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Understanding Curvilinear Sprinting: A Scoping review with EGM of Assessment, Biomechanics, and Training

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Research Article

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Abstract

Background

Curvilinear sprinting is a key performance demand in many sports, requiring athletes to sustain propulsion while continuously redirecting their centre of mass. However, the available evidence has not previously been comprehensively mapped.

Objective

To map the conceptualisation, occurrence, assessment methods, measurement properties, biomechanical and neuromuscular characteristics, performance determinants, and training and rehabilitation applications of curvilinear sprinting in sport.

Methods

A scoping review was conducted in accordance with JBI methodology and reported in accordance with PRISMA-ScR guidance. PubMed/MEDLINE, Scopus, Web of Science Core Collection, and SPORTDiscus were searched from inception to 17 August 2026, with supplementary citation searching. Evidence was charted across predefined domains and synthesised descriptively using counts, study characteristics, and an evidence gap map.

Results

A total of 118 studies were included, with 67 (56.8%) published between 2023 and 2026. Soccer/football (n = 56) and athletics/track (n = 31) dominated the evidence base, and male-only samples were most common (n = 77). Evidence was concentrated in performance/determinants (n = 106), assessment (n = 104), training/adaptation (n = 81), and biomechanics/neuromuscular outcomes (n = 78), whereas evidence concerning rehabilitation/return-to-sport remained limited (n = 17). Tighter curves generally reduced sprint velocity and produced consistent differences between the inside and outside limbs. Curvilinear sprint tests generally demonstrated good reliability, linear speed explained only part of curvilinear sprint performance, and training studies indicated partly task-specific adaptations despite heterogeneous protocols.

Conclusions

Curvilinear sprinting is a distinct form of multidirectional speed that warrants dedicated assessment and training. The evidence base is expanding rapidly but remains concentrated in male soccer and athletics cohorts. Priorities include research involving female athletes, rehabilitation and return-to-sport

applications, non-soccer team sports, standardised measurement methods, and adequately powered longitudinal studies of curve-specific training.

Key Points

Curvilinear sprinting is a distinct speed quality: curve radius and direction constrain attainable velocity and produce consistent differences between the inside and outside limbs in force application, kinematics, contact behaviour, and neuromuscular recruitment.

The evidence base is substantial but uneven: among the 118 included studies, soccer/football and athletics dominated, male-only cohorts were most common, and the evidence was concentrated in assessment, performance determinants, biomechanics, and training.

Future research should prioritise female athletes, rehabilitation and return-to-sport applications, non-soccer team sports, standardised measurement methods and device agreement, and adequately powered longitudinal studies of curve-specific training interventions.

1. INTRODUCTION

High-speed locomotion in sport does not occur exclusively along straight trajectories, with curvilinear sprinting representing a substantial proportion of maximal-velocity actions in soccer [1]. Athletes repeatedly sprint along curved paths to evade opponents, create or close space, recover defensively, negotiate track bends, or move efficiently between bases. In professional soccer, approximately 86% of sprint actions have been reported to involve some degree of curvature, highlighting the limited ecological validity of assessing sprint capacity solely through linear tests [2]. Curvilinear sprinting (CS) can be defined as high-intensity or maximal running performed along a continuously curved trajectory, requiring the athlete to preserve forward propulsion while continuously redirecting the centre of mass towards the centre of the curve [1, 3]. Linear and curvilinear sprint performances share only part of their variance, and evidence across soccer, basketball, baseball, handball, and track and field indicates that CS is a partly independent locomotor quality with sport-specific implications [4–8].

The mechanical basis of this distinction is the need to orient ground-reaction force toward the centre of the curve while simultaneously maintaining sufficient vertical support and tangential propulsion [9–13]. Maximum attainable velocity decreases as curve radius decreases; compared with straight sprinting, maximal velocity has been reported to be approximately 10.0% lower on a 17.2-m radius and 4.1% lower on a 36.5-m radius [9]. Curve negotiation also redistributes ground-reaction forces and produces marked leg-specific asymmetries. The inside limb generally exhibits longer ground-contact time, lower vertical and resultant ground-reaction forces, and greater centripetal-force production, whereas the outside limb contributes more strongly to vertical and anterior-posterior propulsion [3, 9–12]. Kinematic data further demonstrate greater ankle eversion, hip adduction, and hip external rotation in the inside limb [3], while electromyographic findings indicate distinct functional roles between limbs during curve sprinting. The inside leg appears to behave along a continuum toward a cross-step manoeuvre, with greater

recruitment of internal-rotation-related musculature such as the semitendinosus and adductors, whereas the outside leg behaves more like a continuum side-step, with greater activation of the biceps femoris and gluteus medius [1]. Joint-contact-force modelling additionally suggests that curved versus straight sprinting modifies hip and ankle loading to a greater extent than knee loading [14]. These findings indicate complementary, rather than interchangeable, inside- and outside-limb roles during CS.

These mechanical differences have direct implications for assessment. The most established field-based protocol in soccer uses the 9.15-m-radius penalty arc over a running distance of approximately 17 m and has demonstrated high inter-session reliability (ICC approximately 0.89–0.93) and low intra-session variability (CV approximately 0.87–1.15%) [4]. Sport-specific approaches have subsequently been developed for basketball, baseball, and handball, while newer technologies include smartphone applications, foot pods, global positioning systems, inertial sensors, and acceleration–speed profiling [6–8, 15, 16]. In basketball, a three-point-line CS test has shown high reliability and different acceleration and velocity outputs compared with linear sprinting [6]. In baseball, foot-pod technology provides reliable segment-specific information during curvilinear base running [7]. More recently, a handball-specific test based on the 6-m goal-area line demonstrated good between-session reliability and excellent reliability when three trials were averaged, further illustrating how existing sport-specific geometry may be used to create ecologically relevant CS assessments [8]. However, protocols remain heterogeneous in radius, arc angle, distance, starting procedures, trial structure, surface, and measurement technology.

Beyond measurement, the determinants and trainability of CS remain incompletely understood. Curvilinear performance is associated with linear acceleration and maximal speed, vertical jumping, change-of-direction ability, lower-limb strength, inter-limb asymmetry, and acceleration–speed profile characteristics [5, 17–19]. Hip-adductor, hip-abductor, and knee-flexor strength may explain a substantial proportion of CS performance variance, while greater symmetry in both hip-adductor and hip-abductor strength has been associated with superior performance in both directions [18]. Importantly, the relationship between curvilinear and linear sprint performance appears to weaken with age and increasing specialisation: in youth soccer players, the correlation between average CS and 20-m linear sprint time decreased from r = 0.78 in U15 players to r = 0.39 in U20 players, with the latter association no longer statistically significant [20]. Over the same age range, directional CS asymmetry increased from approximately 2.7% to 7.2%, with performance improving on the faster (“good”) side but not on the slower (“weak”) side [20]. These findings suggest that curvilinear sprinting may become increasingly task-specific with advancing age and specialisation and reinforce the need for age-sensitive assessment and bilateral development during youth progression. Curve radius and side dominance also appear to constrain acceleration–speed profiles, particularly late acceleration and theoretical maximal speed [16]. Intervention research is emerging but remains comparatively sparse. Randomised studies in young soccer players suggest trajectory-specific adaptation, with curvilinear sprint training improving CS performance while also transferring to selected linear sprint and change-of-direction outcomes [21]. Six-week programmes using different radii have likewise produced improvements in multidirectional speed and sprint mechanics, although the extent to which adaptations are radius-specific is still uncertain [22].

Despite rapid growth in the field, the evidence remains fragmented across biomechanical research in athletics, sport-specific field testing, measurement property studies, match and competition analyses, correlational investigations, acute experiments, rehabilitation-oriented research, and training interventions. Terminology is inconsistent, testing procedures are not standardised, and the relative influence of sport, sex, age, competitive level, curve geometry, direction, and measurement technology has not been comprehensively mapped. Previous reviews have addressed broader aspects of sprinting, running biomechanics, and high-intensity actions in sport, but no synthesis has comprehensively integrated the available evidence on curvilinear sprint assessment, biomechanics, performance determinants, and training across sports [23–25]. Therefore, the purpose of this scoping review is to map and describe the available evidence on curvilinear sprinting in sport, with particular emphasis on how CS is defined and operationalised, where and how it occurs, how it is assessed, the reliability and validity of available methods, its biomechanical and neuromuscular characteristics, the physical determinants associated with performance, and the acute and chronic effects of curvilinear sprint training. This synthesis is intended to identify areas of evidence concentration, methodological inconsistency, and priority gaps requiring further research.

2. METHODS

2.1. Protocol and reporting standards

This scoping review was conducted in accordance with JBI methodology for scoping reviews and the methodological guidance of Peters et al. [26, 27]. The review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) [28]. In addition, the 2026 evidence review informing the ongoing PRISMA-ScR update was used to strengthen reporting transparency, particularly with respect to the use of an explicit Population-Concept-Context (PCC) eligibility framework, documentation of protocol deviations, description of the data collection process, and complementary textual and visual presentation of findings [29]. The literature search methods were reported in accordance with PRISMA-S [30]. The review protocol was prospectively developed and registered on the Open Science Framework (OSF) on 9 August 2026 (**Registration DOI**: https://doi.org/10.17605/OSF.IO/45KAB; **associated project**: https://osf.io/7kh2c). Any deviations from the protocol identified during the conduct of the review were documented and reported transparently.

