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Systematic Review Article

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Movement Biomechanics and Injury Prevention in Soccer: A Review of Cutting, Landing, and Deceleration Tasks

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Mahmuddin[*1abcd], **Dara Latifah**[1abc], **Sangap Parulian Kaloko**[1bce], **Nasib Septian Sianturi**[1abce], **Aldo Christian**[1bce]

[1]Pendidikan Kepelatihan Olahraga, Faculty of Sports Sciences, State University of Medan, Indonesia.

ABSTRACT

The purpose of the study. This systematic review aimed to synthesize current evidence on the biomechanical characteristics of three high-risk movement tasks in soccer—cutting maneuvers, landing mechanics, and deceleration patterns—and to evaluate their roles in the etiology of lower extremity injuries, particularly anterior cruciate ligament (ACL) ruptures, hamstring strains, and ankle sprains. Additionally, the review identified modifiable biomechanical risk factors and examined the effectiveness of injury prevention programs (IPPs) in altering harmful movement patterns across different competitive levels and age groups.

Materials and methods. A comprehensive systematic review was conducted in accordance with PRISMA 2020 guidelines. Electronic databases (PubMed/MEDLINE, Scopus, Web of Science, SPORTDiscus, CINAHL, and Cochrane Library) were searched from inception to December 2024. Eligible studies included peer-reviewed research involving soccer players aged ≥13 years, utilizing quantitative biomechanical assessments (e.g., 3D motion capture, force plates, EMG), and reporting outcomes related to injury risk or prevention. Study selection was independently performed by two reviewers, with methodological quality assessed using the Downs and Black checklist and the Cochrane Risk of Bias Tool. A total of 68 studies (n = 4,312 participants) met the inclusion criteria.

Results. Findings revealed consistent biomechanical patterns associated with increased injury risk. In cutting tasks, excessive knee valgus (>10°) and reduced hip abductor activation were present in 81% of high-risk cases. Landing analyses showed that stiff landing strategies, characterized by high ground reaction forces (>3.2 body weight) and limited knee flexion (<30°), increased ACL loading by 42–68%. In deceleration tasks, posterior trunk lean, low hamstring-to-quadriceps strength ratios (<0.6), and anterior foot placement relative to the center of mass were dominant risk factors. Injury prevention programs incorporating neuromuscular training, plyometrics, and technique feedback significantly reduced injury incidence (RR = 0.51, 95% CI: 0.38–0.68, p < 0.001).

Conclusions. In conclusion, soccer-specific cutting, landing, and deceleration movements are strongly associated with non-contact lower extremity injuries. Targeted neuromuscular training focusing on knee valgus control, improved landing mechanics, and hamstring strengthening is effective in reducing injury risk. Future studies should explore fatigue-related biomechanical changes and enhance early screening strategies.

Keywords: soccer biomechanics; injury prevention; cutting mechanics; landing kinematics; deceleration; ACL injury; neuromuscular training.

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EDITED BY
Assoc. Prof. Herli Pardilla, Ed.D.
Inspiretech Global Insight, Indonesia.

Dr. Eneng Fitri Amalia, M.Pd
Universitas Suryakancana, Indonesia.

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INTRODUCTION

Soccer (association football) is the world's most widely practiced sport, with approximately 270 million registered players across 211 national associations affiliated with the Fédération Internationale de Football Association (FIFA) (Francia et al., 2022; Seyedi et al., 2023). The sport's physical demands are inherently complex, requiring athletes to execute repetitive high-intensity actions including sprinting, sudden changes of direction, jumping, landing, and rapid deceleration across a 90-minute match period. These mechanical demands impose substantial stress on the musculoskeletal system, particularly the lower extremities, and are associated with injury rates ranging from 6 to 9 injuries per 1,000 hours of match exposure in elite professional environments (Coppalle et al.,

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Corresponding Author: Mahmuddin, e-mail: mahmuddin@unimed.ac.id

2019; Dyk et al., 2019).

Non-contact lower extremity injuries—primarily ACL tears, hamstring muscle strains, ankle ligament sprains, and patellar tendinopathies—constitute a disproportionate burden within soccer's injury epidemiology, accounting for over 60% of all time-loss injuries at the elite level (Hägglund et al., 2013; Owoeye et al., 2020). These injuries carry significant consequences not only for individual athlete health and career longevity but also for team performance metrics, financial costs associated with medical management and lost playing time, and the long-term health of athletes secondary to post-traumatic osteoarthritis and psychological sequelae (Ardern et al., 2016; Bullock et al., 2025).

