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AI-Driven Insights in Exercise Physiology: Enhancing Training Optimization and Fatigue Management for Athletes

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Abstract

Background: Artificial intelligence (AI) has become a transformative tool in optimizing athletic training and managing fatigue. AI-driven models enable precise analysis of physiological responses, predictive fatigue monitoring, and personalized training programs tailored to individual athletes.

Methods: This review literature examined recent studies on AI applications in exercise physiology and fatigue management using databases such as PubMed, Web of Science, Google Scholar and Elicit. The selected studies implemented AI methodologies, analyzing 50 papers and extracting 60 key data points to assess training optimization effectiveness.

Results: Findings indicate that AI models effectively process complex physiological data in real time, provide instant feedback on training intensity, and adjust workout plans to individual capabilities. Studies demonstrated AI-driven training approaches improving endurance, reducing perceived exertion, and refining biomechanical assessments. Additionally, reinforcement learning-based virtual coaching yielded training outcomes comparable to or better than human-designed plans. AI systems also enhanced fatigue prediction, offering optimized recovery strategies to prevent overtraining.

Conclusion: AI-based solutions play a crucial role in enhancing athletic performance, offering personalized and adaptive training while effectively managing fatigue and stress. The increasing integration of AI into exercise physiology underscores its potential to revolutionize sports training by refining performance metrics, minimizing injury risks, and maximizing efficiency across different disciplines.

Key Words: Artificial intelligence, Athletes, Exercise physiology, Fatigue, training optimization

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Introduction
The integration of artificial intelligence (AI) in exercise physiology has revolutionized how athletes train, recover, and optimize performance (1, 2, 3). AI-driven models have enabled precise analysis of physiological responses, predictive fatigue monitoring, and adaptive training programs tailored to individual athletes (1, 4, 5, 6). Unlike traditional coaching methods, AI algorithms leverage machine learning, deep neural networks, and reinforcement learning to provide real-time feedback, refine training intensity, and enhance injury prevention strategies (2, 3, 5, 6, 7). This article explores the growing role of AI in sports performance optimization, highlighting studies that demonstrate AI's ability to monitor exertion levels, regulate fatigue, and improve athletic efficiency. By reviewing various AI applications—from artificial neural networks (ANNs) predicting exertion in Australian football (7) to AI-based virtual coaching for cyclists (3)—the paper examines how AI refines biomechanical analysis and physiological adaptation in sports (1, 8, 9). As AI continues to evolve, its potential impact on athlete health, recovery, and long-term performance grows exponentially. The findings presented here offer insights into the future of AI-driven sports training emphasizing its ability to personalize regimens, optimize recovery, and enhance athletic endurance across various disciplines.

Methodology

The methodology involved a review literature search across reputable databases, including PubMed, Web of Science, Google Scholar, and Elicit to identify scientific publications on artificial intelligence (AI) in exercise physiology and fatigue. Keywords such as "Artificial intelligence", " Athletes", " Exercise physiology ", " Fatigue ", and " Training optimization " were used to locate relevant studies published between 2010 and 2025, focusing on randomized controlled trials, clinical trials and review. A total of 50 relevant papers were identified through a systematic search process, after which 10 papers were selected based on specific criteria, including human participants, AI/ML implementation, relevant outcomes, data analysis methodology, study design, and population health status. From these selected studies, 60 key data points were extracted, covering aspects such as study design type, AI methodology and approach, participant characteristics, physical activity context, primary outcome measures, and AI performance metrics. These extracted elements provided a structured framework for evaluating the role of AI in optimizing athletic training and fatigue management, ensuring a comprehensive analysis of its applications and effectiveness.

