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Playing Surface Characteristics and Their Effects on Football Performance: A Systematic Review

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Abstract

Background

The characteristics of the playing surface are increasingly recognised as key determinants of football-specific performance.

Objectives

This systematic review synthesises mechanistic and applied evidence on how natural grass, artificial turf, and sand influence physical, physiological, neuromuscular, and perceptual outcomes in football players.

Methods

Following PRISMA guidelines, a comprehensive search of PubMed, SPORTDiscus and Web of Science (1990–2024) identified 4,008 records, of which 16 studies met the eligibility criteria.

Results

Locomotor responses were the most surface-sensitive domain: artificial turf generally elicited higher external loads, including greater sprint frequency, acceleration demands, and total running distance, whereas natural grass facilitated more efficient sprint mechanics in specific cohorts. Sand consistently imposed greater metabolic cost and reduced running efficiency. Physiological responses (heart rate, lactate) showed minimal between-surface differences, suggesting that internal load is more strongly driven by task constraints than by surface type. Neuromuscular outcomes revealed limited acute variation, although isolated evidence indicated greater residual hamstring fatigue following exposure to artificial turf. Perceptual responses were inconsistent and appeared moderated by surface familiarity. A critical limitation across studies was the scarce reporting of objective mechanical surface properties—such as shock absorption, deformation, and rotational traction—restricting mechanistic interpretation.

Conclusion

Overall, the findings highlight the importance of integrating mechanical characterisation, standardised football-specific protocols, and contextual covariates when evaluating player–surface interactions. These results inform evidence-based training design, load management, and pitch selection in football.

Key Points

- Playing surface type meaningfully influences football-specific physical performance, with artificial turf generally eliciting greater external running demands, while internal physiological responses remain largely similar across surfaces.
- Mechanical properties of the pitch—such as shock absorption, deformation, and rotational traction—play a more decisive role than the nominal surface category itself, yet most studies fail to report these metrics.
- Sand surfaces impose substantially higher metabolic and neuromuscular load, reducing running efficiency and sprint performance, and should be used strategically for specific training aims rather than football-specific technical work.

Background

Playing surfaces are a key determinant of both player safety and sporting performance [1]. The primary function of a sports surface is to provide a safe and reliable platform for physical activity, while enabling athletes to perform consistently and effectively [2]. Accordingly, modern surface construction and maintenance increasingly aim to optimise performance in a standardised manner [3]. Advances in surface technologies—particularly in artificial turf systems—have been driven by the evolving demands of the sports industry, in which surface quality is widely regarded as integral to achieving optimal outcomes [4]. At a mechanistic level, changes in surface properties can alter movement patterns and performance outputs [5], and empirical evidence suggests that surface elasticity may be related to athletic performance [6]. More recently, innovation in artificial turf has increasingly focused on system components such as infill materials—including organic alternatives—because they can modify traction- and stiffness-related behaviour and may shape both player perceptions and performance-relevant player–surface interactions [7]. Reflecting this, sport governing bodies and international standardisation committees (e.g., the Fédération Internationale de Football Association, FIFA) have developed and promoted quality assurance programmes to support consistent surface standards [8].

In football, surface effects are particularly relevant because performance depends on repeated high-intensity actions and rapid player–surface interactions. Football-specific movements—such as sprinting, accelerating, decelerating, and changing direction—are highly sensitive to the mechanical behaviour of the pitch, as the surface mediates traction, impact attenuation, and energy return during these actions [9–12]. Consequently, examining mechanical properties is essential for understanding how different surfaces shape player–surface interaction in football contexts. Structural components of artificial turf systems can further modify mechanical behaviour and, in turn, performance: for example, sub-base composition (e.g., compacted gravel) may enhance durability while maintaining safety standards [13]. Moreover, variations in artificial turf system design have been associated with differences in physiological responses and technical execution, particularly during high-intensity actions, highlighting the need to consider surface design in performance planning [14].

Despite this mechanistic rationale, evidence from applied football studies remains fragmented and sometimes inconsistent. While a growing body of research has examined surface-related performance outcomes in football, studies vary widely in design, protocols, and outcome selection, limiting comparability and contributing to mixed findings. A structured synthesis is therefore warranted to support evidence-based decision-making in football training and surface design. This rationale aligns with broader methodological developments in sports science, in which systematic review approaches have been proposed to evaluate contextual influences on performance in elite football [15].

Existing football literature has reported divergent findings across key outcome domains. For injury-related outcomes, evidence remains conflicting, with some cohort analyses indicating no meaningful differences in injury incidence between surface types, while acknowledging that patterns may depend on context and player characteristics [8, 16–18]. Previous work also indicates that familiarity with the playing surface, together with relevant contextual factors, may influence players' perceptions of risk and recovery [19]. Beyond injury, several studies have explored performance and physiological responses across surfaces. For instance, sprint mechanics differ across compliant and deformable surfaces: biomechanical analyses show substantial changes in stride characteristics and propulsion when comparing sand with firmer surfaces, accompanied by increased energy cost and altered neuromuscular demands [13, 20, 21]. Training and match simulations on softer surfaces such as sand have also been linked to greater energy expenditure and altered internal load compared with harder surfaces [1, 22–24], with reports of higher lactate and heart rate responses during football activity on sand relative to artificial turf and hard surfaces [25]. Meanwhile, evidence comparing artificial and natural turf suggests that performance differences may depend on the task demands: linear sprint speed often decreases on more deformable surfaces [13, 26–28], whereas certain change-of-direction actions may be facilitated on artificial turf, potentially due to differences in rotational traction and shock absorption [29]. Nonetheless, not all studies agree, with

some reporting similar physiological demands across artificial and natural turf, and others indicating higher demands on natural surfaces [30, 31].

Critically, several methodological limitations constrain interpretation and reduce the transferability of current findings. Many applied studies do not report objective mechanical characterisation of the playing surface (e.g., peak shock absorption, peak deformation, peak torque and torque at 10º), making it difficult to attribute observed performance differences to specific surface properties rather than broad surface labels (e.g., “natural” versus “artificial”). In addition, heterogeneity in football tasks (e.g., small-sided games, repeated-sprint tests, simulated matches), participant characteristics, environmental conditions, and levels of surface familiarisation further complicate cross-study comparison and may partly explain inconsistent results.

Given the multifactorial influence of surface characteristics on performance, injury risk, and player perception—and considering recent regulatory developments affecting pitch management (e.g., updates to FIFA quality programmes and EU restrictions on microplastics)—a systematic evaluation of the evidence is timely. Therefore, the aim of this systematic review was to critically synthesise evidence on how different playing surfaces (natural grass, artificial turf, and sand) influence football-specific performance outcomes, including sprinting, acceleration, physiological load, neuromuscular responses, and perceptual variables. By consolidating current evidence, this review is intended to inform practitioners, coaches, sport governing bodies and sports federations in evidence-based decisions regarding training design, load management, and surface selection, and to identify methodological priorities (including surface characterisation and protocol standardisation) to guide future research.

Methods

Experimental Approach to the Problem

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [32], and structured using the PICO framework (Participants, Intervention, Comparison, Outcomes; see Table 1). The protocol was prospectively registered in the PROSPERO database (CRD42024605254). A comprehensive search strategy was implemented to identify studies evaluating physical performance in football players across different playing surfaces (natural grass, reinforced natural turf systems, and artificial turf). Searches were conducted in three major databases—PubMed, SPORTDiscus, and Web of Science—covering the period from January 1st, 1990, to January 30th, 2024. The following search terms were used: (“soccer” OR “football”) AND (“artificial” OR “synthetic” OR “natural”) AND (“grass” OR “turf” OR “sand”).

Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria: (1) original empirical research involving amateur, semi-professional, or professional football players; (2) football activities performed on natural playing surfaces or natural turf necessarily among the included surfaces; (3) publication in a peer-reviewed journal indexed in either the Journal Citation Reports (JCR) or Scimago Journal Rank (SJR); (4) written in English; (5) assessment of physical performance variables during training sessions or competitive matches; and (6) full-text availability.

Data Extraction and Quality Assessment

The following variables were summarized in a preformatted spreadsheet: authors, year of publication, and characteristics of the study participants. Data extraction, quality assessment, and risk of bias evaluation were conducted independently

and in duplicate by two reviewers (A.M. and J.P.). Discrepancies were resolved by consensus through consultation with a third independent reviewer (J.G.), in accordance with the Cochrane Collaboration guidelines [33].

Table 1
Eligibility Criteria Based on the PICOS Framework

Component	Detail
Participants	Male and female football players across all competitive levels, including amateur, semi-professional, professional, and youth categories.
Interventions	Type of playing surface used during football activity: natural grass, artificial turf, sand, and asphalt.
Comparisons	Physical and physiological responses across different surfaces, specifically comparing natural grass with artificial turf, sand, and asphalt.
Outcomes	Performance-related outcomes including physical (e.g., speed, acceleration, distance), physiological (e.g., heart rate, lactate, fatigue), technical (e.g., passes, tackles), and perceptual (e.g., RPE, comfort, surface preference) measures.
Study designs	Quantitative research designs, including experimental, quasi-experimental, and descriptive studies.

