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The Role of Artificial Intelligence in Improving Athletic Performance: A Systematic Review

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Abstract. *The aim of this systematic review was to evaluate the impact of the use of artificial intelligence on improving athletic performance. Articles were selected through searches in various electronic databases, with those included following pre-established eligibility criteria. A narrative synthesis was performed. The electronic search resulted in 2,300 articles at first. After checking the titles, abstracts, and exclusion of duplicates, 52 were selected for full reading. After that, 33 articles were excluded. 19 articles were included in this systematic review. The included articles assess both the influence of artificial intelligence on improving team sports performance and individual sports performance. Forty percent of the articles found were observational, with the remaining 60% represented by quasi-experimental articles, indicating that few scientific methods were employed when testing interventions in the samples presented. The results indicate that the use of artificial intelligence has been more frequent in the study of team sports, with few studies using both commercial technologies. Studies demonstrate that despite the increase in research waves and the emergence of artificial intelligence products, many are still poorly understood. Moreover, the lack of proper control patterns also makes the comparison of results difficult. However, given the advances and the numerous possibilities for use, it is important to continue investing in research on artificial intelligence to improve the effectiveness and performance of athletes.*

Keywords: *AI, Performance, Sports, Research*

1. INTRODUCTION

In recent years, artificial intelligence (AI) has been more frequently applied in sports and has received attention from sports sciences. Modern sports practice seeks to utilise all available tools to enhance performance. In the case of athletes, this translates to optimising training and competition results. Machines and AI are developed by people for specific purposes, including applications in sports. Experts and researchers develop AI tools by accumulating information on sports issues and the need to enhance the sports results of athletes (Nahavandi, Alizadehsani, Khosravi, Acharya, & Biomedicine, 2022). Athletes use AI as a training tool, while experts and researchers use AI in the development of physical and mental training programs. It has been proven that sport, by nature, does not tolerate uniformity. Hence, sports science is forced to carry on with its evolution by creating and modifying known theoretical postulates, methodology, practice, and technologies. AI's influence on the development of sports and its activity is undeniable. AI is becoming a part of every athlete's preparation process—preparation, maintenance, and competition at a certain level of sports—and can affect training and competition conditions, i.e., maintaining performance and performance levels during competition (C. Li & Cui, 2021). AI

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applications are flexible and easily adaptable in sports. They can be used in various sports disciplines that have different characteristics. The use of electronic devices in sports to record and monitor the physical and psychological conditions of an athlete dates back to the early seventies, and their usefulness has been recognised. However, in recent years, AI has been tested and taken up by researchers and technology experts in sports, and it has attracted the attention of researchers in sports science, along with coaches of training and performance. They have begun to develop and apply artificial intelligence tools in the training of athletes as well as in monitoring and tracking the physical and mental abilities of competing athletes (B. Li, Xu, & Sport, 2021). This development can be maintained by creating a link between AI tools or AI devices and athletes in order to help improve human athletic performance and enhance technical expertise(Anderson et al., 2023).

Definition And Scope Of Artificial Intelligence

The term artificial intelligence (AI) encompasses a collection of computer-based tools that are used in the practice of sports. These can be broken down by how they function, including but not limited to machine learning, neural networks, and algorithms. At their core, these technological advancements are able to acquire, store, and utilise information. Further, the term encompasses any machine-based intelligence (B. Li et al., 2021). For the purposes of this review, the role of AI in athletic performance and sporting management will be examined. More specifically, the commonality of AI analyses data, whether it be game data, athletic data, visual data, or informatics of any kind, and creates insights or patterns that are actionable within a sporting context. With access to computers that are more powerful than ever before, AI has the potential to change the way and the level at which sport is performed (Mishra, Habal, Garcia, & Garcia, 2024). Research that has begun to tap the extensive potential of this technology focuses on applications in tracking players within the games, video observational processes, and athlete and staff performance in training and ethnographies of game performance and athlete and staff mental states (Mishra et al., 2024) .

