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EXPLORING THE USE OF ARTIFICIAL INTELLIGENCE IN MOTOR LEARNING IN TENNIS

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ABSTRACT. Sports have always been an important component of human culture due to the combination of neuro-psychic skills, strategic planning, and physical excellence. With the discovery and rapid development of artificial intelligence, its applicability in the sports domain is becoming increasingly evident, and its deep integration is an inevitable trend at this moment. In sports, artificial intelligence combined with data analysis highlights unparalleled opportunities regarding motor learning, outcome prediction, decision-making capabilities, and performance optimization. The integration of methodologies offered by artificial intelligence represents an innovative approach to enhancing athletic performance, which will continue to evolve as a foundation for the technology of sports science. The technique and tactics of tennis have reached a high level due to the evolution of sports equipment, and in response to this phenomenon, coaches have increasingly leveraged the physical training of athletes as it has developed. Following a review of the literature from recent years, we concluded that the data obtained through artificial intelligence provide specific details that can assist coaches and tennis players both in planning training and in the motor learning process. Furthermore, the results obtained through AI in sports analysis, especially for a fast and strategic sport like tennis, have effects on the level of optimization of athletic performance, which implicitly reflects on the competitive results of players. Therefore, this study aims to provide information to tennis coaches and players on how artificial intelligence can be utilized to facilitate motor learning with the objective of optimizing athletic performance. Additionally, we believe that the application of artificial intelligence in the training of tennis players offers specialists insights that can facilitate the adaptation of training methodologies to optimize the motor learning process. By utilizing this information in training, coaches can adapt training methods to meet the demands of modern tennis, thereby improving player outcomes. With technological advancement, the continuous exploration of the motor learning process through artificial intelligence is justified in the attempt to achieve significant or even major progress in optimizing athletic performance in tennis.

Keywords: motor learning, tennis, artificial intelligence

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INTRODUCTION

In the field of sports, the pursuit of improvement and excellence is ever-present. Athletes, coaches, and analysts are constantly seeking innovative methodologies to gain a competitive advantage.

Due to technological advancements in recent years, sports specialists have turned their attention to a variety of mobile electronic devices capable of recording and interpreting a wide range of parameters related to physical exertion (Stoicescu & Stănescu, 2015). Consequently, they have adopted new technologies to enhance game techniques as swiftly as possible. In this dynamic landscape of performance enhancement, the integration of artificial intelligence (AI) emerges as a transformative force, with prospects grounded in the data obtained.

As we know, artificial intelligence has significantly developed in recent years, transforming it into an important tool for optimizing athletic performance across most sports. The interest in all aspects of artificial intelligence has remarkably increased in recent years, and a substantial expansion in its diverse applications, particularly in sports, is anticipated.

Tennis is regarded as an elegant sport that has gradually spread worldwide. Due to the rapid advancements in information technology achieved in recent years, its applicability in the sports domain has become increasingly extensive. Thus, it can be asserted that, in tennis, this information technology plays an essential role. On one hand, it can transform the traditional training model into an innovative one, while on the other hand, it can provide coaches and athletes with significantly more effective training methods. The utilization of data analysis technology in the training of tennis players can furnish coaches with a comprehensive and relevant information base. By collecting, organizing, and analyzing data obtained during training sessions or official matches, the accuracy and efficiency of the training process can be amplified, thereby contributing to the optimization of athletic performance (Siqi Mi, 2025).

TOPIC ADDRESSED

The Impact of advanced technologies on sports performance analysis

Performance analysis in tennis pursues five primary objectives:

1. *Evaluation of tactics:* assessment of game strategies employed.
2. *Evaluation of technique*: analysis of the execution of specific movements in the game.

3. *Displacement analysis*: investigating the efficiency and economy of court movements.

4. *Database creation and modeling*: developing a data repository and predictive performance models.

5. *Provision of educational tools*: offering educational resources for both coaches and athletes (Bozděch, Puda & Grasgruber, 2024).

