Advanced Journal of Management, Humanity and Social Science

Journal homepage: https://www.ajmhss.com/

DOI: https://doi.org/10.5281/zenodo.21863046

Artificial Intelligence in Sports Medicine: A Narrative Review of Applications for Injury Prevention and Physical–Psychological Performance Enhancement in Athletes

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Article info
Received: 11.06.2026
Accepted: 05.08.2026
Available Online: 09.08.2026
Checked for Plagiarism: Yes

Keywords:
Artificial Intelligence; Machine Learning; Athletic Injuries; Sports Medicine; Mental Health

ABSTRACT

Background: Artificial intelligence (AI) is increasingly integrated into sports science, offering novel tools for injury surveillance, performance optimization, and psychological well-being monitoring in athletes. Despite growing adoption of machine learning (ML), computer vision, and wearable-sensor technologies, evidence regarding their clinical effectiveness and translational value remains fragmented across disciplines.

Objective: This article reviews and synthesizes current scientific evidence on the application of AI-based systems for reducing musculoskeletal injury risk and enhancing physical and psychological performance in athletic populations, with emphasis on methodological rigor and practical implementation.

Methods: A narrative synthesis was conducted drawing on systematic reviews, scoping reviews, and primary studies indexed in PubMed, Scopus, Web of Science, IEEE Xplore, and SPORTDiscus, focusing on peer-reviewed literature published between 2015 and 2026. Studies employing machine learning, deep learning, computer vision, wearable sensors, and AI-driven psychological monitoring in sport contexts were prioritized.

Results: Evidence indicates that AI-integrated wearable technologies and predictive analytics (e.g., random forests, convolutional neural networks, force-plate-derived biomechanical models) can identify injury risk factors, particularly in lower-limb musculoskeletal injuries, and support individualized rehabilitation protocols. Concurrently, AI-based facial expression analysis, physiological signal processing, and machine learning classifiers show emerging capacity to detect early markers of psychological stress and mental fatigue in elite athletes, complementing established sports-psychiatry frameworks. However, heterogeneity in study design, limited external validation, and "black-box" model interpretability remain significant barriers to clinical translation.

Conclusion: AI holds substantial promise for a proactive, individualized approach to athlete health management spanning biomechanical injury prevention and mental health surveillance. Future research should prioritize prospective validation, algorithmic transparency, and ethical frameworks for real-world deployment in athletic populations.

Introduction

Athletic participation, ranging from recreational to elite competitive levels, is associated with a substantial and persistent burden of musculoskeletal injury. Overuse and acute injuries remain highly prevalent among competitive athletes, representing one of the most significant threats to athletic career longevity and performance continuity (Jsportrs) [1].

Beyond the physical toll, sports injury has increasingly recognized as intertwined with stressor-related psychological disorders, prompting calls for integrated frameworks that address both physical and mental health outcomes in competitive athletes (Jhse) [2]. This dual burden underscores the need for monitoring systems capable of capturing the complex, multifactorial interactions between

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biomechanical load, physiological status, and psychological state.

Historically, injury prevention and performance monitoring in sport have relied on periodic clinical screening, subjective coach observation, and single-modality assessments such as isokinetic strength testing or self-reported wellness questionnaires. These approaches, while clinically useful, are inherently limited in their capacity to process high-dimensional, continuous data streams or to detect subtle precursors of injury and psychological strain before they become clinically manifest. This methodological gap has created fertile ground for the incorporation of artificial intelligence (AI) into sports science and sports medicine practice.

Over the past decade, AI encompassing machine learning (ML), deep learning (DL), computer vision, and smart sensor technologies has emerged as a transformative tool across sport-related domains. Systematic evidence syntheses have documented the application of these methodologies across individual and team sport settings, spanning injury prevention, rehabilitation, training optimization, and performance analytics (Clinmedkaz) [3]. In particular, machine learning and deep learning techniques such as random forests, convolutional neural networks, and artificial neural networks have demonstrated an ability to analyze complex, multidimensional datasets, detect latent patterns, and generate predictive insights that inform individualized injury-risk assessment (nih) [4]. Complementing these computational advances, wearable sensor technologies integrated with AI and ML algorithms now enable real-time monitoring of biomechanical, physiological, and performance-related parameters in ecologically valid training and competition environments (Jsportrs) [۱].

