 1.9		
	Total: 35								
Zhang et al. (2024)	F: 70	College soccer	F: 19.90 ± 1.42	F: 163 ± 0.05	F: 54.23 ± 6.09	F: 20.34 ± 1.96	F: 8.04 ± 1.45	No significant difference between males and females ($p > 0.05$)	Prospective cohort study
	M: 149		M: 20.06 ± 1.70	M: 177 ± 0.06	M: 69.13 ± 8.62	M: 22.11 ± 2.36	M: 8.09 ± 1.73		
	Total: 219								
Marques et al. (2023)	F: 31	Soccer players	F: 20 ± 2	Not specified	Not specified	Not specified	F: 2.81 ± 1.64	No significant difference between groups was found $p = 0.779$	Cross-sectional
	M: 36		M: 20 ± 1				M: 2.56 ± 1.25		
	Total: 67								
Ogul and Ercan (2022)	F: 28	Recreational athletes	F: 21.8 ± 1.2	F: 164.4 ± 5.5	F: 57.1 ± 5.8	F: 21.1 ± 1.1	F: 7.6 ± 1.8	Females demonstrated significantly higher scores compared to males (7.61 ± 1.81 vs. 6.22 ± 1.97 , $p = 0.009$).	Cross-sectional
	M: 27		M: 21.7 ± 0.9	M: 177.3 ± 6.5	M: 73.5 ± 10.1	M: 23.3 ± 2.6	M: 6.2 ± 2.0		
	Total: 55								
Kuenze et al. (2018)	F: 127	Individuals following ACL reconstruction	F: 19	F: 168.0	F: 65.7	F: 23.3	F: 6.1 ± 2.3	$p < 0.001$	Cross-sectional
	M: 41		M: 20	M: 180	M: 83.2	M: 25.7	M: 4.6 ± 2.3		
	Total: 168								
Garbentyé-Apolinskienė et al. (2018)	F: 16	Basketball athletes	F: 15.42 ± 0.27	F: 176 ± 0.07	F: 64.88 ± 7.11	F: 20.9	F: 6.6 ± 1.8	Not specified	RCT
	M: 15		M: 15.36 ± 0.29	M: 184 ± 0.09	M: 67.20 ± 11.81	M: 19.8	M: 6.9 ± 2.3		
	Total: 31								
Jacobs et al. (2018)	F: 20	Recreationally active population	F: 23.4 ± 2.8	F: 166 ± 6.2	F: 58.9 ± 6.7	F: 21.4	F: 5.1 ± 1.5	Non-significant $p = 0.624$	RCT
	M: 20		M: 24.4 ± 1.8	M: 184 ± 6.1	M: 79.6 ± 7.8	M: 23.5	M: 5.1 ± 2.2		
	Total: 40								
Bell et al. (2016)	F: 19	A population engaged in recreational physical activities	F: 21.2 ± 1.4	F: 169.9 ± 6.1	F: 71.9 ± 9.2	F: 24.9	F: 5.3 ± 2.1	The p -value of 0.56 indicates a non-significant result	RCT
	M: 20		M: 20.9 ± 1.2	M: 178.6 ± 8.7	M: 78.9 ± 5.6	M: 24.7	M: 4.7 ± 2.3		
	Total: 39								
Welling et al. (2016)	F: 20	Athletes participating in team ball sports	F and M: 22.50 ± 1.62	F and M: 180 ± 0.14	F and M: 72.4 ± 10.38	F and M: 22.3	F: 3.1 ± 0.7 ^b	Not statistically significant ($p > 0.05$)	RCT
	M: 20						M: 2.8 ± 1.0 ^b		
	Total: 40								
de la Motte et al. (2016)	F: 90	Individuals applying to join the United States Army	F: 20.9 ± 3.2	F: 162.7 ± 6.9	F: 60.5 ± 7.9	F: 22.9 ± 2.5	F: 6.5 ± 1.8	$p < 0.001$	Prospective cohort study
	M: 431		M: 20.8 ± 3.0	M: 176.4 ± 7.2	M: 75.7 ± 11.4	M: 24.3 ± 3.1	M: 5.5 ± 2.1		
	Total: 521								
Wesley et al. (2015)	F: 18	Sports participants	F: 19.2 ± 0.9	F: 169 ± 7.8	F: 65.2 ± 7.1	F: 22.8	F: 6.3 ± 1.9	$p \leq 0.05$	Cross-sectional
	M: 18		M: 19.4 ± 1.4	M: 185.4 ± 6.5	M: 83.1 ± 13.2	M: 24.2	M: 5.0 ± 2.3		
	Total: 36								
Lam and McLeod (2014)	F: 99	Athletes participating in school-level competitive sports	F: 19.1 ± 1.1	F: 167 ± 8.4	F: 63.6 ± 9.0	F: 27.2	F: 5.8 ± 2.3	Statistically insignificant ($p > 0.05$)	Cross-sectional
	M: 116		M: 19.4 ± 1.5	M: 181.4 ± 8.5	M: 76.6 ± 10.6	M: 19.4	M: 5.1 ± 2.5		
	Total: 215								

