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Additional material is published
online only. To view please visit
the journal online.

Cite this as: Mahmood A. The
Role of AI and Wearables in Injury
Prediction and Performance
Optimization. Premier Journal
of Artificial Intelligence
2025;4:100019

DOI: [https://doi.org/10.70389/
PJAI.100019](https://doi.org/10.70389/PJAI.100019)

Received: 30 May 2025

Revised: 19 July 2025

Accepted: 19 July 2025

Published: 12 August 2025

Ethical approval: N/a

Consent: N/a

Funding: No industry funding

Conflicts of interest: N/a

Author contribution:
Abdullah Mahmood –
Conceptualization, Writing –
original draft, review and editing

Guarantor: Abdullah Mahmood

Provenance and peer-review:
Unsolicited and externally
peer-reviewed

Data availability statement:
N/a

The Role of AI and Wearables in Injury Prediction and Performance Optimization

Abdullah Mahmood

ABSTRACT

The combination of artificial intelligence (AI) and wearable technology is now changing sports science, health care, and human performance. The review carefully examines how AI-enabled wearable devices are helping to prevent injuries and enhance athletes' performance. Using material from different fields, it assesses the value of today's wearable technology, including GPS trackers, heart rate monitors, and inertial sensors. It utilizes machine learning to identify injury risks, detect unusual performances, and enhance training plans. This review examines how AI is currently used to make sense of real-time physiological and biomechanical data and discuss its value for professional athletes and individuals recovering from injuries. It also examines the challenges of implementing these systems, including questions about data quality, privacy concerns, and the fact that many predictive models are difficult for nonexperts to interpret. The review combines studies from various fields to provide an overall view and help identify weaknesses in current approaches. This review explores explainable AI and the integration of wearables and personalized medicine. According to experts, combining AI and wearables has significantly changed how people monitor and improve their health.

Keywords: AI-enabled wearables, Injury prediction, Performance optimization, Machine learning in sports, Wearable health technologies

Introduction

Artificial intelligence (AI) and wearable technology have recently significantly changed sports science, health monitoring, and human performance. More athletes, clinicians, and researchers rely on data these days, which is why AI-enabled wearables for predicting injuries and enhancing physical performance has gained increasing attention.¹ AI stands for the simulation of human intelligence in machines, allowing them to review data, detect patterns, choose actions, and learn as they go. AI is primarily used with wearables to handle and extract meaning from the vast amount of data collected from the body.² Fitness trackers, smartwatches, and clothing equipped with sensors are wearable devices that constantly gather information on heart rate, exercise, muscle use, and sleep. Drawing on historical data, injury prediction helps identify musculoskeletal or other body injuries before onset. Performance optimization is about enhancing an individual's physical output, how quickly they recover, and how they work efficiently by utilizing real-time data and analytics.³ People are becoming increasingly aware of this issue because athlete careers are lasting longer, health care needs are rising, and the importance of prevention is becoming more apparent. Preventing sports injuries and designing individual training is highly valuable in the sports and

fitness worlds.⁴ This document reviews the state of AI-powered wearables by examining how they are used to recognize the likelihood of injury and enhance athletic performance. It draws on the latest research, notes technical and moral challenges, and suggests what might arise in the future.⁵ In connecting technological knowledge with real-world applications, this review covers everything researchers, practitioners, and stakeholders need to understand about utilizing AI and wearable data for improved health and sports outcomes.

Methodological Framework and Evidence Grading Literature Search Strategy

A search around multiple electronic databases was conducted to form a structured search to cover a comprehensive synthesis of literature on AI and wearable technology in injury prediction and performance optimization. It was conducted mainly in PubMed, Google Scholar, IEEE Xplore, and ScienceDirect, with additional searches of institutional repositories and whitepapers specific to the industry.

The last search was conducted on April 30, 2024, considering literature published between January 2015 and April 2024. Specific search queries were used based on a combination of the Boolean operators to provide sensitivity and specificity to each database. The basic Boolean string involved:

((wearable technology) OR (wearable devices))
AND ((artificial intelligence) OR (machine learning) OR (deep learning)) AND ((injury prediction) OR (performance optimization) OR (training load))
AND (sports OR athletics OR health care).

To refine the search results, the following filters were added: articles written in English, articles using human subjects (6 subjects of the study were represented by athletes of age 13+), and articles with a retrievable outcome related to injury prediction, physical performance, or health monitoring.