Parallel to advances in injury prediction, a smaller but growing body of research has begun to address the psychological dimension of athletic performance through AI. Elite athletes face well-documented risks of anxiety and other mental health difficulties related to competitive stressors (Kmanpub) [5], a concern formally acknowledged in the International Olympic Committee's consensus statement on mental health in elite athletes, and further reinforced by the first international consensus statement on sports psychiatry (Kmanpub) [6,7]. Building on this recognition, emerging AI frameworks employing physiological signal processing, facial expression analysis, and longitudinal machine learning models have shown preliminary capacity to identify stress phenotypes and predict psychological strain, in some cases before conscious symptom awareness, positioning AI as a potential complement to established athlete mental health frameworks Systematic evidence syntheses have documented the application of these methodologies across individual and team sport settings, spanning injury prevention, rehabilitation, training optimization, and performance analytics (ResearchGate

Despite this rapid proliferation of AI applications, the field remains characterized by fragmentation: physical injury-prediction research and psychological monitoring research have largely developed in parallel rather than integrated tracks, and concerns persist regarding limited external validation, heterogeneous methodological quality, and the interpretability of "black-box" algorithmic outputs In particular, machine learning and deep learning techniques such as random forests, convolutional neural networks, and artificial neural networks have demonstrated an ability to analyze complex, multidimensional datasets, detect latent patterns, and generate predictive insights that inform individualized injury-risk assessment (nih) [4,9]. Given the accelerating pace of technological development and its direct implications for athlete health, performance, and career longevity, a critical, integrative appraisal of the current evidence base is warranted.

- ✓ **Aim of this article:** This paper critically reviews and synthesizes current scientific evidence on the application of AI-based technologies for reducing injury risk and enhancing both physical and psychological performance in athletes, identifies methodological limitations of the existing literature, and outlines priorities for future research and clinical translation

Methodology

Given the heterogeneous, rapidly evolving, and cross-disciplinary nature of the literature on artificial intelligence in sport-related injury prevention and psychological performance, a narrative review methodology was adopted rather than a formal systematic review, consistent with recommendations for topics where the evidence base is too methodologically diverse for meta-analytic pooling [10]. To ensure methodological transparency and rigor despite the absence of a fixed systematic protocol, the review followed the quality criteria outlined in the Scale for the Assessment of Narrative Review Articles (SANRA), which specify explicit justification of the review's importance, a clearly stated aim, a transparent description of the literature search strategy, systematic referencing, sound scientific reasoning, and appropriate presentation of evidence [11,12]. A structured literature search was conducted across PubMed/MEDLINE, Scopus, Web of Science, IEEE Xplore, and SPORT Discus, in line with search strategies employed in recent systematic and scoping reviews on AI applications in sports science and biomechanics [3,9]. The search covered publications from January 2015 to July 2026, reflecting the period during which AI-based methodologies including machine learning, deep learning, computer vision, and wearable-sensor technologies became substantively integrated into sports medicine and sports psychology research. Search terms combined controlled vocabulary and free-text keywords, including "artificial intelligence," "machine learning," "deep learning," "wearable sensors," "sports injury," "injury prediction," "rehabilitation," "athlete mental health," and "sports psychiatry," combined using Boolean operators. Eligible sources comprised peer-reviewed original research articles, systematic reviews, scoping reviews, and consensus statements published in English that addressed AI-based interventions targeting human athletic populations across injury prevention, rehabilitation, performance optimization, or psychological monitoring domains; studies involving purely computational simulations without human-participant validation, non-peer-reviewed conference abstracts, and publications unrelated to athletic or exercise populations were excluded. Given the narrative design, source selection and synthesis relied on the authors' critical appraisal and thematic organization of the retrieved literature rather than a predefined PRISMA-based screening protocol, an approach consistent with methodological guidance for narrative reviews addressing emerging, multidisciplinary technologies [12,13]. All included sources were cited according to the Vancouver referencing style, with numerical citation order corresponding to the sequence of first appearance in the text.

