



## Wearable Inertial Sensors for Field-Based Lower Limb Biomechanical Assessment in Soccer Players: A Systematic Review

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### ABSTRACT

**Background:** Lower limb injuries are a major concern in soccer due to sprinting, deceleration, cutting, change of direction, jumping, landing, and kicking demands. Laboratory based biomechanical assessment provides high accuracy, but it is often less practical for capturing real on field movement demands. Wearable inertial sensors offer a portable alternative; however, evidence regarding their use remains heterogeneous. **Objective:** This systematic literature review aimed to synthesize how wearable inertial sensors have been used to assess lower limb biomechanics in soccer players, the movement tasks and biomechanical parameters measured, and the evidence regarding their validity, reliability, and practical applicability for injury risk screening and return to play assessment. **Methods:** A literature search was conducted in Scopus using terms related to wearable inertial sensors, soccer, lower limb, biomechanics, injury risk, rehabilitation, and return to play. The selection process followed PRISMA 2020. From 155 records, 26 empirical studies were included. Extracted data covered study design, participants, sensor type and placement, measurement setting, movement tasks, biomechanical parameters, practical applications, and key findings. **Methodological quality** was assessed using the JBI Analytical Cross-Sectional Checklist. **Results:** Included studies used IMUs, accelerometers, GPS accelerometer systems, and other wearable sensors placed on the trunk, pelvis, thigh, shank, tibia, foot, and ankle. Dominant tasks included cutting, change of direction, sprinting, running, jumping, landing, hopping, and rehabilitation tasks. Main parameters included joint kinematics, tibial acceleration, PlayerLoad, loading response, joint load, asymmetry, and centre of pressure variables. **Conclusion:** Wearable inertial sensors are useful for supporting biomechanical screening, workload monitoring, rehabilitation, and return to play assessment, but they are not yet sufficient as standalone injury prediction tools. Future research should standardize protocols, validation procedures, reliability testing, and prospective study designs.

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## INTRODUCTION

Soccer imposes significant physical and biomechanical demands, requiring players to execute various explosive maneuvers including sprinting, acceleration, deceleration, rapid changes of direction, jumping, landing, and kicking within the volatile environment of a match (McBurnie & Dos' Santos, 2022; Zhang, 2021). These activities subject the lower extremities to substantial mechanical stress, particularly impacting the knee, ankle, hip, hamstrings, and the anterior cruciate ligament (Torres-Banduc et al., 2022; Zeng et al., 2025). Consequently, injuries to the lower limbs remain a primary concern for soccer players across all levels, from youth and amateur to semi-professional and professional (Beron-Vera et al., 2024; Wang et al., 2025). In the context of injury mitigation and return to play protocols, biomechanical assessment of the lower limbs is essential; it facilitates the identification of high-risk movement patterns, inter limb asymmetries, abnormal loading responses, neuromuscular deficits, and compensatory strategies during rehabilitation or following an injury (Helme et al., 2021; Turner et al., 2024).

Historically, biomechanical evaluations have relied on laboratory-based setups, such as force plates, motion capture, and controlled video analysis (Chalitsios et al., 2024; Guppy et al., 2023). Despite their high precision, these methods are often impractical for real world soccer applications due to high costs, complex logistical requirements, and testing environments that fail to capture the nuances of on field play (Sheng et al., 2020; Yeung et al., 2024). The emergence of wearable inertial technology such as inertial measurement units, accelerometers, gyroscopes, and multi sensor systems has enabled more portable, ecologically valid, and soccer specific assessments (Liang et al., 2025; Marris et al., 2021). These devices effectively monitor a variety of sport specific tasks, including sprinting, cutting, jumping, kicking, and balance exercises, as well as rehabilitation activities (Santicchi et al., 2024; Vieira et al., 2024). The resulting data is diverse, encompassing metrics like joint kinematics, tibial acceleration, loading responses, ground reaction forces, PlayerLoad, asymmetry, and indicators of movement strategy (Paolo et al., 2021; Zhao et al., 2023).