Inclusion and Exclusion Criteria Inclusion Criteria

- Those investigations aimed to use AI on wearable device data during sports or in health care.
- Studies related to injury prevention, workload tracking, or performance improvements.
- The inclusion of peer-reviewed journal articles, conference proceedings, and systematic reviews published since 2015 up to 2024.
- Research has been conducted on amateur or professional athletes/patients undergoing rehabilitation or on the general human population, exercising.

Exclusion Criteria:

- In vitro or animal experimentation.
- Opinion articles and news without the use of an empirical/theoretical framework.
- Articles that merely talk about algorithm development are devoid of context in wearables.
- Duplicates and non-English articles.

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow and Screening Process

Transparency was achieved using a simplified PRISMA framework. The first result comprises 472 articles. The resultant 111 full-text studies were considered eligible based on title and abstract screening of empirical studies ($n = 263$ excluded). After additional lack-of-relevance or incomplete-methodology exclusion ($n = 43$), 68 studies were retained in the final synthesis. The PRISMA chart describes the screening and selection process, guaranteeing reproducibility and methodological integrity.

Evidence Grading

To assess methodological rigor and better communicate the strength of findings, we applied a simplified

Table 1 | Simplified grading system

Study Type	Count	Symbol	Example Citation
RCT	12	▲	Shah et al. ¹
Cohort/Obs.	31	■	Chidambaram et al. ²
Narrative Review	25	●	Chen and Dai ³

grading system to the 68 included studies (Table 1):

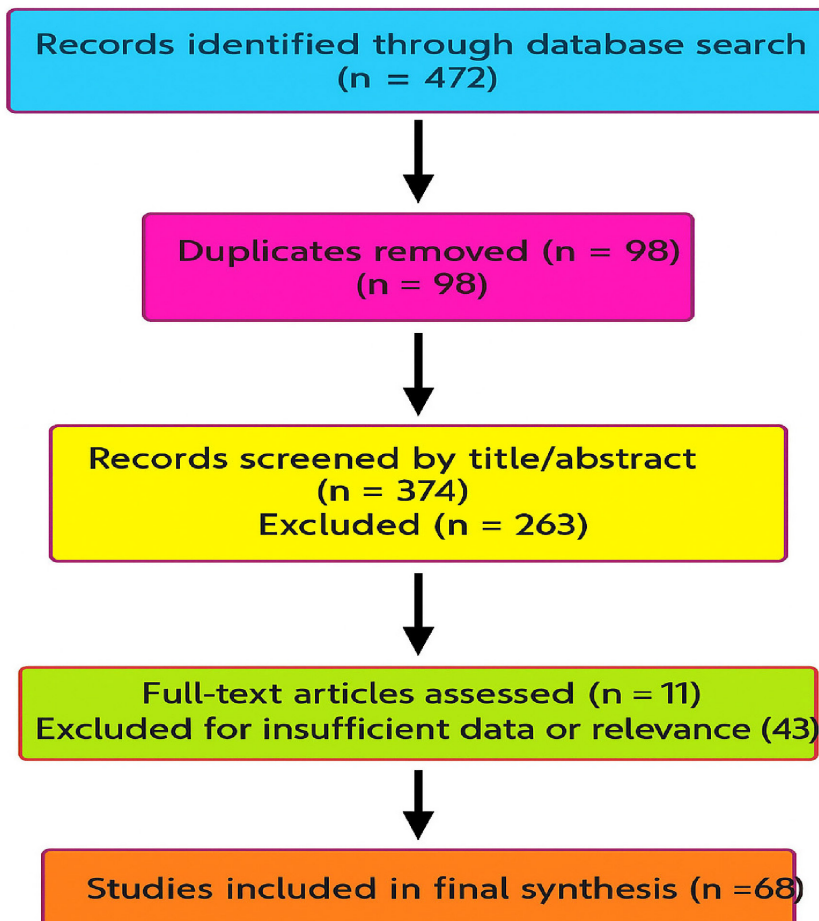
- ▲ Randomized Controlled Trial (RCT) – high internal validity; controlled design.
- Cohort or Observational Study – moderate strength; naturalistic data over time.
- Narrative or Theoretical Review – helpful for conceptual insights; lower empirical strength.