Findings

AI in Injury Risk Prediction and Prevention. The most extensively documented application of AI in sports science pertains to the prediction and prevention of musculoskeletal injury. Systematic and scoping reviews spanning studies from 2015 to 2024 report the use of diverse AI methodologies including machine learning, neural networks, computer vision, and smart sensor systems across both individual and team sport settings, with applications grouped into injury prevention, rehabilitation, training optimization, and performance analytics [3,9]. Within this literature, supervised learning algorithms such as random forests, convolutional neural networks, and artificial neural networks have demonstrated the capacity to process complex, multidimensional biomechanical and physiological datasets to generate individualized injury-risk profiles, outperforming traditional single-variable screening approaches [4]. Force-plate–derived metrics analyzed through AI-assisted models have shown particular promise: a retrospective analysis of 155 female NCAA Division I athletes found that vertical countermovement jumps force-time metrics carried meaningful associations with noncontact lower-body injury risk, supporting the feasibility of algorithmic screening tools in applied team settings [14]. Beyond generic musculoskeletal risk, AI has been applied to specific high-burden pathologies; for example, machine learning approaches have been explored to support diagnosis, surgical planning, and outcome prediction in the management of anterior cruciate ligament (ACL) injuries, one of the most career-threatening injuries in competitive sport [15]. Collectively, these findings indicate that AI-based injury-prediction models can shift practice from reactive, post-injury management toward proactive identification of at-risk athletes, although predictive performance varies considerably across sports, cohorts, and algorithmic architectures [9].

AI-Integrated Wearable Technology and Rehabilitation. A parallel and rapidly growing body of evidence addresses the integration of AI with wearable sensor technologies for continuous, real-time monitoring of athletes both during training and throughout rehabilitation. Narrative and scoping reviews describe how wearable sensors combined with machine learning enable real-time monitoring of biomechanical, physiological, and performance-related data, supporting individualized training prescriptions, injury prevention strategies, and gait analysis during return-to-play protocols [1,9]. Emerging sensor modalities extend beyond conventional inertial measurement units; for instance, wearable biosensors capable of analyzing sweat biochemical markers have been proposed as a means of tracking physiological and metabolic status relevant to fatigue and recovery monitoring in athletic populations [16]. Inertial measurement units (IMUs) combined with AI-driven signal processing have similarly been extended from simple activity recognition toward more sophisticated force-estimation applications, allowing indirect estimation of joint loading without laboratory-based instrumentation [17]. These technologies collectively support the concept of a continuous "digital thread" linking training load, biomechanical exposure, and rehabilitation progress, though most available evidence derives from small, sport-specific cohorts with limited external validation [1].