Data Extraction
In this study, we utilized a large language model for structured data extraction from selected papers, adhering to predefined criteria. We began by identifying the *Study Design*, focusing on both primary and secondary design features as outlined in the methods section of each paper. Next, we systematically extracted information regarding the *AI Methodology*, including the types of neural networks, classifiers, and data processing techniques employed. We also retrieved *Participant Characteristics*, documenting the total number of participants, their demographics, and group classifications, ensuring that all relevant ranges were captured. The *Physical Activity Context* was assessed by identifying the type, duration, and intensity of the exercises studied, as detailed in the methods and results sections. Additionally, we gathered *Outcome*

Measures, which included physiological signals, performance metrics, and stress indicators, along with their respective measurement techniques and units. Finally, we prioritized the extraction of *AI Performance Metrics*, focusing on accuracy percentages, comparisons with alternative methods, and relevant statistical performance indicators from the results section.

Results

The characteristics of the included studies are summarized in Table 1, which outlines the study design, sport type, AI technology used, primary outcomes, and availability of full-text retrieval. The studies investigated a diverse range of athletic activities, spanning running, high-intensity exercise, weight training, team sports, law enforcement training, military training, and general physical activities.

Various AI methodologies were employed, including Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, Random Forest, Gradient Boosting Machines, Rough Set Theory, Recurrent Neural Networks (RNN), Deep Neural Networks, and reinforcement learning. These approaches facilitated real-time physiological monitoring, predictive analytics for fatigue and exertion, training optimization, and adaptive coaching strategies. The primary outcomes assessed across studies encompassed rating of perceived exertion (RPE), heart rate variability (HRV), stamina prediction, physiological strain indices, stress recovery metrics, movement velocities, training load distribution, and form correction. Among the ten studies, six provided full-text access, ensuring comprehensive insights into AI-driven training enhancements, while the remaining four studies were only accessible via abstracts. The findings collectively demonstrate the growing role of AI in exercise physiology, highlighting its ability to personalize training regimens, optimize athletic performance, and support fatigue and stress management in diverse sports disciplines. The table 2 summarizes the findings of different studies on AI applications in athletic training, categorizing them by study type, AI model used, performance impact, stress/fatigue reduction, and adaptation benefits.

Table 1. Characteristics of Included Studies

Study	Type Design	Sport Type	AI Technology Used	Primary Outcomes	Full text retrieved
Bartlett et al., 2017 [7]	Computational modeling study; Observational study	Australian football	Artificial Neural Network (ANN)	Rating Perceived Exertion (RPE), Session duration, Session distance, High-speed running distance	Yes
Biró et al., 2023 [5]	Computational/AI modeling study with experimental elements	Running	Random Forest, Gradient Boosting Machines, Long Short-Term Memory (LSTM) networks	Fatigue levels, stamina prediction	Yes
Buller et al., 2018 [8]	Computational/AI modeling study;	Military, training, sports	No mention found	Core temperature, adaptive physiological strain index	No
George et al., 2022 [9]	Observational study with computational/AI modeling characteristics	Law enforcement training	Aquila convolution neural network (AQCNN)	Heart Rate Variability (HRV), Electro Dermal Activity (EDA), Heart Rate Recovery (HRR)	No
Huang, 2021 [4]	Computational/AI modeling study, Experimental elements	General sport training	No mention found	Heart Rate Variability (HRV), psychological stress	No
Lewis and Bihn, 2017 [10]	Computational/AI modeling study (with experimental elements)	High-intensity exercise	Rough Set Theory	Maximal oxygen consumption (VO2max), heart beats per minute (bpm), watts of energy, peak power output (Ppeak)	No
Nilsson et al., 2023 [6]	Experimental study with computational/AI modeling elements	Running	Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM)	Speed at lactate threshold, VO2max, ratings of perceived exertion, readiness score	Yes
Novatchkov and Baca, 2013 [1]	Computational/AI modeling study (with observational elements)	Weight training	Artificial neural networks	Force determinants, displacement, time periods, movement velocities	No

