BLOCKCHAIN TECHNOLOGY IN SPORTS: ENHANCING ATHLETE MENTAL AND COGNITIVE PERFORMANCE TRACKING

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Abstract. *Blockchain technology, initially developed for cryptocurrencies, has evolved into a versatile tool with applications across industries, including healthcare, finance, and now sports. This study investigates the role of blockchain in enhancing athlete performance tracking by integrating physical and cognitive metrics. Traditional methods often lack objectivity and security, while blockchain offers decentralised, tamper-proof, and real-time data tracking, addressing these challenges. The primary goal of this article is to explore how blockchain technology can enhance the tracking of athletes' mental and physical performance. The article aims to provide a comprehensive framework for understanding the integration of blockchain in sports, focusing on its potential to address current challenges in performance monitoring, improve data security and integrity, and enable more effective and personalized training and competition strategies. A systematic review of literature was conducted to examine blockchain's applications in sports. The analysis focused on its capabilities for performance tracking, data security, and integration with wearable technology. Metrics like strength, endurance, attention, decision-making, and cognitive fatigue were evaluated through blockchain-enabled systems. Blockchain enhances both physical and cognitive performance tracking by providing secure, real-time, and tamper-proof data. It facilitates personalised training programs by integrating metrics such as agility, focus, and decision-making. Wearable technology combined with blockchain enables continuous monitoring while safeguarding athlete privacy. The technology also ensures transparent record-keeping, useful for talent scouting and dispute resolution. Blockchain technology revolutionises athlete performance management by addressing traditional monitoring challenges. It offers a holistic approach to integrating physical and cognitive metrics, ensuring data security and enabling predictive insights for training and competition. However, issues like scalability, adoption resistance, and regulatory barriers need resolution for widespread implementation. Future studies should focus on the long-term impacts of blockchain on athlete development, scalability in sports organisations, and integration with emerging technologies like AI and IoT. Addressing regulatory and ethical challenges will be crucial for its adoption in the global sports industry.*

Keywords: blockchain, sports performance, cognitive tracking, data security, real-time monitoring, athlete management, wearable technology, decentralised ledger, privacy
JEL Classification: D91, H55, M14
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Introduction. Blockchain technology, initially developed to support cryptocurrency, has been clutching the transformation of healthcare, financial, and supply chain management industries. It is a decentralised, distributed digital ledger technology that makes cross-organizational record exchanges faster, more transparent, and secure without third-party mediators. This decentralisation reduces the risks associated with violations, frauds, and manipulations, offering users better security and trust in the data presented to them.

It works in the sport industry on managing cognitive and physical performance through real-time data to help athletes in adjusting and adapting for informed decision-making on their behalf. Blockchain technology is helpful in how an individual tracks the cognitive aspect of performance: attentiveness, choice-making, and coping-up with stress. While most traditional methods of performance monitoring fall well short of sufficiency or real effectiveness, blockchain technology revolutionises such truths by making the methods holistic in approach-assessing an entity's performance with an integrated physical and cognitive assessment.

Blockchain technology also guarantees better data in that once input in the system, it cannot be added to, deleted, or altered. This leads to a better comprehension of the shift in performances over time and the probable causes for changes. With more coaches coming up with smarter methods for using the performance data, blockchain does present an able path forward for the sports industry.

From being just a vehicle for cryptocurrencies, blockchain technology is transitioning into application in various industries, sure enough proof that the technology is revolutionary. In its quest to detect instantaneous results with higher precision, it becomes quite valuable in the way athletes and sports organisations work. Tracking of mental and physical performance will be refined with the application of Blockchain in the sports industry; therefore, the resultant features will improve to promote sports performance management.