The grading has been applied throughout the review and in tables where possible. It provides a reader with a quick assessment of how robust the evidence of support is and what this evidence says. The best grade applicable was taken when methods were used in studies (Figure 1).

Overview of Wearable Technologies in Sports and Health Care

The ways in which wearable technology contributes has advanced significantly over the past two decades, from basic pedometers and simple heart rate devices to now providing precise readings of multiple complex health and movement data. First created for fitness purposes, wearables are now used by top athletes in medical rehabilitation and for preventive health.⁶ In the early 2000s, wearable devices started measuring simple motion and heart rate. However, smartwatches and fitness bands emerged with enhanced capabilities as sensors, communication technology, and mobile phones became smaller. AI and cloud computing are combined in wearables, allowing users to receive real-time suggestions, forecasts, and personalized tips.⁷ Wearables are now available to monitor key health and performance metrics in individuals.

Field-based sports heavily utilize global positioning system (GPS) technology to track movement, speed, distance, and location changes. Heart rate variability (HRV) indicates the balance between the body's primary automatic systems and a person's readiness for physical activity.⁸ Detecting motion, orientation, and force caused by impact, accelerometers, and gyroscopes provide valuable information about biomechanics and fatigue. Electromyography (EMG) sensors detect how muscles work and are utilized in rehabilitation and performance training.⁹ Furthermore, these devices are now designed to monitor sleep patterns, respiratory rhythm, and skin temperature, allowing them to determine an athlete's state of rest. Most of the time, data is gathered without harming the user and remains continuous, using Bluetooth Low Energy, ANT+, and Wi-Fi to send the data to mobile applications or cloud-based platforms. The systems utilize machine learning to analyze raw sensor information and interpret it to provide valuable data.¹⁰

**Fig 1 | PRISMA flow diagram of literature screening and inclusion process**

Leading products in this area demonstrate the various applications for which they are used. The purpose of wearable fitness tracker brand (WHOOP) bands is to measure strain, assess recovery, and evaluate sleep quality using HRV and skin temperature. Fitbit devices help people track their health by monitoring activity, heart rate, and sleep. Catapult Sports is popular with professional teams for tracking GPS, load, and movement activity. Heart rate monitoring and GPS come together in Polar's training analytics system.¹¹ The Oura Ring is a small device that tracks sleep, readiness, and recovery using various sensors. As these innovations develop, they help build the infrastructure needed for AI-driven injury prevention and performance enhancement. These innovations develop and help establish the infrastructure required for protecting from harm and boosting performance with AI (see Figure 2).

Role of AI in Analyzing Wearable Data

Thanks to AI, wearable technologies can turn vast amounts of raw data on the body's activity and health into something valuable and useful. Due to the combination of AI and wearables, we can continuously monitor and analyze data for injury prevention and enhanced performance. Machine learning, artificial neural networks, and deep learning are the three most commonly used AI techniques in data analysis, as they bring different strengths.¹² Both machine learning algorithms are widely applied to detect unusual events, explore patterns in data, and predict future outcomes.

They utilize available, annotated data to detect changes in gait, heart rate, or muscle function, which may indicate an approaching injury or poor performance. Deep learning, within the field of machine learning, is capable of extracting essential features from challenging data with minimal support from humans.¹³

Unstructured and high-dimensional data, such as signals from wearable sensors, are best handled by these models, making them effective at tasks like classifying movement and detecting fatigue. Data space is primarily managed by convolutional neural networks (CNNs), while recurrent neural networks (RNNs) typically deal with time series data.¹⁴ AI is commonly integrated into wearable electronics through synchronized apps or cloud-based platforms. They process AI models using edge computing or central servers to rapidly analyze sensor data and provide users with timely insights, advanced alerts, and forecasts. Real-time AI analysis is now being integrated into specific devices, reducing the time it takes for responses.¹⁵ AI excels in uncovering details that a standard approach often overlooks. In this way, AI can identify small changes in training load, stride, or heart rate that may indicate the onset of overuse injuries, even when human experts do not notice them. AI enhances personalization by analyzing a user's previous behavior and then tailoring its predictions to that individual's specific needs.¹⁶

AI enables wearable devices to work so effectively, allowing for the fine-detail monitoring of many individuals. Thanks to its pattern analysis, anomaly



Fig 2 | Wearable health technologies to make people healthier⁵

detection, and prediction capabilities, health care transitions from one-off treatments to the continuous management of health and wellness. These abilities will increase the individualization of both training and recovery information, where AI is an absolute necessity in wearables with health care and sporting uses (see Figure 3).