With the emergence and development of advanced technologies, such as Internet of Things (IoT) connectivity, a significant opportunity has arisen for extensive exploration of motor learning and sports performance analysis.

In recent years, technological advancements and their related applications have exerted a major influence on daily life, particularly within the sporting domain. According to statistics, at the beginning of 2020, over 7.7 billion people and 30 billion devices were interconnected within IoT networks worldwide. Furthermore, it has been demonstrated that by the end of the same year, the number of connected devices had reached 75.44 billion (Rui, 2023).

IoT is defined as "a global network of sensors, devices, and objects that can automatically detect and transmit data, enabling the monitoring, management, and processing of an environment, endowing it with intelligent behavior" (Rui, 2023).

Integration of technology in tennis motor learning

In contemporary tennis, a significant component of athletic mastery is represented by the rapid advancement of technological and scientific progress. Concurrently, there has been a proliferation in the accessibility of specific tennis equipment (Siqi Mi, 2025).

In the training of tennis players, the utilization of information systems, modern communication tools, and AI-based technologies increasingly influences motor learning and athletic performance. Consequently, these factors play a major role in the evolution of training methodologies and the application of efficiency principles specific to tennis. The optimal implementation of current training methodologies in tennis, considering their specific attributes, is a fundamental requirement for enhancing the effectiveness of training programs and optimizing athletic performance (Rui, 2023).

There exists a multitude of typologies of intelligent ecosystems designed for athletes, based on the IoT system. Each of these presents a distinct set of operational characteristics, as illustrated in the diagram below:

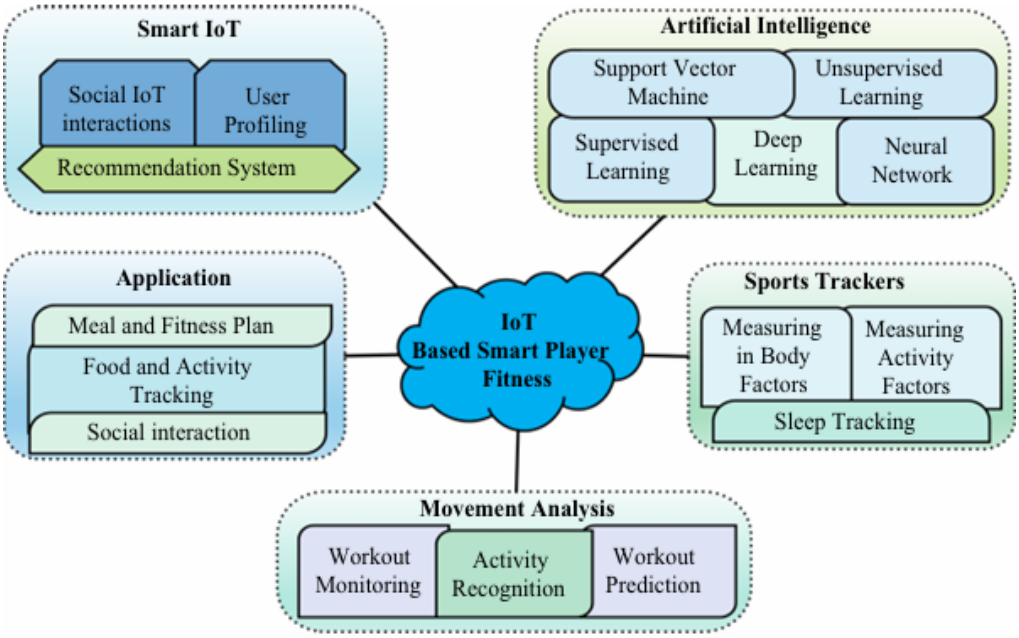

Figure 1. Taxonomies of Intelligent Ecosystems in Sports (Rui, 2023)

