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Sprint Biomechanics Associated With Hamstring Strain Injury in Football: A Systematic Review and Mechanistic Synthesis

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Abstract

Background. Hamstring strain injury (HSI) is one of the most common non-contact injuries in football and frequently occurs during sprinting. Although several studies have examined sprint biomechanics in relation to HSI, findings remain dispersed across epidemiological and laboratory-based investigations, limiting the understanding of how sprint mechanics may contribute to injury risk.

Aim. To systematically synthesise evidence regarding the association between sprint biomechanics and HSI in football players, with particular attention to lumbopelvic control, neuromuscular activation, and force-production characteristics.

Methods. A systematic review was conducted according to PRISMA 2020 guidelines and registered in PROSPERO (CRD420251248990). Searches were performed in Scopus and PubMed. Studies involving football players that investigated sprint-related biomechanical variables and reported injury outcomes or biomechanical indicators associated with HSI were eligible. Due to substantial heterogeneity in study design, biomechanical measurements, and outcome reporting, findings were synthesised narratively.

Results. Six studies met the inclusion criteria, including two prospective cohort studies, one case–control study, and three mechanistic laboratory investigations. Prospective evidence suggested that greater gluteus maximus and trunk muscle activation during sprinting were associated with lower HSI occurrence, whereas increased anterior pelvic tilt and thoracic side bending were associated with greater injury susceptibility. Athletes with previous HSI demonstrated larger fatigue-related reductions in horizontal force production during repeated sprinting. Mechanistic studies consistently identified the late-swing and early-stance phases as periods of elevated strain and activation of the biceps femoris long head.

Conclusions. Current evidence suggests that impaired lumbopelvic control, altered neuromuscular activation, and reduced horizontal force production may contribute to increased hamstring loading during sprinting in football players. While causal inferences remain limited by the small number and heterogeneity of available studies, integrating epidemiological and mechanistic evidence provides a framework for understanding sprint-related HSI mechanisms and may inform injury prevention and rehabilitation strategies.

Keywords: Football performance; hamstring strain injury; horizontal force production; lumbopelvic control; neuromuscular activation; sprint biomechanics

1. INTRODUCTION

Hamstring strain injury (HSI) remains the most common non-contact injury in football and continues to impose substantial performance and economic burdens on professional clubs. Although established risk factors such as eccentric knee flexor weakness, short biceps femoris fascicle length, and excessive training-load exposure have been widely investigated, many injuries still occur during high-speed sprinting, suggesting that biomechanical factors may play an important role in injury development (Ekstrand et al., 2023; Timmins et al., 2016). During sprinting, the biceps femoris long head (BFlh) is exposed to high elongation velocities and substantial eccentric loading, particularly during the terminal swing phase when it contributes to decelerating knee extension and preparing the limb for ground contact (Schache et al., 2012). However, established risk factors alone do not fully explain how sprint-specific movement patterns generate injurious loading conditions, underscoring the need to understand the biomechanical mechanisms underlying sprint-related HSI better.

In recent years, research has increasingly focused on sprint biomechanics as a potential contributor to HSI risk (Dewi et al., 2025; Kalema et al., 2022; Mendiguchia et al., 2021; Sanjaya et al., 2025). Several biomechanical characteristics have been proposed, including lumbopelvic alignment, trunk posture, neuromuscular activation strategies, and horizontal force-production capabilities during sprinting (Edouard et al., 2021; Mendiguchia et al., 2021). These factors may influence the magnitude and distribution of loading experienced by the hamstring muscle-tendon unit, particularly the BFlh, during high-speed running (Schache et al., 2012; Yu et al., 2017). However, their relative contribution to injury susceptibility remains uncertain because findings have been generated using diverse methodological approaches, ranging from prospective injury-surveillance studies to laboratory-based biomechanical investigations and musculoskeletal simulations (Huygaerts et al., 2020; Kalema et al., 2022). Consequently, the extent to which these biomechanical factors consistently contribute to HSI risk in football players remains unclear.