Injury Prediction: State of the Art

When combined with wearable technology, AI enables the early detection of problems such as musculoskeletal strain, overtraining, or physiological imbalance before any injury symptoms are apparent in a person.¹⁷ Reliable measurement and analysis of various athlete data fed through devices help them and their trainers proactively prevent injuries. This method shifts from the traditional way of responding to health problems to one that focuses on prevention. To predict injuries with AI-enhanced wearables, algorithms are trained on historical data that includes injury information.¹⁸ They identify relationships between factors such as decreased heart rate variability, leg imbalances, drastic changes in exercise plans, or insufficient rest and a person's likelihood of sustaining an injury.

Decision trees, support vector machines, logistic regression, and, more frequently today, deep learning are all used to detect signals of impending injuries.¹⁹ For example, RNNs and long short-term memory (LSTM) models are best suited for looking at data that changes over time, such as signals from movement or heart rate. Research studies and real-world device applications have demonstrated the effectiveness of radar

technology. Experts in elite soccer have combined GPS data with AI models to determine that excessive stress and uneven activity patterns reveal an increased risk of soft tissue injuries.²⁰ Similarly, researchers have used wearable sensors and machine learning to identify collegiate runners at the most significant risk, leveraging their stride and cadence patterns for assistance. AI and wearable devices are being utilized in basketball to manage fatigue and balance, leading to lower levels of stress-related injuries (Table 2).

Although plant-based medications have yielded positive results, various challenges remain.²¹ A significant issue is that the system incorrectly identifies some athletes who are not at high risk. This situation often results in unnecessary training program changes, which can create problems or distrust between users and the company. Figure 4 discusses the AI-driven injury prediction pipeline, showing the relationship between sensor input (e.g., gait, HRV) and outcome variables (e.g., overuse injuries, recovery metrics).

Alternatively, missing the warning signs of injury can be very dangerous. These results typically depend on the data quality and the sensors' accuracy.²² Data accuracy can be affected when sensors are placed at different locations, have noisy signals, or change from device to device. Furthermore, most models are not widely applicable. AI models designed for one type of sport may not perform optimally for other sports or groups. The scarcity of large, varied, standardized data sets in sports and health conditions also exacerbates the issue. We must also pay attention to ethical matters.²³

Since injury prediction utilizes health data, questions arise about maintaining privacy, obtaining consent, and determining who owns the data. In addition, AI models based on deep learning, which are often difficult to understand, can make it challenging to explain and hold people accountable for their decisions.²⁴ Overall, AI technology in wearable devices significantly improves injury prediction, with increasing support from research in sports and the medical field. Still, problems related to technology, ethics, and suitability should be solved so that genetics can be used responsibly and fairly in medicine.²⁵ As more research and data become available, these tools should become more effective at predicting injuries, supporting athlete care, and managing various aspects of human performance.

Performance Optimization Through AI and Wearables

AI, working with wearables, has transformed how athletes and sports enthusiasts track and improve their abilities. Wearables regularly capture body function and exercise data, helping us to discover when we are tired, how much we have trained, and whether we are recovering.²⁶ AI provides a better understanding of data and enables a training program tailored to each person, allowing them to perform at their best and minimize the risk of injury. Many aspects of fatigue and load are measured by wearable devices using metrics such as heart rate, HRV, activity levels, muscle tension, and sleep quality.²⁷