TRAINING FREQUENCY AND THE ROLE OF ARTIFICIAL INTELLIGENCE IN MOTOR LEARNING PROCESSES

It has been demonstrated that the frequency of training undertaken by a tennis player has a positive and significant influence on the acquisition of technical skills or proficiencies. Furthermore, the automated assessment of tennis strokes during training sessions plays a crucial role in optimizing athletic performance, preventing injuries, and facilitating rapid recovery post-exertion. To maximize the feedback provided by coaches, it is essential to utilize artificial intelligence. This technology aids in obtaining highly accurate data for evaluating players' technical skills, including stroke mechanics, by employing objective indicators to optimize athletic performance. The objective indicators focus on the following:

- Accuracy/precision of technical executions;
- Consistency/uniformity of performance;
- Execution speed/ball velocity (Bačić & Hume, 2018).

Recent studies have suggested that the development of a tennis training system utilizing artificial intelligence offers a range of high-precision data, which facilitates the creation of a personalized training program tailored to the specific characteristics of each player. Furthermore, the utilization of new AI technologies in technical training within tennis indicates a significant improvement compared to traditional technical preparation, by refining fundamental motor patterns that reduce the risk of injuries and establish a solid foundation for the development of tennis-specific skills and competencies. Additionally, the acquisition of specific motor skills is achieved more easily and rapidly through AI-assisted training systems. Moreover, both cognitive capacity development and the transfer of motor skills are facilitated with ease through virtual reality technologies. Virtual reality technology is particularly beneficial for players' mental fortitude and tactical approach to matches, as it provides athletes with clearer visualization and the practice of responses to various game situations without the physical strain and stress associated with current official matches (Liu et al., 2024).

Integration of New Technologies in Tennis

1. *Virtual Reality (VR) Technology* serves as a connection point between human beings and computers, distinguished by the following fundamental characteristics:

- Immersiveness
- Interactivity
- Conceptualization

Virtual Reality Technology is presented as an optimal integration of information technology, simulation technology, multimedia technology, artificial intelligence, microelectronics technology, detection technology (via sensors), and more. Additionally, VR can create an adaptable multidimensional informational space, with extremely vast application prospects, simulating human sensory functions (sight, hearing, touch). This capability allows for the engagement of an individual in a computer-generated virtual environment that interacts with them in real time through language, gestures, and other means. In tennis, the implementation of VR offers athletes a different approach to training, significantly enhancing the effectiveness of training sessions and the safety of players (Siqi Mi, 2025).

Researchers have found that in tennis, athletes can practice in scenario-specific contexts akin to official matches, even when these are facilitated by virtual reality. These virtual scenarios assist players in adopting varying levels of motor skills that can be utilized in competitions, thereby enhancing their

sports performance precisely during critical moments of the game, ultimately aiding them in securing victories. Another advantage of training within a virtual reality environment is that it provides a safe practice framework, significantly contributing to injury prevention (Liu et al., 2024).

According to Bodemer (2023), the VR environment offers a context where the repetition of tennis-specific exercises considerably reduces the physical strain experienced from conventional training methods.

2. The *wearable devices* operate based on sensors applied to the human body, smartwatches, or, in this case, sensors affixed to tennis rackets, which transmit information regarding bodily activity or the velocity imparted to the tennis ball to other electronic devices via a wireless network. The advantages of these devices include their compact size, extensive multifunctionality, and low energy consumption, among others. The utilization of smart sensors facilitates real-time monitoring of physical condition, measuring biomechanical parameters and functional movements of players. Consequently, coaches gain access to detailed and precise data aimed at optimizing training effects and, implicitly, competitive sports outcomes (Siqi Mi, 2025).

3. *Smart ball launchers* are robotic equipment with advanced programming capabilities for speed, spin, and direction. These devices can significantly influence motor learning in tennis and can be adapted to all levels of training. Moreover, smart launchers can also be employed in the tactical preparation of players due to their functions (direction, varying effects, and speed of the tennis ball).