Existing literature has investigated sprint-related HSI mechanisms from several distinct perspectives, including prospective injury-surveillance studies, biomechanical analyses, and mechanistic laboratory investigations. Prospective studies have primarily identified sprint-related biomechanical characteristics associated with future injury. In contrast, laboratory-based investigations have focused on muscle–tendon strain, neuromuscular activation patterns, and sprint kinetics, without clinical follow-up of injury. Consequently, the available evidence remains fragmented across epidemiological and mechanistic research domains, limiting the understanding of how specific sprinting characteristics contribute to hamstring injury susceptibility in football players. Therefore, this systematic review aimed not only to synthesise the available evidence but also to integrate epidemiological findings with mechanistic biomechanical evidence to provide a more comprehensive understanding of sprint-related HSI risk. Particular attention was given to lumbopelvic control, neuromuscular activation patterns, and horizontal force-production characteristics as potential contributors to hamstring loading during sprinting.

2. METHODS

2.1. Study design. This systematic review was conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Haddaway et al., 2022), and the protocol was prospectively registered in PROSPERO (ID: CRD420251248990).

2.2. Search strategy. The search strategy was conducted systematically in accordance with the PRISMA 2020 guidelines. The database search was conducted on 8 December 2025. Scopus was used as the primary database because of its extensive coverage of international journals in biomechanics and sports science, and the search was supplemented with PubMed to ensure comprehensive identification of relevant studies. Reference lists of all eligible studies were also manually screened to identify additional articles that may not have been retrieved through the electronic database search.

The keywords used were combinations of terms related to football, sprinting, sprint biomechanics, and injury risk. The Scopus search query was: (TITLE-ABS-KEY (football OR soccer) AND TITLE-ABS-KEY (sprint OR sprinting) AND TITLE-ABS-KEY (biomechanic OR kinematic OR "ground reaction force" OR GRF OR EMG OR "hamstring activation" OR "trunk lean" OR "step length" OR "contact time") AND TITLE-ABS-KEY (injury OR strain OR risk)).

The PubMed search query was: (("soccer"[Title/Abstract] OR "football"[Title/Abstract]) AND ("sprint"[Title/Abstract] OR "sprinting"[Title/Abstract]) AND ("biomechanics"[Title/Abstract] OR "ground reaction force"[Title/Abstract] OR "hamstring"[Title/Abstract] OR "EMG"[Title/Abstract] OR "trunk lean"[Title/Abstract] OR overstride[Title/Abstract]) AND (injury[Title/Abstract] OR strain[Title/Abstract] OR "injury risk"[Title/Abstract])).

The search was not restricted by publication year but was limited to peer-reviewed articles published in English. Gray literature sources (e.g. theses, dissertations, conference proceedings, and preprints) were not included because the review was restricted to peer-reviewed journal articles. All records retrieved from both databases were exported to reference management software for duplicate removal and subsequent screening. The search strategy was adapted to each database's indexing structure and search syntax.

2.3. Study selection and eligibility criteria. The selection process was conducted in several stages. All records identified through database searching were imported into a reference management software, and duplicate records were removed. Title and abstract screening were subsequently performed to identify potentially relevant studies. Full-text articles of potentially eligible records were then assessed against the predefined eligibility criteria. Two independent reviewers conducted the screening and full-text assessment, and disagreements were resolved through discussion. A third reviewer acted as arbiter when consensus could not be reached.

Studies were eligible if they: (1) included football players; (2) assessed sprint-related biomechanical variables (e.g. lumbopelvic alignment, trunk posture, neuromuscular activation, or force-production characteristics); (3) reported HSI occurrence or biomechanical indicators associated with HSI risk; and (4) employed prospective cohort, case–control, cross-sectional, or laboratory-based biomechanical designs.

Studies were excluded if they involved non-football populations, lacked sprint biomechanics assessments, were reviews, editorials, or conference abstracts without original data, or did not report relevant injury-related outcomes.

2.4. Study selection and data extraction. Data from studies that entered the full-text stage were extracted using a standard form. The information collected included: authors and year of publication, sample characteristics (age, gender, player level), study design, sprint task used (acceleration, maximal velocity, or change of direction), biomechanical instruments (3D motion capture, 2D video, EMG, IMU, force plate), biomechanical variables measured, types of injuries or injury risk factors analysed, and key findings related to the relationship between sprint biomechanics and injury risk. Two assessors performed the extraction independently to ensure consistency, and differences were resolved through discussion.

2.5. Risk of bias assessment. Risk of bias was assessed using the Risk Of Bias In Non-randomised Studies of Interventions (ROBINS-I) tool. The following domains were evaluated: confounding, participant selection, classification of exposures, deviations from intended exposures, missing data, outcome measurement, and selection of reported results. Two reviewers independently assessed all eligible studies, and disagreements were resolved through discussion.