Literature review. Blockchain is a distributed, distributed digital archive technology that enables trustworthy and transparent exchange of valuable information and data from one node to another across the distributed network of potential networks without any requirement of leadership (Nakamoto, 2008). This is through cryptographic methods that are used to protect the data this makes it almost impossible to adjust the data once it is recorded. Some of the characteristics of blockchain include decentralisation, which removes the need for middlemen; transparency which means all the members of the network harness equal information; and non-editable features that imply that once data has been recorded in a block, the information cannot be changed.
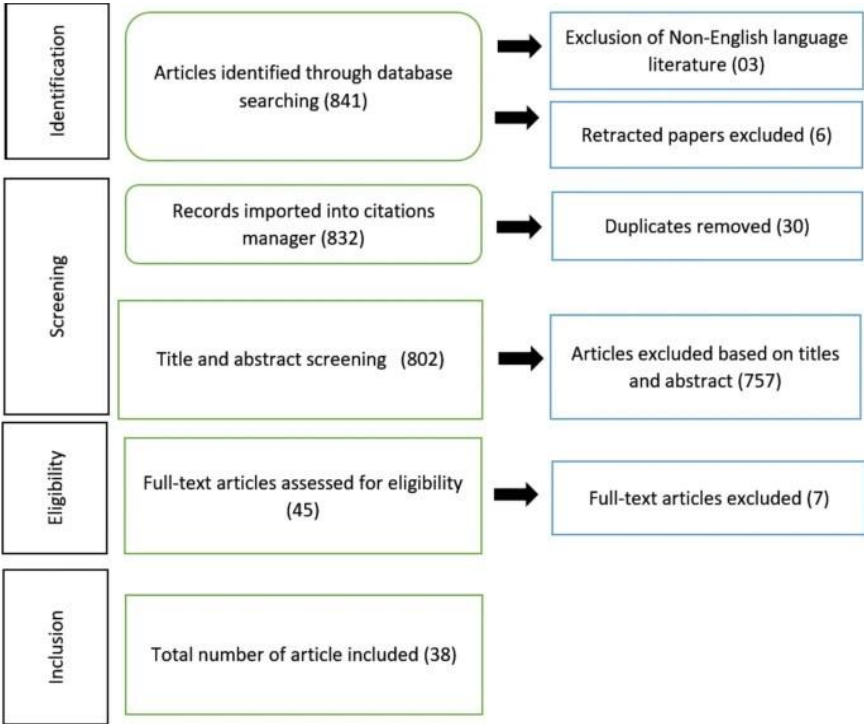
Figure 1. How block chain works

Today's Use of Blockchain. Originally developed for cryptocurrencies, blockchain has expanded into industries such as healthcare, finance, and supply chain management, demonstrating its benefits of decentralisation, security, and transparency (Schulz et al., 2019). In healthcare, blockchain enables secure sharing of patient data among caregivers and institutions while maintaining privacy and preventing data leaks (Johnstone et al., 2017). In finance, blockchain enhances transaction speed, reduces costs by removing intermediaries, and supports smart contracts and asset digitization, minimising human error (Swan, 2015). In supply chain management, blockchain facilitates real-time tracking, reduces fraud, and ensures product authenticity, improving efficiency and customer trust (Fosso Wamba et al., 2020).
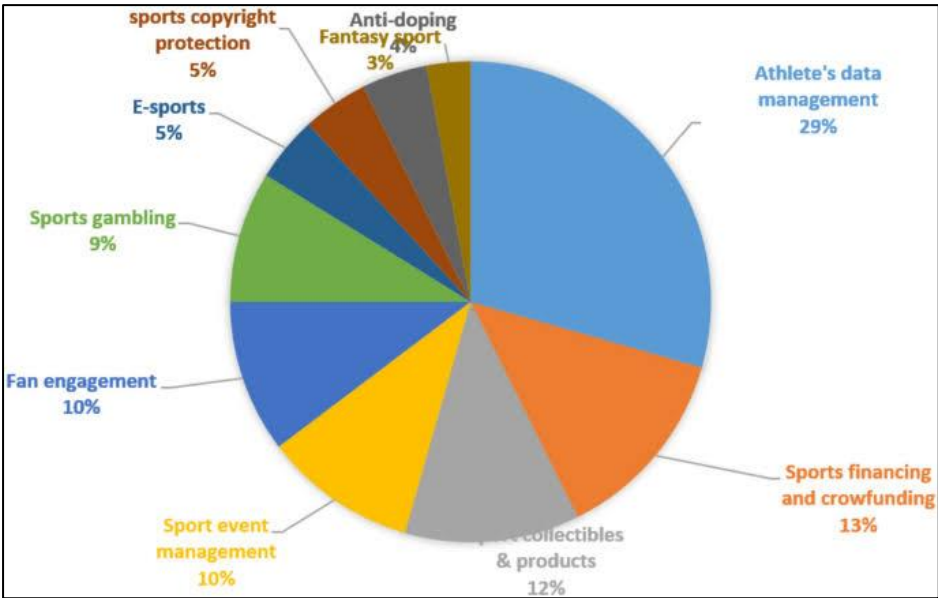