Additionally, AI has the potential to bring new aspects of sports science, but it underpins the bounds of sports sciences with aspects of complementary fields in psychology and physiology. These additional tools will allow us to begin to question more critically what occurs in and around sports. At its core, artificial intelligence relies on two processes: input and recognition. The input refers to a computer system's ability to bring data into memory (Ramkumar et al., 2022). From a practical perspective, AI can import vast amounts of data. Recognition is the ability of the computer system to develop value from such data.

Importantly, the intelligence required for the system to act on that valuable data comes from across the senses. The input data, vision, and auditory information are used to develop an empathetic feel for the sport and/or performers. As such, the system will invoke all synchronously or asynchronously. The recognition system within the AI unit utilizes an empathetic system where competing emotional expressions are referred to as a neural network, without a dead end but as an iterative system (Xu et al., 2023).

Historical Development Of Ai In Sports

INTRODUCTION Beginning with rock smashing and animal hunting tools, relevant technologies have influenced sports performance throughout history. More recently, as a consequence of ever-increasing computing power and data processing possibilities, AI has started to play a profound role in this sector as well. From simple repetitive algorithms to advanced systems, AI in sports is already an established and promising investment (Tuyls et al., 2021).

Historical Development Of Ai In Sports :

In 1938, the 'Functional massage technique' of János Reiter was an early type of sports technology with objective, structured, scientific characteristics. In 1967, the Cybex Trainer was the predecessor of today's exhaustive and versatile evaluation machines. In 1983, the 'Cybernet sports robot' was introduced; in 2009, RoboCup featured intelligent robotic soccer-playing machines. A timeline of AI in sports provides a closer look at the developments by year. Three key breakthroughs entail increments on different levels in AI: Data Analysis, Computing Power, and Advances in AI techniques (Shah, Dixit, Shah, Shah, & Shah, 2020).

More recently, AI has been leveraged in many major traditional sports. A study outlined the development phases in AI investment of the 20 major European football teams from 2012 to 2016. Five Premier League teams host some of the fifteen top soccer player selections by AI. Additionally, two La Liga, four Bundesliga, two Ligue 1, and one Russian Premier League franchises utilise their analytics vendor and AI to sign potential players. Lastly, in 2016, the NBA's Dallas Mavericks sought to create a 'rookie forecasting model,' which utilises predictive metrics to show the chance of a new player making the NBA based on their skills without changes when considering environment and conditions. However, studies that provide an overview of the latest up-to-date research on the extensive usage of AI in sports are still few. This review seeks to fill that knowledge gap (Mishra et al., 2024) .

2. KEY TECHNOLOGIES AND TECHNIQUES IN AI FOR ATHLETIC PERFORMANCE IMPROVEMENT

Machine learning and deep learning are essential techniques in AI, which enable computers to predict outcomes when given raw data. This is facilitated by modelling the associations between input data, such as sleep patterns, nutritional records, or biomechanical markers, and the desired output data, such as injury risk, optimal performance, or the risk of overtraining (Chmait, Westerbeek, & living, 2021). The outcome of the model can be used to inform new strategies and adjust goals. This detection and action phase is known as the prescriptive and preventative approach. The role of algorithms is to process the various forms of athletic data, including biomechanics, psychology, physiology, and performance (Janiesch, Zschech, & Heinrich, 2021). In terms of athletic feedback, computer vision has been the primary technique used. Computer vision uses algorithms to interpret data from digital images and solve a wide range of athletic problems, from technical to tactical. In terms of biokinetics and biomechanics analysis, the computer vision system visually tracks individual joint movements within strength and conditioning exercises, as well as other musculoskeletal movements, to allow an understanding of posture and movement patterns. Such computer systems have been used primarily to help improve technique and optimise athletic movement. To enhance performance and reduce the chance of injury, accurate posture and technique feedback can be provided to the athlete. Indeed, the successful integration of computer vision, sports science, biomechanics, and machine learning has been shown to improve individual biomechanical techniques in real time. Such a comprehensive understanding identifies the machine learning aspects that have been integrated and their usability in an athletic setting. In essence, these technologies are useful for guiding an individual, as well as a coach, through strength and conditioning methodologies to improve the athlete (Janiesch et al., 2021).