2.2. Eligibility criteria

Eligibility criteria were structured according to the PCC framework recommended for scoping reviews [26, 27]. The population comprised human participants of any sex, age, competitive level, or training status, including youth, adult, recreational, trained, elite, professional, and para-athletes. Injured or clinical populations were eligible only when curvilinear sprinting was evaluated as a rehabilitation, return-to-sport, or functional performance outcome; these populations were mapped separately. Animal studies were excluded. The concept of interest was curvilinear sprinting, defined as maximal running performed

along a continuously curved trajectory. Eligible terminology included curvilinear sprint, curved sprint, curve sprint, bend sprint, arc sprint, circular sprint, nonlinear sprint, curvilinear running, and curved high-speed running. Studies were eligible when they examined definitions or conceptualisation, occurrence in competition, test development, measurement properties, performance outcomes, biomechanics, kinetics, kinematics, spatiotemporal characteristics, neuromuscular or physiological responses, physical determinants, directional asymmetry, acute protocol manipulation, rehabilitation applications, or training effects. Studies examining only linear sprinting, agility, or discrete cutting tasks were excluded unless curvilinear sprint data were reported separately. All sport and performance settings were eligible, including field, court, track, laboratory, training, competition, rehabilitation, talent identification, and return-to-sport environments. Randomised and non-randomised interventions, crossover and repeated-measures studies, cohort and cross-sectional studies, test development and measurement property studies, biomechanical and physiological investigations, observational match analyses, case series, theses, dissertations, and conference reports with sufficient methodological and outcome data were eligible. Reviews were not included as primary evidence but were screened for additional eligible original studies. Editorials, commentaries, opinion pieces, protocols without results, non-English-language publications, and records with insufficient curvilinear-sprint data were excluded; the latter included studies in which curved sprinting was mentioned but no CS-specific outcome or extractable result was reported.

2.3. Information sources and search strategy

PubMed/MEDLINE, Scopus, Web of Science Core Collection, and SPORTDiscus via EBSCOhost were searched from database inception to 17 August 2026. Supplementary searching included Google Scholar, backward reference-list screening, forward citation searching, and citation searching of sentinel studies. Citation chasing was supported by CitationChaser where appropriate [31]. No publication-date restriction was applied. The search strategy combined terms describing curved trajectories with terms describing sprinting or high-speed running. Database-specific subject headings, controlled vocabulary, free-text terms, truncation, phrase searching, and proximity operators were applied where supported. The search strategy was developed iteratively and prepared for peer review in accordance with the PRESS guideline [32]. Full search strategies for all databases are presented in Table 1. Search reporting followed PRISMA-S recommendations, including identification of the information source, platform, search fields, and reproducible search syntax [30].

Table 1
Search strategies for electronic bibliographic databases

Database	Search strategy
PubMed/MEDLINE	("curvilinear sprint*"[Title/Abstract] OR "curved sprint*"[Title/Abstract] OR "curve sprint*"[Title/Abstract] OR "bend sprint*"[Title/Abstract] OR "arc sprint*"[Title/Abstract] OR "circular sprint*"[Title/Abstract] OR "nonlinear sprint*"[Title/Abstract] OR "non-linear sprint*"[Title/Abstract] OR "curvilinear running"[Title/Abstract] OR "curved running"[Title/Abstract] OR "bend running"[Title/Abstract] OR ((curve*[Title/Abstract] OR curvilinear[Title/Abstract] OR bend[Title/Abstract] OR arc[Title/Abstract]) AND (sprint*[Title/Abstract] OR "high-speed running"[Title/Abstract] OR "high speed running"[Title/Abstract])))
Scopus	TITLE-ABS-KEY("curvilinear sprint*" OR "curved sprint*" OR "curve sprint*" OR "bend sprint*" OR "arc sprint*" OR "circular sprint*" OR "nonlinear sprint*" OR "non-linear sprint*" OR "curvilinear running" OR "curved running" OR "bend running" OR ((curve* OR curvilinear OR bend OR arc) W/3 (sprint* OR "high-speed running" OR "high speed running")))
Web of Science Core Collection	TS=("curvilinear sprint*" OR "curved sprint*" OR "curve sprint*" OR "bend sprint*" OR "arc sprint*" OR "circular sprint*" OR "nonlinear sprint*" OR "non-linear sprint*" OR "curvilinear running" OR "curved running" OR "bend running" OR ((curve* OR curvilinear OR bend OR arc) NEAR/3 (sprint* OR "high-speed running" OR "high speed running")))
SPORTDiscus (EBSCOhost)	TX ("curvilinear sprint*" OR "curved sprint*" OR "curve sprint*" OR "bend sprint*" OR "arc sprint*" OR "circular sprint*" OR "nonlinear sprint*" OR "non-linear sprint*" OR "curvilinear running" OR "curved running" OR "bend running" OR ((curve* OR curvilinear OR bend OR arc) N3 (sprint* OR "high-speed running" OR "high speed running")))

*** **[INSERT** Table 1 **HERE]** ***

2.4. Study selection

All records were exported to EndNote ™ 21 (Clarivate, Philadelphia, PA, USA), where duplicates were removed using a combination of automated and manual procedures. Deduplicated records were imported into Rayyan for screening [33]. Before formal screening, the eligibility criteria were piloted on a sample of records to improve consistency between reviewers. Two reviewers independently screened titles and abstracts, followed by an independent full-text assessment of potentially eligible reports. Disagreements were resolved by discussion and, when necessary, consultation with a third reviewer. Reasons for exclusion were recorded during the full-text assessment. The study-selection process was documented in a PRISMA-ScR flow diagram [28, 29]. Where a full-text report could not be obtained, an abstract or bibliographic record was retained only when it contained sufficient methodological and outcome information to establish eligibility and permit meaningful charting; these records were explicitly labelled as abstract-only evidence and were not treated as equivalent to data extracted from full-text reports.

2.5. Data charting and data items

A standardised data-charting form was developed a priori from the review questions and piloted before full extraction. Consistent with JBI recommendations, data were extracted by one reviewer and verified by a second reviewer, with the charting form refined iteratively when additional relevant variables emerged [34]. Extracted bibliographic and methodological information included authorship, publication year, country, publication type, study design, study objective, and research setting. Population variables included sample size, sex, age, anthropometry, sport, playing position, competitive level, training status, and, where applicable, injury or return-to-sport status. Curvilinear sprint terminology and operational definitions were recorded verbatim. Protocol-level variables included direction, radius, arc angle, path length, total sprint distance, lane or field markings, trajectory constancy, starting procedure, approach distance or entry velocity, footwear, surface, environmental conditions, number of trials, and recovery duration. Measurement methods included timing gates, global navigation satellite systems, radar or laser devices, video analysis, inertial sensors, electromyography, force platforms, pressure insoles, foot pods, and smartphone applications. Where available, sampling frequency, filtering, timing-gate placement, velocity and acceleration derivation, acceleration–speed profiling, curve radius calculation, segment-specific analysis, and equations used to quantify curvilinear sprint deficit or asymmetry were charted. Performance outcomes included total and split sprint times, mean and maximal velocity, acceleration, repeated-sprint performance, curvilinear sprint deficit, and directional asymmetry. Biomechanical and neuromuscular outcomes included ground contact and flight times, step length and frequency, centre-of-mass and trunk inclination, foot placement, ankle inversion/eversion, hip kinematics, joint contact forces, tibial acceleration, muscle activation, and vertical, anterior-posterior, medial-lateral, resultant, and centripetal ground-reaction forces and impulses. Differences between the inside and outside limbs and radius-dependent effects were extracted separately where reported. Potential determinants included linear sprinting, change-of-direction speed, strength, power, reactive strength, jumping, force–velocity characteristics, anthropometry, maturation, and technical variables. Competition studies were charted for frequency, distance, direction, tactical purpose, playing position, phase of play, and contextual characteristics. Intervention studies were charted for programme duration, weekly frequency, session volume, intensity, curve radius, progression, comparator, adherence, adverse events, and acute or chronic outcomes.

2.6. Critical appraisal of individual sources

Formal appraisal of risk-of-bias or methodological quality was not used as an eligibility criterion because the purpose of this scoping review was to map the breadth, characteristics, methods, and gaps in the evidence rather than to estimate a pooled intervention effect. This approach is consistent with JBI guidance, which considers critical appraisal optional in scoping reviews when it is not required to address the review objective [26, 28]. Methodological limitations reported by the study authors, as well as design-specific limitations identified during charting, were nevertheless recorded and considered when interpreting evidence concentrations and gaps.

2.7. Data synthesis and presentation

No meta-analysis was planned. Findings were synthesised descriptively and organised into predefined evidence domains: (1) terminology and conceptualisation; (2) occurrence and contextual demands; (3) assessment protocols; (4) measurement properties; (5) performance characteristics; (6) biomechanical and neuromuscular characteristics; (7) performance determinants; (8) training and adaptation; and (9) rehabilitation and return to sport. Numerical findings were summarised using counts, proportions, ranges, medians, and other appropriate descriptive statistics. Evidence was mapped by publication year, country of the first author's primary institutional affiliation, sport, sex, age group, competitive level, study design, curve radius, sprint distance, and measurement technology. Country was assigned according to the first author's primary affiliation because the geographical location of data collection was not consistently reported and many studies included authors from multiple countries. Results were presented using a PRISMA-ScR flow diagram and tables summarising study characteristics, testing protocols, measurement properties, biomechanical and neuromuscular outcomes, and interventions. Where informative, an evidence-gap map was used to visualise concentrations of evidence and under-researched areas, consistent with contemporary distinctions between scoping reviews, mapping reviews, and evidence-gap maps [35]. In keeping with the 2026 PRISMA-ScR update recommendations, visual summaries were accompanied by explanatory text rather than presented as stand-alone displays [29].