## LITERATURE REVIEW

Despite the growing adoption of wearable inertial sensors in soccer, the existing body of research remains inconsistent, characterized by significant variation in sensor types, placement strategies, target movement tasks, biomechanical metrics, participant populations, and practical objectives (Arzehgar et al., 2025; Swain et al., 2023). While certain studies advocate for these sensors as tools for injury risk screening particularly regarding ACL related risks and movement patterns during cutting or directional changes others emphasize their efficacy in workload monitoring, rehabilitation, and return to play support (Ajdaroski, 2023; Seshadri et al., 2021). Furthermore, evidence concerning the validity, reliability, and practical applicability of these sensors lacks full standardization (Olsen et al., 2024; Tan et al., 2023). Consequently, this systematic review aims to synthesize how wearable inertial sensors have been applied to assess lower limb biomechanics in soccer players under field conditions, identifying the specific movement tasks and parameters measured, and

evaluating whether current evidence sufficiently supports their use for injury screening and return to play protocols (Davidoviča et al., 2025; Vieira et al., 2024).

## METHODOLOGY

This systematic literature review was conducted to synthesize current empirical research regarding the application of wearable inertial sensors for assessing lower limb biomechanics in soccer players under field conditions. The investigation specifically targeted studies that utilize these sensors for injury risk screening, monitoring rehabilitation progress, and supporting return to play decision making. Adhering to the PRISMA 2020 guidelines, the methodological framework encompassed systematic identification, screening, and eligibility assessment, followed by quality appraisal, data extraction, and narrative synthesis of the selected literature.

This systematic literature review was guided by the following research questions:

RQ1: How have wearable inertial sensors been used to assess lower limb biomechanics in soccer players under field-based conditions?

RQ2: What lower limb biomechanical parameters and movement tasks have been measured using wearable inertial sensors for injury risk screening and return to play assessment in soccer players?

RQ3: What evidence exists regarding the validity, reliability, and practical applicability of wearable inertial sensor based lower limb biomechanical assessment for injury risk screening and return to play assessment in soccer players?

Studies were eligible for inclusion if they represented original, empirical research involving soccer or association football players. Included articles were required to utilize wearable inertial technology such as inertial measurement units, accelerometers, or gyroscopes to evaluate lower limb biomechanics or movement related parameters. Additionally, eligible research had to focus on injury risk screening, injury prevention, rehabilitation, workload monitoring, return to play, or the validation of field-based applications. Studies examining soccer specific or field relevant tasks, including sprinting, running, cutting, jumping, landing, change of direction maneuvers, balance, kicking, training or match activities, and return to play testing, were also considered.

Conversely, studies were excluded if they were non empirical publications, such as systematic or scoping reviews, meta-analyses, bibliometric analyses, editorials, commentaries, opinion papers, protocols, or book chapters. Research was also deemed ineligible if it did not involve soccer players, focused on non-soccer football codes (e.g., American, Australian, Gaelic, or rugby football), or targeted head injuries, concussions, or traumatic brain injuries using sensors like mouthguards or helmets without incorporating lower limb biomechanical outcomes. Furthermore, studies lacking the use of wearable sensor technology or failing to report relevant biomechanical/movement metrics in the context of injury management or return to play were excluded.

The systematic literature search utilized the Scopus database, which was selected due to its comprehensive coverage of peer reviewed research within the domains of sports science, biomechanics, rehabilitation, engineering, and health.