Evaluation of Risk of Bias

Risk of bias in the included studies was assessed using two complementary tools, following established methodological standards [14]. The Risk Of Bias In Non-randomized Studies – of Interventions (ROBINS-I) [34] was applied to studies with non-randomized designs (e.g., cohort and case-control), while the Newcastle-Ottawa Scale adapted for cross-sectional studies (NOS-xs) [35] was used for descriptive designs.

The ROBINS-I tool evaluates seven domains of potential bias: (i) confounding; (ii) participant selection; (iii) classification of interventions; (iv) deviations from intended interventions; (v) missing data; (vi) outcome measurement; and (vii) selection of the reported result. Each domain was rated using the following symbols: <<✓>> for low risk, <<□>> for high risk, and <<!>> when information was unclear or insufficient. The overall risk of bias was determined by the highest risk level identified across domains.

The NOS-xs tool assesses three core domains: Selection, Comparability, and Outcome. Each criterion was scored with a <<□>> if it met quality standards, or a <<□>> if it did not. The criteria included: (i) sample representativeness; (ii) sample size justification; (iii) handling of non-responses; (iv) clarity and reliability of exposure measurement; (v) control of confounding variables; (vi) validity and reliability of outcome assessment; (vii) appropriateness of statistical methods; and (viii) clarity in reporting results. Total scores ranged from 0 to 8 stars, with studies classified as high risk (0–3), moderate risk (4–6), or low risk (7–8).

To ensure consistency and minimize subjectivity, two independent reviewers conducted the assessments. Discrepancies were resolved through discussion or consultation with a third reviewer.

2.4.1.ROBINS-I

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Figure 2 near here

2.4.2 NOS-X

Figure near here

Results

The flow diagram in Fig. 3 illustrates the selection process. Out of a total of 4,008 articles, 944 remained after duplicate removal. Subsequently, 886 publications were excluded for not meeting the eligibility criteria. The full-text eligibility of 58 articles was assessed, and 40 of them were excluded for multiple reasons. Ultimately, 16 studies were included [22, 28, 31, 36–48]. Table 1 presents the general characteristics of the study participants, while Tables 2 detail the specific characteristics.

Figure 4 near here

All studies included in this review were published in English and Spanish between 2007 and 2023. A total of 16 studies were analyzed, comprising of 9 non-randomized intervention designs [31, 37, 39, 41–44, 46, 48] and 7 cross-sectional evaluations [22, 28, 36, 38, 40, 45, 47].

The majority of studies were conducted in European countries, including Spain [28, 41, 42, 45], the United Kingdom [31, 38, 39, 46], Sweden [37], Portugal [22, 44], and France [43]. Additional contributions came from South America [40, 47] and North Africa [36].

The total sample comprised 392 football players (male and female), ranging from youth to professional categories. Participant age varied between 12.4 and 28.8 years, with most studies reporting anthropometric data such as height, weight, and body fat percentage [41, 42].

All studies assessed physical performance in football across different playing surfaces, including natural grass, artificial turf (2nd and 3rd generation systems), and sand. The most frequently analyzed variables were sprint speed, acceleration, total distance covered, heart rate, lactate concentration, jump performance (Countermovement Jump, CMJ; Squat Jump, SJ), and perceived exertion (Rate of Perceived Exertion, RPE; Visual Analogue Scale, VAS). Several studies also examined biomechanical parameters such as stride length, contact time, and propulsion phase [20], as well as neuromuscular fatigue and recovery markers [31, 46].

Artificial turf was the most commonly studied surface, often compared with natural grass under match or simulated conditions [37, 38, 41, 43, 48]. Sand was included in three studies, primarily in the context of training load and neuromuscular adaptation [22, 23, 44].

Table 2 summarizes the general characteristics of the included studies, while Table 3 details the physical variables assessed, measurement methods, and key findings.

Table 2
General Characteristics of the Included Studies

Citation	n	Surface	Study design	Sport	Age (years)	Height (cm)	Weight (kg)	Body fat (%)
López-Gómez et al., 2020 [40]	18M	Artificial (monofilament 3G) -Natural	Non-randomized Studies - of Interventions	Football	12.4 ± 0.5	151	45	-
Modric et al., 2023 [48]	31M	Artificial-Natural	Non-randomized Studies - of Interventions	Football	26	-	-	-
Ammar et al., 2019 [36]	9M	Artificial (3rd generation) - Natural (FIFA 1 Star)	cross-sectional studies	Football	21.8 ± 1.1	178 ± 6,2	69.4 ± 9.8	11.4 ± 2.5
Hughes et al., 2013 [38]	17M	Artificial (FIFA 2 Star)-Natural	cross-sectional studies	Football	22.8 ± 2.1	179 ± 5	76.3 ± 5.7	-
Andersson et al., 2007 [37]	72M + 21F	Artificial (2nd and 3rd generation) - Natural	Non-randomized Studies - of Interventions	Football	28.8 ± 5.2 M / 24.3 ± 4.9 F	181 ± 3 M / 170 ± 2 F	72.2 ± 4.7 M / 62.9 ± 4.9 F	-
Sánchez-Sánchez et al., 2014 [28]	18M	Artificial 4 surfaces with different bases (gravel/asphalt) and elastic layers (with/without)	cross-sectional	Football	22.44 ± 1.72	175 ± 6	73.74 ± 8.47	14.74 ± 4.15
Sánchez-Sánchez et al., 2016 [45]	20M	Artificial 4 surfaces with different bases (gravel/asphalt) and elastic layers (with/without)	cross-sectional studies	Football	21.65 ± 3.10	176.45 ± 4.75	69.38 ± 3.84	11.46 ± 4.23
Nédélec et al., 2013 [43]	12M	Artificial (3rd generation)-Natural	Non-randomized Studies - of Interventions	Football	17.7 ± 0.5	180.2 ± 6.0	71.9 ± 6.9	9.4 ± 2.0
López-Fernández et al., 2018 [42]	16M	Artificial (3rd generation Natural	Non-randomized Studies - of Interventions	Football	22.17 ± 3.43	177.12 ± 5.24	69.16 ± 4.55	-
López-Fernández et al., 2018 [41]	16F	Artificial -Natural-Sand	Non-randomized Studies - of Interventions	Football	19.56 ± 1.97	161.57 ± 5.83	57.74 ± 4.89	24.93 ± 4.1
Rago et al., 2016 [44]	8M	Artificial (FIFA 2-star) -Sand	Non-randomized Studies - of Interventions	Football	23.6 ± 2.3	176.3 ± 7.08	70.6 ± 6.91	-
Viviescas et al., 2021 [47]	19F	Artificial (FIFA 2-star) -Natural	Non-randomized	Football	22 ± 4.6	151 ± 36	57 ± 5.7	18 ± 4.6

Notes: F: female; M: male; CM: centimeters; KG: kilograms; %: percentage.

Citation	n	Surface	Study design	Sport	Age (years)	Height (cm)	Weight (kg)	Body fat (%)
			Studies - of Interventions					
Page et al., 2020 [31]	18M	Artificial (FIFA 1 Star)-Natural	Non-randomized Studies - of Interventions	Football	24 ± 4	181.1 ± 6.3	74.3 ± 6.1	-
Stone et al., 2016 [46]	8M	Artificial (2nd and 3rd generation) - Natural	Non-randomized Studies - of Interventions	Football	20.3 ± 1.4	177.1 ± 7.7	72.5 ± 7.2	-
Jones et al., 2020 [39]	15M	Artificial (FIFA 1 Star)-Natural	Non-randomized Studies - of Interventions	Football	22.13 ± 2.36	-	-	-
Brito et al., 2012 [22]	16M	Artificial (3rd generation) -Sand-Asphalt	Non-randomized Studies - of Interventions	Football	22.4 ± 4.4	174.1 ± 4.4	71.3 ± 6.6	-
Notes: F: female; M: male; CM: centimeters; KG: kilograms; %: percentage.								

Table 2
Detailed Characteristics of Performance Outcomes, Assessment Methods, and Key Findings

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
López-Gómez et al., 2020 [40]	Colombia, regional youth selection	Speed, acceleration, contact time, flight time, contact phase, support phase, propulsion phase, stride, cadence	OptoGait optical system (5 m), sprint tests	Speed (m/s): p = 0.170, r = 0.229 Acceleration (m/s²): p = 0.058, r = 0.316 Contact time (s): p = 0.500, r = 0.113 Flight time (s): p < 0.001, r = 0.592 Contact phase (s): p = 0.040, r = 0.342 Support phase (s): p < 0.001, r = 0.621 Propulsion phase (s): p < 0.001, r = 0.563 Stride length (cm): p = 0.845, r = 0.032 Cadence (steps/s): p = 0.744, r = 0.054	Running pattern varies by surface; contact phase influences speed on natural, while flight time and stride affect acceleration on natural
Modric et al., 2023 [48]	Latvia, professional men's league	Total distance, low/moderate/high intensity running, total and high-intensity accelerations/decelerations	GPS 10 Hz (Catapult Vector S7), match analysis (n = 32), contextual factor control	-Total Distance: Higher on AT ES = 0.28 [0.04 to 0.52] -Moderate-intensity running: Higher on AT ES = 0.41 [0.16 to 0.65] -High-intensity running: Higher on AT ES = 0.23 [−0.02 to 0.47] Centre Defenders: -Total Distance: Higher on AT (ES = 0.55 [0.02 to 1.07])	Artificial turf increases physical demand, especially for defensive and midfield players, regardless of match outcome or opponent level