4. *The machine learning* occurs through algorithms that process data from sensors worn by players during training. This significantly enhances the refinement of technical skills, including shot execution techniques and movement actions specific to the game of tennis. Automated learning provides coaches with the ability to improve players' techniques through personalized training programs aimed at optimizing tennis-specific technical skills (Perri et al., 2022).

In tennis, personalized learning plays a crucial role in acquiring and developing specific technical skills. Through individualized learning, athletes can exhibit enhanced capabilities regarding their understanding and refinement of specific motor skills, ultimately aimed at optimizing athletic performance (Koopman et al., 2020).

Additionally, experts suggest that another interpretation of personalized learning involves combining learning tasks with complementary, non-specific tennis activities, thereby facilitating the acquisition process of technical skills.

5. *Action Recognition Systems* can be realized through the integration of three distinct algorithmic modules:

- Posture recognition model (Open Pose-bm);
- Skeletal action recognition network (AA-GCN - Attention-Augmented Graph Convolutional Network);
- CTFC-GCN Structure (Channel Topology Feature Fusion Graph Convolutional Network).

An example of a comprehensive skeletal action recognition process through the integration of semantic information is explained and illustrated below (see Fig. 2).

1. *System Input*: The model receives an RGB video stream as input.
2. *Posture Estimation*: The Open Pose-bm algorithm is applied to perform human posture estimation; this step generates a lightweight JSON file containing the total number of frames and the 2D coordinates of 13 joint landmarks for each frame.
3. *Classification*: Based on a priori information, the connectivity relationship between joints (the skeletal graph) is constructed. The dataset is then divided into training-validation sets and input into the AA-GCN skeletal network for action recognition.

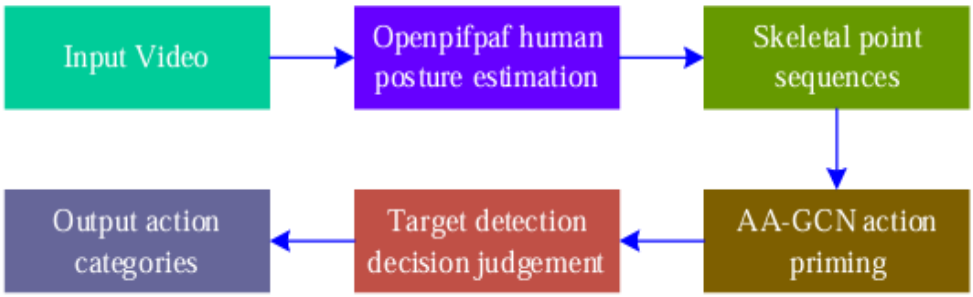

Figure 2. Human action recognition process (Siqi Mi, 2025)

In Figure 3, you will find a model for the detection and analysis of the biomechanics of specific actions in the game of tennis.