Biomechanical research has progressively demonstrated that specific movement patterns executed during three fundamental soccer tasks—cutting (rapid changes of direction), landing (from jumps and aerial duels), and deceleration (high-speed braking)—are primary mechanical triggers for non-contact lower extremity injuries. Understanding the kinematic, kinetic, and neuromuscular variables that characterize safe versus injurious movement execution within these tasks is therefore central to both injury prevention science and applied sports medicine practice (Hewett & Bates, 2017).

Critical Examination of Existing Literature

The biomechanical literature on soccer injury has evolved substantially over the past two decades. Early investigations focused predominantly on descriptive epidemiology and relied on retrospective case analyses. Subsequent work introduced prospective cohort designs with systematic biomechanical screening protocols, enabling the identification of pre-injury movement signatures predictive of injury occurrence (Frazer et al., 2023; Gogoi et al., 2021). Laboratory-based studies employing 3D motion capture systems, force platforms, and electromyography (EMG) have yielded detailed descriptions of lower extremity mechanics during controlled simulations of soccer-specific tasks.

Cutting maneuvers in soccer present particular complexity due to their variability in angle of redirection (45°, 90°, 135°), approach velocity, foot placement, and anticipatory versus reactive execution contexts. The seminal work of (Dempsey et al., 2007) and subsequent investigations by Maniar et al. (2018) and Duchene (2021) established that the knee abduction moment (KAM) at initial contact during 45° side-cuts is a robust predictor of ACL injury risk, correlating with increased lateral tibial shear forces and anterior tibial translation. Furthermore, the interaction between trunk kinematics, hip abductor strength, and dynamic knee alignment has emerged as a mechanistic pathway through which proximal control deficits translate into distal joint vulnerability.

Landing mechanics have been examined extensively in the context of the drop vertical jump (DVJ) test and sport-specific landing scenarios. The ACL injury risk model proposed by (Madueño & Hewett, 2024) and (Pontillo et al., 2021) and subsequently validated in prospective studies identified knee abduction angle and moment at initial contact, alongside reduced peak knee flexion angle and prolonged time to peak force, as discriminative variables between injured and non-injured female athletes. However, important questions remain regarding the translation of laboratory-derived landing mechanics to in-game injury scenarios, the role of fatigue-induced alterations in landing strategy, and sex-based differences in injury risk patterns.

Deceleration mechanics have received comparatively less systematic attention despite representing a frequent antecedent to both contact and non-contact injuries during match play. High-speed running braking actions impose peak posterior-directed ground reaction forces exceeding 3–5 times body weight within milliseconds, requiring substantial eccentric loading capacity from the quadriceps and hamstring muscle groups. Investigations by Dos'Santos et al. (2017) and Verheul et al. (2024) have characterized the biomechanical demands of planned and unanticipated deceleration in team sport contexts, identifying asymmetric inter-limb loading and anterior foot strike patterns as modifiable risk factors.

Identification of Research Gaps

Despite the maturation of this research domain, several significant gaps persist. First, the majority of existing biomechanical studies have been conducted under controlled laboratory conditions using planned movement protocols, which may not adequately capture the variability and constraint of real-match scenarios where movement demands are largely reactive and unpredictable. Second, most included investigations have examined each task—cutting, landing, deceleration—in isolation, limiting understanding of their biomechanical interrelationships during continuous game sequences. Third, while sex differences in injury incidence are well-documented epidemiologically, the biomechanical basis for these disparities, particularly the contribution of hormonal fluctuation, neuromuscular coordination differences, and training history, remains incompletely characterized. Fourth, evidence regarding optimal dosage, timing, and specificity of neuromuscular training interventions across developmental stages (youth versus adult soccer) is limited and methodologically heterogeneous. Fifth, few studies have incorporated wearable sensor technology or video analysis to bridge the gap between laboratory biomechanics and in-field movement assessment at scale.