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				-Moderate-Intensity Running: Higher on AT (ES = 0.91 [0.36 to 1.44]) -High-Intensity Running: Higher on AT (ES = 0.67 [0.14 to 1.19]) -Total Accelerations: Higher on AT (ES = 0.38 [–0.15 to 0.89]) -Total Decelerations: Higher on AT (ES = 0.31 [–0.22 to 0.82]) Centre Midfielders: -Total Distance: Higher on AT, but only in matches won (ES = 0.61 [0.10 to 1.09]) - Moderate-Intensity Running: Higher on AT (ES = 0.79 [0.28 to 1.28]) -High-Intensity Running: Higher on AT (ES = 0.44 [–0.06 to 0.92]) -Total Accelerations: Higher on AT (ES = 0.37 [–0.12 to 0.85]) -Total Decelerations: Higher on AT (ES = 0.34 [–0.15 to 0.82]) Fullbacks: -Total Distance: Higher on AT (ES	

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				= 0.28 [−0.23 to 0.78]) - Moderate-Intensity Running: Higher Higher on AT (ES = 0.49 [−0.03 to 0.99]) -High-Intensity Running: Higher on AT (ES = 0.38 [−0.13 to 0.89]) Wide Midfielders: - Moderate-Intensity Running: Higher on AT (ES = 0.53 [−0.01 to 1.05]) -Total Accelerations: Higher on AT (ES = 0.40 [−0.13 to 0.92]) -Total Decelerations: Higher on AT (ES = 0.31 [−0.22 to 0.82]) (No significant differences in Total Distance and High-Intensity Running. Forwards: -No differences between AT and NG -High Decelerations: Lower on AT (ES = − 1.5 [−2.37 to − 0.53])	
Ammar et al., 2019 [36]	Tunisia, regional professional players	Total and peak distance in RSA test, fatigue index, RPE, feeling scale, lactate, CK, LDH, CRP, NEU, LYM, MON	RSA test (6 × 30 s sprints with direction changes), blood analysis,	RSA sprint block effect: p = 0.001, ES = -1.97 (Artificial), ES = -1.66 (Natural)	Artificial turf improves RSA performance and reduces physiological and perceptual

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
			RPE and FS scales	Surface effect on RSA performance: p = 0.03 Sprint blocks 4–6: Block 4: p = 0.009, ES = 0.91 Block 5: ES = 0.84 Block 6: ES = 0.63 Total distance covered: p = 0.018, ES = 1.15 Best distance covered: p > 0.05 Fatigue index: p > 0.05 RPE: p = 0.04, ES = -0.49 Feeling Scale (FS): p = 0.02, ES = 0.81 Lac: p = 0.03, ES = -0.80, 95% CI (-1.67 to 0.14) NEU: ES = -0.16, 95% CI (-1.03 to 0.72) LYM: ES = -0.94, 95% CI (-1.82 to 0.02) Other biomarkers: p > 0.05 (no significant differences).	load compared to natural turf
Hughes et al., 2013 [38]	UK, semi-professional players	Heart rate, lactate, 15 m sprint, agility (L-test), vertical jump, sprint-agility with turn and cut	Football simulation protocol (SSP), lactate analysis, HR monitor, SmartSpeed and SmartJump	Lactate: p > 0.05 Heart rate: p > 0.05 L-agility time (s): p ≈ 0.05, ES = 0.36 60 m sprint time (s): p > 0.05, ES = 0.14	Physiological responses and fatigue were similar on both high-quality surfaces; small differences in specific maneuvers like turns and agility

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Vertical jump (cm): p > 0.05, ES = 0.12	
Andersson et al., 2007 [37]	Sweden, elite male and female leagues	Total distance, high-intensity running, sprints, tackles.	Video analysis (time-motion and technical), VAS questionnaires	Standing time (%): p > 0.05, artificial turf = 21.0%, natural grass = 19.8% Walking (%): p > 0.05, artificial turf = 41.6%, natural grass = 42.9% Low-intensity running (%): p > 0.05, artificial turf = 30.6%, natural grass = 30.4% High-intensity running (%): p > 0.05, artificial turf = 6.9%, natural grass = 6.9% Total distance covered (km): p > 0.05, artificial turf = 10.19 km, natural grass = 10.33 km High-intensity running distance (km): p > 0.05, artificial turf = 1.86 km, natural grass = 1.87 km Sprinting distance (km): p > 0.05, artificial turf = 0.31 km, natural grass = 0.32 km Activity changes (n): p > 0.05, artificial turf = 1290, natural grass = 1284 High-intensity running bouts (n): p > 0.05, artificial turf = 185, natural grass = 186	Artificial turf modifies playing style (more possession, less aggression); male players perceive it as more physically and technically demanding

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Sprints (n): p > 0.05, artificial turf = 21, natural grass = 22 Total passes per team per game: p < 0.05, artificial turf = 305, natural grass = 249 Midfield zone passes per game: p < 0.05, artificial turf = 148, natural grass = 107 Long passes: p > 0.05 Successful short passes: p > 0.05 successful long passes: p > 0.05 Successful long low passes: p = 0.13 (trend toward lower success on artificial turf: 63.4% vs. 73.2%) Crosses, throw-ins, free kicks, shots on goal, goals scored: p > 0.05	
Sánchez-Sánchez et al., 2014 [28]	Spain, amateur players with experience on artificial turf	RSA (times, speed, fatigue), jumps (CMJ, SJ, 15s), ball kicking speed, perception (VAS), lactate	GPS: Spi Pro X (GPSports, 10 Hz); Jumps: Optojump Next (Microgate, Italy); Ball speed: Radar Stalker ATS System™ (Radar Sales, MN, USA); Lactate: Lactate Scout; Perception: VAS scale; Mechanical properties: Advanced Artificial Athlete and	RSA (s): p = 0.009 VMAX (km/h): p = 0.849. VMEAN (km/h): p = 0.190. Peak HR (bpm): p = 0.969. % Diff CMJ height: p = 0.040. % Diff SJ height: p = 0.019. FR (%): p < 0.001, F = 451.63	The mechanical properties of artificial turf influence physical performance but not physiological load; comfort perception is lower on softer surfaces

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
			Rotational Resistance Tester (Deltec Metaal, Netherlands)	StV (mm): $p < 0.001$, $F = 326.92$ ER (%): $p < 0.001$, $F = 161.26$ RT (N·m): $p < 0.001$, $F = 83.81$	
Sánchez-Sánchez et al., 2016 [45]	Spain; amateur players in simulated game situations	Total distance, maximum speed, number of sprints, accelerations, impacts, heart rate, perception (VAS)	GPS: Spi Pro X (GPSports, 10 Hz); Heart rate: Polar Team System; Software: Team AMS R1 2013.22 (GPSports); Mechanical properties: according to EN 15330-1:2014 standard (FR, StV, ER, RT); Perception: VAS scale	Total distance (m): $p = 0.535$, $F = 0.735$ Work:rest ratio: $p = 0.804$, $F = 0.329$ HR mean (% HRmax): $p = 0.850$, $F = 0.265$ HR mean (bpm): $p = 0.873$, $F = 0.234$ HR peak (% HRmax): $p = 0.646$, $F = 0.556$ HR peak (bpm): $p = 0.765$, $F = 0.384$ number of sprints (n): $p = 0.020$, $F = 3.489$ sprint Vmax mean (km/h): $p = 0.004$, $F = 4.787$ high-intensity distance (% total distance): $p = 0.095$, $F = 2.202$ high-intensity distance (m): $p = 0.178$, $F = 1.683$ duration of sprints (s): $p = 0.085$, $F = 2.300$ average sprint distance (m): $p = 0.051$, $F = 2.730$ maximum acceleration peak	The mechanical properties of artificial turf influence physical performance (especially in high-intensity actions), but not physiological load; harder surfaces favor sprint performance and game perception

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				(m/s²): p = 0.120, F = 2.011 Accelerations: 1.5–2.0 m/s²: p = 0.320, F = 1.190 2.0–2.5 m/s²: p = 0.232, F = 1.462 2.5–2.75 m/s²: p = 0.680, F = 0.505 > 2.75 m/s²: p = 0.477, F = 0.840 Decelerations: 1.5–2.0 m/s²: p = 0.563, F = 0.686 2.0–2.5 m/s²: p = 0.374, F = 1.053 2.5–2.75 m/s²: p = 0.729, F = 0.434 > 2.75 m/s²: p = 0.785, F = 0.355 Impact analysis – artificial turf systems: Light impacts (5–6 G): p = 0.889, F = 0.210 Light/moderate impacts (6–6.5 G): p = 0.871, F = 0.236 Moderate/heavy impacts (6.5–7 G): p = 0.684, F = 0.499 Heavy impacts (7–8 G): p = 0.573, F = 0.670 Very heavy impacts (8–10 G): p = 0.926, F = 0.156	