2.6. Data synthesis. Due to substantial heterogeneity in study design, biomechanical measurement techniques, injury definitions, and outcome reporting, a meta-analysis was not considered appropriate. Therefore, findings were synthesised narratively following guidance for systematic reviews of heterogeneous evidence. Studies were grouped according to major biomechanical domains, including lumbopelvic alignment, trunk posture, neuromuscular activation patterns, and horizontal force-production characteristics. The direction and consistency of findings were compared across studies to identify common biomechanical mechanisms associated with HSI risk.

3. RESULTS

3.1. Study selection. A total of 197 records were identified through database searching (Scopus *n* = 69; PubMed *n* = 128). After removing 35 duplicates, 162 records were screened based on title and abstract. Of these, 155 records were excluded for the following reasons: reasons for exclusion included lack of sprint biomechanics focus (*n* = 102), absence of injury-related outcomes (*n* = 56), non-football populations (*n* = 20), review/commentary articles (*n* = 8), and other reasons (*n* = 4). Therefore, the sum of exclusion categories exceeded the total number of excluded records. Categories were not mutually exclusive. Seven full-text articles were assessed for eligibility, with one excluded due to the unavailability of the full-text document. Finally, six studies met the inclusion criteria and were included in the systematic review, consisting of two prospective cohort studies, one case–control study, and three mechanistic laboratory studies. The study selection process is presented in Figure 1.