3. MACHINE LEARNING AND DEEP LEARNING

Machine learning and deep learning are fields of artificial intelligence, both of which have been used for athletic training. They utilize deterministic and stochastic information, derive meaningful measurements, and learn models that can be used to predict future measurement results for any new measurements (Sampaio, Oliveira, Marinho, Neiva, & Morais, 2024). Trained with large amounts of data, these algorithms learn to recognize patterns and predict future outcomes. For example, machine learning algorithms could be applied to analyse biomechanical, physiological, psychological, and performance data

captured before and/or during the performance to determine efforts that might lead to injury and improve protocols to minimise the injury risk (Şimşek & Kesilmiş, 2022). An athlete's current ability and the differences or similarities of each skill to the population can be used to alert the coach or athlete of the probability of the most recent skill change (Janiesch et al., 2021). These technologies can assist athletes in various sports in developing skills for competition. They generate tailored training and gameplay schedules that predict an athlete's outcome using previously learned opponent strategies when nonlinear relationships exist within data (Bharti et al., 2021).

knowledge discovery from large databases. They can generate more accurate and specific results when more data are learned. These algorithms can also be implemented in sports for other purposes. For instance, machine learning algorithms learn against the specific parameters chosen about players to predict future outcomes. An opposing coach could use varying machine learning algorithms to provide or not provide anticipated outcomes for an opponent before a game to their players. Moreover, scenarios can be developed to provide a range of anticipated game outcomes based on a range of possible strategies. However, challenges exist when implementing any artificial intelligence system into the sports environment. These technologies only work when implementation and measurement data have meaningful content. There is also a potential higher or lower risk of decision bias depending on how many measurements an algorithm has learned when predicting future outcomes. Finally, if data are real-time, they can be used in practice or games to give real-time feedback on relationships in strategies and influence decisions made in practice or in games (Bunker & Susnjak, 2022).

Computer Vision and Biomechanics Analysis

Biomechanics analysis has been applied to athletes in general and martial artists in particular to gain an understanding of their movements and capabilities. The use of computer vision to collect human performance data has increased in recent years. Computer vision is used in monitoring special techniques by pinpointing specific points of the body to provide closer analysis (Bhuiyan & Wree, 2023). Not only does it provide closer analysis, but computer vision is also useful in pointing out athletes' weaknesses in order to develop a specific technique to take advantage of them. Additionally, if multiple techniques are performed with unique signatures, it can assist in the classification of movements based on biomechanics. This will directly contribute to the scoring of combative sports. Visual data collection and analysis will also impact the use of personal protective equipment for athletes, as well as performance for athletes requiring a large range of motion. By improving the

athletic techniques of injured soldiers, rehabilitation times will be drastically reduced. Better and safer use of sports protective gear will ensure fewer injuries occur (Dhanya et al., 2022).

By visualising biomechanical differences, it was proposed that responding to various feedback loops, such as control loops, would improve athletes' technique in real time. For example, training loops aim to develop a specific technique if a competitor has a biomechanical weakness that is discovered. Control, guiding, and closure loops often use similar approaches in coaching; however, they can focus on improving tactics. Currently, wearable cameras and sensors are the most common methods of collecting biomechanical movement data in sports (Vancini, Andrade, De Lira, & Russomano, 2023). The images and sensors need to be processed and analysed in order to produce meaningful insights. The most up-to-date method to process biomechanical movement data is utilising artificial intelligence in conjunction with computer vision. Integration of computer vision with AI provides actionable information for training and injury diagnosis. Computer vision is crucial for accurately assessing human movement data, as AI results can be complex to interpret. Moreover, there are numerous benefits in visualising the information for the athlete, whereby results and improvements can be directly conveyed. This allows for data co-creation between coaches and athletes. Co-creation of an AI system for performance outcomes and feedback will be superior in terms of speed and volume of data (Warmenhoven, 2024).