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Severe impacts (> 10 G): p = 0.614, F = 0.605 Total number of impacts (n): p = 0.706, F = 0.467 maximum peak of impact (G): p = 0.672, F = 0.516	
Nédélec et al., 2013 [43]	France; professional players	Jumps (SJ, CMJ), sprint (6s), eccentric isokinetic torque, perception (sleep, fatigue, muscle soreness, stress, recovery)	Jumps: Kistler force platform Sprint: Woodway Force 3.0 non-motorized treadmill Torque: Con-Trex dynamometer HR: Polar Team System Perception: Borg, Hooper, TQR, localized pain scales	Heart rate (bpm): p > 0.05 feeling scale: p > 0.05 Squat Jump (SJ): -Surface × time interaction: p = 0.01 -48 h post-test: lower performance -Decrement on natural grass (p < 0.05), ES = 0.40. -Main effect of time: p < 0.001 -Performance impairment immediately post-test: p < 0.001 Countermovement Jump (CMJ): -No surface × time interaction: ES = 0.04–0.12 (trivial) -Main effect of time: p = 0.01 -Performance impairment immediately post-test: p = 0.01 -Performance impairment at 24 h: p < 0.05	Artificial turf does not cause greater fatigue or delay recovery in familiarized players; negative perception may depend on lack of familiarity with the surface

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Hamstring Peak Torque: -No surface × time interaction -Main effect of surface: $p < 0.05$ -Main effect of time: $p < 0.05$ significant changes from baseline immediately and at 24 h: $p < 0.05$ Sprint performance (mean power output, mean speed, peak speed): -No significant changes from baseline trivial differences between surfaces: ES = 0.01–0.17 Fatigue: -Main effect of time: $p < 0.001$ increase of 1 unit (to “average-high”) observed immediately after the test for both surfaces: $p < 0.001$ Muscle soreness: -Main effect of time: $p < 0.01$	
López-Fernández et al., 2018 [42]	Spain; amateur players	Mean and peak HR, % time > 85% HRmax, mean and max speed, repeated sprint test, agility test (time, speed, fatigue)	GPS: GPSports HPU HR: Polar Team System Photocells: Microgate	Heart rate (HRmean as %HRmax): Artificial turf (AT): -Bout 1: +7.59%, $p < 0.001$, ES =	Mechanical properties (absorption, deformation, energy return) are more relevant than surface type;

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
			Witty Mechanical properties: Advanced Artificial Athlete	1.465 -Bout 2: +4.11%, p = 0.017, ES = 0.849 -Bout 3: +8.24%, p = 0.036, ES = 0.786 Natural grass (NG): -Bout 1: +8.24%, p < 0.001, ES = 1.946 -Bout 2: +8.24%, p < 0.001, ES = 1.328 -Bout 3: +4.25%, p = 0.048, ES = 0.967 Presprint phase: significant difference in NG between bouts -Bout 3 > Bout 1: +11.9 bpm, p = 0.006, ES = 1.434 Repeated sprint test performance: -No significant differences between surfaces (p > 0.05 for all variables) Agility test (presprint phase, bout 1): NG slower than AT: Agility test 2: +0.60 s, p = 0.018, ES = 1.034 S-AR turn time: +0.31 s, p = 0.027	small agility differences may not be relevant for training

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Best time: +0.52 s, p = 0.042, ES = 0.867 Average speed higher on AT: + 1.17 km/h, p = 0.037, ES = 0.807	
López-Fernández et al., 2018 [41]	Spain; sub-elite female players (second division)	Mean and peak HR, % time > 85% HRmax, pre/post CMJ, perception (12 VAS items)	HR: Polar Team System Jumps: Optojump Next Perception: VAS scale (12 items) Surfaces: NG (25 mm), AT (60 mm, SBR + sand), DT (dry and uniform)	Physiological responses – SSG formats and surfaces: Natural grass vs. dirt: -HR mean and HR peak higher on natural grass than on dirt: p < 0.05 Natural grass vs. artificial turf: HR mean (%HRmax): +3.31%, p = 0.029, ES = 0.856 HR mean (bpm): +6.68 bpm, p = 0.012, ES = 0.838 HR high intensity (% time): +19.07%, p = 0.041, ES = 0.934 Internal load zones – SSG 600 and surface comparisons: Natural grass vs. other surfaces: -Zone 5: NG > dirt: +13.77%, p = 0.048, ES = 0.564 -Zone 6: NG > artificial turf: +19.21%, p < 0.001, ES = 0.819	Field size and surface influence internal load in SSGs; natural grass generates higher load than artificial; dirt is not recommended; very large fields may reduce intensity

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				NG > dirt: +26.65%, p < 0.001, ES = 1.420 Countermovement Jump (CMJ) – artificial turf, natural grass, and dirt: -Coefficient of variation: p > 0.05 Visual Analogue Scale (VAS) – player perceptions across surfaces and pitch sizes: -Main difference between natural grass and artificial turf: VAS8 – suitability for tackling: SSG 400: NG > AT by + 18.98 a.u., p = 0.001, ES = 0.768 SSG 600: NG > AT by + 19.16 a.u., p < 0.001, ES = 0.837 SSG 800: NG > AT by + 13.71 a.u., p = 0.021, ES = 1.257	
Rago et al., 2016 [44]	Portugal; semi-professional players	Distance, speed, accelerations/decelerations, perception (RPE), technical actions	GPS: GPSports SPI Elite (15 Hz interpolated); Perception: Visual Analogue Scale (VAS); Technique: Video notational analysis	Physical Variables and Rating of Perceived Exertion: -Total distance covered was significantly greater on turf than on sand (P < 0.05), with a large effect size (ES = 0.80). -Time spent in low-intensity running was	Sand imposes greater muscular load and can be used for strength or rehabilitation; not suitable for maximum speed or specific technical training

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				significantly higher on turf (P < 0.05; ES = 0.60). -Time spent in high-intensity running was significantly higher on turf (P < 0.05; ES = 0.48). -Time spent in high-intensity activity was significantly higher on turf (P < 0.05; ES = 0.41). -Time spent jogging was significantly higher on sand (P < 0.05; ES = 0.81). -Time spent in low accelerations was significantly higher on turf (P < 0.05; ES = 0.82). -Time spent in low decelerations was significantly higher on turf (P < 0.05; ES = 0.59). -Time spent in high accelerations was significantly higher on sand (P < 0.05; ES = 0.52). -Time spent in maximum accelerations was significantly higher on sand (P < 0.05; ES = 0.91). -Time spent in high decelerations was significantly higher on sand (P < 0.05; ES = 0.51). -Time spent in maximum decelerations was significantly	

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				higher on sand (P < 0.05; ES = 0.88). -Average speed was significantly higher on turf (P < 0.05; ES = 0.80). -Peak speed was significantly higher on turf (P < 0.05; ES = 0.80). -Estimated energy cost (EC) showed no significant difference between surfaces (P > 0.05; ES = 0.30). -Metabolic power (Pmet) showed no significant difference (P > 0.05; ES = 0.23). -Fatigue-related changes over time were not significant for any physical variable (P > 0.05). -Rating of Perceived Exertion (RPE) was significantly higher on sand (P < 0.05; ES = 0.72).	
Viviescas et al., 2021 [47]	Colombia; professional female players	Speed, acceleration, flight time, contact time, cadence, energy, step angle, support and propulsion phases	Optical system: OptoGait; Anthropometry: ISAK level 2, Harpenden caliper, Tanita scale, SECA stadiometer	-Speed: P < 0.001. Natural turf (higher speed) -Cadence: P < 0.001. Natural turf (higher cadence) -Energy:P < 0.001. Artificial turf (higher energy) -Flight time: P < 0.001. Artificial turf (longer flight time)	Natural turf allows more efficient and faster sprint pattern; artificial turf involves higher energy expenditure and biomechanical alterations; body composition influences performance

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				-Contact phase: P < 0.001. Favored surface: Artificial turf (longer contact phase) -Step angle: P < 0.001.Favored surface: Artificial turf (greater step angle)	
Page et al., 2020 [31]	UK; amateur players	Peak isokinetic torque (eccKF and conKE), Nordic break angle, jump height (CMJ and SJ)	Isokinetic: Biodex System 2 (60, 180, 240°/s); Jumps: Smartjump (Fusion Sport); Nordic angle: 2D analysis with Kinovea; Protocol: SAFT90 (90 min)	Concentric Knee Extensor Peak Torque (conKE PT). At 60°/s (p = 0.391), 180°/s (p = 0.009), and 240°/s (p = 0.440): -No significant differences reported across time or between surfaces. -No effect sizes or p-values indicating statistical significance. Nordic Break Angle: -No significant differences between surfaces or time points. Countermovement Jump Height (CMJ): -Trial × Time interaction: Not significant (p = 0.967) -Main effect of trial: Not significant (p = 0.821) Squat Jump Height (SJ):	Artificial turf generates greater residual fatigue in hamstrings at 180°/s; surface should be considered when planning recovery and training load

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Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				-Trial × Time interaction: Not significant (p = 0.575) -Main effect of trial: Not significant (p = 0.826)	
Stone et al., 2016 [46]	UK; amateur players	Total Player Load and by planes (AP, ML, V), distance, RPE, muscle soreness (VAS)	GPS with triaxial accelerometer: MinimaxX S4 (Catapult)	Total Accumulated PlayerLoad: -Main effect of surface: P = 0.55. No difference between natural and artificial turf Surface × location interaction: P = 0.98. Not significant. Axial Plane Loading: -Anteroposterior loading: Surface: P = 0.31. not significant -Mediolateral loading: Surface: P = 0.70. Not significant -Vertical loading: Surface: P = 0.76. Not significant Relative Axial Contributions to Total Load. Main effect of surface: -Anteroposterior: P = 0.60. Not significant -Mediolateral: P = 0.56. Not significant -Vertical: P = 0.45. Not significant	Surface does not affect mechanical load during football-specific activity; sensor location influences magnitude and load pattern, useful for monitoring and rehabilitation

