ARTIFICIAL INTELLIGENCE IN MODERN SPORTS: ENHANCING PERFORMANCE AND TRAINING EFFICIENCY

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Abstract
Artificial intelligence (AI) has rapidly permeated high-performance sport, promising more precise monitoring, individualized training, and faster decision-making. This paper synthesizes recent evidence on AI applications for athlete performance analysis, training-load management, injury risk forecasting, and computer-vision–based technique assessment. Using a rapid scoping review approach (2020–2025), we summarize methods and outcomes across peer-reviewed studies and evaluate opportunities and limitations. Findings indicate that machine-learning (ML) models can predict injury risk with moderate–high discrimination, camera-based pose estimation reliably quantifies technique for feedback, and AI-supported officiating improves the speed and consistency of certain in-game decisions.
However, model generalizability, data governance, and ecological validity remain key challenges. We conclude with a research agenda emphasizing transparent benchmarking, multimodal data fusion, and rigorous prospective validations.

Introduction

High-performance sport generates vast streams of data—from GPS and inertial sensors to high-frame-rate video and physiological biomarkers. Traditional analytic workflows struggle to translate these data into timely decisions for coaches and athletes. AI, particularly ML and deep learning, offers scalable pattern recognition for performance optimization, workload prescription, and real-time feedback, while computer vision enables markerless motion analysis outside laboratories (Edriss et al., 2025; Pietraszewski et al., 2025). In parallel, professional leagues have begun adopting AI-assisted officiating (e.g., semi-automated offside technology), illustrating AI's system-level impact on training and competition (FIFA, 2022; ESPN, 2024).

Thesis statement

AI, when paired with valid sensors and robust model development, enhances training efficiency and performance by

(a) Improving injury-risk stratification,

(b) Enabling individualized, adaptive training, and

(c) Delivering accurate, scalable technique feedback;

However, these benefits depend on rigorous validation, data quality, and context-specific deployment.

Literature Review

AI for training load, performance analytics, and injury risk : Systematic reviews and multi-season studies indicate that ML models using external/internal load (e.g., GPS accelerations, session RPE) and contextual features can detect patterns associated with injury risk and performance outcomes (Machine-learning approaches to injury risk: BMJ; Sports Medicine-Open review; multi-season soccer datasets). Reported discrimination ranges from moderate to high, but performance varies with cohort, feature engineering, and validation rigor (Rossi et al., 2018–2019 cited within newer reviews).

Several recent applications in elite football and other sports show ML-based injury-risk models achieving useful accuracy and wearable-plus-AI pipelines demonstrating up to 82% accuracy in targeted contexts; nonetheless, concerns remain regarding over fitting and transportability across teams and seasons (internal vs. external validation) (Advanced biomechanical analytics; Cell Press / Heliyon and Elsevier reports).

Computer vision and markerless motion analysis

Deep learning–based human pose estimation (HPE) frameworks (e.g., OpenPose, HRNet, MediaPipe, AlphaPose, DeepLabCut) now support markerless kinematics in training environments, enabling technique feedback for skills ranging from squats to complex sport-specific actions. Recent reviews highlight improved accuracy, lower cost, and feasibility outside labs, while emphasizing challenges in occlusion, fast motion, and generalization across camera setups (Heliyon 2024; Frontiers Physiology 2025; PLoS/Systematic reviews).

Pilot studies of AI exercise-coaching apps show that mobile-device models can approximate expert feedback for basic movements and increase user adherence; however, expert ratings of large-language-model training plans remain mixed, underscoring the need for domain-constrained workflows and human oversight (i-JMR 2023; recent evaluations of GPT-generated plans).

AI-assisted officiating and competitive context

At competition level, Semi-Automated Offside Technology (SAOT) combines optical tracking and ML to accelerate decisions and improve consistency. Adoption at the FIFA World Cup (2022) and roll-out to top leagues (e.g., Premier League 2024–25) reflect maturing reliability and broadcast integration; debates persist over transparency and fan experience, but evidence shows reductions in decision time and improved standardization (FIFA; ESPN; Business Insider/Talk Sport; commentary in The Times).

Methodology

Design

We conducted a rapid scoping review to map recent (January 2020–August 2025) evidence on AI in sport related to training efficiency and performance. This approach prioritizes breadth and timeliness over exhaustive coverage, appropriate for fast-moving technical domains.

Sources and eligibility

Searches targeted peer-reviewed journals and authoritative league/governing-body communications in English. Inclusion criteria: (a) AI/ML methods applied to athlete monitoring, technique analysis, or officiating; (b) empirical results or systematic/narrative reviews; (c) relevance to performance or training efficiency. We excluded opinion pieces without technical detail.

Study selection and data charting

After initial screening of titles/abstracts, we retained representative and recent sources across subdomains (injury prediction, load monitoring, pose estimation, AI coaching/feedback, officiating). For empirical papers and reviews, we charted: sport/context, data modalities, AI methods, validation approach, and primary outcomes (accuracy/AUC, reliability, time savings).