The search strategy was formulated by targeting the primary concepts central to this review, specifically: wearable inertial sensors, soccer, lower limb biomechanics, movement tasks, injury risk, rehabilitation, and return to play. Consequently, the following Boolean search string was implemented: (("wearable inertial sensor\*" OR "inertial sensor\*" OR "inertial measurement unit\*" OR IMU OR IMUs OR acceleromet\* OR gyroscope\* OR "wearable sensor\*" OR "wearable technolog\*" OR sensor\*) AND (soccer OR "association football" OR football) AND ("lower limb" OR "lower extremit\*" OR knee OR ankle OR hip OR hamstring OR ACL OR leg OR limb) AND (biomechanic\* OR kinematic\* OR movement OR gait OR running OR sprint\* OR jump\* OR landing OR balance OR workload OR "player load" OR "training load") AND (injur\* OR risk OR prevention OR rehabilitation OR "return to play" OR "return to play")) AND NOT ("systematic review" OR "systematic literature review" OR "meta analysis" OR bibliometric)

The search was structured to identify empirical investigations regarding the use of wearable sensors for evaluating lower limb biomechanics in soccer, while explicitly omitting secondary literature such as reviews, meta-analyses, and bibliometric publications.

The methodological quality of the included research was evaluated utilizing the Joanna Briggs Institute Analytical Cross-Sectional Checklist. This specific tool was selected due to the prevalence of quantitative empirical designs within the review, including cross sectional, observational, biomechanical, validation, and field-based studies. The assessment criteria encompassed the transparency of inclusion criteria, the accuracy of participant and setting descriptions, the validity and reliability of exposure and outcome measures, the management of potential confounders, and the appropriateness of the statistical methodologies employed. This appraisal was intended to contextualize the evidence rather than to facilitate the automatic exclusion of studies.

Data extraction was systematically performed utilizing a structured template aligned with the research questions. The extracted components encompassed:

Table 1. Data Extraction

| Extracted Component       | Description                                                                        |
|---------------------------|------------------------------------------------------------------------------------|
| Study ID                  | Author, year, and study identification information                                 |
| Study Aim                 | Main objective of the study                                                        |
| Study Design              | Research design or methodological approach                                         |
| Participants              | Sample size, age, sex, playing level, and injury status where available            |
| Sensor Type and Placement | Type of wearable sensor used and anatomical location of sensor placement           |
| Measurement Setting       | Field, training, match like, laboratory, rehabilitation, or return to play setting |

|                                     |                                                                                                                           |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Movement Task/ Activity             | Movement tasks assessed, such as running, sprinting, cutting, jumping, landing, balance, kicking, or rehabilitation tasks |
| Lower limb Biomechanical Parameters | Biomechanical variables measured, such as kinematics, acceleration, load, asymmetry, or movement strategy                 |
| Clinical/Practical Application      | Relevance to injury risk screening, rehabilitation monitoring, workload monitoring, or return to play assessment          |
| Key Findings                        | Main findings related to validity, reliability, feasibility, or practical use                                             |

## RESULT AND DISCUSSION

### *Study Selection Process*

The study selection process followed the PRISMA 2020 framework, including identification, screening, eligibility assessment, and final inclusion stages. The literature search conducted through the Scopus database identified 155 records related to wearable inertial sensors and lower limb biomechanical assessment in soccer players. After title and abstract screening, studies that did not meet the eligibility criteria were excluded. Subsequently, full-text assessment was performed to determine the suitability of studies based on predefined inclusion and exclusion criteria. Finally, 26 empirical studies were included in this systematic literature review.