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				No surface × location interaction in any plane (P ≥ .26, η^2 ≤ .042). Total distance covered: P = 0.75, η^2 = .014 → Not significant Post-exercise RPE: P = 0.98. Not significant Post-exercise VAS (pain):P = 0.61. Not significant	
Jones et al., 2020 [39]	UK; amateur players	Lactate, sprint (15 m, 60 m), agility (L-AR), CMJ, RSI, CK, muscle soreness (PMS)	Protocol: Soccer Simulation Protocol (SSP, 90 min); Jumps: SmartJump; Sprint and agility: SmartSpeed (Fusion Sport); CK: Reflotron; Pain: VAS scale	Variables with no significant differences between surfaces (P > 0.05): -Blood lactate (BLa) → P > 0.05 -Single 15-m sprint time → P > 0.05 -Agility run → P > 0.05 -Countermovement Jump (CMJ) → P > 0.05 -Multiple Rebound Jump (MRJ) → P > 0.05 -10-m sprint → P > 0.05 -60-m sprint → P > 0.05 -Lateral Agility Run (L-AR) → P > 0.05 (in pre–post comparison) -Recovery variables (CK, PMS, performance at	Surface type does not significantly affect physiological response or recovery after simulated match; artificial turf does not require specific recovery planning

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				24h and 48h) → P > 0.05 -Total distance covered → P = 0.75 -Post-exercise RPE → P = 0.98 -Post-exercise VAS → P = 0.61 Variables with significant difference between surfaces (P > 0.05): -Lateral Agility Run: Faster on natural turf, P = 0.014, η^2p = 0.599 (moderate-to-large effect).	
Brito et al., 2012 [22]	Portugal; amateur players	HR, lactate, distance, speed, intense actions, VAS, SJ, CMJ, sprint 5 and 30 m	GPS: GPSports SPI Elite; HR: Polar Team System; Lactate: Lactate Pro; Jumps and sprint: Digitime 1000, Speed Trap II; Perception: VAS (4 items)	-Time spent sprinting: Higher on asphalt than sand and turf, P < .01 -Time spent in low-speed running: Lower on asphalt and turf than sand, P < .001 -Time spent jogging: Higher on asphalt and turf than sand, P < .01 -Total distance covered, average speed, max speed: Higher on asphalt and turf than sand, P < .05 -Number of sprints performed: Higher on asphalt than sand and turf, P < .01 -Number of high-intensity actions:	All surface types induce high cardiovascular and muscular load; perception of effort and physiological response vary by surface type

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				Higher on asphalt than turf, P < .05 -Mean heart rate (absolute and relative), relative peak HR: Lower on asphalt than turf, P < .05 -Time at 90–95% HRmax: Lower on asphalt than turf, P = .013 -Time at 70–80% HRmax: Higher on asphalt than turf, P = .015 -Blood lactate concentration: Lower on asphalt than sand and turf, P < .05 -Average sprint duration: P > .05 -High-intensity actions (asphalt vs. sand): P > .05 -Absolute peak heart rate: P > .05 -VAS1: Lower on asphalt than sand, P < .001 -VAS2: Lower on asphalt than sand and turf, P < .001 -VAS3: Lower on asphalt than sand and turf, P < .01 -VAS4: Lower on asphalt than sand and turf, P < .01 -Squat Jump (pre- vs post-game) P < 0.001: ↓ from 0.415 m to:	

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Reference	Context	Physical variables	Measurement methods	Associations	Relevant findings
				-Sand: 0.383 m -Turf: 0.398 m -Asphalt: 0.387 m Countermovement Jump (pre- vs post-game) P < 0.00: ↓ from 0.412 m to: Sand: 0.406 m Turf: 0.397 m Asphalt: 0.387 m No significant differences between surfaces: -Squat Jump and countermovement Jump decrements P > 0.05 -5-m sprint P > 0.05 -30-m sprint P > 0.05 -Sprint performance decrements between surfaces P > 0.05	

Note: AP: Anteroposterior; BF: Biceps Femoris; CK: Creatine Kinase; CMJ: Countermovement Jump; CRP: C-Reactive Protein; EMG: Electromyography; ER: Energy Restitution; FR: Force Reduction; FS: Feeling Scale; GPS: Global Positioning System; HR: Heart Rate; LDH: Lactate Dehydrogenase; LYM: Lymphocytes; ML: Mediolateral; MON: Monocytes; NEU: Neutrophils; PMS: Perceived Muscle Soreness; RF: Rectus Femoris; RPE: Rating of Perceived Exertion; RSA: Repeated Sprint Ability; RSI: Reactive Strength Index; RT: Rotational Traction; SJ: Squat Jump; SSP: Soccer Simulation Protocol; StV: Standard Vertical Deformation; TQR: Total Quality Recovery; V: Vertical; VAS: Visual Analogue Scale; VL: Vastus Lateralis; conKE: Concentric Knee Extension; eccKF: Eccentric Knee Flexion.

Discussion

To the authors' knowledge, this systematic review provides the first comprehensive synthesis examining the effects of playing surface type—natural grass, artificial turf, and sand—on football-specific physical, physiological, and perceptual performance outcomes. Although previous research has addressed selected aspects of player–surface interaction in isolation, the present review consolidates evidence across multiple performance domains, thereby offering an integrated and multidimensional overview of the current literature

The analysis revealed substantial heterogeneity in study designs, measurement protocols, and reported outcomes, highlighting the methodological challenges inherent in evaluating player–surface interactions. Although advances in third generation artificial turf have narrowed several previously reported disparities with natural grass—particularly with respect to impact attenuation and traction-related behaviour—meaningful surface-dependent nuances remain. Evidence indicates

that variations in key mechanical properties (e.g., force reduction/impact absorption, energy restitution, and rotational traction) can translate into differences in football-specific physical outputs and players' subjective perceptions, even when the surface category is nominally the same (i.e., '3G artificial turf') [28]. Likewise, structural features such as fibre height, the presence of an elastic layer, and sub-base configuration have been shown to modify impact attenuation and biomechanical loading responses, reinforcing that residual performance and perceptual differences may persist despite technological improvements [12].

Taken together, the evidence indicates that surface-related effects are multi-factorial and may manifest differently depending on the outcome domain and the context of exposure. Accordingly, the remainder of this discussion is organised into four performance domains—locomotor variables, physiological demands, neuromuscular responses, and perceptual experiences—to provide a structured interpretation of how surface characteristics may modulate football-specific performance. The resulting synthesis has practical implications for training design, load management, and surface selection in both competitive and developmental settings.

Locomotor Performance: Sprinting, Acceleration, and Movement Patterns

The most consistent differences favouring artificial surfaces were found in locomotor variables related to sprinting, acceleration, and high-intensity actions. Multiple studies showed that players reached higher speeds, performed more sprints, and accumulated greater total distances on artificial turf, particularly among defenders and midfielders [36, 38, 43]. Higher rotational traction and lower impact absorption on these surfaces appear to enhance explosive actions, especially when the surface exhibits intermediate mechanical properties [27]. Recent research has further demonstrated that the type of performance infill used in artificial turf systems significantly affects rotational traction under varying normal stress conditions. Vegetal infills such as cork and pine exhibit higher internal friction angles than traditional End-of-Life Tires, potentially influencing both performance and injury risk [7].

However, these benefits do not always reach statistical significance. For instance, Hughes et al. [38] and López-Gómez et al. [40] reported slightly improved sprint and acceleration performance on artificial turf, but without significant differences compared to natural grass. Furthermore, studies such as Viviescas et al. [47] suggest that, in specific populations, natural turf may facilitate more efficient running patterns, characterized by lower energy expenditure and higher cadence, highlighting the interaction between surface type and players' anthropometric characteristics.

Sand, although less frequently examined, demonstrated adverse effects on speed and distance covered [46], aligning with previous studies showing its high energy absorption [13, 23]. While sand may be beneficial for strength development or rehabilitation, it is unsuitable for training aimed at maximal speed or technical specificity. This is likely due to the unstable and deformable nature of sand, which increases muscle activation and reduces elastic energy return, thereby impairing running economy and sprint performance [49].

However, most of these studies have a limitation: they do not provide values from tests of the surface's mechanical properties (i.e., impact absorption, vertical deformation, rotational resistance, among others). These factors provide an indicator that allows for the analysis of the causes of the interaction between the player and the surface [50]. Even if a surface appears identical, there may be significant differences in its mechanical properties that explain some of the results.

Physiological demands: heart rate, lactate, and perceived exertion

Results regarding internal load were more variable and appear to be more influenced by the experimental design than by the surface itself. Some studies reported higher internal loads on artificial turf, particularly during small-sided games or

prolonged simulations [22, 31]. However, others found no significant differences in heart rate or lactate accumulation between natural and artificial surfaces [16, 45].

Notably, in contexts where players were familiar with artificial turf, they seemed to tolerate repeated efforts better, exhibiting lower fatigue, reduced perceived exertion, and lower levels of lactate and inflammatory markers [38, 41]. This supports the idea that prior adaptation to a surface may be a key factor in physiological response, beyond the physical characteristics of the pitch.