Table 2. Blockchain used in sports industry

The Potential for Blockchain in Sports. Blockchain's application in healthcare, finance, and supply chain management demonstrates its versatility in solving complex problems (Schulz et al., 2019). In sports, blockchain is emerging as a valuable tool for tracking athletes' physical and mental performance in real time. Data from wearables can be securely recorded on a blockchain, accessible only to authorised coaches, safeguarding athlete privacy and promoting accountability within sports organisations (Swan, 2015). Additionally, blockchain's immutable records ensure accurate tracking of performance cycles, aiding in training adjustments. As seen in other industries, blockchain's transparency and security offer new opportunities for enhancing performance management in sports (Johnstone et al., 2017).
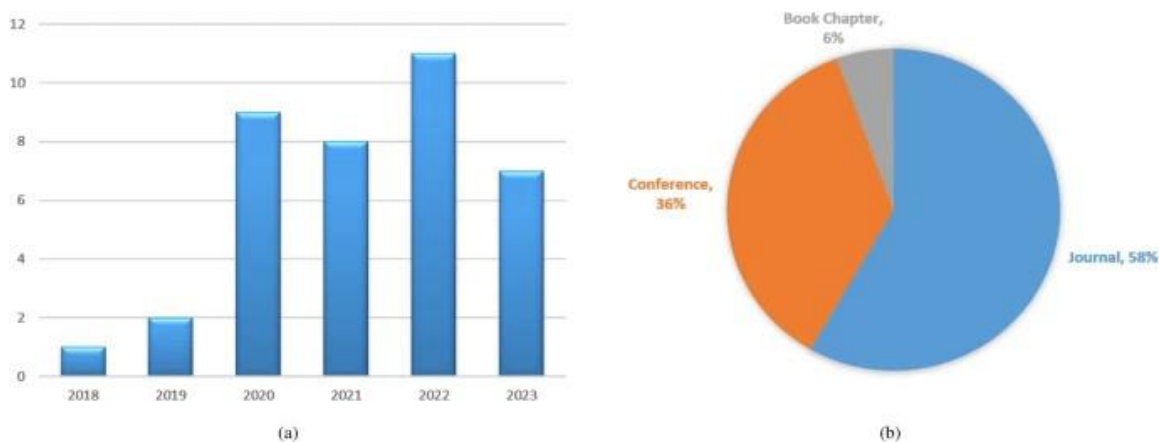

Figure 3. The results of literature review about Blockchain used in sports industry

(a) Evolution of the selected studies over the years
(b) Type of publication

As we aimed to better examine the adoption of Blockchain in sports, the collected articles were further analysed from the perspective of the field of sports they discuss, where we have classified the adoption area of our papers into traditional sports and digital sports. Traditional sports are characterised as physical activity involving competition between athletes or teams as well as recreational sports, such as football, tennis, handball, taekwondo, running...etc.

Thus papers in this class propose use cases in these sports from different angles (performance improvement, management and governing, fan engagement... etc.). Meanwhile, the digital sports category encompasses three application areas; sports gambling, fantasy sports, and Esports. We have found that our included sources predominantly discuss traditional sports use cases with 34 (81%) papers, meanwhile, only 8 papers (19%) discuss digital sports use cases as shown in Fig. 3b.

Since each paper addresses one or more use cases, we provide the following analysis where we discuss each blockchain application area in the sports industry, explain the rationale for adopting this technology in these areas, and discuss the examples of blockchain-based solutions presented in our resource pool.

Aims. The primary goal of this article is to explore how blockchain technology can enhance the tracking of athletes' mental and physical performance. The article aims to provide a comprehensive framework for understanding the integration of blockchain

in sports, focusing on its potential to address current challenges in performance monitoring, improve data security and integrity, and enable more effective and personalized training and competition strategies.

The main objectives of the article are:
– Review existing challenges in monitoring athletes' mental and physical performance using traditional methods.
– Explore how blockchain can provide secure, real-time tracking of performance metrics.
– Assess how blockchain technology can address issues of data privacy and integrity in sports performance management.
– Investigate how blockchain applications can enhance training protocols, competitions, and overall athlete well-being.

Methodology. A systematic review of literature was conducted to examine blockchain's applications in sports. The analysis focused on its capabilities for performance tracking, data security, and integration with wearable technology. Metrics like strength, endurance, attention, decision-making, and cognitive fatigue were evaluated through blockchain-enabled systems.