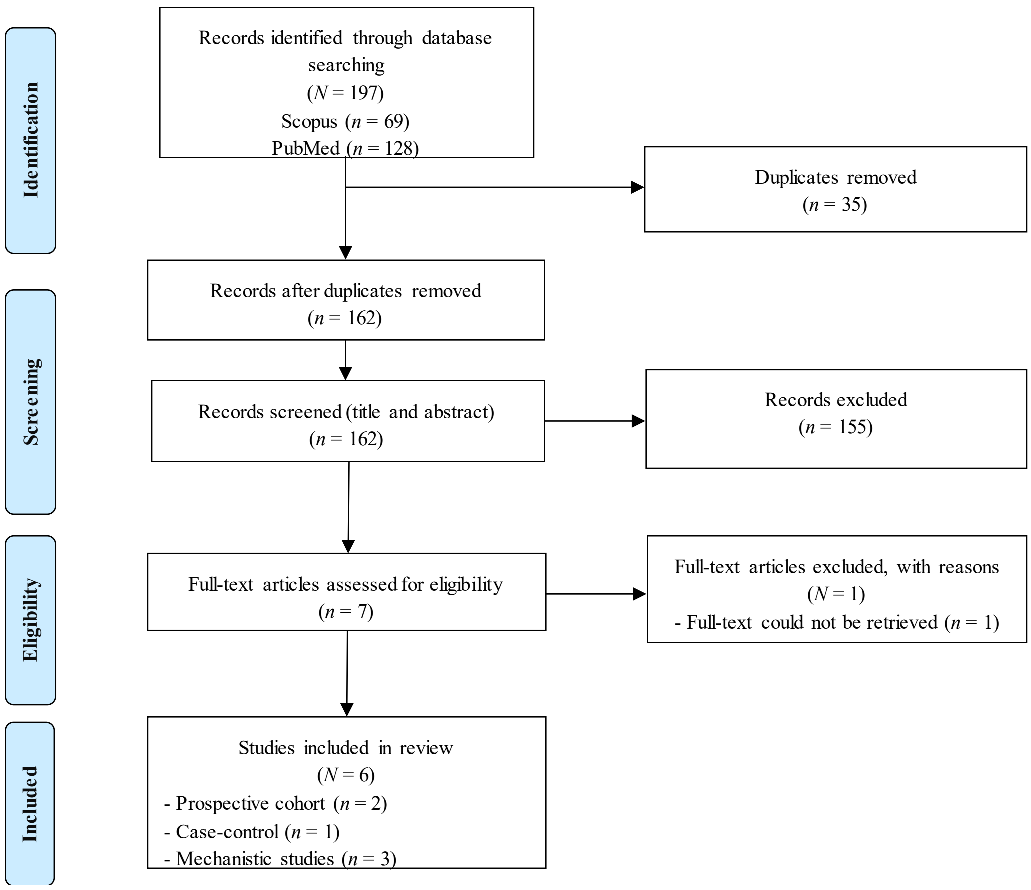

Figure 1. **PRISMA 2020 flow diagram of the study selection process**

3.2. Characteristics of included studies

Six studies, published between 2016 and 2025 and conducted in Belgium, Australia, Qatar, and Spain, met the inclusion criteria. Sample sizes ranged from 10 to 60 male soccer athletes, including amateur, semi-professional, and professional players. Two studies applied prospective cohort designs using laboratory-based maximal sprint tests with electromyography (EMG) or three-dimensional motion capture to prospectively track HSI incidence over 1.5 competitive seasons. One study used a case–control approach based on repeated-sprint performance to retrospectively identify athletes with previous HSI. Three studies adopted mechanistic laboratory designs investigating sprint biomechanics without clinical follow-up, using musculoskeletal modelling, in-shoe force measurements, and kinematic analyses to identify theoretical injury mechanisms. A summary of study characteristics is presented in Table 1.

Table 1. **Summary of included studies on sprinting biomechanics and hamstring injury risk**

Study	**Design**	**N**	**Task**	**Exposure**	**Outcome**	**Injury Definition**	**Main Findings**
Schuermans et al. (2017a)	Prospective cohort	$N = 60$ male amateur	Max sprint (lab, EMG)	Gluteal activation, trunk activation	HSI over 1.5 seasons	Time-loss HSI by clinical exam	Greater gluteal & trunk activation during swing reduced HSI risk ($p < .05$)
Schuermans et al. (2017b)	Prospective cohort	$N = 60$ male amateur	Max sprint (3D kinematics)	Pelvic tilt angle, thoracic side bending	HSI over 1.5 seasons	Time-loss HSI by clinical exam	Higher anterior pelvic tilt & thoracic side bending during swing associated with HSI occurrence
Lord et al. (2019)	Case–control test	$N = 40$ male semi-pro	10 × 6 s repeated sprint	Horizontal force reduction	Identification of HSI	Prior HSI causing ≥1-week absence	Previous HSI was associated with greater fatigue-induced reduction in horizontal force. Force reduction identified injury status with 77% sensitivity and 85% specificity

Study	Design	N	Task	Exposure	Outcome	Injury Definition	Main Findings
Romero et al. (2022)	Repeated-sprint lab	$N = 51$ male amateur	12 × 30 m repeated sprint	Fatigue effects on kinetics & kinematics	Biomechanical adaptation	No clinical HSI	Fatigue reduced horizontal force and altered trunk/hip/knee angles during touchdown with heterogeneous patterns affecting theoretical HSI risk
Le et al. (2024)	Experimental lab study	$N = 10$ male soccer (healthy)	3 × 15 m sprint (initial acceleration vs max speed)	Hamstring strain %, elongation velocity, EMG activation	Potential injury phases inferred from biomechanics	Not applicable (no injury follow-up)	High strain + high activation occurs in late swing & early stance; BFlh shows highest strain and longest duration
Astrella et al. (2025)	Cross-sectional	$N = 21$ male semi-pro	40 m overground sprint (3D IMU + musculoskeletal model)	Hip/pelvis orientation, MT strain	Peak MT strain of hamstrings	Not applicable (mechanistic study, no injury follow-up)	BFlh showed the greatest MT strain during acceleration. Higher anterior pelvic tilt and hip flexion predicted peak MT strain, especially during early steps. Suggested biomechanical basis for acceleration-phase hamstring injuries

3.3. Risk of bias assessment

Table 2. **Risk of bias assessment of included studies using the ROBINS-I tool**

Study	Overall ROBINS-I
Schuermans et al. (2017a)	Moderate
Schuermans et al. (2017b)	Moderate
Lord et al. (2019)	Serious
Romero et al. (2022)	Serious
Le et al. (2024)	Serious
Astrella et al. (2025)	Serious

The ROBINS-I assessment identified two studies with moderate risk of bias and four studies with serious risk of bias (Table 2; Figures 2–3). The most common source of bias was confounding (D1), particularly among mechanistic and laboratory-based studies that relied on surrogate biomechanical outcomes rather than prospective injury data. Participant selection (D2) was generally rated as moderate risk due to convenience sampling, whereas exposure classification (D3), deviations from intended exposure (D4), and selective reporting (D7) were predominantly judged as low risk. Outcome measurement (D6) was frequently rated as moderate risk because several studies inferred hamstring injury risk from biomechanical indicators rather than clinically confirmed injuries. These findings indicate that the current evidence base is constrained by methodological limitations and should be interpreted cautiously.