2.8. Protocol deviations and transparency

Any departures from the prospectively developed protocol were documented during the review and are reported in the final manuscript, in line with emerging PRISMA-ScR reporting recommendations [29]. In particular, the source of evidence used for data extraction from each record was documented so that full-text and abstract-only charting could be distinguished. The review team maintained source-level traceability linking each study and its extracted variables to the relevant full-text pages or abstract record, whenever available.

3. RESULTS

3.1. Selection of sources of evidence

The study-selection process is presented in Fig. 1, which was generated using the PRISMA 2020 flow diagram generator (Shiny app) [36]. The database searches yielded 2,340 records, comprising 508 from PubMed, 168 from Web of Science Core Collection, 193 from Scopus, and 1,471 from SPORTDiscus. After removal of 896 duplicate records, 1,444 records were screened, of which 1,164 were excluded. A total of 280 reports were assessed for eligibility, resulting in 110 studies being included through the database-search pathway. Citation searching identified eight additional records [31], all of which were retrieved, assessed for eligibility, and included, yielding a final total of 118 studies [1–22, 37–132]. Across the included studies, sample size was reported in 111 studies and age in 110 studies, yielding a cumulative reported sample of 3,051 participants and a median sample size of 19 (interquartile range, 12–30). The breadth of the evidence base reflects the wide range of assessment, biomechanical,

performance, and applied training studies conducted across soccer, athletics, basketball, and other sport settings.

*** **[INSERT** FIGURE 1 **HERE]** ***

3.2. Characteristics of included studies

The included studies were published between 1987 and 2026, with a clear recent expansion of the field. A total of 67 studies (56.8%) were published between 2023 and 2026, indicating that curvilinear sprinting has become a rapidly growing area of sports science research (Fig. 2). The evidence base was distributed across 58 journals, although a small number of outlets accounted for a relatively large share of publications. Journal of Strength and Conditioning Research was the most frequent source (n = 11), followed by Applied Sciences (n = 7), Journal of Human Kinetics (n = 6), Biology of Sport (n = 5), and Scandinavian Journal of Medicine and Science in Sports, Journal of Biomechanics, Sports Biomechanics, Journal of Sports Sciences, and the International Journal of Environmental Research and Public Health (n = 4 each) (Fig. 3). This distribution across journal reflects the multidisciplinary nature of the topic, spanning strength and conditioning, biomechanics, sports medicine, and performance analysis [1–22, 37–132].

By sport, soccer/football dominated the evidence base with 56 studies (47.5%), followed by athletics/track with 31 (26.3%), basketball with 9 (7.6%), and running-specific research with 9 (7.6%). Smaller clusters of evidence were also identified in baseball, handball, rugby league, and floorball, as well as mixed or other sport settings (Fig. 3). This profile mirrors the applied importance of curvilinear sprinting in team sports, particularly soccer, while also showing a parallel body of research in track and field and running biomechanics [1–22, 37–132].

Male-only samples were most common, accounting for 77 studies (65.3%). Mixed-sex samples were reported in 19 studies (16.1%) and female-only samples in 11 studies (9.3%), while sex was not reported in 11 studies (9.3%). Despite the predominance of male cohorts, the presence of female soccer, basketball, and handball athletes indicates a growing but still comparatively limited body of evidence in female athletes [1–22, 37–132].

When country-level data were summarised in the project evidence map, the greatest concentrations were observed in Spain (n = 43), New Zealand (n = 22), the United States (n = 19), the United Kingdom and Brazil (n = 17 each), Australia (n = 15), France (n = 13), and Norway (n = 10), with smaller clusters in Ireland, Italy, Greece, Poland, China, and Sweden (Fig. 2). Because these values represent country occurrences within the evidence map, totals may exceed the number of unique included studies. Overall, the geographical distribution indicates that curvilinear sprint research has been led mainly by research groups in Europe and Oceania, with additional important contributions from North and South America and fewer contributions from Asia [1–22, 37–132].

*** **[INSERT** FIGURE 2 **HERE]** ***

When studies were classified according to their primary evidence focus, biomechanical or neuromuscular investigations formed the largest group (*n* = 38, 32.2%), followed by intervention or training studies (*n* = 24, 20.3%), cross-sectional or correlational investigations (*n* = 23, 19.5%), measurement-property studies (*n* = 17, 14.4%), and other observational studies (*n* = 9, 7.6%). Only a small number of case studies and conference abstracts were identified. At the domain level, the most frequent evidence categories were performance/determinants (n = 106), assessment protocol (n = 104), training/adaptation (n = 81), biomechanics/neuromuscular (n = 78), occurrence/context (n = 70), and measurement properties (n = 68). These patterns show that the literature has focused primarily on how curvilinear sprinting is assessed and performed, while more limited evidence is available for rehabilitation and return-to-sport applications [1–22, 37–132].

*** **[INSERT** FIGURE 3 **HERE]** ***

3.3. Evidence gap map

The evidence gap map (Fig. 4) showed that evidence was most frequently represented in the performance/determinants domain (106 study–domain occurrences) and assessment (n = 104), followed by training/adaptation (n = 81), biomechanics/neuromuscular outcomes (n = 78), occurrence/context (n = 70), and measurement properties (n = 68), whereas rehabilitation/return-to-sport was the least represented domain (n = 17). Because individual studies could contribute to more than one evidence domain, these categories were not mutually exclusive [1–22, 37–132]. Across sports, soccer/football contributed the largest number of domain entries, including assessment (n = 50), measurement properties (n = 32), biomechanics/neuromuscular outcomes (n = 33), performance/determinants (n = 52), training/adaptation (n = 43), occurrence/context (n = 35), and rehabilitation/return-to-sport (n = 13). Athletics/track represented the second-largest evidence cluster, contributing to assessment (n = 30), measurement properties (n = 18), biomechanics/neuromuscular outcomes (n = 30), performance/determinants (n = 28), training/adaptation (n = 22), occurrence/context (n = 19), and rehabilitation/return-to-sport (n = 1) [1–22, 37–132].

By contrast, all other sport settings were comparatively sparse. Basketball contributed 6 assessment and 7 performance/determinant entries, but only 1 rehabilitation/RTS entry; running/general studies contributed between 6 and 9 entries across most domains but none in rehabilitation; baseball and handball were represented by only 2 and 1 assessment studies, respectively; and rugby league and floorball each contributed isolated training or occurrence records [1–22, 37–132]. This pattern indicates that curvilinear sprinting is now more extensively studied in soccer and athletics but remains underdeveloped in other invasion, striking, and court sports in which curvilinear acceleration and sprinting may also be practically relevant [1–22, 37–132].

*** **[INSERT** FIGURE 4 **HERE]** ***

From an evidence-gap perspective, future research priorities were classified as major, moderate, or minimal according to the size and breadth of the current evidence base, together with the practical

importance of the topic (Table 2). Major priorities were identified for research involving female athletes (n = 11), rehabilitation/RTS applications (n = 17), non-soccer team-sport transferability (n = 31 studies outside soccer and athletics), and rigorous longitudinal studies of curve-specific training. Moderate priorities were identified for youth- and maturation-focused research, measurement properties and device agreement (n = 68), acute fatigue and recovery responses (n ≈ 53), and ecologically valid monitoring of CS occurrence during matches (n = 70). Minimal priorities were assigned to additional simple cross-sectional association studies and to general biomechanical research, because these areas already contain comparatively larger evidence clusters, even though some sport-specific questions remain open [1–22, 37–132].

Table 2
Future research priorities within curvilinear sprint subtopics

Subtopic	Indicative evidence count	Priority	Rationale
Female-specific curvilinear sprint evidence	11	Major	Only a small female-only evidence base was identified, despite the clear need for sex-specific assessment, biomechanics, training, and rehabilitation data.
Rehabilitation and return-to-sport applications	17	Major	This was the sparsest major domain, indicating that translational evidence for injury management, progressive re-exposure, and return-to-performance remains limited.
Non-soccer team sports and field-transferability	31	Major	The literature was heavily concentrated in soccer and athletics, leaving basketball, baseball, handball, rugby league, and floorball under-represented.
Longitudinal randomized curve-specific training studies	81	Major	Although training/adaptation was common, truly curve-specific, adequately controlled, and longer-term interventions remain comparatively limited and heterogeneous.
Youth, maturation, and longitudinal development	38	Moderate	Youth evidence exists but is concentrated largely in male soccer cohorts; maturation- and sex-stratified longitudinal work is still needed.
Measurement properties and device agreement	68	Moderate	Reliability evidence is growing, but criterion validity, inter-device agreement, and minimum-detectable-change data remain inconsistent across technologies and protocols.
Acute physiological, fatigue, and recovery responses	53	Moderate	Acute-response work remains smaller than the performance and biomechanics literature, particularly outside repeated-sprint paradigms.
Match occurrence and ecological load quantification	70	Moderate	Occurrence/context evidence is substantial but dominated by soccer, and still needs better integration with competition analytics and external-load monitoring.
Mechanistic biomechanics across realistic radii and surfaces	78	Minimal	Biomechanical evidence is comparatively mature, especially for force, kinematics, and radius effects, although some sport-specific gaps remain.
Simple cross-sectional performance associations	106	Minimal	The literature already contains a substantial number of cross-sectional association studies linking curvilinear sprinting with linear speed, power, and COD outcomes.