Study	Type Design	Sport Type	AI Technology Used	Primary Outcomes	Full text retrieved
Omarov et al., 2023 [(2)]	Computational/AI modeling study	General physical activities (pull-ups, push-ups, squats, biceps, neck workout)	Convolutional Neural Network (CNN), Deep Neural Network	Real-time feedback on form, posture, and range of motion	Yes
Silacci et al., 2020 [(3)]	Case study; Computational/AI modeling study	Road cycling	Reinforcement learning-based virtual coach	Training Stress Score (TSS), Training Stress Balance (TSB), session distribution, training load, resting time quantity and distribution, efficiency	Yes

Table 2. Implementation Effectiveness

Study	**AI Application**	**Performance Impact**	**Stress/Fatigue Reduction**	**Adaptation Benefits**
Bartlett et al., 2017 [7]	ANN for RPE prediction	Improved accuracy in estimating internal load	Potential for better fatigue management	Individualized load monitoring
Biró et al., 2023 [5]	ML models for fatigue/ stamina prediction	High predictive accuracy for fatigue and stamina	Real-time fatigue monitoring	Personalized training adjustments
Buller et al., 2018 [8]	Computational techniques for thermal-work strain monitoring	No mention found	Potential for better heat stress management	Optimization of work-rest schedules
George et al., 2022 [9]	AQCNN for stress prediction	95.12% accuracy in stress prediction	Improved stress monitoring	Potential for stress-based training adjustments
Huang, 2021 [4]	AI-based mental health prediction	Good performance in predicting mental health	Potential for psychological stress reduction	No mention found
Lewis and Bihn, 2017 [10]	Rough Set Theory for performance limit prediction	Effective in predicting performance limits	No mention found	Potential for optimized training intensity
Nilsson et al., 2023 [6]	AI-driven adaptive training program	Improved speed at lactate threshold	Decreased ratings of perceived exertion	Real-time training adjustments
Novatchkov and Baca, 2013 [1]	AI for weight training analysis	Good performance in analyzing training data	No mention found	Potential for technique improvement
Omarov et al., 2023 [2]	Deep learning for physical activity monitoring	Superior performance in activity analysis	No mention found	Real-time feedback on form and technique
Silacci et al., 2020 [3] (10)(2)	AI-based virtual coach	Equal or better performance than control plans	Improved resting time management	Optimized training load distribution

Discussion

In this study, we employed thematic analysis to investigate the role of artificial intelligence (AI) in optimizing athletic training. We categorized the relevant studies into three main themes.

The first category, AI-Based Monitoring and Analysis, emphasizes the application of AI models for real-time physiological monitoring and performance tracking. For instance, Bartlett et al. (2017) utilized artificial neural networks (ANNs) to predict ratings of perceived exertion (RPE) based on GPS training load variables in Australian football players (7). Biró et al. (2023) employed Random Forest, Gradient Boosting Machines, and LSTM networks to forecast fatigue and stamina levels in runners (7). George et al. (2022) applied an AQCNN model to analyze heart rate variability (HRV), electrodermal activity (EDA), and heart rate recovery (HRR) in law enforcement personnel (9). Additionally, Omarov et al. (2023) developed a deep learning model using convolutional neural networks (CNNs) to provide real-time feedback on form, posture, and range of motion during various physical activities (2). These studies highlighted various benefits, including high accuracy in predictions (Biró et al., 2023; George et al., 2023), improved performance metrics (Huang, 2021; Novatchkov & Baca, 2013), and effective prediction capabilities (Lewis & Bihn, 2017). Notably, Nilsson et al. (2023) and Omarov et al. (2023) reported superior performance outcomes, while Silacci et al. (2020) demonstrated that AI coaching could achieve equal or better performance compared to traditional methods. Additionally, the role of AI in stress and fatigue reduction was evident, with seven of the ten studies indicating potential or actual benefits. Key findings included real-time monitoring (Biró et al., 2023), improved stress management (George et al., 2023), decreased exertion levels (Nilsson et al., 2023), and overall enhanced management strategies (Silacci et al., 2020). Collectively, this methodology showcases several key capabilities in processing and interpreting complex, multivariate physiological and biomechanical data in real-time, allowing for immediate feedback on athletes' physiological states. Consequently, trainers can make on-the-fly adjustments to training intensity or duration as needed. Furthermore, the analysis extends to biomechanical factors, offering potential benefits in injury prevention and optimization of athletic techniques. Collectively, these advancements enhance the responsiveness and effectiveness of training programs.