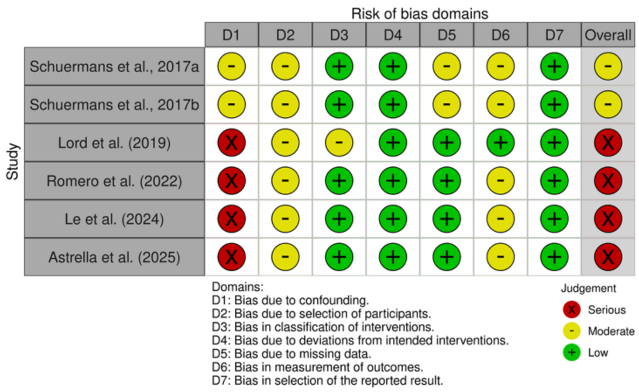

Figure 2. **Traffic-light plot of ROBINS-I assessment**

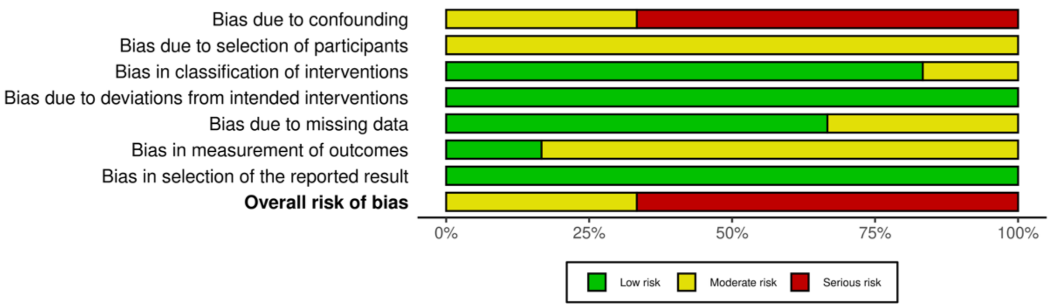

Figure 3. **Summary plot of ROBINS-I domains**

Given the predominance of moderate-to-serious risk of bias across the included studies, the findings were synthesised narratively, with particular attention to the consistency of evidence across different biomechanical domains.

3.4. Synthesis of findings

3.4.1. Lumbopelvic and trunk mechanics

The prospective cohort studies identified lumbopelvic control as a key biomechanical factor associated with increased risk of HSI. Players who subsequently sustained HSI demonstrated greater anterior pelvic tilt and increased thoracic side bending during sprinting compared with uninjured players. These movement patterns may increase strain on the BFlh by altering pelvis orientation and increasing posterior chain loading during the swing phase. Consistent with these findings, mechanistic modelling studies showed that increased hip flexion and pelvic motion were associated with greater muscle–tendon strain during sprint acceleration.

3.4.2. Neuromuscular activation patterns

Neuromuscular control emerged as another important factor influencing HSI susceptibility. Greater normalised activation of the gluteus maximus during front swing and trunk musculature during backswing was associated with a reduced risk of time-loss HSI during a 1.5-season follow-up. These findings suggest that proximal neuromuscular activation may contribute to pelvic stabilisation during high-speed running and potentially reduce excessive loading of the hamstring muscle-tendon unit. Laboratory investigations further demonstrated that the BFlh experiences peak elongation and activation demands during late swing and early stance, supporting the role of neuromuscular control in sprint-related injury mechanisms.

3.4.3. Horizontal force production and fatigue

The case–control study demonstrated that players with a previous HSI exhibited greater fatigue-induced reductions in horizontal force production during repeated sprinting than non-injured players. This finding indicates that residual deficits in sprint-specific force-generation capacity may persist even after return to play. Similarly, laboratory studies examining sprint fatigue reported biomechanical alterations that may compromise force application and increase hamstring loading. Collectively, these findings suggest that the ability to maintain horizontal force production under fatigue may represent an important component of sprint-related HSI risk.