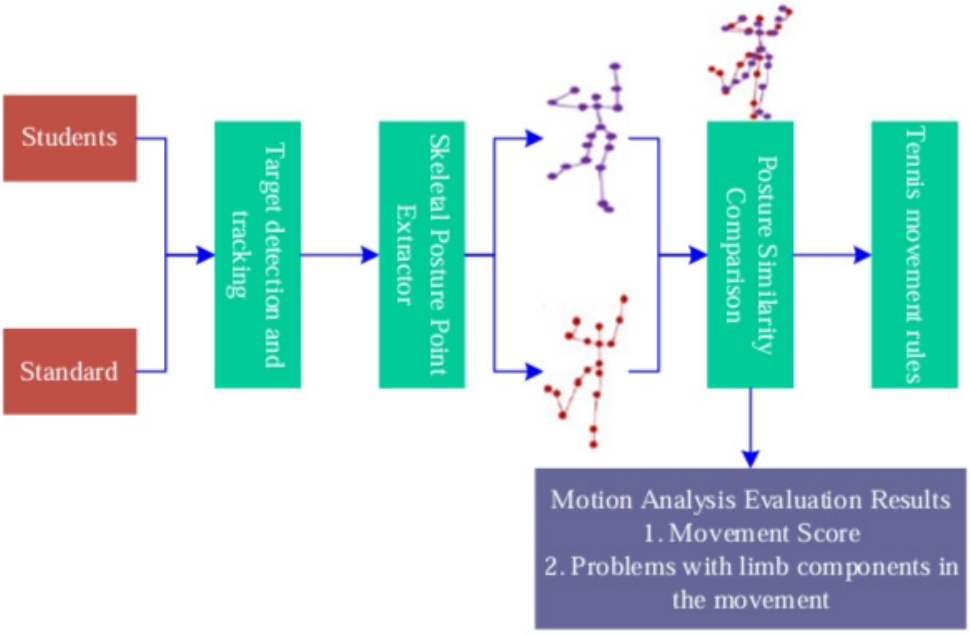

Figure 3. Overall design of tennis action recognition and analysis system

In tennis, sport-specific motor actions can be subjected to methodological analysis through two distinct paradigms:

1. - the motor gesture as a *continuous-time sequence*: specifically, the body joints execute a spatial displacement; consequently, the velocity data of these trajectory points provide a comprehensive description of the movement dynamics;

2. - the execution of a technical skill (e.g. the serve) as *a motor act*: defined by the force exerted at the radiocarpal joint (wrist) and subsequent postural transitions; in this framework, the recognition of the motion segment is achieved through the continuous assessment of body posture (Ruan & Zhang, 2022).

Researchers assert that these innovative technologies possess the capacity to facilitate specific and beneficial modifications within training regimens, grounded in measured performance and the identification of technical deficiencies throughout athletes' preparation sessions. They emphasize the need for athletic progress to be monitored with the intention of motivating players by highlighting improvements made over time.

Supporting this idea, Taghavi (2019) stated that sensors utilized in training, such as smartwatches, significantly contribute to the collection of data regarding technical skills, including the detection of tennis strokes, leading to a heightened level of performance.

Through the systematic acquisition, aggregation, and storage of performance indicators, coaches and athletes are afforded the opportunity to understand the level of play in real-time and can enhance specific technical skills to optimize athletic performance.

It is important to note that the accuracy of visual recognition algorithms largely depends on external conditions, such as lighting or game speed, and the integration of these technologies into the educational process of sports requires a well-defined methodological framework (Prăjescu & Abalașei, 2025).

CONCLUSION

The identification of technologies related to artificial intelligence underscores the dynamic and evolving nature of applications developed with its assistance, particularly in tennis. As the sport continues to progress alongside technological advancements, these analytical systems have the potential to provide even more data in the future.

Current research on sports performance analysis and optimization will continue to furnish tennis players and coaches with valuable insights based on concrete data, thereby aiding in the personalization and efficiency of training methods. Advancements in machine learning and neural networks will enhance the predictive capacity regarding athletic performance in tennis, facilitating more precise and effective training regimens. The utilization of computer vision and deep learning technologies will lead to innovative solutions for real-time monitoring and feedback, transforming traditional training approaches and methods of game analysis. Consequently, players and coaches will have the opportunity to access information during matches, which may optimize game strategy and performance.

However, the advantages offered by artificial intelligence come with certain inherent limitations. Training conducted solely through technology may reduce an athlete's self-regulation capacity and hinder the development of intuitive skills. Additionally, the high costs associated with these devices may restrict their usage.

Ongoing research into the relationship between artificial intelligence and motor learning in tennis will support interdisciplinary collaborations and the development of new learning systems for the sport. This will create new opportunities for research and innovation, contributing, to some extent, to the evolution of tennis and the history of sports.

AUTHOR CONTRIBUTIONS
The author has made a substantial, direct, and intellectual contribution to the work and approved it for publication.

CONFLICT OF INTEREST
The author declare no conflicts of interest.

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