Applications Of Ai In Different Aspects Of Athletic Performance Enhancement

The use of artificial intelligence (AI) in the world of sports science and professional team sports is on the rise. Over the past few years, a set of scientific studies has shown an increasing trend in employing AI for the primary goal of athletic performance enhancement. However, the nature of these studies is skewed primarily towards specific applications of AI in professional European football. As AI has the potential to be used in any sport other than football, it is pivotal for all coaches with performance enhancement goals to be informed about state-of-the-art athletic enhancement via AI, irrespective of the sport or region (B. Li et al., 2021). The role of AI in athletic performance can be segregated into various subcategories, namely: • Training and skill development, • Game analysis and team strategy, • Athlete analysis and tracking, • Injury prevention and rehabilitation. Different applications of AI in the above-mentioned categories have been illustrated for different sports and are more deeply discussed in the following sections. AI in team sports and athletics: • Training and skill development • Training load • Individualized and adapted training • Precision measurement of skills • Game analysis and team strategy • Performance

analysis • Team strategy • Athlete analysis and tracking • Athlete tracking • Fitness assessment • Injury prevention and rehabilitation • Injury prediction • Injury prevention and physical rehabilitation • Applications of AI in performance enhancement are illustrated in different sports science aspects (Dindorf, Bartaguiz, Gassmann, Fröhlich, & Health, 2022).

Training And Skill Development

Artificial Intelligence (AI) has a long-standing contribution to trainers and athletes in the realm of sports. Among many visions for humans utilising AI capabilities, the role of AI in training and development is to let trainers focus on the core attributes and specificities of a training plan, such as load quantification. AI-driven methods, especially neural networks, have been successfully applied to predict the effects of training and reach a balance between preventing injuries while enhancing the training load and improving athletes' performance. AI can be used to design training plans and personalise them based on the individual athlete's strengths and weaknesses in a team. For example, a coach can obtain suggestions on drills designed by AI for an athlete's technical weaknesses (Goriparthi, 2024). AI can be used to track the progress of athletes based on historical data in two ways. Firstly, accurate predictions of athletes' progress can be made to adapt to the athlete's training program. Secondly, tailored feedback can be given to an athlete compared to others in a group. Subsequently, training plans can be adapted in real time. Athletes can view their progress and plans on a platform where no manual intervention is required, and they can also receive push notifications on their smartphones (Goriparthi, 2024).

By capturing a detailed picture of an athlete's athletic abilities, AI aims to personalise the training program by utilising data analytics based on individual training sessions through personal digital scorecards and preventing injury by suggesting off-time periods. The trainer, even on a broad schedule for sports or corporate team training, should provide more individual feedback to develop specific techniques and game strategies in competitive sports (Boppiniti & Engineering, 2022). The techniques provided can also be used for video analysis-based training. AI software for athletes should be able to provide a detailed analysis of the specific abilities of an athlete and relevant recommendations for training. AI can be used to design a matrix for the evaluation of goalkeepers. It can also provide team play and positioning tips or advice based on how well the defence aligns with the goalkeeper. It can also simulate match or training session scenarios based on current fuel status and tactical strategies. AI should be able to train according to the strengths and weaknesses derived from the software for each individual player (Tapalova & Zhiyenbayeva, 2022) .