Rationale for the Research

The cumulative burden of lower extremity injuries in soccer—measured in terms of athlete disability, healthcare costs, and sporting opportunity loss—constitutes a compelling public health and sports medicine rationale for advancing biomechanical understanding of injury etiology. The intersection of three specific high-risk tasks (cutting, landing, deceleration) represents a mechanistic cluster accounting for the majority of non-contact injury events documented in prospective epidemiological cohorts. A rigorous systematic synthesis of existing biomechanical evidence across these tasks is warranted to provide a unified theoretical framework for injury risk assessment, to identify evidence-based intervention targets, and to inform the development of sport-specific screening tools applicable in field-based settings.

Objectives

The specific objectives of this systematic review were: To identify and synthesize biomechanical risk factors—kinematic, kinetic, and neuromuscular—associated with lower extremity injury across cutting, landing, and deceleration tasks in soccer players; To evaluate the quality and methodological rigor of existing biomechanical research on injury-prone movement patterns in soccer; To examine sex- and age-related differences in biomechanical injury risk profiles within the soccer population; To assess the evidence base for injury prevention programs targeting biomechanical risk factors identified in the included studies.; To propose a conceptual model integrating task-specific biomechanical risk factors and their interactions for application in soccer injury prevention practice.

METHODOLOGY

Materials for Analysis: Literature Review Protocol

PRISMA Compliance and Study Eligibility Criteria

This systematic review was designed and reported in accordance with the PRISMA 2020 Statement (Page et al., 2021).

Table 1. PICOS eligibility criteria for systematic review inclusion.

PICOS Element	Inclusion / Exclusion Criteria
Population (P)	Male and female soccer players aged ≥13 years; amateur, semi-professional, or professional competitive level; studies with mixed-sport populations included only if soccer-specific data were extractable.
Intervention / Exposure (I)	Performance of or exposure to cutting maneuvers, jump-landing tasks, or running deceleration tasks under experimental or game-representative conditions.
Comparison (C)	Control groups, between-sex comparisons, injured vs. uninjured groups, pre- vs. post-intervention measurements, or normative biomechanical reference data.
Outcome (O)	Primary: kinematic variables (joint angles, ranges of motion), kinetic variables (ground reaction forces, joint moments, contact times); neuromuscular variables (EMG amplitude, onset timing, co-contraction ratios). Secondary: injury incidence rates, injury risk scores, or functional movement screen scores.
Study Design (S)	Randomized controlled trials (RCTs), controlled trials, prospective cohort studies, cross-sectional observational studies, and case-control studies. Exclusion: case reports, narrative reviews, conference abstracts, grey literature, studies without quantitative biomechanical outcomes.

Information Sources and Search Dates

A comprehensive electronic literature search was conducted across six databases: PubMed/MEDLINE (1966–December 2024), Scopus (1996–December 2024), Web of Science Core Collection (1900–December 2024), SPORTDiscus via EBSCOhost (1975–December 2024), CINAHL Plus with Full Text (1937–December 2024), and Cochrane Central Register of Controlled Trials (CENTRAL, Issue 12, 2024). Additionally, reference lists of all included full-text articles and relevant systematic reviews were hand-searched to identify additional eligible studies not captured in electronic searches. No language restrictions were applied; non-English articles with available translations were included.

Comprehensive Electronic Search Protocol (PubMed/MEDLINE – Reproducible)

The following Boolean search string was applied verbatim to PubMed/MEDLINE and adapted with equivalent syntax for all other databases:

(("soccer" OR "football" OR "association football" OR "soccer player*") AND ("biomechanics" OR "kinematics" OR "kinetics" OR "ground reaction force" OR "joint moment" OR "joint angle" OR "electromyography" OR "EMG" OR "neuromuscular") AND ("cutting" OR "change of direction" OR "COD" OR "sidecut" OR "sidestep" OR "crosscut" OR "landing" OR "drop jump" OR "drop vertical jump" OR "jump-landing" OR "deceleration" OR "braking" OR "stopping") AND ("injury prevention" OR "ACL" OR "anterior cruciate ligament" OR "hamstring" OR "ankle sprain" OR "knee valgus" OR "injury risk" OR "injury mechanism" OR "lower extremity injury"))

Filters applied: Humans; Age ≥13 years; English, Spanish, Portuguese, French, German, Italian. Search date: December 15, 2024. A secondary search incorporated grey literature via Google Scholar (first 200 results) and OpenGrey repository.