Results. Performance then is not only physical but also mental as the nature of athletic work seeks to address. These components therefore need to be unravelled in full so as to capture the intricacies of improving an athlete's performance.

Physical Performance Metrics. Physical performance is commonly assessed through various metrics, including:

Strength: This is the performance of muscles to do work by applying force on any object which opposes it. For example it can be measured through weight training regime, or in fundamental activities that are involved in the daily activities like lifting, or bench press. Strengthening muscles is important to athletes particularly to those who engage in brief bursts of energy for example sprinting or football.

Endurance: Endurance is an assessment of the capacity of an athlete or individual to put up with long exercise. It is usually measured in aerobic exercising, as for instance being able to run a given course within a given time. Strength is desired in a variety of games such as; running, racing , cycling and swimming and many more.

Speed: Speed is one of the most special motor skills that means the ability to move fast over a short space of a time period. It is mostly measured in sprinting events and is of relativity in soccer sport, track and field sport and basketball sport.

Agility: Specifically, agility can be described as the capacity of an athletic personality to move in different patterns at a high speed while keeping body balance. This skill is equally helpful in those games that involve transitional movement patterns like Basketball, Soccer, Tennis.

Cognitive Performance Metrics. In addition to physical capabilities, cognitive performance plays a significant role in athletic success.

Performance then is not only physical but also mental as the nature of athletic work seeks to address. These components therefore need to be unravelled in full so as to capture the intricacies of improving an athlete's performance.

1. *Attention and Focus*: Blockchain enables secure, real-time tracking of an athlete's attention span and focus during training or competition, allowing for accurate data analysis and feedback.

2. *Decision-Making*: Blockchain stores cognitive performance data transparently, helping athletes and coaches monitor decision-making speed and accuracy over time without data tampering.

3. *Memory and Learning*: Blockchain ensures the integrity of long-term memory and learning assessments, providing reliable insights into how athletes retain and apply strategies or skills in their sport.

Current technologies for monitoring athletic performance, such as wearable devices, offer insights into physical metrics but struggle to capture mental performance indicators like cognitive fatigue and decision-making. These mental metrics often rely on subjective self-reports, which can be influenced by mood, motivation, and external pressures, highlighting the need for more objective, standardised assessments (Schulz et al., 2019).

Data security is also a concern, as centralised storage systems for performance data are vulnerable to breaches, tampering, and loss. This raises issues about data integrity and the privacy of athletes' sensitive information (Schulz et al., 2019). Blockchain technology offers a potential solution, providing a decentralised, tamper-proof system for securely tracking both physical and mental performance metrics in real-time. Blockchain's ability to store data securely while giving athletes control over its access and use can address these challenges (Schulz et al., 2019).

While current methods are valuable, integrating technologies like blockchain could transform the monitoring and management of both physical and cognitive performance, enhancing data security and privacy.

Blockchain's Potential in Sports. Blockchain technology stands out for its capacity to store data and prevent tampering. In sports, data on athlete performance—both physical and mental—holds sensitivity and value. Blockchain provides a decentralised ledger with encrypted data making it almost impossible for unauthorised users to access or change information. This protects the privacy of athletes' health and performance records while keeping things transparent (Kshetri 2017). The unchangeable records of blockchain also create an audit trail, which plays a key role to validate athletes' growth and performance, and to resolve disputes during competitions (Murray et al. 2021).

Blockchain systems can support instant data input letting coaches, trainers, and athletes keep an eye on physical and mental stats right away. Devices you wear that track how athletes move, their vital signs, or even their state of mind can send data straight into a system powered by blockchain. This makes sure the info stays safe and easy to access without anyone messing with it (Schulz et al. 2019). Keeping tabs on things as they happen can help spot issues, like when someone's tired or not thinking as clearly so training plans can change as needed.

Decentralised records could provide a transparent history of an athlete's training, achievements, and health data, which can be especially useful for talent scouts, sponsorships, or during transfers between teams (Fosso Wamba et al., 2020). This

decentralised record-keeping ensures the integrity of the data and allows athletes to have more control over their personal performance information.

Improving Cognitive Function and Performance.

Blockchain and Cognitive Data: When it comes to sports like cricket, which requires quick decision making capabilities combined with focus that is unwavering then top cognitive performance from athletes can be a game changer. Conventional ways of testing cognitive function (like psychometric and speed tests) do not provide the feedback necessary in real-time nor reliably to improve mental performance during an athletic event. Real-time data measuring height and skip counts, along with cognitive markers of focus (Slaboda et al., 2021), decision speed, or stress levels can be written to a blockchain via wearables and/or other cognitive tracking tools in the context of athlete performance (8). This data can then be shared safely with coaches or medical personnel ensuring correct mental welfare tracking without worrying about having their health breached.