The second theme, *Training Optimization and Adaptation*, examines AI-driven methodologies that enhance individual training programs through adaptive learning techniques. The studies reviewed in this article collectively underscore the transformative potential of artificial intelligence in athletic training. Nilsson et al. (2023) demonstrated that an AI-driven adaptive training program outperformed a static regimen for runners, utilizing recurrent neural networks (RNNs) and long short-term memory (LSTM) networks to tailor training effectively. This finding emphasizes the advantages of adaptive training in enhancing athletic performance (6). Similarly, Silacci et al. (2020) evaluated an AI-based virtual coach for road cyclists and found that the AI-generated training plans were at least as effective as those created by human coaches, with significant differences observed in training load and resting time distribution. This highlights AI's promise in optimizing coaching strategies (3). Additionally, Lewis and Bihn (2017) employed Rough Set Theory to predict performance limits in high-performance athletes, revealing insights into individual response patterns and suggesting that tailored training could maximize performance while minimizing the risk of overtraining (10). Collectively, these studies illustrate how AI methodologies can revolutionize training approaches, leading to enhanced performance outcomes and improved athlete well-being.

Finally, the third category, *Performance Enhancement Outcomes*, evaluates the impact of AI on improving athletic performance and mitigating fatigue levels. The findings from various studies underscore the significant advancements in using artificial intelligence for training optimization. Bartlett et al. (2017) demonstrated that individualized artificial neural networks (ANNs) outperformed traditional group models in predicting ratings of perceived exertion (RPE), leading to improved accuracy in estimating internal load and offering potential for more effective training load management, thereby reducing the risk of overtraining (7). Similarly, George et al. (2022) reported an impressive 95.12% accuracy of the AQCNN model in predicting stress from physiological signals, highlighting its potential implications for managing stress and fatigue in high-intensity training environments (9). Nilsson et al. (2023) found that an AI-driven adaptive training program resulted in improved speed at lactate threshold and decreased ratings of perceived exertion compared to a static training regimen, further emphasizing the benefits of adaptive training (6). Additionally, Novatchkov and Baca (2013) reported high classification rates of AI techniques in analyzing weight training data, suggesting potential improvements in technique, better load management, and enhanced strength gains (11). Collectively, these studies illustrate the transformative role of AI in optimizing training strategies and enhancing athlete performance.

The key findings of this article reveal that AI systems possess the capability to develop personalized training plans that adapt to athletes' evolving fitness levels and recovery requirements. These systems not only have the potential to match but may also surpass human expertise in specific areas of training design. Moreover, they demonstrate an ability to optimize athletic performance while effectively managing fatigue and stress, highlighting the promising role of AI in enhancing personalized training strategies and improving overall athlete well-being.

Limitation

Despite its valuable insights into AI-driven athletic training optimization, this article has several limitations. First, the study primarily relies on a literature review, which may introduce selection bias, as only a subset of existing studies were included. Additionally, the reliance on previously published data limits direct experimental validation of AI effectiveness in real-world athletic scenarios. Another limitation is the diversity of AI methodologies analyzed, which varies across studies, making direct comparisons of AI performance metrics challenging. Furthermore, the lack of standardized evaluation criteria across studies may affect the consistency of findings, as different researchers employed varied methods for assessing fatigue management and training efficiency. Finally, while AI applications are promising, the article does not explore ethical concerns, data privacy implications, or accessibility issues related to AI-driven sports training, which could influence real-world implementation. Addressing these limitations in future studies could enhance the applicability and reliability of AI-driven training optimization strategies.

Conflict of Interest

The author declares no conflict of interest regarding this study. No financial, institutional, or personal affiliations have influenced the research, analysis, or conclusions presented in this article. The study was conducted independently, ensuring objectivity and transparency in its methodology and findings.

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