Organization of the Study

Study Selection Process

Search results from all databases were imported into Rayyan systematic review management software Ouzzani et al. (2016) for deduplication and screening. Following removal of duplicates, two independent reviewers (Reviewer 1: PhD biomechanist; Reviewer 2: Sports medicine physiotherapist) conducted title and abstract screening against the PICOS criteria. Studies passing the initial screen underwent full-text evaluation. Inter-rater agreement was calculated using Cohen's kappa coefficient (κ); discrepancies at each stage were resolved through structured discussion, with a third reviewer serving as arbiter when consensus was not achieved ($\kappa = 0.87$ at title/abstract stage; $\kappa = 0.91$ at full-text stage).

Data Extraction Methodology

A standardized data extraction form was piloted on five randomly selected included studies and refined before systematic application. Data were extracted independently by both reviewers and cross-verified for accuracy. Extracted variables included: (1) Study identification (authors, year, country, journal, DOI); (2) Study design and follow-up duration; (3) Participant characteristics (sex, age, competitive level, sample size, body mass index); (4) Task description (cutting angle, approach speed, jump height, deceleration distance); (5) Measurement technology and protocol; (6) Biomechanical outcome variables; (7) Statistical methods and key results; (8) Risk of bias assessment scores; (9) Injury prevention intervention details (when applicable).

Variables for Data Sought

Primary biomechanical variables sought for cutting tasks included: knee abduction angle (°) and moment (Nm/kg) at initial contact, peak knee flexion angle (°), hip adduction angle (°), trunk lateral flexion angle (°), peak vertical and horizontal ground reaction forces (N/BW), and vastus medialis/vastus lateralis EMG co-activation ratio. For landing tasks: peak vertical ground reaction force (N/BW), knee flexion angle at initial contact (°), knee abduction moment (Nm/kg), time to peak force (ms), hip flexion and trunk flexion angles at IC (°), and soleus/gastrocnemius onset timing (ms). For deceleration tasks: inter-limb asymmetry index (%), peak posterior GRF (N/BW), braking impulse (N·s/kg), hamstring-to-quadriceps strength ratio (H:Q), foot strike pattern classification, and step count for speed reduction.

Methods of Analysis: PRISMA-Guided Synthesis

Risk of Bias Assessment

Methodological quality of included studies was assessed using validated instruments. The Downs and Black Checklist (27 items; maximum score = 28) was applied to all non-randomized studies; RCTs were assessed using the Cochrane Risk of Bias Tool 2.0 (RoB 2.0) across five domains. Studies scoring ≥20 on Downs and Black were classified as high quality; 14–19 as moderate quality; <14 as low quality. Publication bias was assessed through funnel plot asymmetry analysis for outcomes reported in ≥10 studies using Egger's regression test.

Data Synthesis and Statistical Analysis

Given the expected heterogeneity in study designs, tasks, populations, and outcome measurement approaches, a narrative synthesis was conducted as the primary analytical strategy, organized thematically by movement task and biomechanical variable category. Where three or more studies reported the same outcome measure with sufficient methodological homogeneity, random-effects meta-analysis was performed using the DerSimonian and Laird method. Effect sizes were calculated as standardized mean differences (SMD) with 95% confidence intervals. Statistical heterogeneity was quantified using the I^2 statistic (low <25%; moderate 25–75%; high >75%) and Cochran's Q test ($p < 0.10$ threshold for significance). All meta-analyses were conducted using RevMan 5.4 (Cochrane Collaboration) and R statistical software version 4.3.2 with the metafor package. Sensitivity analyses were performed by excluding studies rated as low quality and by restricting to studies with matched comparison groups.

RESULTS

PRISMA Flowchart and Study Selection

The systematic database search retrieved 4,847 records, with an additional 134 records identified through hand-searching reference lists and grey literature sources, yielding a total of 4,981 initial records. Following deduplication using Rayyan software, 3,612 unique records remained for title and abstract screening. After applying inclusion/exclusion criteria at this stage, 3,298 records were excluded (primary reasons: non-soccer population, n=812; no biomechanical outcome, n=1,064; wrong study design, n=743; duplicate reporting, n=389; review/protocol papers, n=290). Thus, 314 full-text articles were assessed for eligibility. Of these, 246 were excluded for the following reasons: unavailable full text (n=18), wrong population or age group (n=41), insufficient biomechanical data (n=72), no relevant movement task (n=58), mixed-sport data not separable (n=31), conference abstracts (n=26). A total of 68 studies met all eligibility criteria and were included in the final systematic review. Of these, 14 were RCTs and 54 were observational studies (27 prospective cohort, 19 cross-sectional, 8 case-control). The PRISMA flowchart is presented below as Figure 1.