(Continues)

TABLE 2 | (Continued)

Study (y)	Sample size (n)	Population	Age (y) ^a	Height (cm) ^a	Weight (kg) ^a	Body mass index ^a	Less score (errors) ^a	Comparison F versus M	Type of study
Theiss et al. (2014)	F: 55 M: 222 Total: 277	US military trainees	F and M: 19.3 ± 0.8	F and M: 177.4 ± 7.37	F and M: 75.79 ± 9.2	F and M: 24.1	F: 5.6 ± 0.5 ^b M: 5.1 ± 0.2 ^b	$p = 0.05$	Cross-sectional
Smith et al. (2012)	F: 63 M: 29 Total: 92	Athletes from colleges and high schools	F: 18.0 ± 1.7 M: 18.5 ± 2.5	M and F: 171.9 ± 12.4	M and F: 70.9 ± 15.6	M and F: 24	F: 5.0 ± 1.9 ^b M: 5.5 ± 2.1 ^b	The p -value of 0.22 indicates a non-significant result.	Case-control
Beutler et al. (2009)	F: 1046 M: 1707 Total: 2753	US military trainees	18–24	F: 1.66 ± 0.07 M: 1.78 ± 0.07	F: 63.0 ± 7.8 M: 77.4 ± 12.3	F: 22.9 ± 3.1 M: 24.3 ± 3.1	F: 5.3 ± 1.5 M: 4.7 ± 1.7	$p < 0.001$	Prospective cohort study
DiStefano et al. (2009)	F: 83 M: 90 Total: 173	Football players	F: 14 ± 2 M: 13.0 ± 2.0	F: 162 ± 8 M: 164 ± 13	F: 51 ± 10 M: 51 ± 14	F: 19.4 M: 19	F: 5.8 ± 1.9 M: 4.4 ± 1.7	Not specified	Cluster-RCT

Abbreviations: ACL, Anterior Cruciate Ligament; ACLR, Anterior Cruciate reconstruction; F, females; LESS, Landing Error Scoring System; M, males; NCAA, National Collegiate Athletic Association; RCT, randomized controlled trial; US, United States; Y, year.
^aMean ± standard deviation values for age (years), Height (m), Weight (kg), Body Mass Index and LESS score (errors).
^bWeighted mean ± standard deviation values calculated according to sample size.

approach—such as using the average of multiple jumps versus selecting the best single jump—may introduce inconsistencies in reported LESS scores (Distefano et al. 2013; Jacobs et al. 2018; Kuenze et al. 2018). Standardizing protocols for future research in crucial to ensure consistency and comparability across diverse study settings, thus enabling more reliable conclusions on sex-related differences in landing mechanics.

The diversity in study design and population samples led to substantial heterogeneity in the meta-analysis ($I^2 = 55\%$), which may limit the reliability of pooled estimates. This heterogeneity, along with potential sources such as differences in participant characteristics, study design, and LESS assessment protocols, contributes to increased uncertainty and lowers the overall quality of evidence, which was rated as very low according to the GRADE framework. Therefore, the findings of this study should be interpreted with caution and should not be overgeneralized. Nevertheless, we incorporated all accessible studies that investigated LESS as a primary outcome, regardless of their design or potential bias, to provide a thorough evaluation of the existing literature. However, it is worth noting that limiting our analysis to randomized controlled trials with low bias risk could potentially yield different interpretations. Additionally, the NOS tool, which was used to assess the risk of bias, may not be fully appropriate for observational cross-sectional studies. Different LESS scoring methodologies, testing protocols, and parameters across studies further contribute to variability, which may influence reported LESS scores and, consequently, the analysis results (Distefano et al. 2013; Garbenytė-Apolinskienė et al. 2018; Hanzlíková et al. 2020).

Research indicates that the influence of sex on LESS scores can differ with age, particularly during puberty. For instance, pubescent females with a history of ACL injuries who have not engaged in preventive programs often show the highest LESS scores, whereas males above 20 years old with no prior injuries typically demonstrate lower scores. Although these factors are critical in understanding sex-based LESS score differences across age groups, they were not specifically examined in this review. Other influences, such as previous injuries (Lam and McLeod 2014), intervention programs (Akbari et al. 2019; Distefano et al. 2013; DiStefano et al. 2009; Garbenytė-Apolinskienė et al. 2018), fatigue (Bell et al. 2016; Gokeler et al. 2014; Wesley et al. 2015), level of sport and competition (DiStefano et al. 2018; Theiss et al. 2014), and levels of strength (Beutler et al. 2009; Lepley et al. 2013), may have a substantial impact on LESS scores, but were beyond the scope of this study.