*** **[INSERT** Table 2 **HERE]** ***

4. DISCUSSION

4.1. Principal findings

This scoping review maps a rapidly expanding and methodologically diverse literature on curvilinear sprinting. Across 118 included studies, the evidence was concentrated in soccer/football and athletics/track, was dominated by male samples, and was weighted toward biomechanical and neuromuscular characteristics, performance determinants, assessment, and training [1–22, 37–132]. The marked increase in publications since 2020, and particularly during 2023–2026, suggests that curvilinear sprinting has moved from a relatively niche biomechanical research question to a broader performance topic spanning field testing, athlete monitoring, match analysis, strength and conditioning, and rehabilitation. Nevertheless, the evidence base remains uneven. Soccer/football accounted for almost half of the included studies, whereas basketball, baseball, handball, rugby league, floorball, and other multidirectional sports were represented by much smaller clusters [1–22, 37–132]. Female-only samples were also uncommon, despite recent work in elite and youth female soccer, basketball, track sprinting, and handball [6, 8, 37, 44, 67, 102, 116, 122]. These characteristics should frame the interpretation of the current evidence: the field now reveals several consistent patterns about the mechanics and assessment of curvilinear sprinting, but the generalisability of these findings across sex, age, sport, curve geometry, competitive level, and training status remains limited.

4.2. Curvilinear sprinting is a distinct locomotor and performance task

A central finding of this review is that curvilinear sprinting should be considered a distinct locomotor and performance task rather than treated as equivalent to linear sprinting. Across track, soccer, court sport, and running studies, the requirement to continuously redirect the centre of mass changes the attainable velocity, force orientation, contact strategy, joint kinematics, and neuromuscular demands [1, 3, 9–13, 53, 69, 93, 119, 121]. The influence of geometry is particularly clear. In one flat-curve sprinting study, maximal velocity was approximately 10.0% lower on a 17.2-m radius and 4.1% lower on a 36.5-m radius than during straight sprinting, with radius also modifying inside- and outside-limb resultant, vertical, and centripetal ground-reaction-force production [9]. However, radius effects appear to depend on the range examined. In soccer-specific testing, Altmann et al. [110] compared 7.15-, 9.15-, and 11.15-m radii and found the three curvilinear trajectories to be very highly interrelated, with correlations with linear sprint performance ranging from r = 0.79 to 0.91. Thus, pronounced radius-dependent effects are more evident across wider geometric contrasts than across the relatively narrow radius range typically used in soccer-specific field tests. Youth soccer acceleration–speed profiling similarly showed that tighter radii constrained both acceleration and theoretical maximal speed, with additional effects of side dominance [93]. Experimental and applied studies using different radii or banking conditions further support the view that curve geometry is not a minor protocol detail but a determinant of the mechanical task itself [9,

22, 66, 72, 110]. Consequently, pooling or directly comparing studies that use substantially different radii, arc lengths, entry velocities, surfaces, or lane configurations may obscure meaningful task-specific effects.

The distinction between the inside and outside limbs emerged as one of the most consistent biomechanical themes. The inside limb generally assumes a greater role in mediolateral control and centripetal force generation, whereas the outside limb contributes more strongly to vertical and tangential propulsion; these functions are accompanied by distinct contact times, foot mechanics, joint moments, and muscle activation patterns (see Fig. 5) [1, 3, 9, 11–13, 69, 108, 119, 121]. Soccer-specific electromyographic work reported greater semitendinosus and adductor activity in the inside limb and greater biceps femoris and gluteus medius activity in the outside limb [1], while studies of bend sprinting have demonstrated side-specific foot pressure distributions, ankle mechanics, non-sagittal joint moments, and centripetal-force strategies [11–13, 69, 108, 119, 121]. More recent joint contact force modelling suggests that curve sprinting may alter shear loading at the hip and ankle to a greater extent than at the knee [14], whereas deceleration along a curved path can increase frontal-plane knee loading compared with straight-line tasks [92]. Together, these data suggest that the curve creates functional asymmetry rather than simply exposing a pre-existing difference between the dominant and nondominant limbs. The relevant comparison is often between the inside and outside limbs within a defined turning direction, not only between the preferred and non-preferred limbs.

*** **[INSERT** FIGURE 5 **HERE]** ***

4.3. Assessment, reliability, and construct specificity

The assessment literature now includes several direct field tests of curvilinear sprint ability supported by evidence of both reliability and validity. The soccer curve-sprint test has demonstrated acceptable-to-high between-session reliability and construct validity, including meaningful but incomplete associations with linear sprint performance, supporting the interpretation of curvilinear sprinting as a related but distinct speed quality [4, 5]. Additional evidence of concurrent validity has been reported for smartphone-based [15] and GPS-derived [128] measurements of curvilinear sprint performance. The assessment literature now includes several direct field tests of curvilinear sprint ability. The soccer curve-sprint test has demonstrated acceptable to high between-session reliability, including inter-session ICC values around 0.89–0.93 with low coefficients of variation [4]. Comparable sport-specific approaches have subsequently been reported in basketball and handball. The basketball 3-point-line test produced ICCs of at least 0.90 and generally low variability for acceleration and velocity outcomes [6], while the recent handball-specific 21.85-m test demonstrated between-session ICCs of 0.88–0.89 for right and left curvilinear sprint performance, CVs of 1.66–1.83%, and direction-specific Minimal Detectable Change 95 values of approximately 0.19–0.21 s [8]. Technology-oriented and profiling studies extend these findings: GPS and local positioning systems, foot pods, inertial systems, three-dimensional motion capture, acceleration–speed profiling, and smartphone applications have all been evaluated for curvilinear running or sprint monitoring [6, 7, 15, 16, 51, 125, 128]. The My Jump Lab application, for example,

provides a low-cost option for curvilinear sprint testing [15], whereas baseball foot-pod data showed generally acceptable between-session stability across linear and curvilinear base-running segments [7].

However, reliability does not imply interchangeability between curvilinear and linear tests. Multiple studies indicate moderate to large associations between linear and curvilinear sprint performance, but these relationships leave substantial unexplained variance and vary by distance, direction, age, and sport [4–6, 8, 17, 19, 67, 83, 107, 116, 122]. In youth soccer, curvilinear sprint performance correlated with linear speed, but relationships with sharper change-of-direction tasks were less consistent [19, 83]. In elite female soccer, linear sprint, curvilinear sprint, change-of-direction, and power outcomes showed moderate to very large interrelationships, yet the pattern of associations differed across constructs [116]. Similarly, acceleration–speed profiling revealed systematic differences between linear and curvilinear sprinting: linear sprints produced higher theoretical maximal speed and steeper acceleration-speed slopes, whereas curvilinear conditions altered theoretical acceleration and showed poorer reliability for some derived slope parameters [16]. These findings support a construct-specific interpretation: linear speed is an important determinant of curvilinear sprinting, but linear sprint testing cannot fully substitute for direct curve-specific assessment.

4.4. Performance determinants and sport-specific context

The literature on performance determinants indicates that curvilinear sprint performance is multifactorial. Linear acceleration and sprint speed consistently account for a meaningful proportion of between-athlete variation [5, 17, 19, 67, 83, 107, 116, 122], while jumping and power measures show additional associations in soccer and basketball [5, 17, 42, 67, 102, 116, 122, 127].

Strength appears particularly relevant when the muscles involved in frontal-plane control and force redirection are considered. A pilot study found strong associations between hip adductor/abductor strength and opposite-direction curvilinear sprint time, with combined hip and knee-flexor strength explaining 67–76% of variance in 30-m curvilinear sprint performance [18]. Track-based research also links curvilinear sprint performance with unilateral strength, jumping, and anthropometric characteristics [70]. At the same time, stronger linear sprint capacity may increase the absolute centripetal and reorientation demands imposed by a curve, meaning that the fastest linear sprinter may not necessarily display the smallest curvilinear sprint deficit [16, 19, 83, 93]. This distinction might be important for talent profiling: performance time, curve deficit, side-to-side asymmetry, and mechanical strategy provide complementary rather than redundant information.

The ecological evidence also supports the relevance of curved sprinting beyond laboratory testing. Match analysis studies in soccer have examined when and how players sprint, positional differences, preceding actions, centripetal force exposure, and contextual variables during match play [39, 56, 75, 77, 97, 98]. These studies show that high-speed actions frequently involve nonlinear trajectories and that curve characteristics can vary with the tactical situation and playing role. Related research in rugby league and basketball demonstrates that curvilinear demands are not unique to soccer [87, 112]. Baseball research further shows that base running represents a distinct applied model in which

segment-specific differences between the inside and outside limbs and path efficiency can be quantified using GPS or foot-pod technology [7, 124, 133]. Collectively, these findings strengthen the ecological argument for sport-specific curvilinear sprint assessment, but they also caution against assuming that a single 17-m or 20-m field test represents all competition-relevant curvilinear actions.

4.5. Training adaptations and practical implications

The intervention literature, although smaller than the assessment and biomechanical literature, is sufficiently developed to suggest that curvilinear sprint performance is trainable and that adaptation is partly task specific [21, 22, 37, 40, 50, 89, 94, 95, 109, 111, 114, 115, 120, 131]. A randomised comparison of linear versus curvilinear sprint training in young soccer players found moderate improvements on both stronger and weaker curve-sprint sides after curvilinear training, with transfer to selected linear sprint and change-of-direction outcomes [21]. Subsequent radius-specific training research showed that curvilinear sprint programmes using both narrow and wide radii can improve curvilinear ability and multidirectional performance, without clear evidence that one radius is uniformly superior [22]. This is consistent with the broader specificity literature: curved-sprint training primarily exposes athletes to continuous redirection of the centre of mass while maintaining forward velocity, whereas larger-angle change-of-direction training typically requires more pronounced deceleration, braking, body reorientation, and subsequent reacceleration. These distinct mechanical demands may explain why adaptations transfer preferentially to different multidirectional tasks [95]. The practical implication is not that all sprint training should become curvilinear, but that exposure to curvilinear sprinting should be deliberately programmed when curve performance is a target quality.