Impact to the athletes: Useful and unique way for tracking all manner of information, providing very secure data which would help physically much as well cognitive performance. Case in point, longitudinal cognitive data can capture mental fatigue states and intervention plans developed that are unique to the person. This could in turn lead to increased much needed focus during training and competition, leading up to potentially better overall performance (Kshetri, 2017). Additionally, coaches and psychologists can use this confidential information to help athletes work on mental resilience and stress management feedback in tandem with a balanced approach to physical academia.

Applications in Training and Competitions: In training, blockchain's potential lies in creating individualised programs that integrate both cognitive and physical data. Athletes' cognitive performance metrics, such as reaction time or decision-making accuracy, can be compared alongside physical metrics like endurance or speed, allowing for a more holistic training approach (Schulz et al., 2019). In competitions, secure blockchain-based performance tracking ensures that records are transparent and immutable, eliminating disputes over data accuracy. It also provides athletes with a competitive edge, as real-time cognitive feedback could lead to in-the-moment adjustments that optimise performance under pressure.

Discussion. While applications of blockchain in athlete performance monitoring are yet to be developed fully, there are still some technological challenges that hinder its implementation. Adapting blockchain in the current structures of sporting institutions is highly challenging and or costly for that reason, it calls for integration with higher technicality in terms of technology implementation and capital as noted by Swan (2015) for smaller clubs and other related sporting institutions. Further, scalability of the blockchain system is a threat especially in regards to the large amount of data from athlete performance and telemetry data (Fosso Wamba et al., 2020).

Data privacy is another issue as athletes would not wish to divulge health and performance information, which may attract hacker attacks. The major limitation that blockchain brings, is the block of data once it is added makes it very hard to rectify such inaccuracy or even delete it (Johnstone et al., 2017).

Finally, adoption in the sports industry is still a concern because the majority of distinct organisations are not willing to change their existing performance tracking systems because of costs, training, and perceived risk of change to new technology (Schulz et al., 2019). The evidence of resistance to change and scepticism about blockchain actually hinders its path towards mainstream adoption.

As blocking technology more extensively used to track athletes' performance, it is also necessary for policies and laws to enhance data protection, especially with such incorporations like GDPR because of the block chain immutability characteristic (Schulz et al., 2019). This makes it necessary to have ethical standards that should be put in place to protect the use of athletes' health related data instead, the athletes can decide how their information should be used. It may also be necessary for sports governing bodies to also set up standard protocols in the use of block chain to enhance fairness within the industry.

Blockchain-based AI or IoT applications can extend to real-time data analysis of athletes' performance, injury or mental health prediction (Murray et al., 2021). Smart IoT devices which are incorporated into blockchain platforms might also improve training and health care solutions (Swan, 2015). Subsequent papers could look at the differences of implementing blockchain-based systems compared with conventional applications, and examine the ramifications of its implementation on several disciplines of sports and initial player use cases (Fosso Wamba et al., 2020).

Conclusion. Blockchain technology - thanks to its decentralised and secure nature - holds enormous potential in transforming the tracking and management of athletes' mental (and) physical performance. This review has underscored how blockchain can facilitate secure: real-time monitoring of athletes' data, thereby ensuring data privacy and integrity. The capacity to monitor cognitive and physical metrics in a tamper-proof manner tackles the existing challenges in performance evaluation. However, it also equips athletes and coaches with more reliable tools for optimising training and competition preparation. Although hurdles exist, the advantages (of) adopting such technology are evident. This may result in significant advancements in the field of sports science.

As the sports industry (1) continues to evolve - becoming increasingly data-driven - blockchain may emerge as a vital asset for monitoring athlete performance and enhancing outcomes. The (2) seamless integration of blockchain with other advanced technologies, including AI and IoT, has the capacity to further revolutionise performance tracking, making it more personalised, predictive and secure. However, for blockchain to achieve comprehensive adoption within the sports ecosystem, several technological, regulatory and ethical barriers must be addressed. Although the potential is vast, this journey is likely to encounter numerous challenges. With persistent innovation and research, blockchain can indeed become an indispensable tool in the domain of sports performance management, because it offers insights that were previously unattainable.

Author contributions. The authors contributed equally.

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