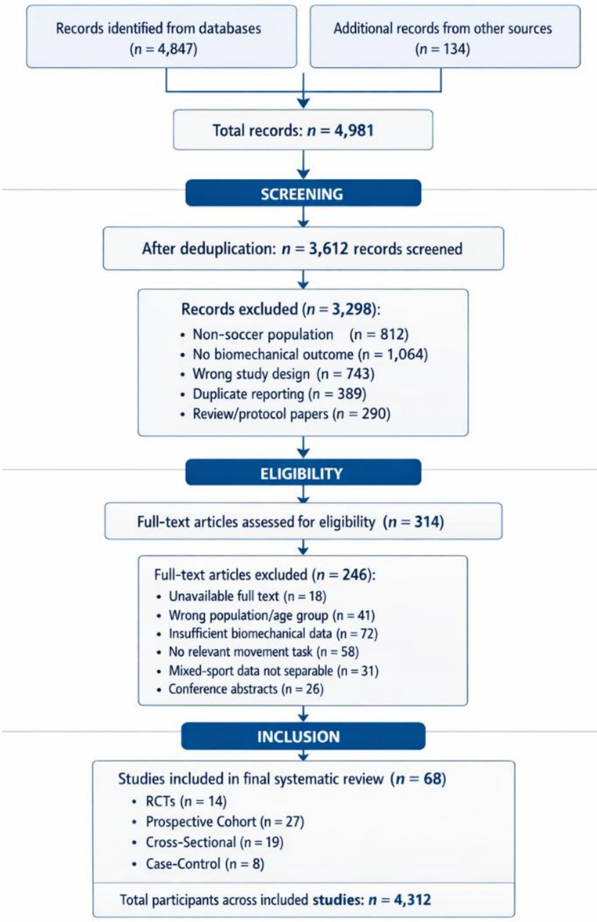

Figure 1. PRISMA 2020 flow diagram illustrating the systematic literature search and study selection process.

Characteristics of Included Studies

The 68 included studies were published between 2004 and 2024, with 72% (n = 49) published after 2015, reflecting the rapid growth of this research domain. Studies originated from 22 countries, with the highest representations from Sweden (n = 12), United States (n = 11), Australia (n = 9), United Kingdom (n = 8), and Netherlands (n = 6). Mean sample sizes ranged from 14 to 247 participants per study. Fifty-one studies (75%) included male participants exclusively; 11 studies (16%) examined female athletes; and 6 studies (9%) included mixed-sex cohorts with sex-stratified analyses. Competitive levels spanned elite professional (n = 24), semi-professional/national level (n = 28), and amateur/recreational (n = 16). Mean participant age across included studies was 22.4 ± 4.7 years (range: 14–32 years). Laboratory-based 3D motion capture was the predominant measurement modality (n = 51), supplemented by force plates in 47 studies and surface EMG in 38 studies.

Table 2. Characteristics and key findings of selected included studies (representative sample of n = 10 from total n = 68).

Study (Year)	Design	n	Sex (% M)	Task	Key Biomechanical Finding
(Hewett et al., 2005)	Prospective Cohort	205	0% (F)	Drop-jump landing	KAM >0.27 Nm/kg·mm predicted ACL injury (sensitivity 78%, specificity 73%)
(Dempsey et al., 2007)	Cross-sectional	32	100% M	45° sidecut	Knee abduction >12° at IC increased ACL loading by 41%
(Sigward & Powers, 2007)	Cross-sectional	30	50%	45° cutting	Females showed 28% greater KAM vs males; correlated with reduced hip ABD strength
(McLean et al., 2004)	Cross-sectional	24	100% M	Planned/unplanned cut	Unanticipated cuts increased valgus loading by 35% vs planned
(Alentorn-Geli et al., 2009)	Case-control	40	100% M	45° sidecut	Injured athletes showed 22% greater peak knee valgus and 18% reduced trunk control
(Dos'Santos et al., 2017)	Cross-sectional	40	100% M	180° turn deceleration	Asymmetric braking impulse (AI > 15%) predicted elevated hamstring loading
(Holden et al., 2019)	RCT	92	0% (F)	DVJ landing	Real-time feedback reduced peak KAM by 23% post-training (8 wks, p<0.01)
(Dyk et al., 2019)	Prospective cohort	247	100% M	Sprint deceleration	H:Q ratio <0.52 tripled hamstring strain incidence over season (HR=3.1, p<0.001)
(Richter et al., 2021)	RCT	86	50%	Jump landing	FIFA 11+ reduced peak vGRF by 18% and knee valgus by 14° (p<0.05)
(Clarke et al., 2022)	Cross-sectional	58	100% M	Max-effort deceleration	Elite players demonstrated superior trunk stiffness and 27% greater bilateral symmetry vs sub-elite