Conversely, sand consistently led to greater perceived effort and higher physiological load [22, 46], likely due to its instability and low energy restitution, which increase the metabolic cost of locomotion. These findings align with biomechanical evidence indicating that locomotion on sand imposes a greater metabolic and neuromuscular demand than on firmer surfaces, with higher oxygen uptake and muscle activation attributed to reduced elastic energy return and surface instability [37, 50, 51].

Neuromuscular response: jump, strength, and fatigue

Regarding neuromuscular outcomes, studies generally suggest that surface type does not significantly impact vertical jump capacity (CMJ, SJ) or general isokinetic strength. However, some authors reported greater residual fatigue in the hamstrings following matches played on artificial turf [49]. Similarly, Nédélec et al. [43] observed increased localized muscle soreness in the glutes and hamstrings on artificial surfaces, possibly reflecting greater eccentric stress, although no functional differences in performance were found.

These findings suggest that while acute performance may not be compromised, recovery planning should consider the type of surface used—particularly during congested schedules or high-load microcycles. In fact, research has shown that artificial turf may increase eccentric loading and muscle damage markers, such as creatine kinase, compared to natural grass, which could explain the greater soreness and fatigue observed post-match [51].

Subjective perception and playing style

Playing surface type also appears to influence players' subjective perceptions of comfort, safety, and fatigue, as well as their playing style. Andersson et al. [40] found that male players perceived artificial turf as more physically and technically demanding, leading to a more possession-oriented style with fewer sliding tackles. Similarly, players reported greater ball speed and ease of offensive actions on harder artificial surfaces [43].

Moreover, familiarization with a particular surface emerged as a key factor in shaping subjective experience, with players accustomed to artificial turf reporting lower discomfort and exertion [37, 42]. These perceptions are consistent with findings that surface hardness and friction can alter movement strategies and tactical decisions, influencing both physical demands and technical execution [46].

This systematic review has several limitations that should be considered when interpreting the findings. First, the included studies exhibited substantial methodological heterogeneity across key design features (e.g., laboratory-based tests versus field simulations and match analyses), surface comparisons (natural grass, different generations/configurations of artificial turf, and sand), and outcome definitions. In particular, differences in task demands (e.g., repeated-sprint ability protocols, small-sided game formats, or simulated match procedures), data acquisition systems (e.g., GPS sampling frequencies and filtering approaches), and the intensity thresholds used to classify high-speed running and accelerations are likely to have contributed to variability in reported effects, thereby limiting direct comparability and precluding robust quantitative synthesis.

Second, the evidential base is constrained by limited sample sizes and an uneven participant profile. Many studies were underpowered to detect small-to-moderate surface effects, increasing the likelihood of type II error and wide uncertainty around estimates. Moreover, the predominance of male cohorts restricts generalisability to female and youth populations,

for whom player–surface interaction may differ due to variations in anthropometrics, footwear–surface coupling, and movement strategy.

Third, a major limitation relates to the inadequate characterisation and control of surface and contextual covariates. In many applied studies, objective mechanical measurements of the surface (e.g., shock absorption/force reduction, vertical deformation, energy restitution, and rotational traction) were either absent or insufficiently reported, making it difficult to attribute observed differences to specific surface properties rather than broad surface labels. Likewise, potentially influential contextual factors—such as footwear specification, environmental conditions (temperature, moisture, maintenance status), prior familiarisation, and scheduling effects—were not consistently controlled or reported, introducing residual confounding. Finally, most studies assessed acute responses to surface exposure, leaving longer-term outcomes (e.g., cumulative fatigue, adaptation to repeated exposure, and season-level load or injury trajectories) largely unexplored.

Taken together, the evidence synthesised in this review points to three research gaps that should be prioritised to strengthen inference and improve practical transferability. First, the majority of applied football studies compare broad surface categories without reporting objective mechanical surface characterisation at the time of testing (e.g., peak shock absorption/force reduction, peak deformation, peak torque and torque at 10º), which limits mechanistic interpretation and undermines meaningful cross-study comparison; field-based evidence indicates that mechanical heterogeneity within the same nominal surface type (e.g., third-generation artificial turf) can translate into measurable differences in football-specific performance and player perceptions [28]. Second, variation in protocols (e.g., RSA formats, small-sided games, match simulations), outcome definitions, and contextual controls (footwear, weather, maintenance status, and surface familiarity) likely contributes to the mixed findings observed across studies; notably, shoe–surface traction has been shown to vary across a season and with environmental/surface conditions, emphasising the need to document key contextual and mechanical factors alongside performance outcomes [52]. Third, the predominance of acute, male-only designs limits understanding of longer-term adaptation, sex- and age-specific responses, and how training periodisation should be tailored across surfaces. Methodologically, future work should therefore (i) report standardised mechanical surface metrics contemporaneously with physical, physiological, and perceptual outcomes; (ii) adopt transparent, replicable football-specific protocols with clearly defined outcomes and contextual reporting; and (iii) employ designs that account for familiarisation and repeated exposure (e.g., within-subject crossover or longitudinal monitoring). In this respect, field approaches that combine in situ mechanical testing with football-relevant performance tasks and player-reported perceptions provide a pragmatic template for improving study quality and interpretability beyond surface labels alone.

Conclusions

This systematic review demonstrates that playing surface type influences football-specific performance in distinct ways. Third-generation artificial turf consistently facilitates higher external loads—particularly sprinting, acceleration, and high-intensity actions—yet these effects are not universal and often depend on positional demands and the mechanical properties of the surface. In contrast, internal physiological responses (e.g., heart rate and lactate) remain largely unaffected by surface type, suggesting that internal load is more strongly shaped by task demands and player-specific factors than by the surface itself. Neuromuscular outcomes also show minimal short-term differences, although isolated evidence indicates greater residual fatigue on artificial turf under certain conditions. Across studies, subjective perception and surface familiarity consistently emerged as influential factors modulating both performance and recovery.

A key finding is that only 3 of the 16 included studies reported objective mechanical characterisation of the surfaces, despite clear evidence that properties such as peak absorption, peak deformation, peak torque and torque at 10º can meaningfully influence performance outputs. This highlights that “type of surface” is an insufficient descriptor and that mechanical properties constitute the most relevant determinants of player–surface interaction.

Taken together, the practical implications are clear: (i) coaches and performance staff should consider the specific mechanical behaviour of each playing surface—not just its nominal category—when planning training content, load distribution, and recovery strategies; (ii) greater attention should be paid to players' familiarity with the surface, particularly when transitioning between natural and artificial systems; and (iii) accumulated fatigue and surface-specific mechanical stress should be monitored over time, as these may interact with performance and recovery even when acute responses appear similar.

Finally, three research priorities emerge: (1) integrating robust internal-load measures (e.g., physiological and neuromuscular markers) to clarify how surface characteristics shape overall demand; (2) developing standardised, football-specific testing protocols that are sensitive to surface-related differences; and (3) routinely reporting contemporaneous mechanical surface properties, which is essential for meaningful comparison across studies and for advancing mechanistic understanding of surface–player interactions.

Abbreviations

• **AP**
Anteroposterior
• **AT**
Artificial Turf
• **BLa**
Blood Lactate
• **BF**
Biceps Femoris
• **CK**
Creatine Kinase
• **CMJ**
Countermovement Jump
• **conKE**
Concentric Knee Extension
• **CRP**
C–Reactive Protein
• **DT**
Dirt Terrain
• **eccKF**
Eccentric Knee Flexion
• **EC**
Energy Cost
• **ER**
Energy Restitution
• **ES**
Effect Size
• **FR**
Force Reduction
• **FS**
Feeling Scale
• **GPS**
Global Positioning System

• **HR**
Heart Rate
• **HRmax**
Maximal Heart Rate
• **LDH**
Lactate Dehydrogenase
• **LYM**
Lymphocytes
• **ML**
Mediolateral
• **MON**
Monocytes
• **NEU**
Neutrophils
• **NG**
Natural Grass
• **NOS**
xs–Newcastle–Ottawa Scale for Cross–Sectional Studies
• **PICO / PICOS**
Participants, Intervention, Comparison, Outcomes
• **Pmet**
Metabolic Power
• **PMS**
Perceived Muscle Soreness
• **PRISMA**
Preferred Reporting Items for Systematic Reviews and Meta–Analyses
• **PT**
Peak Torque
• **ROBINS**
I–Risk Of Bias In Non–randomized Studies of Interventions
• **RPE**
Rating of Perceived Exertion
• **RSA**
Repeated Sprint Ability
• **RSI**
Reactive Strength Index
• **RT**
Rotational Traction
• **SJ**
Squat Jump
• **SSG**
Small–Sided Games
• **SSP**
Soccer Simulation Protocol
• **StV**
Standard Vertical Deformation

• **TQR**
Total Quality Recovery
• **VAS**
Visual Analogue Scale
• **VMAX**
Maximum Velocity
• **VMEAN**
Mean Velocity

Declarations

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Availability of Data and Materials: All data extracted and analysed in this systematic review are contained within the cited studies. No additional datasets were generated.

Ethics Approval: Not applicable. This study is a systematic review and does not involve human participants.

Consent to Participate: Not applicable.