The broader intervention evidence suggests several ways to integrate curvilinear sprinting into strength and speed programmes. Light and very-heavy resisted sprint training both improved linear and curvilinear sprint performance in semi-professional soccer players, although very-heavy loading produced clearer change-of-direction improvements [94]. Flywheel-based interventions improved selected curvilinear sprint outcomes in male and female soccer players [115, 131], while programmes combining curvilinear high-speed running with knee-flexor-biased resistance training improved strength and sprint and jump outcomes in academy players [89]. Among female youth soccer players, six weeks of curvilinear sprint training improved weaker-side curvilinear sprint performance and reduced directional asymmetry. Adding a weighted vest equivalent to 10% of body mass produced a different adaptation profile, with some additional effects on sprint and jump outcomes rather than a simple amplification of the unloaded-training response [37]. Acute repeated-sprint research also indicates that curvilinear and linear repeated-sprint sessions can produce broadly similar metabolic and perceptual responses despite lower running velocity on the curved trajectory [114]. These findings favour a mixed programming model in which straight sprinting develops maximal horizontal speed, curvilinear sprinting develops continuous force redirection and side-specific control, and sharper change-of-direction drills address braking–reacceleration demands that are mechanically different from smooth curvature [21, 22, 94, 95].

4.6. Implications for athlete monitoring and injury-related practice

For practitioners, the evidence argues for greater standardisation of curvilinear sprint testing and reporting. Radius, total path length, arc angle, direction, entry speed, surface, footwear, number of trials, recovery duration, and timing technology all influence the interpretation of results [4, 6, 8, 9, 15, 16, 66, 72, 93, 110, 128]. Reporting only a total time without describing the geometry of the curve limits both reproducibility and transfer to training design. For longitudinal monitoring, changes should be interpreted against both measurement error (e.g., typical error, SEM, or MDC) and, where possible, a predefined smallest worthwhile change/effect, rather than relying solely on percentage change. This distinction is important because a change may exceed measurement error without necessarily being large enough to be practically meaningful. The handball study illustrates this principle with direction-specific MDC95 values [8], while acceleration–speed profiling research indicates that averaging multiple trials can improve between-session precision for derived mechanical variables [16]. This likely reflects the greater trial-to-trial variability of acceleration–speed profile parameters compared with simpler outcomes such as total sprint time, making single-trial estimates more susceptible to measurement noise. Side-specific monitoring is also justified because directional asymmetry can be task dependent and may change across tests or sessions [8, 18, 38, 62, 69, 93, 132].

Injury-related interpretation requires greater caution. The biomechanical evidence demonstrates asymmetrical loading and altered ankle, hip, foot, and knee mechanics on curves [3, 9, 11–14, 53, 69, 108, 119, 121], but mechanical asymmetry is not synonymous with injury risk. One prospective indoor-track study reported asymmetric hindfoot strength changes and a high lower-limb injury incidence, yet did not establish a causal relationship between those strength adaptations and injury [44]. Rehabilitation-oriented evidence remains sparse compared with performance research, although selected studies have begun to incorporate curved running into clinical or return-to-sport contexts [92, 104]. Accordingly, curvilinear running should not currently be framed as inherently injurious or protective. A more defensible interpretation is that curvature changes tissue loading and neuromuscular demands in ways that may be relevant to progression through rehabilitation and return-to-sprinting criteria, but prospective dose–response and injury surveillance evidence is still needed.

4.7. Insights from track & field

Track and field provides the clearest mechanistic model for why curvilinear sprinting should not be treated as a simple variant of straight-line sprinting. Approximately one quarter of the mapped literature was conducted in athletics, sprinting, or closely related track contexts, spanning performance modelling, kinetics, kinematics, electromyography, foot pressure distribution, joint moments, lane/radius effects, fatigue, and chronic asymmetrical adaptations [3, 9, 10, 12–14, 44–46, 49, 51, 53, 54, 57, 58, 63, 65, 66, 68–70, 72, 74, 84, 90, 91, 96, 100, 108, 118–120]. This literature is particularly informative because the bend is compulsory in 200-m and 400-m racing, allowing the mechanical cost of curvature to be isolated more clearly than in field sports. Across these studies, a consistent core constraint emerges: forward

propulsion must be preserved while sufficient centripetal force is generated to redirect the centre of mass [3, 9, 10, 12, 13, 49, 54, 68, 69, 96, 108].

The performance penalty is strongly dependent on geometry. Comparisons of straight versus curved sprinting, different lanes, and different radii show that tighter bends generally reduce attainable velocity and alter force production strategies [9, 45, 58, 66, 68, 72, 90, 96]. Diaz et al. reported maximal velocity reductions of approximately 10% on a 17.2-m radius and 4% on a 36.5-m radius relative to straight running [9]. Indoor track and lane-based studies similarly indicate greater performance constraints on smaller radii and inner lanes [66, 68, 72], while modelling research links indoor 200-m geometry with performance outcomes [45]. These findings indicate that radius is not merely descriptive: it is a dose-defining variable. Accordingly, two curvilinear tests of identical distance should not be considered equivalent when radius, arc length, entry speed, or lane geometry differ.

The inside and outside limbs also perform distinct mechanical functions. Kinematic studies document limb-specific changes in joint angles, stance behaviour, foot placement, and whole-body orientation [3, 51, 53, 74, 84, 88, 119]. Force studies show that mediolateral and centripetal force requirements compete with anterior-posterior propulsion, with the inside leg frequently showing greater constraints on vertical or propulsive force production and the outside leg making an important contribution to redirection and tangential propulsion [9, 10, 12, 13, 49, 54, 69, 96, 108]. Studies of joint moments and power extend these differences to coordinated hip, knee, and ankle actions and to loading outside the sagittal plane [12–14, 49, 63]. Joint contact modelling suggests differences between curvilinear and straight sprinting may be more evident at the hip and ankle than at the knee [14]. Thus, curvilinear sprint performance appears to depend less on producing greater total force than on orienting force effectively while maintaining support, propulsion, and rotational control.

Neuromuscular and fatigue studies reinforce this task-specific asymmetry. Bend sprinting alters muscle recruitment between the inside and outside limbs, including greater medial gastrocnemius activation in the inside leg and distinct muscle activity patterns during indoor 200-m curvilinear versus straight sprinting [100, 121]. Foot pressure and tibial acceleration studies show asymmetry in distal-limb mechanics and impact characteristics [118, 119], whereas 400-m studies indicate that fatigue and muscle activation evolve across the race under repeated exposure to bends in the same direction [46, 91]. A prospective indoor track study also reported asymmetric hindfoot strength adaptations and substantial lower-limb injury occurrence, although it did not establish causality between these adaptations and injury [44]. Performance-oriented studies of bend technique, horizontal force, acceleration mechanics, ankle moment generation, anthropometry, and strength further suggest that curve proficiency requires specific technical and physical capacities [49, 53, 54, 57, 63, 69, 70, 90, 96, 108]. For 200-m and 400-m sprinters, bend-specific monitoring and training therefore appear warranted rather than relying on complete transfer from straight sprinting.

4.8 Curve geometry, banking, traction, and surface as a mechanical dose

A second cross-cutting insight is that the mechanical dose of curvilinear sprinting is determined by more than distance and velocity. Radius directly influences the centripetal-force requirement, whereas lane geometry, banking, surface, and footwear traction modify how the resultant ground-reaction force is oriented and how effectively force can be partitioned between redirection and forward propulsion [9, 66, 73, 78, 94, 100, 105]. During maximal or near-maximal sprinting, tighter curves impose greater mechanical constraints on attainable speed and force application, whereas wider radii reduce, but do not eliminate, inside–outside limb asymmetries [9]. Banking changes the orientation of the resultant ground reaction force and can modify the effective mediolateral demand [66]. Footwear studies also indicate that insufficient traction can limit curve performance, while increasing traction beyond a critical level may provide little additional benefit [73, 80].

These findings have direct methodological implications. Radius, surface, banking, footwear, direction, and entry speed should be reported as core protocol variables rather than optional descriptors. A 6-m court marking, a 9.15-m soccer arc, a 17- to 18-m experimental curve, and an athletics bend represent different exposures. Practically, geometry can also be progressed deliberately: wider radii may provide a lower-curvature entry point, whereas tighter radii increase body lean, mediolateral-force, and limb-specific control demands. The intervention literature suggests that curve ability is trainable, but optimal progression remains uncertain [21, 22, 37, 40]. Future studies should therefore describe curvilinear dose in terms of radius, velocity, arc length, number of contacts, direction, and surface, rather than only total sprint metres.

4.9. Inter-limb asymmetry is task- and direction-specific

The review indicates that inter-limb asymmetry during curvilinear sprinting should primarily be interpreted in relation to the mechanical demands of the task. The inside and outside limbs perform different functions during curve negotiation, and kinetic, kinematic, electromyographic, foot-pressure, and performance studies consistently demonstrate side-specific strategies rather than mechanically interchangeable limb behaviour [3, 9, 12, 13, 69, 84, 95, 118, 119, 121]. Consequently, a bilateral difference observed during curvilinear sprinting should not automatically be interpreted as a performance deficit or dysfunction.

This interpretation is reinforced by evidence showing that both the magnitude and direction of inter-limb asymmetry can vary according to the task assessed. In multidirectional athletes, the limb identified as weaker or more asymmetric during a curve sprint may not be the same limb identified during a 505, 90° change-of-direction, or other multidirectional task [38, 99]. Similarly, side-specific acceleration–speed profiling demonstrates direction-dependent differences in curvilinear sprint capacity [16, 38, 93]. These findings limit the usefulness of a single, task-independent asymmetry score and support interpreting asymmetry within the specific movement, direction, radius, and performance outcome being assessed.