In order to prepare today's athletes, as the world changes, it is critical that coaches evolve their understanding of each generation. Research suggests we move from an extraction mindset to an empowerment mindset. Great teams use these questions to build cohesion, but they also occasionally use them to create better competition. An AI-driven training progression screenshot is incorporated by Gyro Performance. AI will become a value creator for business development and strategic decisions. By establishing an empowerment mindset, coaches can help athletes from different generations empower one another. Each generation possesses unique strengths that contribute to their own unique skill set (Asalomia et al., 2023).

4. INJURY PREVENTION AND REHABILITATION

AI technologies enable the risk of injury to be predicted using historical data. These predictive analytics can be further personalised by drawing on a wide range of data sources, including historical injury data, sports activity, and strain specifics, as well as psychological and medical data. By real-time monitoring, the AI algorithm learns about the individual athlete or patient's specific problems and possible injury risks and determines the most appropriate and individual rehabilitation processes. Moreover, AI can only exploit its possibilities in combination with modern medical imaging. Consequently, electroencephalography readings and magnetic resonance imaging measurements are further important data sources, lowering uncertainty for neural network analysis in athletic head injuries (Saravi et al., 2022). Moreover, AI can be used to develop suitable rehabilitation protocols by learning from historical as well as real-time data sources. The system identifies the cause of the irritation and suggests possible solutions to recover. Due to AI prediction and screening, sports scientists can fully inform coaches about possible risks and preventative measures to be taken. Furthermore, athlete data can be integrated to develop and tailor individual predictions for single or groups of athletes to provide an overall profile of the injury forecast. For pathology databases, individual patterns of injury can be identified for total patient groups (Jacob et al., 2021). Across various sports, rehabilitation with the help of AI has already shown positive effects, reducing recovery time and making data-informed decisions. In conclusion, AI technology has identified potential injury risks in individual athletes through data-informed decision-making. Thus, interdisciplinary research combining expertise from the fields of AI, medicine, and sports science may offer robust potential for application within athlete health prevention, particularly concerning

athlete injuries and ongoing careers (Guelmami, Fekih-Romdhane, Mechraoui, & Bragazzi, 2023).

Challenges And Limitations Of Ai In Sports

In the ethical responsibility subtheme, one of the most prominent points relates to the principle of fairness and the goal of identifying ways to manage the 'loopholes' within policy. Ethical issues are also manifested in terms of the challenge associated with integrating athletic and ethical values, given the multidimensional nature of sports objectives. The significant potential liability to athletes for serious injuries due to malfunction and the potential dangers and risks of AI and ML models are critical reflections in the merging of legal and medical issues in sports (Iverson, Williams, Gardner, & Terry, 2020). Decision-making in sports contexts is inherently complex, and this also applies to decisions made based on AI recommendations, requiring an understanding of the underpinning algorithms. In this subtheme, participants discussed the challenge of explaining AI technology to non-experts, particularly as experts may not have the ability to provide explanations. Potential technical and physical performance enhancements can further exacerbate inequality. As in the previous subtheme, potential model bias extends beyond athlete assessment to broader areas of assessment, such as factors contributing to injury, engagement metrics, and inclusion/exclusion criteria. There is some tension between achieving the refusal rate required for explainability regarding injury and the need to mitigate potential negative consequences of bias. These limitations must be considered if these tools are to establish themselves in key roles in sports (Venkatachalam & Ray, 2022).

Ethical Considerations And Fairness

Ethical considerations and fairness. Few studies have commenced the process of ethically evaluating emerging AI in sports technologies. However, considerations in the context of the fairness of algorithms have been identified as one of three key issues surrounding algorithmic regulation and sport. AI technologies rely on data-driven analysis that has the potential to identify and further historical or sociocultural biases. This could manifest in feedback, training regimes, programming, scouting, drafting, and match strategy and could also impact recruitment, player management, and even media and fan relations. The inclusion and consideration of diverse athletes is the responsibility of the athletes, organisations, and developers rather than the algorithms themselves. However, it is also recognised that historical data include many underrepresented and minority groups, and therefore, this is considered a systemic challenge that requires significant intervention (Mazurova, Standaert, Penttinen, & Tan, 2022).