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References

1. Burillo P, Gallardo L, Felipe JL, Gallardo AM. Artificial turf surfaces: perception of safety, sporting feature, satisfaction and preference of football users. Eur J Sport Sci. 2014;14(Suppl 1):S437–47.
2. Fleming P. Artificial turf systems for sport surfaces: current knowledge and research needs. Proc Inst Mech Eng P: J Sports Eng Technol. 2011;225(2):43–63.
3. Baroud, Nigg. Stefanyshyn. Energy storage and return in sport surfaces. Sports Eng. 1999;2(3):173–80.
4. Gallardo-Guerrero L, García-Tascón M, Burillo-Naranjo P. New sports management software: A needs analysis by a panel of Spanish experts. Int J Inf Manag. 2008;28(4):235–45.
5. Ekstrand J, Nigg BM. Surface-related injuries in soccer. Sports Med. 1989;8(1):56–62.
6. Katkat D, Bulut Y, Demir M, Akar S. Effects of different sport surfaces on muscle performance. Biol Sport. 2009;26(3).

7. Cole D, Fleming P, Roberts J, James D, Benetti M, Wistel K, et al. Comparison of player perceptions to mechanical measurements of third generation synthetic turf football surfaces. Sports Eng. 2023;26(1):5.
8. Kuitunen I, Immonen V, Pakarinen O, Mattila VM, Ponkilainen VT. Incidence of football injuries sustained on artificial turf compared to grass and other playing surfaces: a systematic review and meta-analysis. EClinicalMedicine. 2023;59.
9. McGowan H, Fleming P, James D, McMahon J, Pak J-H, Forrester S. Investigating normal stress effects on the shear and traction characteristics of performance infill materials used in artificial turf surfaces. Sports Eng. 2025;28(1):6.
10. McGowan H, Fleming P, Pak J-H, James D, Forrester S. The effect of rotational velocity on rotational traction across a range of artificial turf surface systems. Sci Rep. 2023;13(1):21631.
11. Ruschkowski J, Varughese JM, Stefanyshyn DJ, Wannop JW. Influence of infill depth and fibre height of artificial turf on rotational traction. Sports Eng. 2024;27(1):13.
12. Sánchez-Sánchez J, García-Unanue J, Gallardo AM, Gallardo L, Hexaire P, Felipe JL. Effect of structural components, mechanical wear and environmental conditions on the player–surface interaction on artificial turf football pitches. Mater Des. 2018;140:172–8.
13. Sánchez-Sánchez J, Felipe JL, Burillo P, del Corral J, Gallardo L. Effect of the structural components of support on the loss of mechanical properties of football fields of artificial turf. Proc Inst Mech Eng Pt P J Sports Eng Tech. 2014;228(3):155–64.
14. Fernandes T, Rago V, Castañer M, Camerino O. Ranking sports science and medicine interventions impacting team performance: a protocol for a systematic review and meta-analysis of observational studies in elite football. BMJ Open Sport Exerc Med. 2024;10(3):1615–21.
15. Gould HP, Lostetter SJ, Samuelson ER, Guyton GP. Lower extremity injury rates on artificial turf versus natural grass playing surfaces: a systematic review. Am J Sports Med. 2023;51(6):1615–21.
16. Ekstrand J, Timpka T, Hägglund M. Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. Br J Sports Med. 2006;40(12):975–80.
17. Felipe JL, Gallardo L, Sanchez-Sanchez J, Plaza-Carmona M, Burillo P, Gallardo A. A qualitative vision of artificial turf football fields: elite players and coaches. S Afr J Res Sport Phys Educ Recreat. 2013;35(2):105–20.
18. Fuller CW, Dick RW, Corlette J, Schmalz R. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 1: match injuries. Br J Sports Med. 2007;41(suppl 1):i20–6.
19. Plaza-Carmona M, Vicente-Rodriguez G, Martín-García M, Burillo P, Felipe J, Mata E, et al. Influence of hard vs. soft ground surfaces on bone accretion in prepubertal footballers. Int J Sport Med. 2014;35(01):55–61.
20. Alcaraz P, Palao J, Elvira J, Linthorne NP. Effects of a sand running surface on the kinematics of sprinting at maximun velocity. Biol Sport. 2011;28(2):15–22.
21. Gaudino P, Gaudino C, Alberti G, Minetti AE. Biomechanics and predicted energetics of sprinting on sand: hints for soccer training. J Sci Med Sport. 2013;16(3):271–5.
22. Brito J, Krustrup P, Rebelo A. The influence of the playing surface on the exercise intensity of small-sided recreational soccer games. Hum Mov Sci. 2012;31(4):946–56.
23. Impellizzeri FM, Rampinini E, Castagna C, Martino F, Fiorini S, Wisloff U. Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. Br J Sports Med. 2008;42(1):42–6.
24. Zamparo P, Perini R, Orizio C, Sacher M, Ferretti G. The energy cost of walking or running on sand. Eur J Appl Physiol. 1992;65(2):183–7.
25. Binnie MJ, Dawson B, Arnot MA, Pinnington H, Landers G, Peeling P. Effect of sand versus grass training surfaces during an 8-week pre-season conditioning programme in team sport athletes. J Sports Sci. 2014;32(11):1001–12.

26. Brechue WF, Mayhew JL, Piper FC. Equipment and running surface alter sprint performance of college football players. J Strength Cond Res. 2005;19(4):821–5.
27. Gains GL, Swedenhjelm AN, Mayhew JL, Bird HM, Houser JJ. Comparison of speed and agility performance of college football players on field turf and natural grass. J Strength Cond Res. 2010;24(10):2613–7.
28. Sánchez-Sánchez J, García-Unanue J, Jiménez-Reyes P, Gallardo A, Burillo P, Felipe JL, et al. Influence of the mechanical properties of third-generation artificial turf systems on soccer players' physiological and physical performance and their perceptions. PLoS ONE. 2014;9(10):e111368.
29. Sassi A, Stefanescu A, Bosio A, Riggio M, Rampinini E. The cost of running on natural grass and artificial turf surfaces. J Strength Cond Res. 2011;25(3):606–11.
30. Di Michele R, Di Renzo AM, Ammazzalorso S, Merni F. Comparison of physiological responses to an incremental running test on treadmill, natural grass, and synthetic turf in young soccer players. J Strength Cond Res. 2009;23(3):939–45.
31. Page RM, Langley B, Finlay MJ, Greig M, Brogden C. The cumulative and residual fatigue response associated with soccer-specific activity performed on different playing surfaces. J Sports Sci. 2020;38(5):568–75.
32. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Br Med J. 2021;372.
33. Chandler J, Cumpston M, Li T, Page MJ, Welch V. Cochrane handbook for systematic reviews of interventions. Hoboken: Wiley. 2019;4(1002):14651858.
34. Sterne JA, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. Br Med J. 2016;355.
35. Carra MC, Romandini P, Romandini M. Risk of Bias Evaluation of Cross-Sectional Studies: Adaptation of the Newcastle-Ottawa Scale. J Periodontol Res. 2025;0:1–10.
36. Ammar A, Bailey SJ, Hammouda O, Trabelsi K, Merzigui N, El Abed K, et al. Effects of playing surface on physical, physiological, and perceptual responses to a repeated-sprint ability test: Natural grass versus artificial turf. Int J Sports Physiol Perform. 2019;14(9):1219–26.
37. Andersson H, Ekblom B, Krustrup P. Elite football on artificial turf versus natural grass: movement patterns, technical standards, and player impressions. J Sports Sci. 2008;26(2):113–22.
38. Hughes MG, Birdsey L, Meyers R, Newcombe D, Oliver JL, Smith PM, et al. Effects of playing surface on physiological responses and performance variables in a controlled football simulation. J Sports Sci. 2013;31(8):878–86.
39. Jones A, Page R, Brogden C, Langley B, Greig M. The influence of playing surface on the loading response to soccer-specific activity. J Sport Rehabil. 2020;29(8):1166–70.
40. López B, Mendoza D. Analysis of the running pattern on artificial and natural surface in adolescent football players. RETOS. 2020;38:109–13.
41. López-Fernández J, Sánchez-Sánchez J, García-Unanue J, Felipe JL, Colino E, Gallardo L. Physiological and physical responses according to the game surface in a soccer simulation protocol. Int J Sports Physiol Perform. 2018;13(5):612–9.
42. Lopez-Fernandez J, Sanchez-Sanchez J, Rodriguez-Canamero S, Ubago-Guisado E, Colino E, Gallardo L. Physiological responses, fatigue and perception of female soccer players in small-sided games with different pitch size and sport surfaces. Biol Sport. 2018;35(3):291–9.
43. Nedelec M, McCall A, Carling C, Le Gall F, Berthoin S, Dupont G. Physical performance and subjective ratings after a soccer-specific exercise simulation: comparison of natural grass versus artificial turf. J Sports Sci. 2013;31(5):529–36.