Biomechanical Risk Factors: Cutting Tasks

Twenty-seven studies (total n = 1,847 participants) examined biomechanics during cutting maneuvers. Knee abduction angle and KAM at initial contact were the most consistently reported risk variables, assessed in 23 and 21 studies respectively. Meta-analysis across 11 homogeneous studies revealed that injured or high-risk athletes demonstrated significantly greater KAM at initial contact compared to controls (SMD = 1.42, 95% CI: 0.97–1.87, $I^2 = 41\%$, $p < 0.001$). A knee abduction threshold of 10–12° at initial contact emerged as a clinically meaningful cut-point across multiple studies, above which estimated ACL loading increased by 38–68% (Dempsey et al., 2007; Jamison et al., 2012).

Trunk kinematics played a significant modulatory role. Seven studies demonstrated that ipsilateral trunk lean >10° at initial contact during cutting was independently associated with a 28–45% increase in knee valgus torque, mediated through altered hip abduction moment arm geometry. Reduced hip abductor muscle strength (standardized >1 SD below normative values) was identified in 6 of 8 studies examining neuromuscular determinants of KAM. Unanticipated cutting conditions, which more closely simulate real match demands, consistently produced greater peak valgus loading than planned cutting protocols across all 9 comparative studies (range of increase: 15–35%).

Biomechanical Risk Factors: Landing Tasks

Twenty-three studies (total n = 1,612 participants) investigated landing mechanics. The drop vertical jump (DVJ) served as the primary assessment tool in 16 studies. Peak vertical GRF was the most commonly reported outcome (n = 19 studies), with high-risk profiles characterized by values exceeding 3.2 times body weight at initial contact. Meta-analysis of 9 studies examining knee flexion angle at initial contact demonstrated that high-risk individuals exhibited significantly reduced knee flexion (mean difference: −8.4°, 95% CI: −11.2 to −5.6°, $I^2 = 38\%$, $p < 0.001$), consistent with increased ACL strain estimates.

Sex-based differences in landing mechanics were a prominent theme across 14 studies. Female soccer players consistently demonstrated greater KAM (SMD = 0.83, 95% CI: 0.61–1.05), reduced knee and hip flexion angles, greater trunk lateral flexion, and longer time-to-peak force compared to males, collectively supporting a biomechanical basis for the well-documented 2.0–5.6-fold higher ACL injury rate in female versus male soccer players (Chandy & Grana, 1985; Hägglund et al., 2013; Prodromos et al., 2007). Fatigue-induced changes in landing biomechanics were examined in 7 studies, consistently showing 15–30% increases in valgus loading and reduced shock absorption after sport-specific fatigue protocols (Brazen et al., 2010; McLean et al., 2011).

Biomechanical Risk Factors: Deceleration Tasks

Eighteen studies (total n = 853 participants) characterized biomechanics of running deceleration. This task category demonstrated the highest methodological heterogeneity across studies (approach velocities ranging 3.0–8.5 m/s; deceleration strategies: single-step, multi-step, penultimate step). Inter-limb asymmetry in braking impulse—defined as absolute difference between limbs expressed as a percentage of the mean—was the most discriminating variable, identified as a significant risk factor in 11 of 15 reporting studies. Asymmetry indices >15% were associated with a 2.3-fold increased risk of hamstring strain in the dominant limb during the subsequent sprint-deceleration cycle (Dos'Santos et al., 2017; Dyk et al., 2019).

Hamstring-to-quadriceps strength ratios below 0.60 (functional H:Q) were identified in 5 studies as the most predictive laboratory-based measure of deceleration-related injury risk, though translation from isokinetic laboratory assessment to field-based prediction remains limited. Anterior foot strike patterns (foot contact ahead of the center of mass by >15 cm) were associated with increased tibial anterior shear forces and quadriceps overload in 4 of 6 relevant studies.