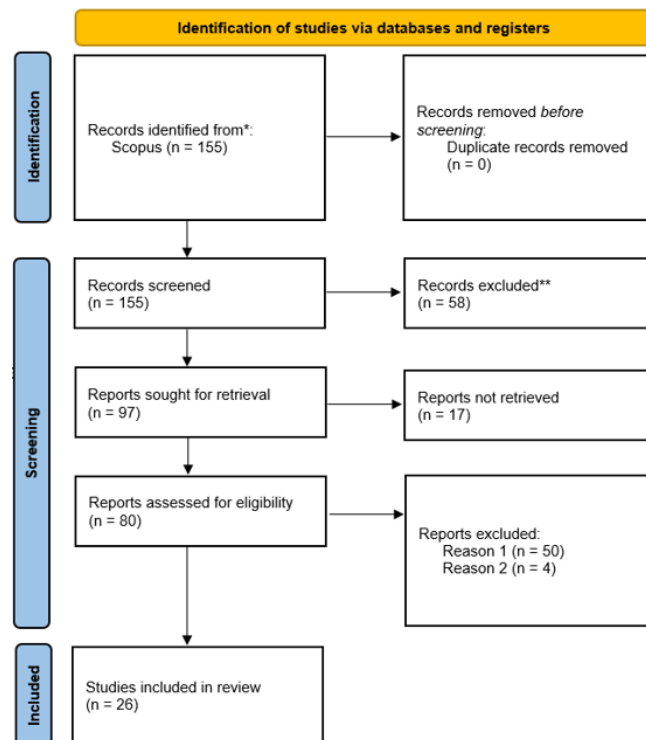


Figure 1. PRISMA 2020 Flow Diagram

### Characteristics of Included Studies

The included studies were published between 2018 and 2026 and involved different research designs, including observational studies, validation studies, reliability assessments, experimental designs, and field-based biomechanical investigations. The participants consisted of soccer players from different competitive levels, including youth, amateur, collegiate, semi-professional, and professional athletes. Several studies also involved athletes undergoing rehabilitation following lower limb injuries.

The methodological characteristics demonstrated variability in participant populations, research settings, sensor configurations, and assessment objectives.

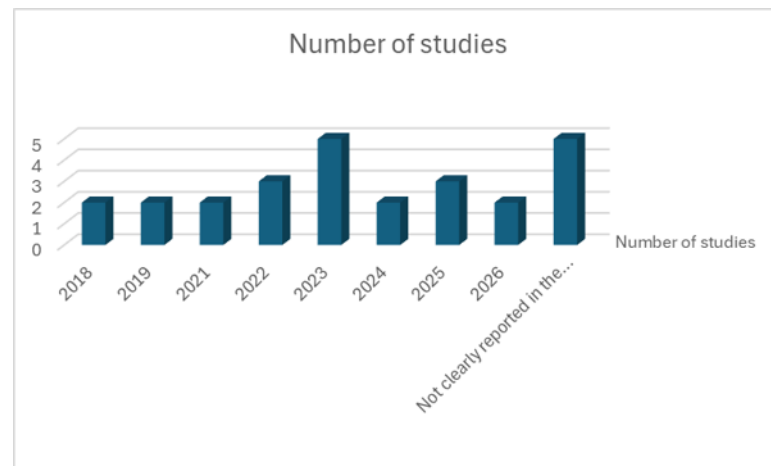


Figure 2. Publication year distribution

### Wearable Sensor Technologies and Measurement Approaches

Various wearable technologies were identified across the included studies. Inertial measurement units (IMUs), accelerometers, GPS-integrated accelerometry systems, and pressure-based wearable devices were commonly used to assess lower limb biomechanics. Sensor placement varied depending on the objective of measurement, including the trunk, pelvis, thigh, shank, tibia, ankle, and foot. Studies focusing on joint kinematics generally applied multi-segment sensor configurations, whereas studies assessing workload, acceleration, and mechanical loading commonly used simplified sensor placements.