4. DISCUSSION

This systematic review synthesised evidence linking sprinting biomechanics to the risk of HSI in male football players across two prospective cohort studies, one case–control study, and three mechanistic laboratory investigations. Despite methodological heterogeneity, three consistent patterns emerged: (1) greater proximal neuromuscular control – particularly gluteus maximus activation during front swing and trunk musculature activation during backswing – was associated with a lower risk of time-loss HSI over 1.5-season follow-up; (2) increased anterior pelvic tilt and thoracic side bending during airborne phases were associated with higher injury risk; and (3) players with prior HSI demonstrated larger reductions in horizontal force production during repeated sprinting, despite return-to-play clearance. Mechanistic modelling supported these observations, showing that the BFlh experiences the most significant strain and most prolonged activation during late swing and early stance.

Taken together, the evidence suggests that impaired lumbopelvic control during the airborne phases of sprinting may lead to increased posterior chain loading. At the same time, residual deficits in sprint force production may persist beyond clinical rehabilitation. Although mechanistic studies cannot establish causality, they provide a coherent biomechanical rationale that aligns with epidemiological patterns reported in longitudinal designs.

4.1. Proximal neuromuscular control

Both cohort studies demonstrated that higher normalised gluteus maximus activation during front swing and greater trunk activation during backswing independently predicted a reduced risk of HSI (Schuermans et al., 2017a; Schuermans et al., 2017b). These findings support the hypothesis that proximal neuromuscular control regulates sprint posture and mitigates eccentric hamstring loading during rapid limb repositioning. The gluteus maximus contributes to pelvic stabilisation, hip extension torque, and force transmission along the kinetic chain (Rudisill et al., 2023). Insufficient proximal activation may lead to compensatory lumbar extension and anterior pelvic tilt, increasing fascicle strain on the hamstrings at high running velocities (Higashihara et al., 2015; Yu et al., 2008). These neuromuscular findings may partly explain the altered pelvic and trunk mechanics observed in subsequently injured players, supporting the concept that proximal control and segmental alignment are closely interrelated during sprinting.

4.2. Pelvic–trunk alignment

The second cohort study identified anterior pelvic tilt and thoracic side bending during swing as predictors of injury (Schuermans et al., 2017b). Anterior tilt increases muscle–tendon length, especially in late swing when the hamstrings act eccentrically to decelerate knee extension (Schache et al., 2012; Yu et al., 2017). Thoracic side bend towards the swing leg may shift the centre of mass, increase hip adduction, and elevate posterior chain loading at touchdown (Kalema et al., 2022). Prior work has similarly demonstrated that pelvic tilt alters the hamstring length–tension relationship, thereby increasing strain accumulation during running (Yu et al., 2017). These results highlight the trunk–pelvis interaction as a key determinant of sprinting-related HSI risk.

4.3. Fatigue and horizontal force production

The case–control study demonstrated that previously injured players showed significantly greater reductions in horizontal force production during repeated sprinting compared to non-injured controls (Lord et al., 2019). The magnitude of force decline identified injury history with moderate diagnostic accuracy, suggesting persistent mechanical deficits despite clearance to return to play. These findings align with recent work showing that low horizontal force capacity (FH0) – but not maximal velocity – was associated with higher HSI risk in professional football (van Dyk & Pecci, 2025). Fatigue reduces hip extensor contribution, alters trunk and kinematics, and may increase hamstring strain at touchdown (Dal Pupo et al., 2017; Wilmes et al., 2021). Persistent deficits in horizontal force production may represent a clinically relevant marker of incomplete sprint-mechanical recovery following HSI. However, prospective studies are required to determine whether reduced horizontal force capacity constitutes a causal risk factor for future injury occurrence.

4.4. Mechanistic evidence

The three mechanistic studies included in this review (Astrella et al., 2025; Le et al., 2024; Romero et al., 2022) consistently identified late swing and early stance as phases associated with the greatest mechanical demand on the BFlh. Across different methodological approaches, including sprint-fatigue protocols, musculoskeletal modelling, and motion-analysis techniques, these studies demonstrated that increases in hip flexion, anterior pelvic tilt, and sprint-related fatigue were associated with greater hamstring muscle–tendon strain. Although these investigations did not include prospective injury follow-up, their findings provide a biomechanical explanation for the epidemiological associations observed in the cohort studies.