Role of AI in Healthcare

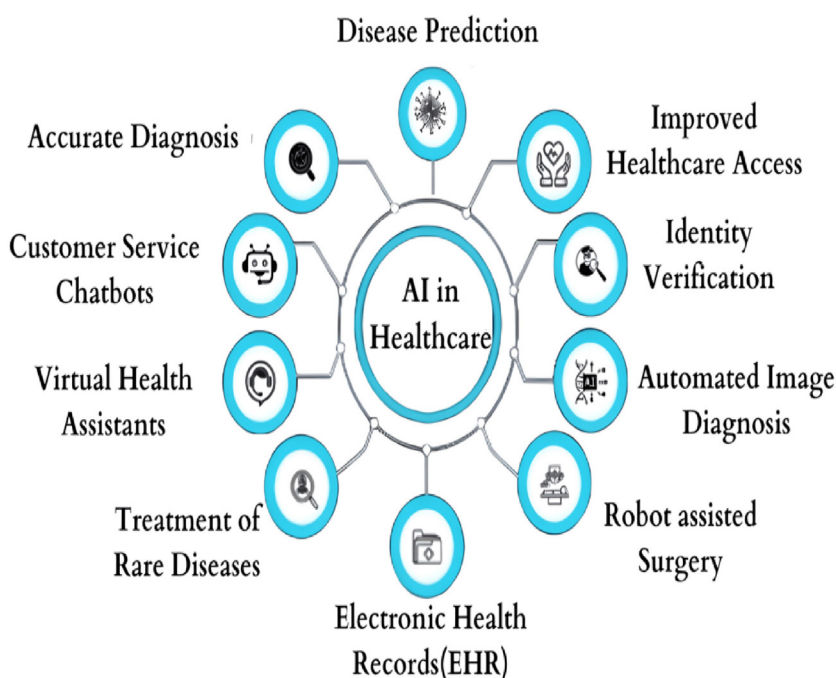
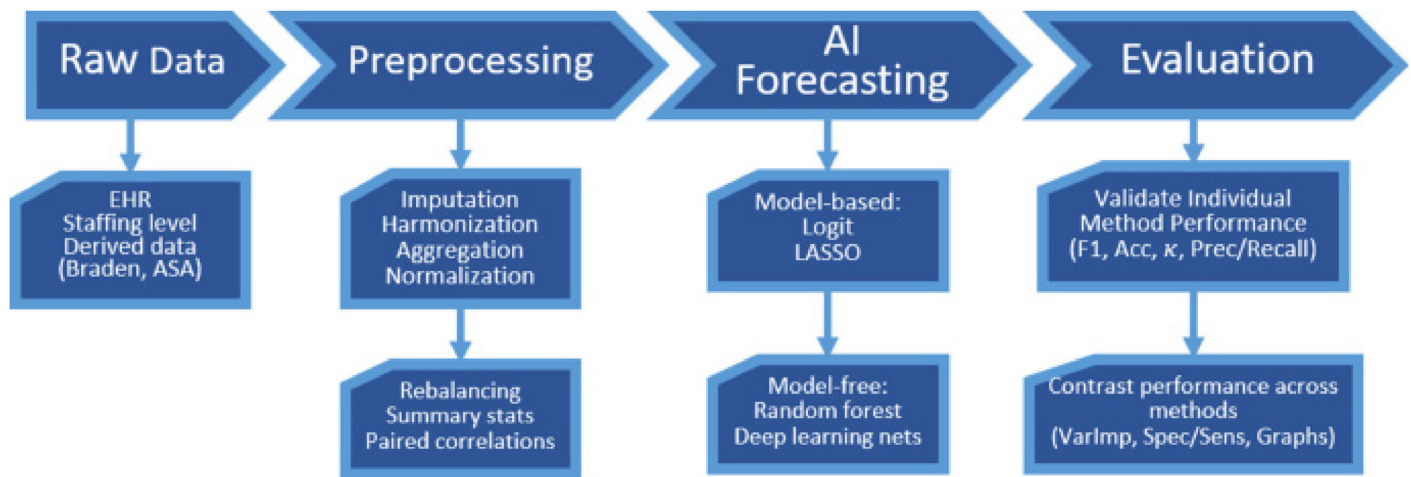


Fig 3 | A review of the role of AI in health care⁸

Table 2 | Comparative evidence table: AI + wearables for injury prediction

Study	Sport/Task	Sensor Stack	Model Type	Sample Size (n)	Accuracy/AUC	Validation Level
Shah et al. ¹ ▲	Soccer (elite)	GPS, HRV, accelerometer	Random forest, RNN	218 players	AUC = 0.87	RCT
Chidambaram et al. ² ■	Multisport (training load)	HRV, EMG, IMU	LSTM, decision trees	142 athletes	Accuracy = 84%	Cohort
Chen and Dai ³ ●	Running (collegiate)	Foot pod, gyroscope	CNN, logistic regression	67 runners	AUC = 0.76	Narrative synthesis
Musat et al. ¹² ■	Basketball (injury tracking)	GPS, HR, force plate	SVM, ANN	88 athletes	Accuracy = 81%	Observational study
Kovoor et al. ⁷ ■	Cycling (pro-amateur)	IMU, HRV, cadence	CNN + KNN hybrid	95 cyclists	AUC = 0.82	Cross-sectional
McDevitt et al. ¹⁰ ●	General biomechanics	EMG, motion capture	Ensemble (XGBoost)	45 subjects	AUC = 0.79	Narrative +
Expert opinion						
Seshadri et al. ¹³ ▲	Rugby/team sports	GPS, accelerometer, gyroscope	Deep neural network	203 athletes	AUC = 0.85	RCT
Yadav et al. ²³ ■	Track and field (rehab phase)	HRV, muscle oxygenation	Logistic regression	61 athletes	Accuracy = 78%	Cohort