From an applied perspective, assessment should therefore determine whether an athlete can perform and tolerate high-speed curvilinear running in both directions and at sport-relevant radii, rather than seeking complete bilateral symmetry. Longitudinal changes that exceed measurement error, are

accompanied by a deterioration in performance, or occur alongside symptoms may warrant further investigation. Conversely, stable side-to-side differences that are consistent with the expected mechanical roles of the inside and outside limbs may reflect task-specific functional specialisation rather than an undesirable asymmetry.

This distinction may also be relevant during rehabilitation and return-to-sport progression. Satisfactory symmetry during straight-line running should not be assumed to demonstrate readiness for high-speed curved running, because curvilinear sprinting introduces direction-, radius-, and limb-specific mechanical demands that are not reproduced during linear sprinting. However, rehabilitation-specific evidence remains limited. Future work should therefore establish direction-specific reference values, measurement-error thresholds and, where appropriate, smallest worthwhile changes, alongside progressive criteria for reintroducing high-speed curvilinear running [8, 38, 99, 104].

4.10. Limitations of the evidence base and of this review

Several limitations temper the strength of inference. First, the evidence base is heterogeneous in terminology, test geometry, measurement technology, study design, and outcome selection [1–22, 37–132]. Curve radii range from very tight experimental paths to standard athletics bends and sport-specific field markings; some studies test standing-start sprinting, whereas others examine maximal-velocity running, repeated sprinting, match-derived trajectories, or base running. Second, the literature is demographically imbalanced. Male-only samples greatly outnumber female-only samples, and soccer/football and track dominate the evidence base [1–22, 37–132]. Third, many studies are small, cross-sectional, or repeated-measures biomechanical investigations, which are appropriate for mechanistic questions but less informative for long-term adaptation, injury risk, and causal determinants. Intervention studies are increasing but remain relatively short and heterogeneous in frequency, volume, radius, loading, and comparator conditions [21, 22, 37, 40, 50, 89, 94, 95, 109, 111, 114, 115, 120, 131]. Fourth, evidence on measurement properties is encouraging, but measurement procedures are not yet standardised across sports, technologies, and derived metrics [4, 6–8, 15, 16, 51, 76, 125, 128].

This review also has limitations inherent to its broad scoping design. Formal risk-of-bias appraisal was not used to exclude or weight studies, consistent with the mapping objective, so evidence concentration should not be interpreted as certainty of evidence. In addition, the very broad inclusion of biomechanical, observational, measurement, clinical, and intervention evidence increases descriptive completeness but reduces direct comparability. These limitations do not undermine the primary aim of identifying what has been studied and where the evidence is concentrated; rather, they reinforce the need to distinguish evidence mapping from quantitative effect estimation [26, 34, 35, 134].

4.11. Recommendations for research and practice

Future research should prioritise a core reporting framework for curvilinear sprint studies. At minimum, investigators should report curve radius, arc angle, total and curved path length, direction, start and entry conditions, surface, footwear, number of trials, recovery, measurement system, sampling characteristics,

and whether outcomes represent the inside/outside limb or better/weaker-performing side. Reliability studies should report both relative and absolute indices, including ICC, CV, MAE, MAPE, RMSE or typical error, and should complement measurement-error estimates with practically meaningful thresholds such as the smallest worthwhile change or effect where appropriate. This distinction is important because a change exceeding measurement error is not necessarily large enough to be meaningful for performance or decision-making [4, 6, 8, 15, 16, 51, 135–139]. Mechanistic studies should continue to integrate force, kinematic, and neuromuscular measures across multiple radii and velocities to determine how athletes meet the centripetal force requirements of curvilinear sprinting and how those strategies change with fatigue, maturation, sex, and expertise [1, 3, 9–13, 53, 93, 121].

Longitudinal work is particularly needed in female athletes, youth athletes across maturation stages, para-athletes, and sports beyond soccer and track. Training trials should directly compare radius, direction, weekly exposure, intensity, resisted versus unresisted conditions, and mixed linear–curvilinear programmes, with sufficient follow-up to establish retention and transfer to competition [21, 22, 37, 40, 89, 94, 114, 120]. Match-analysis research should move beyond simple counts of curved actions toward trajectory-specific exposure metrics that incorporate radius, velocity, acceleration, centripetal force, tactical context, and positional role [39, 56, 75, 77, 97, 98]. For applied practice, the present evidence appears to support including at least one direct curvilinear sprint assessment when curved high-speed running is relevant to the sport, monitoring both directions, and using curve-specific training alongside rather than instead of linear sprinting and sharper change-of-direction work [4, 6, 8, 21, 22].

4.12 Overall interpretation

Overall, the available literature supports curvilinear sprinting as a distinct but related component of multidirectional speed. Its defining feature is continuous redirection of the centre of mass, which imposes radius- and side-dependent constraints on velocity, force application, kinematics, and muscle recruitment [1, 3, 9–14, 93, 121]. Field tests can measure this quality reliably when protocols are standardised [4, 6–8, 15, 16, 128], and performance reflects a combination of linear speed, strength and power, technical control, and curve geometry rather than any single determinant [5, 17–19, 42, 70, 93, 116, 122]. Emerging intervention evidence further suggests that curvilinear sprint ability is modifiable and partly specific to the trajectory trained [21, 22, 37, 40, 89, 94, 95, 114, 115, 131]. The next phase of research should therefore move from demonstrating that curve sprinting differs from linear sprinting toward establishing standardised assessment frameworks, exposure–response relationships, and evidence-based programming principles across a broader range of athletes and sports.

5. CONCLUSION

This scoping review maps 118 studies and shows that curvilinear sprinting has developed from a predominantly track biomechanics topic into a broader sport performance construct with relevance to assessment, athlete monitoring, multidirectional speed development, match analysis, and training. The available evidence consistently indicates that sprinting on a curve is not simply linear sprinting on a different path. As curve radius decreases, attainable speed is increasingly constrained, while the inside

and outside limbs adopt complementary roles in centripetal force generation, vertical support, propulsion, joint positioning, and muscle recruitment. These task-specific demands help explain why linear sprint performance only partially accounts for curvilinear sprint ability and support the use of dedicated curvilinear sprint assessment when sport actions involve continuous changes in running direction.

The evidence base is nevertheless uneven. Soccer/football and athletics account for most studies, male participants remain strongly over-represented, and performance, assessment, biomechanics, and training are considerably better studied than rehabilitation and return-to-sport applications. Existing field tests generally demonstrate useful reliability, and emerging wearable, GPS/GNSS, inertial-sensor, foot-pod, and smartphone approaches may improve ecological monitoring; however, heterogeneity in curve radius, sprint distance, starting procedures, measurement technology, and outcome definitions limits direct comparison between studies. Training evidence is promising and suggests task-specific adaptation, but stronger conclusions require longer interventions, better standardisation, and replication across sexes, age groups, sports, and competitive levels.

Curvilinear sprinting should therefore be considered a distinct component of multidirectional speed rather than a surrogate for linear speed or discrete change-of-direction ability. For practitioners, testing and training should reflect the radii, directions, velocities, and surfaces encountered in the target sport. For researchers, the highest priorities are female-specific evidence, rehabilitation and return-to-sport applications, non-soccer team sports, measurement validity and device agreement, maturation-sensitive longitudinal research, and adequately powered curve-specific training trials. Addressing these gaps will allow the field to move from descriptive evidence toward standardised assessment, mechanistically informed training prescription, and clinically relevant applications.

Abbreviations

AP
anterior
posterior
CMJ
countermovement jump
COD
change of direction
COM
centre of mass
CS
curvilinear sprint;
CV
coefficient of variation
EMG

electromyography
GNSS
global navigation satellite system
GPS
global positioning system
GRF
ground
reaction force
ICC
intraclass correlation coefficient
IMU
inertial measurement unit
JBI
Joanna Briggs Institute
LPS
local positioning system
MAE
mean absolute error
MAPE
Mean absolute percentage error
MDC
minimal detectable change
MSS
maximum sprinting speed
OSF
Open Science Framework
PCC
Population
Concept-Context
PRESS
Peer Review of Electronic Search Strategies
PRISMA
ScR
Preferred Reporting Items for Systematic Reviews and Meta
Analyses Extension for Scoping Reviews
PRISMA
S
PRISMA extension for literature searches
RMSE
root mean square error

RST
resisted/repeated sprint training
RTS
return to sport
SEM
standard error of measurement
TE
typical error

Declarations

Conflicts of Interest

The authors declare no conflicts of interest.

Ethics Approval

Not applicable. This study synthesised data from previously published or publicly available sources and did not involve direct recruitment of human participants.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Protocol and Registration

The review protocol was prospectively developed and registered on the Open Science Framework. The permanent registration DOI is https://doi.org/10.17605/OSF.IO/45KAB. The associated OSF project is available at https://osf.io/7kh2c/.

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Author Contributions

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Data Availability

The study-level data-charting workbook and supporting review materials are available through the associated Open Science Framework project: https://osf.io/7kh2c/.