This systematic review and meta-analysis indicates that females may exhibit slightly higher LESS scores than males, suggesting a greater frequency of landing errors; however, the magnitude of this difference (less than one error) is unlikely to be clinically meaningful and should be interpreted with caution. The overall certainty of the evidence is very low, and substantial heterogeneity across studies, along with variations in participant characteristics and methodologies, further limits the reliability and generalizability of these findings. Moreover, inconsistent and sometimes contradictory results in the literature suggest that sex differences in landing biomechanics are context-dependent and influenced by multiple interacting factors beyond sex alone. Therefore, firm conclusions regarding sex-based differences in

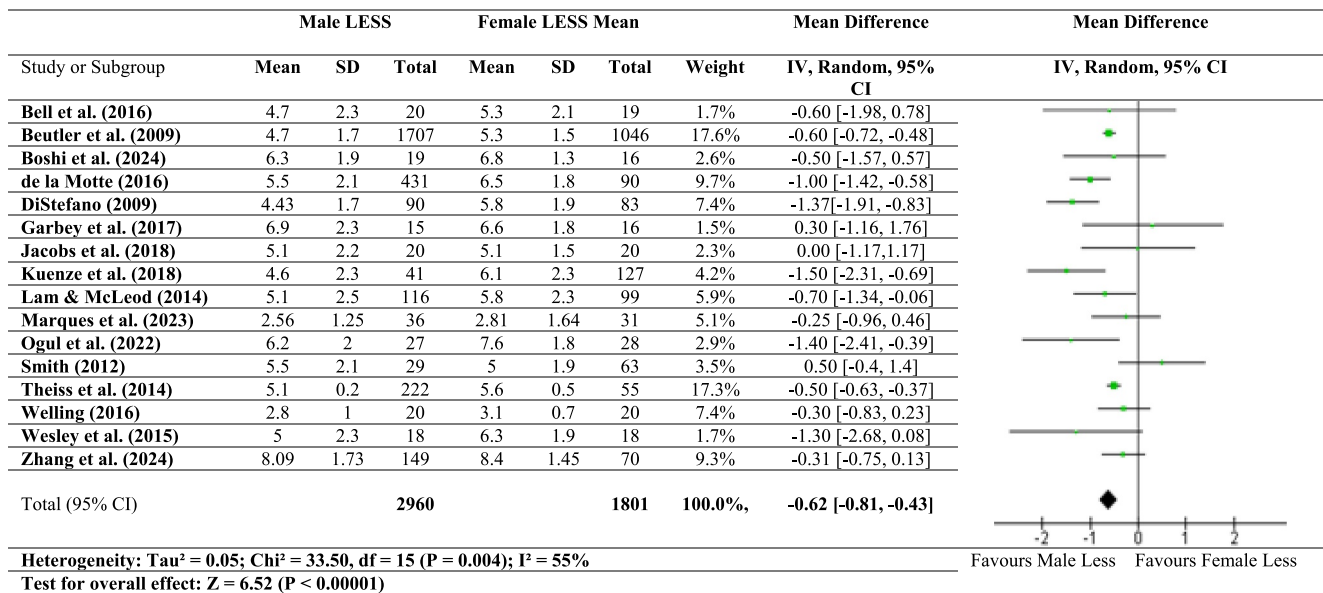


FIGURE 2 | Forest plots illustrating the mean difference (MD) in landing error scoring system scores between genders (females vs. males). CI: Confidential Intervals; F: Females; LESS: Landing Error Scoring System; M: Males; SD: Standard Deviation

LESS scores and their implications for ACL injury risk cannot be drawn, and future research using standardized protocols and more diverse populations is needed to better clarify these relationships and inform targeted injury prevention strategies.

5 | Implications on Physiotherapy Practice

It has been found that females generally score higher on LESS than males. However, the difference of 0.62 errors between the two sexes is not significant enough to have any clinical implications. This indicates that variations in landing mechanics, as evaluated by LESS, might not be the sole factor contributing to the increased overall risk of anterior cruciate ligament (ACL) injuries seen in females.

Author Contributions

M.A. and H.A. conducted the database searches, collected data, and provided initial interpretation of the results. M.S., H.A., A.E.A., and B.S. guided the data interpretation and manuscript drafting processes. M.S.A. was responsible for the initial drafting of the article, which was reviewed and edited with assistance from H.A., A.E.A. and B.S. All authors participated in the conception, design, and data interpretation. All authors critically reviewed the manuscript for important content and approved the final version for submission. All authors have read and approved the final manuscript.

Acknowledgments

The authors have nothing to report.

Funding

The authors have nothing to report.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

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