**Fig 4 | Injury prediction analysis²¹**

Signs of fatigue are often evident in a person's physiology, such as a faster resting heart rate or lower heart rate variability, which suggests additional stress on the nervous system. Load monitoring quantifies both external and internal workloads by measuring distance, accelerations, and the athlete's responses to their effort and fitness.²⁸ To operationalize insights from wearables, Table 3 presents an evidence-graded decision matrix that links physiological thresholds to return-to-sports recommendations.

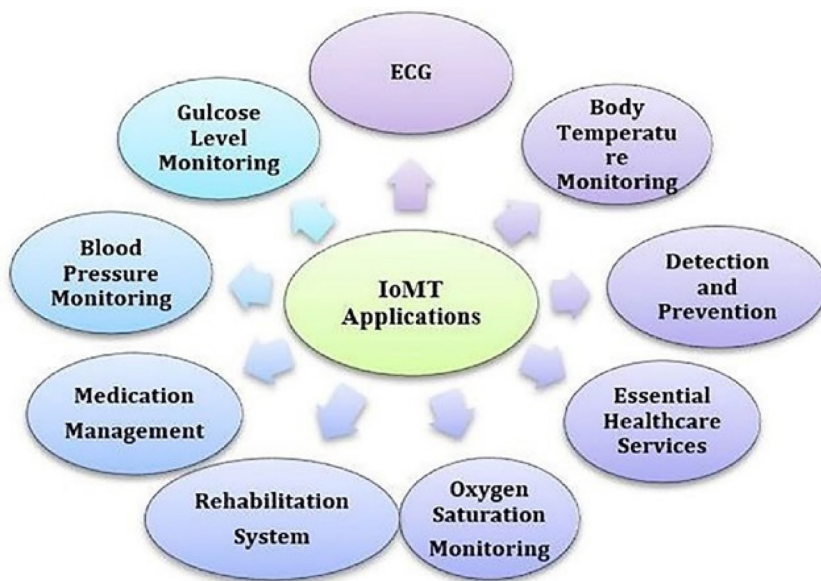
To check recovery status, we monitor sleep duration and quality, measure muscle oxygenation, and use biochemical markers whenever possible. Continuous data means we can monitor when an athlete is ready to train or perform rather than relying on outdated training plans. AI helps to make sense of raw data from wearables and turn those insights into something personal.²⁹ These training models utilize machine learning to determine the optimal workout intensity, exercise duration, and rest breaks tailored to an individual's needs. Figure 5 illustrates the integration of AI-enabled wearable devices within the health care internet of things (IoT) ecosystem, enabling feedback loops for injury prevention and rehabilitation.

By examining earlier performance data, predictive performance modeling provides coaches and athletes with information they can use to refine their strategies ahead of potential plateaus. As a result, reinforcement learning enhances training processes by regularly gathering progress details and feedback from the athlete, leading to highly effective training and less likely to cause overexertion.³⁰ AI and wearable technology are increasingly used in high-level sports today. AI models are used by professional soccer teams, equipped with GPS and accelerometers, to understand the amount of work players do during training and how it affects them in games, thereby helping prevent injuries and sustain peak performance.