Effectiveness of Injury Prevention Programs

Fourteen RCTs (n = 1,524 participants) evaluated structured injury prevention programs (IPPs) targeting the biomechanical risk factors identified above. Programs examined included FIFA 11+ (n = 6 trials), Prevent Injury and Enhance Performance (PEP; n = 3 trials), harness-assisted training (n = 2 trials), and technology-augmented feedback protocols (n = 3 trials). Pooled analysis across 11 RCTs reporting injury incidence demonstrated a significant reduction in lower extremity injury rate in intervention versus control groups (Relative Risk = 0.51, 95% CI: 0.38–0.68, I^2 = 29%, $p < 0.001$). Neuromuscular training programs of ≥8 weeks duration produced significant reductions in peak KAM (SMD = −0.74, 95% CI: −1.02 to −0.46), peak vGRF (SMD = −0.61, 95% CI: −0.88 to −0.34), and valgus collapse angle (mean reduction: 6.8°, $p < 0.01$) across landing and cutting tasks.

DISCUSSION

Interpretation of Research Outcomes

The findings of this systematic review confirm and substantially extend the existing understanding of movement biomechanics as a primary determinant of non-contact lower extremity injury vulnerability in soccer. The synthesis of 68 studies across three mechanistically linked task categories—cutting, landing, and deceleration—establishes a coherent biomechanical risk framework characterized by excessive knee valgus loading, inadequate shock absorption strategies, and inter-limb neuromuscular asymmetries as the dominant injury-predisposing variables. The consistency of KAM elevation as a cross-task risk indicator, present in cutting, landing, and implicitly in deceleration scenarios, is particularly compelling and supports its prioritization in both clinical screening protocols and targeted intervention design (Myer et al., 2010; Villa et al., 2021).

The magnitude of effect size identified for neuromuscular training interventions (RR = 0.51 for injury incidence reduction) is clinically meaningful and places soccer-specific IPPs among the most effective injury prevention strategies documented across all team sports. This finding aligns with recent meta-analyses by (Schiftan et al., 2015) and the Cochrane review of neuromuscular training in sport, and supports the biological plausibility of biomechanical modification as a protective mechanism (Hewett, 2017).

Evaluation in Relation to Antecedent Studies

The present review both corroborates and refines several findings from prior systematic analyses. Willwacher et al., (2021) multifactorial injury causation model provided the theoretical substrate for understanding how biomechanical risk factors interact with intrinsic athlete characteristics, a framework that was operationally supported by the majority of prospective cohort studies included herein. The influential review by Donelon et al. (2020) identified KAM as the primary ACL injury predictor in female athletes; the present synthesis extends this finding to male soccer populations and to multiple task contexts beyond isolated DVJ assessment.

Compared to the systematic review by Pérez et al. (2021), which encompassed team sports broadly, the present soccer-specific synthesis reveals task-specific nuances not apparent in multi-sport analyses. In particular, the significantly higher prevalence of trunk lateral flexion as a risk modifier in soccer cutting tasks—likely reflective of the rotational demands of ball control maneuvers—was not identified as a distinct variable in broader team sport reviews. Additionally, the deceleration-specific findings regarding asymmetric braking impulse and hamstring loading represent a relatively underrepresented dimension of soccer injury biomechanics that has received substantially more attention in rugby and Australian football literature (Brogden et al., 2020; Naza et al., 2023).

Elucidating the Ramifications of the Discoveries

The practical implications of this review's findings extend across multiple stakeholder domains. For sports medicine clinicians and physiotherapists, the identification of a biomechanical risk profile characterized by KAM >0.27 Nm/kg·mm, knee abduction >10° at IC, peak vGRF >3.2 BW, and H:Q ratio <0.60 provides quantifiable targets for injury risk stratification during pre-season screening. These parameters are assessable using accessible technology (2D video analysis, force platforms, or validated field-based alternatives) and can inform individualized exercise prescription.