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Figures

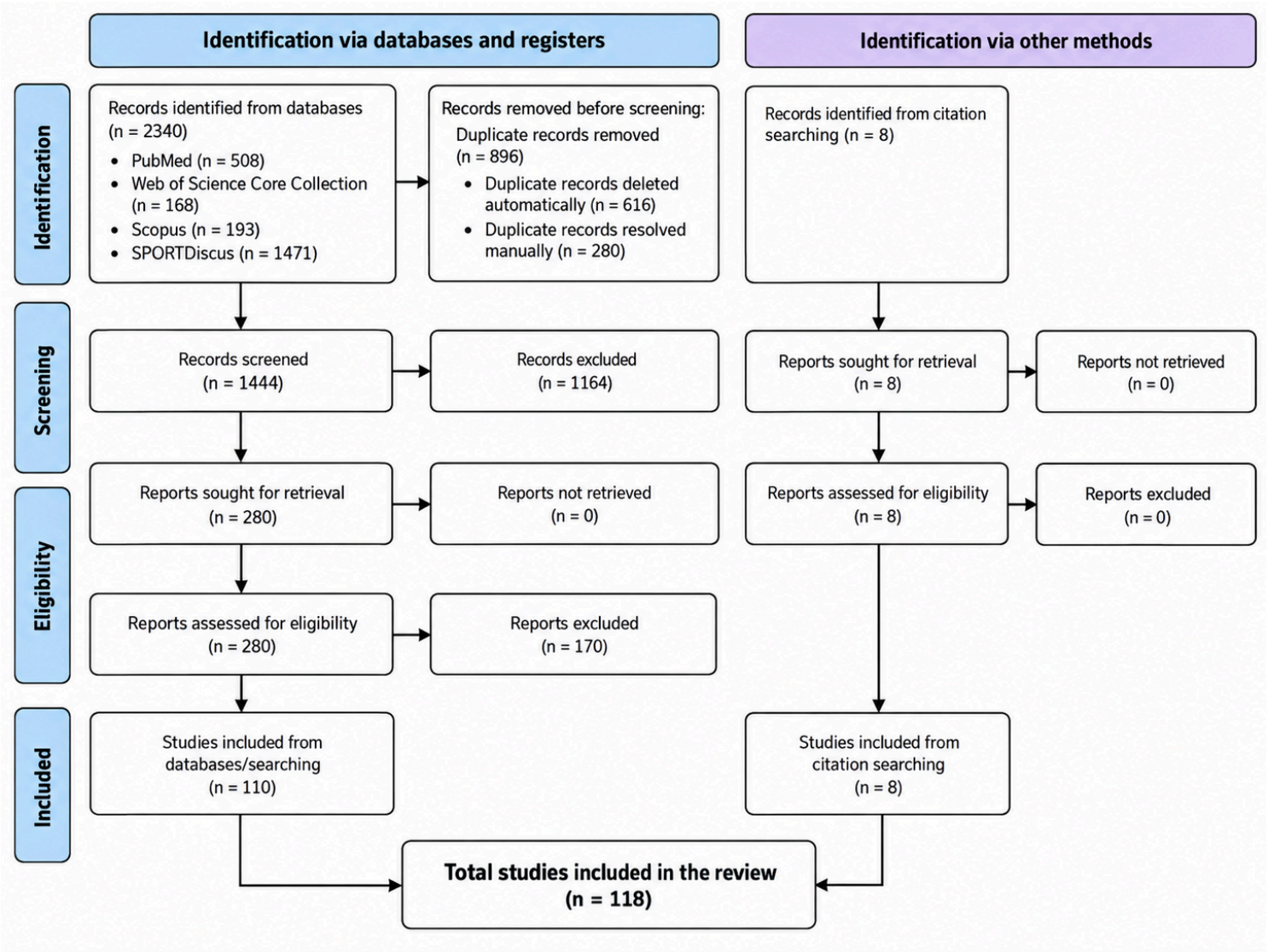


Figure 1

PRISMA Flow Diagram.

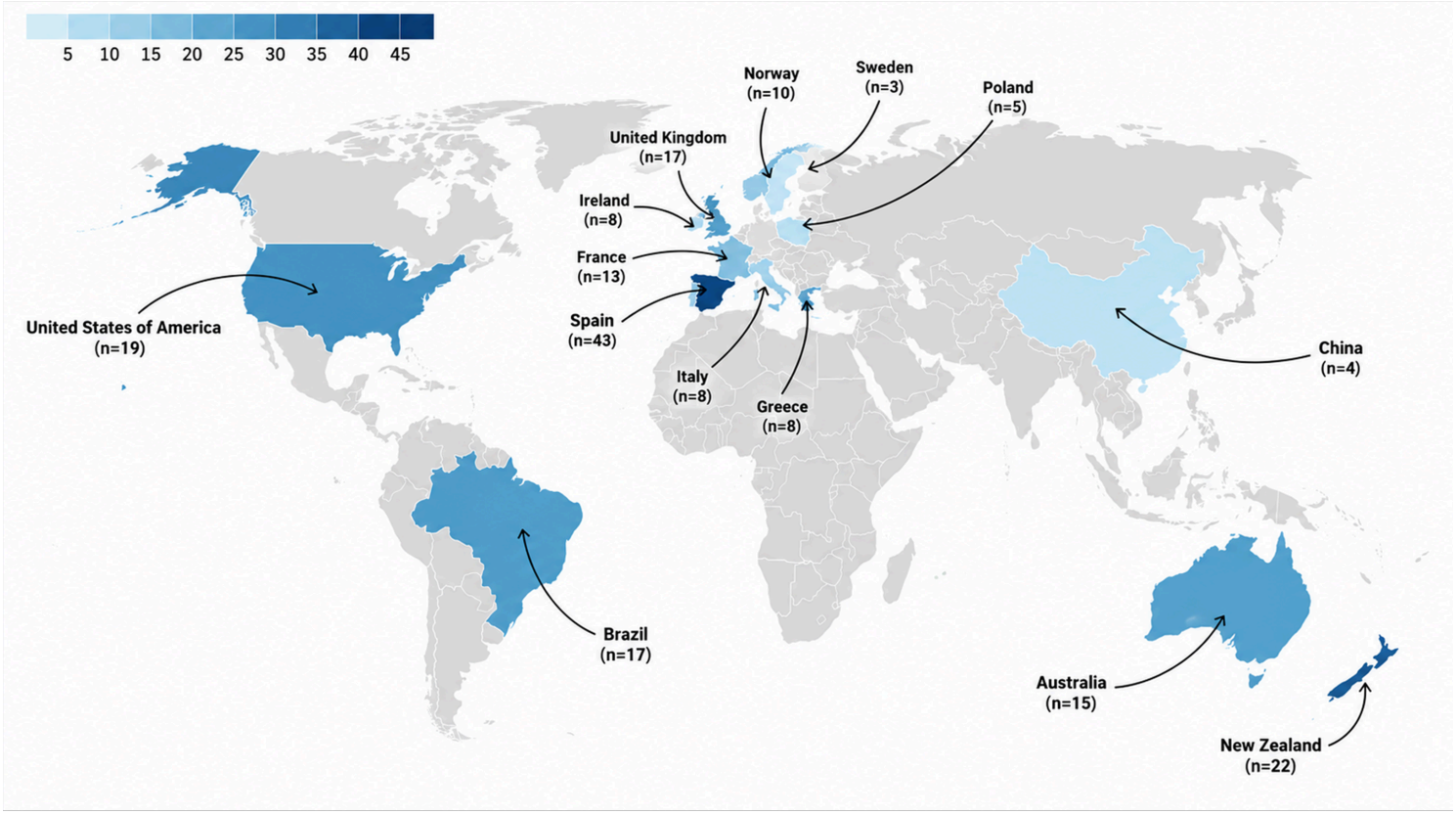


Figure 2

Geographical distribution of evidence occurrences across included studies.