Like skiing, cyclists' metrics and recovery are studied with AI, which enables tailored and optimized training strategies before key races.³¹ Recovery centers utilize this technology, as wearable devices monitor muscle and joint movements during exercises, and AI algorithms analyze the results, recommending adjustments to therapies for improved healing and restoration. As demonstrated by WHOOP bands used by top athletes, ongoing monitoring of strain, recovery, and sleep can inform daily exercise routine. The use of AI-supported

Table 3 | Evidence-graded matrix: linking load/biomarker indicators to training or return to sport (RTS) actions

Load/Biomarker Metric	Threshold/Cut-Off	Interpretation	Recommended Action	Evidence Grade
HRV	↓ >20% baseline (morning)	Parasympathetic fatigue	Reduce intensity; active recovery	■ Cohort Chidambaram et al. ²
Sleep Quality (WHOOP/Oura)	<75% efficiency/<6 h	Inadequate recovery	Delay RTS; monitor stress	● Narrative Chen and Dai ³
Acute: Chronic Workload Ratio	>1.5	Overload risk zone	Taper sessions; increase recovery days	▲ RCT Seshadri et al. ¹³
Muscle Oxygenation (SmO ₂)	<50% resting	Incomplete muscle recovery	Avoid eccentric loading	■ Observational Yadav ²³
Stride Variability/Gait Asymmetry	>10% deviation	Biomechanical instability	Focus on neuromuscular rehab	■ Cohort Musat et al. ¹²
Core Temperature or Skin Temp Deviation	>1.5°C from norm	Heat stress, risk of exertional illness	Halt high-load training	● Narrative McDevitt et al. ¹⁰

**Fig 5 | AI-enabled wearable medical IoT in health care system³⁵**

wearable technologies by NBA teams enables coaches to monitor players' movements and fatigue, allowing them to manage training and game-time schedules more efficiently.³² In clinical rehabilitation, AI is helping designers of wearables create personalized recovery plans tailored to patients who have undergone surgeries or injuries. Overall, utilizing wearables and AI for performance optimization shifts training and recovery decisions toward being scientifically supported and tailored to each individual.³³ Using live data and advanced analytics, players and trainers can enhance their performance and better manage their health in the future.

Limitations and Challenges

Although AI in wearables could improve injury prevention and performance, several significant problems remain and need to be addressed before these devices can be used effectively and ethically. A primary concern is upholding data security and ethics. People wear wearables that routinely gather health and behavioral details, raising questions about how data is stored, shared with others, and used.³⁴ Strong and clear rules

are necessary to handle informed consent, determine data ownership, and mitigate the risks of third parties, such as insurers or employers, misusing health data. Data must be kept safe and used correctly, an area of development that varies in its application across different parts of the world. A further issue is that wearable devices often fail to communicate with each other or adhere to unified standards.³⁵

The market comprises manufacturers that utilize their own sensors, algorithms, and data formats. As a result, it becomes difficult to combine data or produce AI solutions compatible with all platforms. A lack of universal procedures prevents substantial sharing of data and teamwork, which supports making the models more effective and practical for different problems.³⁶ When sensors are not evenly placed, not correctly calibrated, or when the data is of poor quality, AI results can be less dependable. Black-box AI models pose significant challenges that are crucial to address technically and ethically. As deep learning is often used in advanced AI, it becomes challenging for coaches, clinicians, and athletes to understand why some predictions are made with certainty.³⁷

Being unclear about data can weaken trust, make decisions more difficult, and lower accountability, mainly in cases where failing to predict injuries has a significant impact. Still, the field faces difficulties in the available literature and implementation. Most research on sports is based on only a few people or top athletes, so its results cannot be used for most people. In addition, bringing AI-wearable systems into real-life use often faces challenges related to user adoption, sensor durability, and the associated costs.³⁸ To achieve convincing results, research should be conducted over a long period, encompassing multiple sports and large groups. Addressing these problems will ensure that AI and wearables function properly in terms of proactive health and performance management.

Future Directions and Opportunities

Due to advancements in explainable AI (XAI), federated learning, and edge computing, the future applications of AI and wearable devices in both injury prediction and athletic performance enhancement seem very promising. XAI aims to make it possible to understand the reasons behind an AI prediction.³⁹

Thanks to increased transparency, athletes, coaches, and health care providers can trust each other more and make better, more accountable decisions. Instead of sharing data, federated learning allows remote AI models to train on data stored separately.⁴⁰ This makes it possible for researchers to collaborate and maintain proper user privacy. Performing data processing on wearable devices instead of cloud servers through edge computing helps reduce delays, improve the speed at which data is utilized, and enhance its security.