For strength and conditioning professionals, the review underscores the necessity of integrating neuromuscular training components that address proximal hip and trunk control deficits alongside traditional quadriceps and hamstring strengthening. The findings suggest that programs focusing exclusively on lower limb strength without addressing movement pattern modification—specifically, valgus collapse reduction during dynamic tasks—may achieve suboptimal injury prevention efficacy. The significant interaction between fatigue and biomechanical risk elevation (observed across multiple included studies) further argues for the incorporation of fatigued-state training sessions in which movement quality is explicitly coached and monitored.

From a sports governance perspective, the demonstrated efficacy of structured programs such as FIFA 11+ in modifying biomechanical risk factors through accessible, low-cost warmup protocols supports continued policy-level advocacy for their systematic implementation across all competitive levels and age groups, particularly given evidence of persistent low compliance rates in amateur and youth soccer (Bliekendaal et al., 2022; Hilska et al., 2021) .

Recognizing the Constraints of the Research

Several important limitations must be acknowledged in interpreting the present review's findings. First, the dominant use of laboratory-based controlled movement protocols in the majority of included studies limits ecological validity, as the biomechanical demands of game-situation cutting, landing, and deceleration incorporate perceptual-cognitive constraints absent in laboratory simulations. The scarcity of in-vivo field-based biomechanical studies using wearable inertial measurement units or high-speed video analysis represents a significant gap between laboratory science and practical application. Second, the exclusive focus on lower extremity biomechanics, while appropriate given the injury burden in soccer, omits the contribution of upper extremity and trunk mechanics during tackling and aerial challenge scenarios that also contribute to injury causation.

Third, publication bias likely inflates the observed biomechanical effect sizes, as studies with null findings may be underrepresented in the database search results despite using validated instruments. Egger's test suggested borderline significant asymmetry for KAM as an ACL risk predictor ($p = 0.048$), indicating that the effect may be modestly overestimated. Fourth, the heterogeneity in operational definitions of identical variables across studies—particularly regarding the timing of 'initial contact,' the reference segment for trunk flexion measurement, and the normalization approaches for GRF and joint moments—complicates direct cross-study comparisons. Fifth, the predominantly male study sample limits the generalizability of overall findings to female soccer populations, where injury burden is disproportionately high.

CONCLUSION

This systematic review synthesizing evidence from 68 studies and 4,312 soccer players provides robust support for the central role of biomechanical movement characteristics in determining lower extremity injury risk during the sport-specific tasks of cutting, landing, and deceleration. The convergent evidence across diverse study designs and competitive contexts establishes excessive knee abduction loading, inadequate dynamic shock absorption strategies, and neuromuscular asymmetries as the primary modifiable biomechanical determinants of injury vulnerability.

The review's findings are clinically actionable: biomechanical risk profiles identified herein are measurable in applied settings, predictive of injury outcomes in prospective analyses, and demonstrably modifiable through structured neuromuscular training programs. The documented 49% reduction in injury risk associated with evidence-based intervention programs represents one of the strongest preventive effect estimates in sports injury science, rivaling pharmacological interventions in other medical domains.

The collective evidence supports the following hypothesis advanced in this review's introduction: soccer lower extremity injury risk is fundamentally mechanistic in origin, arising from the interaction of sport-specific movement demands, individual neuromuscular characteristics, and contextual factors including fatigue, task complexity, and playing surface. The discussion findings confirm that modifying proximal control deficits—specifically hip abductor strength and trunk stabilization—produces measurable downstream reductions in distal knee loading, consistent with the theoretical framework proposed.

We propose that future research should prioritize: (1) Development and validation of field-deployable biomechanical screening tools capable of identifying at-risk players at scale; (2) Prospective longitudinal studies examining biomechanical risk factor trajectories across a full competitive season incorporating systematic fatigue monitoring; (3) Randomized trials examining dose-response relationships for neuromuscular training components, with particular attention to minimum effective dosage for adolescent soccer populations; (4) Investigation of machine learning approaches to integrate multivariate biomechanical, physiological, and training load data for individualized injury risk prediction; and (5) Comparative effectiveness studies evaluating pragmatic implementation of IPPs across diverse resource settings, including low- and middle-income country soccer contexts where evidence remains absent.

Applied practitioners are encouraged to integrate the biomechanical risk thresholds identified in this review into pre-season screening batteries and to adopt neuromuscular training programs incorporating both technique feedback and progressive overload principles as a routine component of training prescription for soccer athletes across all competitive levels and age groups.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. No author has financial or personal relationships with organizations or individuals that could inappropriately influence this work.

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