44. Rago V, Rebelo AN, Pizzuto F, Barreira D. Small-sided soccer games on sand are more physically demanding but less technically specific compared to games on artificial turf. J Sports Med Phys Fit. 2018;58(4):385–91.
45. Sanchez-Sanchez J, Garcia-Unanue J, Felipe JL, Jimenez-Reyes P, Viejo-Romero D, Gomez-Lopez M, et al. Physical and Physiological Responses of Amateur Football Players on Third-Generation Artificial Turf Systems During Simulated Game Situations. J Strength Cond Res. 2016;30(11):3165–77.
46. Stone KJ, Hughes MG, Stembridge MR, Meyers RW, Newcombe DJ, Oliver JL. The influence of playing surface on physiological and performance responses during and after soccer simulation. Eur J Sport Sci. 2016;16(1):42–9.
47. Viviescas AA, Pinzón DMN, de Souza HCD, Moreno JDE, Medina DB, Delgado JCS. Sprint pattern analysis of professional female soccer players on artificial and natural turf. Retos. 2021;39:483–7.
48. Modric T, Esco M, Perkovic S, Basic Z, Versic S, Morgans R, et al. Artificial turf increases the physical demand of soccer by heightening match running performance compared with natural grass. J Strength Cond Res. 2023;37(11):2222–8.
49. Binnie MJ, Peeling P, Pinnington H, Landers G, Dawson B. Effect of surface-specific training on 20-m sprint performance on sand and grass surfaces. J Strength Cond Res. 2013;27(12):3515–20.
50. Selmi O, Ouergui I, Levitt DE, Marzouki H, Knechtle B, Nikolaidis PT, et al. Training, psychometric status, biological markers and neuromuscular fatigue in soccer. Biol Sport. 2022;39(2):319–27.
51. Roberts J, Osei-Owusu P, Harland A, Owen A, Smith A. Elite football players' perceptions of football turf and natural grass surface properties. Procedia Eng. 2014;72:907–12.
52. Thomson A, Whiteley R, Wilson M, Bleakley C. Six different football shoes, one playing surface and the weather; Assessing variation in shoe-surface traction over one season of elite football. PLoS ONE. 2019;14(4):e0216364.

Figures

	A	B	C	D	E	F	G	Risk
Ammar et all., 2019 [38]	!	✓	✓	✓	✓	✓	✓	!
Hughes et al., 2013 [39]	!	✓	✓	✓	✓	✓	✓	!
Sánchez-Sánchez et al., 2014 [27]	!	✓	✓	✓	✓	✓	✓	!
Sánchez-Sánchez et al., 2016 [41]	!	✓	✓	✓	✓	✓	✓	!
Nédélec et al., 2013 [42]	!	✓	✓	✓	✓	✓	✓	!
López-Fernández et al., 2018[a] [43]	!	✓	✓	✓	✓	✓	✓	!
Rago et al., 2016 [37]	!	✓	✓	✓	✓	✓	✓	!
Page et al., 2020 [47]	!	✓	✓	✓	✓	✓	✓	!
Stone et al., 2016 [48]	!	✓	✓	✓	✓	✓	✓	!
Jones et al., 2020 [49]	!	✓	✓	✓	✓	✓	✓	!
Brito et al., 2012 [25]	!	✓	✓	✓	✓	✓	✓	!

Figure 1

Risk of Bias Assessment Using the ROBINS-I Tool

A. Is there a risk of bias due to confounding?; **B.** Is there a risk of bias in the selection of participants into the study?; **C.** Is there a risk of bias in the classification of interventions?; **D.** Is there a risk of bias due to deviations from intended interventions?; **E.** Is there a risk of bias due to missing data?; **F.** Is there a risk of bias in the measurement of outcomes?; **G.** Is there a risk of bias in the selection of the reported result?

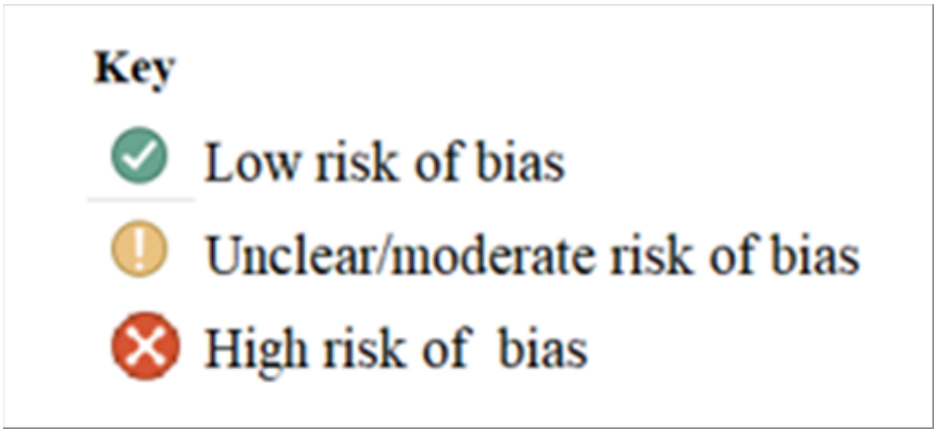


Figure 2

Key of risk of bias

	A	B	C	D	E	F	H	Risk
López-Gómez et al., 2020 [36]	★	✕	★	★	★	★	★	✓
Modric et al., 2023 [45]	★	✕	★	★	★	★	★	✓
Andersson et al., 2008 [40]	★	✕	★	★	★	★	★	✓
López-Fernández et al., 2018b [44]	★	✕	★	★	★	★	★	✓
Viviescas et al., 2021 [46]	★	✕	★	★	★	★	★	✓

Figure 3

Overview of Risk of Bias in Cross-Sectional Studies (NOS-xs)

A. Is the sample representative of the target population?; **B.** Is the sample size justified?; **C.** Are non-respondents described and handled appropriately?; **D.** Is the exposure clearly defined and reliably measured?; **E.** Were the most important confounding factors controlled for?; **F.** Was the outcome assessment valid and reliable?; **G.** Were appropriate statistical tests used?; **H.** Are the results clearly reported?

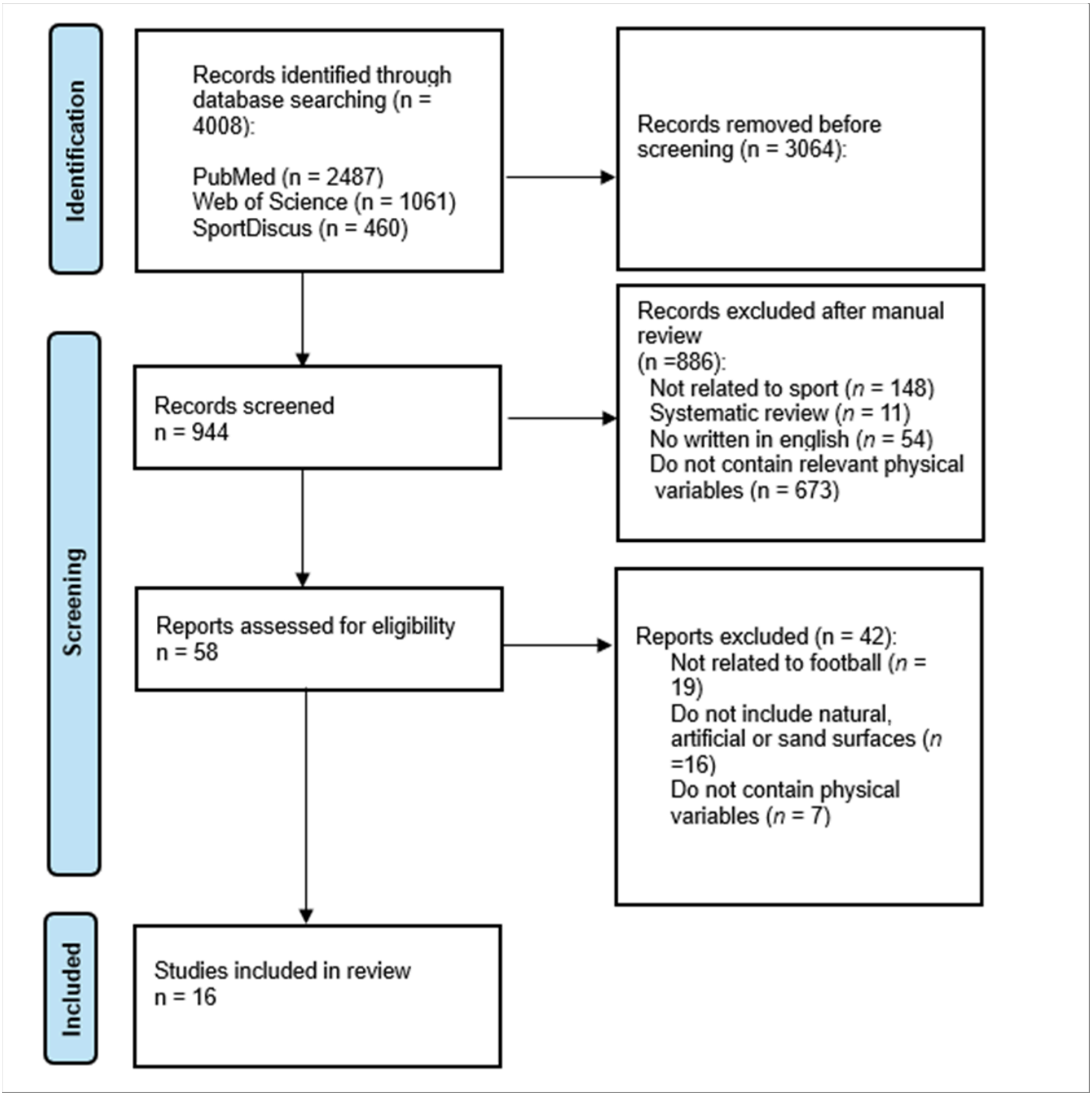


Figure 4

PRISMA Flow Diagram of Study Selection

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- PRISMA2020checklist.pdf