AI in Performance Optimization and Movement Analysis. In addition to injury-focused applications, AI methods have been applied to enhance athletic performance through advanced movement and technique analysis. Deep learning–based computer vision systems have been used for posture and movement identification, enabling detailed kinematic feedback without reliance on marker-based motion capture systems traditionally confined to laboratory settings [18]. Machine learning algorithms have also been applied to sport-specific performance prediction tasks, including outcome and performance forecasting in disciplines such as cricket and endurance multisport events, illustrating the breadth of AI's applicability across performance analytics domains [19]. Such tools increasingly allow coaching staff to combine biomechanical, physiological, and contextual competition data into integrated performance-optimization frameworks, although the generalizability of sport-specific models across different competitive levels and populations remains an open methodological question. AI in Psychological Monitoring and Mental Performance. A comparatively newer but expanding area of investigation concerns the application of AI to athletes' psychological states. This is a clinically significant domain given that elite athletes face well-documented risks of anxiety and other stressor-related conditions linked to competitive demands [5,2]. Recent work has developed and validated machine learning frameworks incorporating physiological signal processing and facial expression analysis capable of identifying discrete "stress phenotypes" and predicting the onset of psychological strain in elite athletes, in some cases before conscious symptom awareness, using longitudinal, mixed-methods designs with elite cohorts [8]. Notably, this research found that team-sport athletes exhibited more pronounced facial expression cues than individual-sport athletes, challenging earlier assumptions about emotional expressivity and underscoring the need for personalized model calibration rather than one-size-fits-all algorithmic thresholds [8]. Complementing these findings, digital mental health solutions including AI-supported psychological screening and tracking tools have been proposed as scalable components of hybrid care models for athlete populations, potentially reducing stigma by offering discreet, automated support alongside traditional clinical pathways [20]. Deep learning architectures, including convolutional neural network models originally developed for physiological feature extraction, have further been explored as technical building blocks for such athlete-monitoring systems[٢١].

Methodological Quality and Cross-Cutting Limitations. Across both the injury-prevention and psychological-monitoring literatures, reviewers consistently note substantial heterogeneity in study design, sample size, and outcome definitions, alongside a scarcity of prospective, externally validated trials [4,9]. The interpretability of many deep learning architectures commonly described as "black-box" systems has been repeatedly identified as an ethical and practical barrier to clinical adoption, particularly in contexts requiring accountable, explainable decision-making for athlete health and eligibility decisions [8]. Furthermore, AI models trained primarily on data from controlled laboratory tasks have been shown to underperform relative to those trained on data captured during authentic competitive conditions, highlighting the importance of ecologically valid training data for real-world model deployment [8].

Discussion

The findings synthesized in this review indicate that AI-based technologies are reshaping two historically distinct domains of athlete care musculoskeletal injury management and psychological well-being by enabling earlier, more individualized, and more continuous forms of monitoring than traditional clinical assessment permits. This convergence is consistent with broader narrative reviews describing AI's transformative role across biomechanics, performance enhancement, sports medicine, health monitoring, coaching, and talent identification [22]. However, several cross-cutting issues emerge when these findings are considered collectively, warranting critical discussion regarding evidentiary strength, clinical translatability, and ethical governance.

First, despite considerable methodological innovation, the overall strength of evidence supporting AI-based injury prediction remains moderate at best. Predictive models such as those built on countermovement jump force-time metrics or wearable-sensor-derived biomechanical indices demonstrate statistically meaningful associations with injury risk, yet most studies remain retrospective, single-cohort, and sport-specific, limiting generalizability across populations, competitive levels, and sexes [14,9]. This mirrors a broader pattern noted across systematic reviews of AI in sports biomechanics, where methodological heterogeneity and inconsistent outcome definitions constrain direct comparison and pooled synthesis of effect sizes [3,4]. Prospective, multi-site validation studies analogous to those required for clinical prediction rules in general medicine will be necessary before such models can be responsibly incorporated into return-to-play or team-selection decisions.

Second, the psychological monitoring literature, while conceptually promising, is markedly less mature than its injury-prediction counterpart. The demonstrated capacity of machine learning models to detect stress phenotypes and anticipate psychological strain before conscious symptom awareness represents a potentially valuable complement to established frameworks such as the International Olympic Committee consensus statement on mental health in elite athletes and the first international consensus statement on sports psychiatry [6,7,8]. Nonetheless, the finding that team-sport and individual-sport athletes exhibit differential facial expression cues illustrates the risk of applying uncalibrated, population-level models to heterogeneous athlete subgroups, potentially generating false reassurance or false alarms if deployed without individualized calibration [8]. This concern is compounded by evidence that models trained on data from controlled laboratory paradigms tend to underperform when applied to ecologically valid competitive settings, suggesting that psychological AI tools validated in artificial contexts may not reliably generalize to real competition environments.