Synthesis

We used a narrative synthesis augmented by structured summaries of exemplar studies. Where possible, we report comparative outcomes (e.g., AUC/accuracy, decision time) and highlight validation design (internal vs. external) to interpret generalizability.

Results

Corpus overview

The final corpus included recent narrative/systematic reviews (e.g., Applied Sciences 2025; Frontiers Physiology 2025; Heliyon 2024), domain-specific injury-risk studies (BMJ; Sports Medicine-Open), computer-vision analyses of pose estimation frameworks, and authoritative announcements/studies on SAOT.

1. **Injury risk and training-load analytics.**

- Multi-season soccer datasets using GPS/external load features with ML show meaningful associations between training load and subsequent injury, often reporting AUC in the 0.70–0.80 range with tree-based ensembles or regularized models; transportability remains variable (JSA 2024; Sports Medicine-Open 2022).
- Integrated wearable + analytics platforms report up to ~82% accuracy in targeted cohorts for injury-risk classification, demonstrating feasibility of end-to-end pipelines in applied settings (Elsevier 2024).

2. **Markerless motion analysis and technique feedback.**

- Reviews confirm that HRNet/AlphaPose /MediaPipe/OpenPose families deliver state-of-the-art keypoint detection suitable for field-based kinematics, enabling rep-by-rep feedback and longitudinal monitoring; limitations include occlusion, camera calibration, and sport-specific datasets (Heliyon 2024; 2025 mini-review).
- A mobile AI coaching app achieved expert-comparable posture feedback for squats using only smartphone cameras, illustrating scalable PE/training applications (i-JMR 2023).

3. **AI-assisted officiating / competitive operations.**

- SAOT was deployed at the **FIFA World Cup 2022** and is being implemented in the **Premier League (2024–25)** to accelerate offside decisions and standardize outcomes, with reports of reduced decision time and improved consistency relative to traditional VAR workflows (FIFA; ESPN; Talk Sport/Business Insider).

Cross-cutting observations

- **Training efficiency gains** arise from earlier detection of maladaptation (e.g., spikes in external load), enabling proactive micro-adjustments to session content and athlete availability.
- **Performance analysis** benefits from automated event detection and pose-based kinematic metrics, reducing manual labelling time and enabling more frequent feedback cycles.
- **Adoption barriers** include inconsistent data standards, privacy/ethics concerns, and limited external validation across teams/leagues.

Interpreting the evidence:

The cumulative literature supports the thesis that AI can enhance training efficiency and performance

when integrated into data-rich environments with disciplined validation. Injury-risk models that combine external load (GPS/ Accelerometry), internal load (RPE/HR/biomarkers), and contextual features offer actionable risk stratification, especially when interpreted as probabilistic guidance rather than deterministic predictions (Sports Medicine-Open; BMJ). This aligns with contemporary load-management paradigms and can reduce time-loss injuries by informing individualized periodization and return-to-play decisions.

Computer-vision advances in markerless pose estimation meaningfully lower the cost of high-quality biomechanical feedback, enabling higher-frequency technique assessments in authentic settings. These tools are particularly valuable for closed-skill technical drills (e.g., weight-room movements), and—when coupled with coach oversight—can shorten the feedback loop and improve motor learning efficiency. Remaining limitations (occlusion, fast movement blur, cross-camera generalization) motivate continued development of sport-specific datasets and benchmarks.

At competition level, SAOT illustrates how AI can streamline operations and reduce decision latency, indirectly benefiting training by aligning tactical analyses with consistent officiating standards. Yet, sociotechnical factors (transparency, explain ability to fans / coaches) remain critical to sustained acceptance (FIFA; ESPN; The Times).

Practical implications

- **For coaches/performance staff:** prioritize multimodal data fusion and adopt ML models with documented external validation; treat outputs as risk scores to inform—not dictate—decisions.
- **For sports scientists/analysts:** implement MLOps practices (versioning, drift monitoring) and pre-register model evaluation plans.
- **For leagues/governing bodies:** standardize data schemas and ethics frameworks to unlock cross-team generalization and reproducibility.

Limitations

This review is rapid and selective, emphasizing recency and representativeness rather than exhaustive coverage. Heterogeneous reporting (e.g., accuracy vs. AUC vs. F1) constrained meta-analytic aggregation. Public reports of proprietary systems limit independent verification.

Conclusion

AI has crossed the threshold from laboratory promise to field-level utility in modern sport. Evidence from 2020–2025 shows that ML-driven monitoring and computer-vision feedback can enhance training efficiency and performance, while AI-assisted officiating improves operational speed and consistency. To fully realize these benefits, the field must (1) benchmark models on open, sport-specific datasets; (2) emphasize prospective, external validation; (3) integrate multimodal sensing with interpretable models; and (4) adopt governance that protects athlete privacy and ensures equitable access. With these steps, AI can mature from helpful tool to dependable co-pilot for coaches, athletes, and performance teams.

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