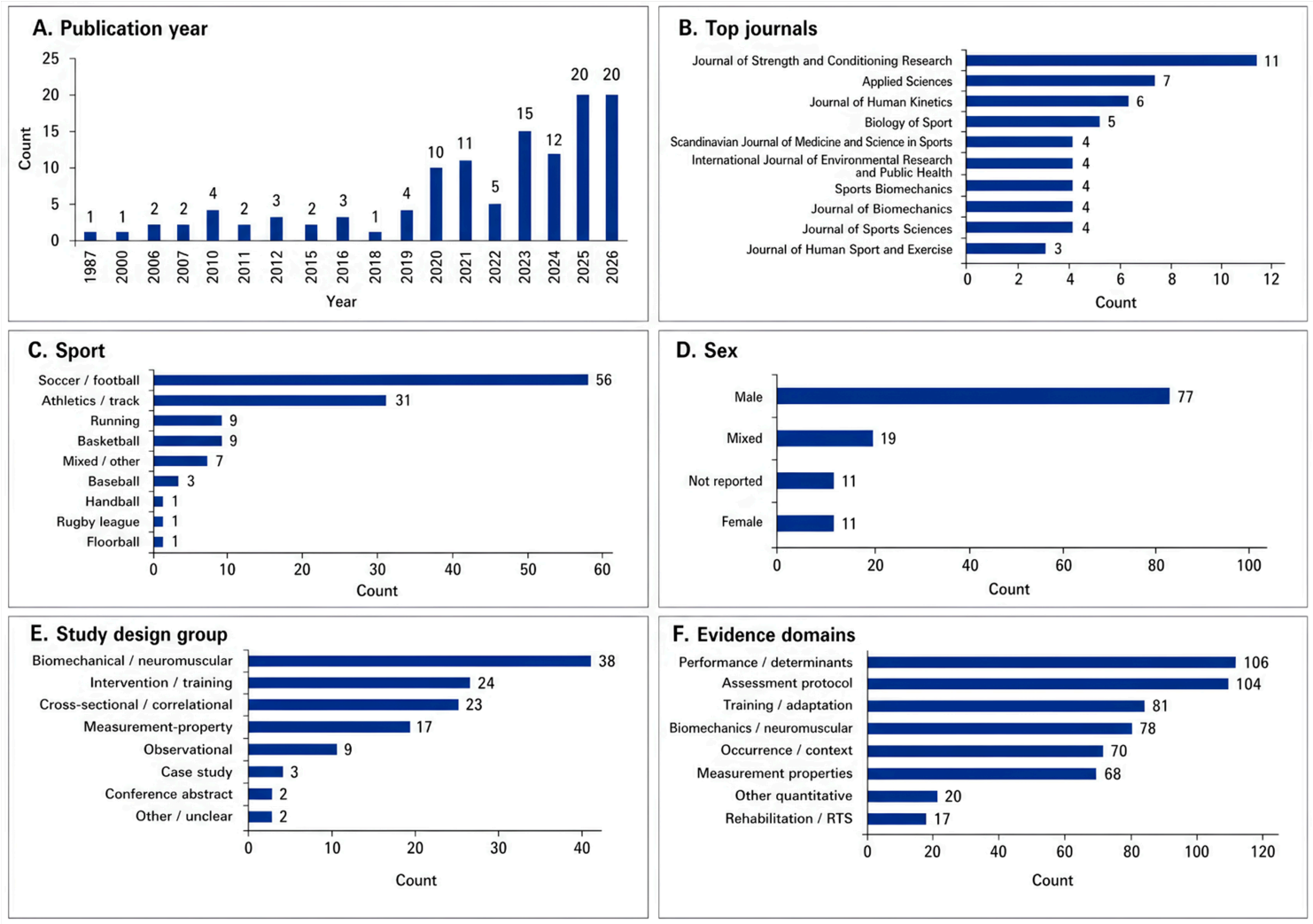


Figure 3

Summary of key study characteristics. Panel A, publication year; Panel B, top journals; Panel C, sport; Panel D, sex; Panel E, study design group; Panel F, evidence domains.

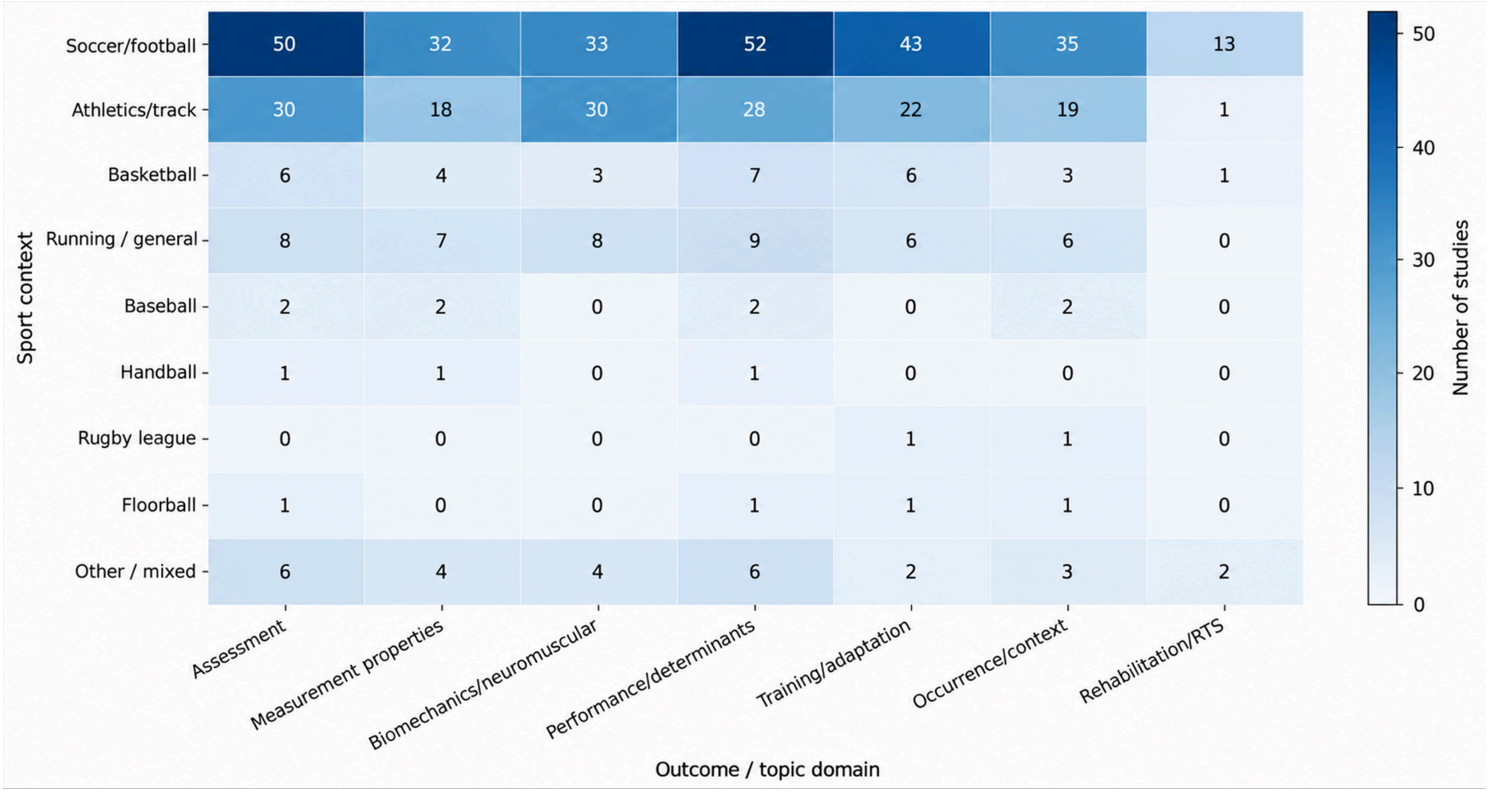


Figure 4

Evidence gap map heat matrix of the 118 included studies. Cells show the number of studies by sport context and outcome/topic domain. Darker cells indicate larger evidence clusters, whereas lighter cells indicate relative evidence gaps.

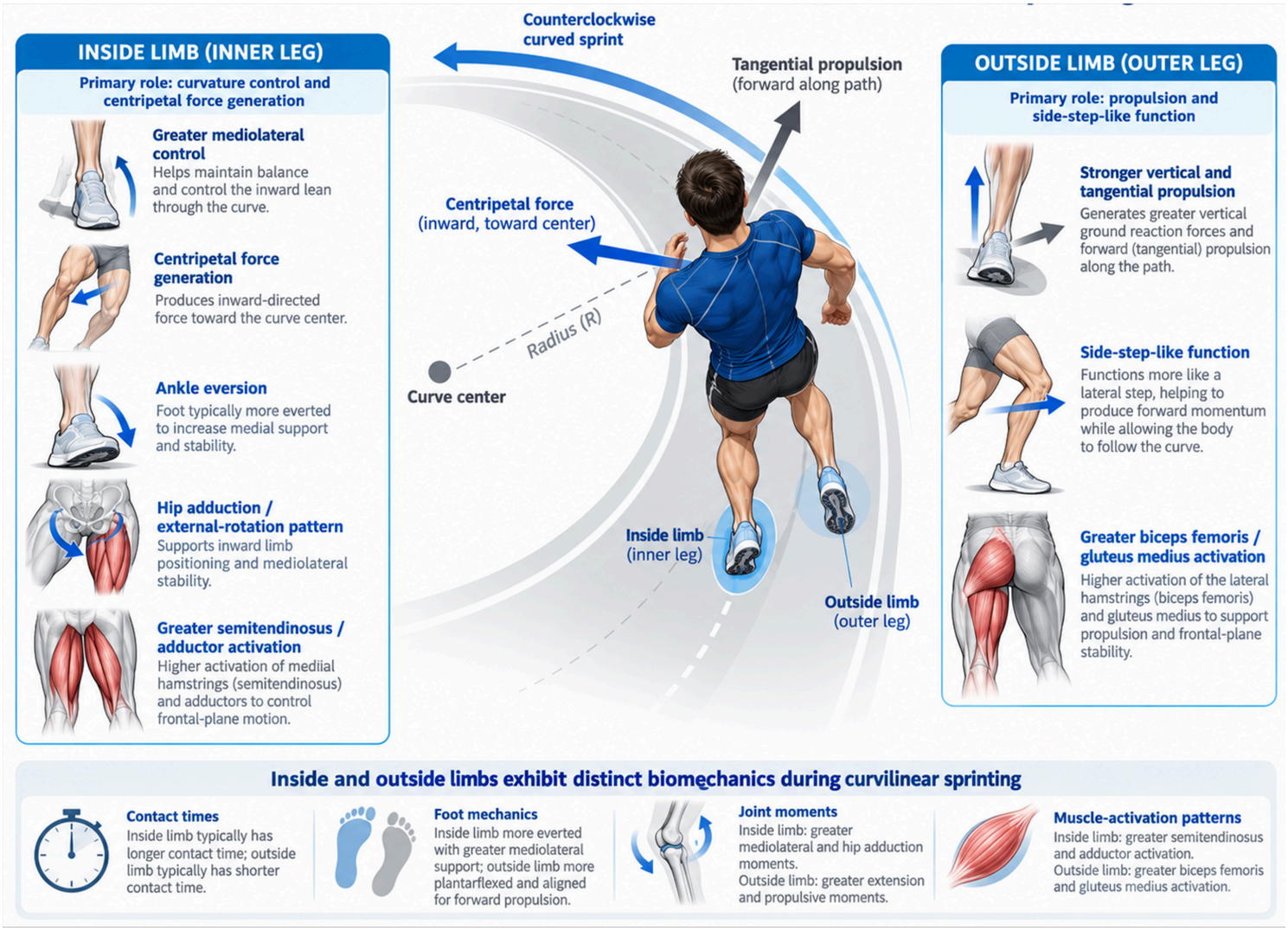


Figure 5

Functional Roles of the Inside and Outside Limbs During Curvilinear Sprinting