Table 2. Methodological Characteristics Flow

| Technology Layer              | Body Placement Layer              | Main Measurement Purpose                                  |
|-------------------------------|-----------------------------------|-----------------------------------------------------------|
| IMU / inertial sensor system  | Pelvis, thigh, shank, foot, trunk | Joint kinematics, movement pattern, ACL related screening |
| Triaxial accelerometer        | Tibia, Achilles, C7, trunk        | PlayerLoad, acceleration, impact load, loading response   |
| GPS + accelerometry           | C7/trunk or wearable unit         | External workload and movement load monitoring            |
| Smart socks / pressure sensor | Foot/plantar surface              | Plantar pressure and centre of pressure assessment        |

|                      |                                        |                                                           |
|----------------------|----------------------------------------|-----------------------------------------------------------|
| Multi location setup | Combined lower limb and trunk segments | Segmental biomechanics and field-based movement profiling |
|----------------------|----------------------------------------|-----------------------------------------------------------|

#### *Movement Tasks and Biomechanical Parameters*

The reviewed studies evaluated various soccer-specific movement tasks, including sprinting, running, cutting, change of direction, jumping, landing, hopping, balance activities, kicking, and rehabilitation exercises. The measured biomechanical variables included joint kinematics, tibial acceleration, PlayerLoad, ground reaction force-related parameters, loading response, asymmetry, and centre of pressure variables.

These measurements were collected in different environments, including football fields, training sessions, match-like conditions, laboratories, and rehabilitation facilities.

Table 3. Matrix of Movement Tasks and Biomechanical Parameters

| Main Movement Task           | Dominant Parameters                                                                              | Clinical/Practical Relevance                               |
|------------------------------|--------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Cutting / COD / agility      | Knee valgus, knee flexion, hip/knee/ankle kinematics, tibial acceleration, knee abduction moment | ACL injury risk screening, injury prevention               |
| Running / sprinting          | Tibial acceleration, hip/knee kinematics, angular velocity, Player Load, symmetry index          | Hamstring injury risk, workload monitoring, rehabilitation |
| Jump / landing / hopping     | Landing impact, G force, ground reaction force related measures, PlayerLoad, asymmetry           | Return to play, ACL rehabilitation, lower limb screening   |
| Training / match like drills | PlayerLoad, external workload, triaxial acceleration, mechanical loading                         | Workload monitoring, injury prevention                     |
| Balance / postural task      | COP displacement, COP velocity, stability, postural control                                      | Ankle/lower limb neuromuscular assessment                  |
| Kicking                      | COP variables and postural control during kicking phases                                         | Soccer specific balance and movement control               |

#### *Thematic Findings*

Based on the extracted evidence, four major themes were identified: Injury risk screening, Workload and loading response monitoring, Rehabilitation and return to play support, Validity, reliability, and feasibility assessment. The thematic synthesis demonstrates that wearable sensors are primarily applied as objective monitoring tools to characterize movement patterns and mechanical responses in soccer players.

Table 4. Thematic Synthesis Map

| Theme                                              | Commonly Used Sensors                            | Dominant Movement Tasks                                                          | Main Parameters                                                        | Interpretation                                                                                   |
|----------------------------------------------------|--------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Theme 1: Injury risk screening                     | IMU, wearable inertial sensor, accelerometer     | Cutting, COD, agility, jump landing                                              | Knee valgus, knee flexion, knee loading, tibial acceleration           | Sensors were used to identify high risk movement patterns, particularly ACL related patterns     |
| Theme 2: Workload and loading response monitoring  | Triaxial accelerometer, GPS + accelerometry, IMU | Running, training, match like drills, soccer specific activity                   | PlayerLoad, triaxial acceleration, loading response, external workload | Sensors were used to quantify mechanical load and body responses to soccer activity              |
| Theme 3: Rehabilitation and return to play support | IMU, accelerometer, multi-location sensor setup  | Single leg drop jump, hopping, running, anti-gravity treadmill, functional tests | Asymmetry, loading response, jump performance, stability, kinematics   | Sensors were used as supportive tools for rehabilitation monitoring and return to play readiness |
| Theme 4: Validity, reliability, and feasibility    | IMU, smart socks, accelerometer                  | COD, running, FIFA 11+, treadmill, functional tasks                              | Agreement, reliability, accuracy, precision, recall                    | Evidence supports feasibility, but validity and reliability remain system and parameter specific |

This systematic literature review demonstrates that wearable inertial sensors have contributed to the transition from laboratory-based biomechanical assessment toward field-based evaluation in soccer environments. Traditional laboratory systems provide accurate biomechanical measurements; however, their application during real soccer activities is limited by equipment complexity, cost, and restricted movement conditions. Wearable sensors provide a more practical approach because they allow biomechanical assessment during sport-specific activities performed under realistic conditions.