4.5. Integration with the broader literature

The present findings align with broader epidemiological studies, which show that HSI typically occurs during high-speed running, particularly around terminal swing (Ekstrand et al., 2023; Elliott et al., 2011; Garcia et al., 2022). The multifactorial nature of HSI risk is well documented, including eccentric weakness, short fascicle length, architectural changes, and poor lumbopelvic control (Lovell et al., 2018; Timmins et al., 2016). This review adds nuance by emphasising that activation timing and segment coordination, rather than strength alone, may differentiate injured from non-injured athletes.

The findings should be interpreted in light of the methodological quality of the included studies. Risk of bias assessment indicated that only two studies were classified as having a moderate risk of bias, whereas four studies were judged to have a serious risk of bias. The most common concerns were residual confounding and the reliance on surrogate biomechanical outcomes rather than clinically verified injury events. Consequently, the proposed biomechanical mechanisms should be considered plausible explanatory models rather than definitive causal pathways.

Unlike previous reviews that primarily focused on isolated risk factors such as eccentric strength deficits or fascicle length, the present review integrates prospective injury-surveillance findings with mechanistic sprint-biomechanics evidence. This synthesis suggests that proximal neuromuscular control, lumbopelvic mechanics, and horizontal force-production capacity constitute interconnected components of a common biomechanical pathway that leads to increased hamstring loading during sprinting.

4.6. Practical implications

Clinical and performance staff may translate these insights into applied strategies. First, sprint drill modification emphasising airborne-phase mechanics (front swing, backswing) may help target lumbopelvic control. Second, neuromuscular training prioritising gluteus maximus activation timing and core stabilisation – not only eccentric strength – may reduce anterior pelvic tilt and improve force distribution (van Dyk & Pecci, 2025). Third, coaching cues targeting pelvic control may reduce BFlh strain during critical phases. Finally, fatigue monitoring through horizontal force metrics (FH0) and repeated-sprint tests may help detect post-injury deficits that are not visible through isolated strength testing (Lord et al., 2019; van Dyk & Pecci, 2025). This aligns with the recent consensus that advocates for a combined approach of eccentric loading, sprint exposure, and neuromuscular control development (Rudisill et al., 2023).

4.7. Strengths, limitations, and future research

Strengths of this review include the integration of prospective epidemiological evidence with high-resolution biomechanical and neuromuscular investigations, providing a broader understanding of sprint-related hamstring injury mechanisms. Nevertheless, several limitations should be acknowledged. The included studies were characterised by relatively small sample sizes (10–60 participants), male-only cohorts, and substantial methodological heterogeneity, which precluded quantitative meta-analysis. Sprint protocols varied considerably across studies, ranging from acceleration-focused tasks and repeated-sprint tests to maximal-velocity sprinting, potentially influencing biomechanical outcomes and limiting direct comparisons. Differences in EMG acquisition and normalisation procedures may also have affected the interpretation of neuromuscular activation findings.

Furthermore, participants ranged from amateur to professional football players, which may limit the generalisability of the findings. Several mechanistic investigations were conducted under controlled laboratory conditions that may not fully replicate the complex biomechanical and environmental demands encountered during match play. Finally, although mechanistic studies provide valuable explanatory context, they cannot establish causal relationships between sprint biomechanics and subsequent hamstring injury occurrence.

Future research should bridge the gap between laboratory precision and field applicability by using on-pitch IMU–EMG systems, larger multicentre prospective cohorts evaluating biomechanical predictors of injury, and integrated models that combine muscle morphology, architecture, neuromuscular function, and sprint biomechanics. Advances in machine-learning approaches may further enable individualised injury-risk prediction based on repeated-sprint profiles, biomechanical characteristics, and fatigue trajectories.

5. CONCLUSIONS AND PERSPECTIVES

This review suggests that sprint-related biomechanical characteristics may contribute to HSI risk in football players. The most consistent findings involved proximal neuromuscular control, lumbopelvic and trunk mechanics, and the maintenance of horizontal force production during sprinting. Prospective evidence suggests that greater gluteal and trunk-muscle activation is associated with a reduced risk of HSI, whereas increased anterior pelvic tilt and altered trunk mechanics may increase hamstring loading during critical sprint phases.

Reduced horizontal force production following fatigue may indicate persistent sprint-mechanical deficits after injury. Integrating epidemiological and mechanistic evidence suggests that injury prevention strategies should address lumbopelvic control, neuromuscular coordination, and sprint-specific force production rather than focusing exclusively on isolated strength measures.

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