When combined with genomics and personalized medicine, AI-equipped wearables are a promising field.⁴¹ Using physiological measurements and genetic information, it is possible to design individualized treatments that suit an individual's risks of injury or ability to heal. This merging of ideas could transform how personal training, rehabilitation, and preventive health care are handled through precise data recommendations. While most attention is now focused on top athletes, there is still plenty of room for wearables to be useful in amateur sports, recreation, and public health.⁴² Other than the technical barriers, there are ethical and regulatory concerns when implementing in real life. Addressing the safety and ethics issues pertinent to the AI-wearable systems, this is summarized in Box 1.

With AI-equipped wearables, tracking health and physical movement is made easier, helping spot injury risks early and supporting better daily training. Sharing wearable device data with public health could enable experts to identify trends in the population, support prevention activities, and aid in chronic disease care.⁴³ Overall, improvements in AI understanding, privacy-focused methods, new developments in personal genetics, and broader adoption will drive the next significant wave of growth. Our research will help improve injury prevention and physical performance, and make high-quality health monitoring accessible to various groups.

Limitations

Although this review provides a valuable synthesis of existing evidence on the role of AI-enabled wearables in predicting injuries and optimizing performance, a number of limitations must be noted to put the findings into perspective.

First, narrative review studies cannot provide a high level of reproducibility and can be biased as the review

can be selective and even subjective. Though methods of inclusion and search were described in the Methods Appendix, there was no systematic review process (e.g., risk-of-bias score or meta-analysis), which might limit the applicability of the findings. The systematic framework using a PRISMA-type approach and quantitative synthesis may increase rigor and comparability in future studies.

Second, there is the problem of heterogeneity of data sources. The papers included in the review are based on several sports disciplines, population segments (elite or recreational athletes), types of sensors (HRV, GPS, EMG, inertial measurement unit [IMU]), and AI models (classic machine learning [ML], deep learning, and ensemble models). This variability enhances the scope of the review while restricting the possibility of generalizing some results or finding universally effective AI-wearable combinations. For example, a CNN learning specific gait patterns and trained on soccer could not be easily deployed to basketball or rehabilitation contexts. Uniformity in the location of sensors, file data types, and measuring standards would work wonders in the field.

Third, a limitation with a small-sample bias is relevant in most of the articles, particularly those with wearable prototypes or AI applications in trials. Research conducted on fewer than 50 participants is often acceptable, introducing problems of reduced statistical power and the likelihood of developing overfitting. Moreover, most datasets are often not demographically diverse (e.g., in terms of sex, age, and fitness level), and the predictions made by AI may be biased and exclude important groups.

Overall, although the review offers novel insights into a fast-moving research area, the limitations of the narrative synthesis approach, variations in data sets, and sample size prevent the application of such findings to wider populations. Future directions of scalable, standardized, inclusive AI-wearable research will be needed to turn such innovations into effective clinical and sports-related usage.

Conclusion

Particular cogitation is dedicated to how AI and wearable technologies reshape the way of predicting injuries, and how high performance is attained. A wearable device powered by AI technology allows individuals to track various parameters, detect possible injury risks,

Box 1 | Safety and ethics in AI-enabled wearables

Domain	Key Issues	Implications and Solutions
Data protection	Wearables collect sensitive biometric data under health privacy laws like GDPR (EU) and CCPA (California).	Systems must ensure informed consent, secure storage, encryption, and user control over data sharing.
Data ownership	Ambiguity exists over whether data belongs to the user, the device provider, or the institution.	Clear agreements and user-centric models (e.g., opt-in for data sharing) are essential for trust and fairness.
Explainability (XAI)	Many AI models (e.g., deep learning) are "black boxes," making explaining decisions like RTS clearance difficult.	Adopting XAI frameworks allows users and clinicians to understand and trust predictions.
Accountability	In injury or health incidents, unclear AI reasoning can hinder legal or medical accountability.	XAI, audit trails, and documentation of decision rationale are crucial in risk-prone applications.

and design training programs. Facial recognition and prediction have improved well with the help of machine learning. Conversely, the areas that still pose a significant challenge to the popularization of AI are data privacy, device interoperability, and the lack of knowledge regarding how AI functions. XAI, federated learning, and links to genomics will solve these problems and improve trust and personalization across all users. This type of technology has not spread to everyone so far, so the performance and preventive care may be enhanced for many people. Overall, the integration of AI and wearables is creating personalized health prevention, which already has the potential to contribute to sports science and health care.

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