The ability to measure movement characteristics during sprinting, cutting, jumping, and landing provides important information regarding how athletes respond to actual performance demands. Therefore, wearable sensor technology represents a valuable complementary approach for understanding lower limb biomechanics in soccer.

The findings indicate that wearable sensors are frequently applied for assessing movement patterns associated with lower limb injury risk, particularly during cutting, change of direction, and landing tasks. These movements generate substantial mechanical demands on the knee and lower extremity, which are commonly involved in soccer injuries.

Parameters such as knee kinematics, tibial acceleration, joint loading, and movement asymmetry provide objective information regarding potentially unfavorable movement strategies. However, injury occurrence is influenced by multiple interacting factors, including physical condition, training exposure, fatigue, previous injury history, and environmental factors. Therefore, wearable sensors should not be interpreted as independent injury prediction tools.

Wearable sensors also provide valuable information regarding mechanical workload monitoring. Variables such as PlayerLoad, acceleration-based metrics, and external workload indicators allow practitioners to quantify physical demands during training and competition. This information may support individualized training management by identifying excessive mechanical exposure and monitoring athlete responses. Nevertheless, differences in sensor systems and analytical approaches remain a challenge for establishing universal workload interpretation standards.

Another important application of wearable sensors is rehabilitation monitoring and return to play assessment. The reviewed studies indicate that these devices can detect movement asymmetry, altered loading patterns, and functional deficits after lower limb injuries.

The objective information obtained from wearable sensors may assist clinicians in evaluating rehabilitation progression. However, return to play decisions require integration of biomechanical data with clinical examination, functional testing, psychological readiness, and sport-specific performance evaluation.

Although wearable sensors demonstrate promising practical applications, their implementation remains limited by methodological differences among studies. Variations in sensor placement, device specifications, movement protocols, and measured variables reduce comparability between investigations. Future development requires standardized procedures and stronger validation against established biomechanical assessment methods such as motion capture systems and force platforms.

## **CONCLUSIONS AND RECOMMENDATIONS**

This systematic literature review concludes that wearable inertial sensors provide a practical approach for assessing lower limb biomechanics in soccer players under field-based conditions. These technologies are capable of measuring various biomechanical parameters related to movement quality,

mechanical loading, injury risk screening, rehabilitation monitoring, and return to play assessment.

However, current evidence indicates that wearable sensors should be considered complementary assessment tools rather than standalone systems for predicting injuries or determining athlete readiness. Their effectiveness depends on appropriate sensor selection, measurement protocols, and interpretation within clinical and sporting contexts.

Future implementation should emphasize standardized assessment procedures, integration with clinical evaluation, and development of evidence-based interpretation frameworks to maximize the practical value of wearable sensor technology.

## FURTHER STUDY

This review has several limitations that should be considered. First, the included studies demonstrated substantial methodological heterogeneity involving differences in sensor technology, anatomical placement, participant characteristics, movement tasks, and biomechanical variables. This variation limits direct comparison between studies.

Second, although wearable sensors have demonstrated feasibility for biomechanical monitoring, evidence regarding their ability to predict actual injury occurrence remains limited. Most studies have focused on movement characterization, validation, or short-term assessment rather than prospective injury prediction.

Future research should prioritize longitudinal study designs involving larger and more diverse populations, including female athletes, youth players, and different competitive levels. Further investigations should also establish standardized sensor protocols, improve reliability assessment, and evaluate whether sensor-derived biomechanical indicators can provide clinically meaningful information for injury prevention and return to play decision-making.

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