Third, the interpretability of AI systems constitutes a recurring and substantive barrier across both injury-related and psychological applications. The "black-box" nature of many deep learning architectures complicates clinical accountability, particularly when algorithmic outputs inform decisions with direct consequences for athlete health, playing time, or contractual status [8,4]. This concern parallels ethical debates in general healthcare AI, where transparency, explainability, and clinical validation across diverse populations have identified as prerequisites for responsible deployment [23]. Emerging work specific to sport has similarly identified fairness and bias, transparency and explainability, privacy and data ethics, and accountability as the four principal ethical concerns associated with AI adoption in athletic contexts, with privacy and data-related risks featuring most prominently across the literature [24,25].

Because athlete-monitoring systems often integrate sensitive physiological, biomechanical, and psychological data streams, safeguarding this information through informed consent, data minimization, anonymization, and compliance with data protection frameworks such as GDPR and HIPAA has been proposed as an essential governance requirement rather than an optional safeguard [24,26].

Fourth, algorithmic bias represents a particular concern in athletic applications, where training datasets may disproportionately represent certain sports, competitive levels, sexes, or ethnic groups, risking the perpetuation or amplification of existing inequities in athlete health management if deployed without regular auditing and recalibration using diverse, representative data [24,25]. This issue is not unique to sport but reflects broader challenges documented in the application of AI and machine learning across healthcare more generally, where rigorous validation across diverse populations remains a persistent gap in translating algorithmic promise into equitable clinical benefit [23,26].

Taken together, these findings suggest that while AI offers a scientifically credible and increasingly evidence-supported pathway toward proactive, individualized athlete care, its responsible integration into applied sports medicine and sports psychology practice requires parallel investment in methodological rigor, explainable model architectures, and robust ethical governance frameworks. The current literature, though expanding rapidly, remains at an early stage of clinical maturity, and stakeholders including sports medicine physicians, sport psychologists, data scientists, and governing bodies will need to collaborate closely to ensure that technological innovation translates into safe, equitable, and clinically meaningful improvements in athlete outcomes.

Conclusion

The evidence reviewed in this article demonstrates that artificial intelligence has become a scientifically substantiated and rapidly expanding tool for addressing two interconnected dimensions of athlete welfare: the prevention and management of musculoskeletal injury, and the monitoring of psychological well-being and mental performance. Machine learning and deep learning models, when integrated with wearable sensor technologies and biomechanical assessment tools, show demonstrable capacity to identify injury-risk profiles, support individualized rehabilitation, and enable continuous, real-time monitoring that surpasses the resolution of traditional periodic clinical screening. In parallel, AI-driven physiological and behavioral analysis is beginning to offer a complementary, data-informed approach to detecting early markers of psychological stress in elite athletes, aligning with and extending established sports-psychiatry frameworks. Nonetheless, the current evidence base remains constrained by methodological heterogeneity, limited prospective and cross-population validation, and the persistent interpretability challenges associated with complex algorithmic models. These limitations compounded by unresolved ethical considerations surrounding data privacy, algorithmic fairness, and accountability, which addressed proportionately given the sensitivity of athlete health and performance data. Consequently, AI should currently be regarded as a valuable adjunct to, rather than a replacement for, clinical judgment by sports medicine physicians, physiotherapists, sport psychologists.

Future research should prioritize large-scale, prospective, and externally validated studies conducted under ecologically valid competitive conditions; the development of explainable AI architectures suitable for high-stakes athlete-management decisions; and the establishment of standardized ethical and data-governance frameworks tailored specifically to sport contexts. With continued methodological refinement and responsible implementation, AI holds substantial promise for advancing a more proactive, personalized, and holistic model of athlete care one that integrates physical injury prevention with psychological health monitoring to support both performance and long-term athlete well-being.

Disclosure Statement

No potential conflict of interest reported by the authors.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions
All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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