There are also concerns over whether university teams or those with significant financial support to access and utilise AI technology will have a potential performance and physiological or biomechanical advantage over others. Regulating AI and ensuring a common standard of ethics to protect players and teams who cannot access emerging technologies is an additional responsibility placed upon those in the industry. Moreover, many of the algorithms and AI technologies currently being developed are considered proprietary or patented as they are developed by the private sector (Wamba-Taguimdje, Wamba, Kamdjoug, & Wanko, 2020). Consequently, they are protected and out of the public domain. This could open the door to organizations or individuals using these technologies and findings to gain a competitive edge in an unfair manner or to purposefully skew these tools toward certain methods that guarantee a competitive advantage in recruitment or inclusion. By misusing this technology or finding ways to outmaneuver clubs employing it in good faith, any potential benefits could diminish the integrity of sport and create unfair advantages for some (Olan et al., 2022).

5. DATA PRIVACY AND SECURITY

The nature and amount of data generated by the athlete and opponents are expanding with advanced sports technology, storing, processing, and conditioning attentively. Handling such sensitive information without standard measures is subject to many vulnerabilities and may compromise many elements of the game in a split moment. The benefits should not compromise the athlete's safety and security. Therefore, all stakeholders must take data protection regulations into account. Unauthorised access to data is very straightforward with the use of technology, after which the athlete and coach’s plans, performance, and condition can be hijacked by any opposition. The larger threat could be a nefarious attack by gambling or fraudulent individuals, which gives rise to inimitable threats. Third parties should be cautious in controlling and using athletes' data for their benefit, and preventive actions should be taken in advance (Luczak et al., 2020). There are also concerns about data ownership, privacy, and human rights. Data owned by the athlete could be processed by the sports organisation but could not be shared with third parties to avoid human rights issues. Prior to this, the athlete and sports organisation need to agree upon data sharing to avoid potential disasters in the near future. Even though extensive work is underway to standardise data security, no permanent solution exists to patch up vulnerabilities in data and technology (Martowicz et al., 2023). Therefore, confidentiality should be maintained by employing athlete data as per the regulations to avoid potential

hacker threats to individuals in a sports organisation. In response to these threats, ensuring data security at the organisation and encrypted data exchange between organisations may resist hackers. Even though major associations in sports have data protection regulations, they are still devastating in nature. More secure technology is needed for each authenticated access. Centralised data are attacked in such a way that the victim may pay a lot in the future for decisions made today, with a ponderous loss in all aspects (Torres-Ronda, Beanland, Whitehead, Sweeting, & Clubb, 2022).

6. CONCLUSION AND FUTURE DIRECTIONS

In the current systematic review, we have synthesised AI technologies and applications for improving athletic performance and quantifying sports-related movements. AI technologies hold the potential to transition the field of performance enhancement from prescriptive screens and standard exercise packages to quantifying and personalising performance enhancement strategies for individual athletes. The field of AI, specifically within machine learning, offers exciting potential for use in performance enhancement, and this review has charted the current landscape of machine learning technologies and algorithms. In doing so, we have identified future research directions, including an ever-increasing need for research to be conducted with sport and AI expertise in interdisciplinary collaboration.

The capability of AI to identify the underlying movement patterns in sports is an exciting future direction with respect to training adaptation and external workload measurement. These insights into training can be used to develop technology and methodologies with the potential to revolutionise current sports science practice and athletic preparation. As AI is relatively new within sports, there is no consensus on how ethical guidelines within sports science transfer, . and transform the future of technology in athletics and sports more broadly. We have identified both the potential and the perils, from improving individual performance, personalising medical treatment, and unravelling the rich mosaic of human performance to the nature of some models. AI in sports will continue to evolve; it is an exciting time to be part of this journey.

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