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Original Article

Innovative technologies in sports games: A comprehensive investigation of theory and practice

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Abstract
Problem statement and purpose. The advent of modern technologies has facilitated the conduct of complex research in "real-world conditions," even during competitions. Thereby reducing the financial resources and time required by scientists and coaches to obtain research results. The primary aim of this study was to comprehensively investigate and elucidate contemporary innovative trends in sports science theory. This study aims to assess the practical efficacy and applicability of these innovations in sports preparation through meticulous analysis. By bridging the gap between theoretical advancements and their real-world implementation, this study aims to provide valuable insights into the evolving landscape of innovative technologies in sports games, thereby contributing to the enhancement of sports performance and training methodologies. **Approach and methods.** Bibliometric techniques were applied in this study to gather highly cited papers in sports sciences published during 2005-2023. The method of expert evaluations was used to determine the modern trends in the use of innovative technologies to improve the effectiveness of elite athletes` preparation. During physical activity, a thorough analysis utilizing diverse methods was performed on 17 women and 24 men, encompassing elite athletes in basketball, handball, and volleyball. The analysis considered both biomechanical and psychophysiological indicators. Mathematical and statistical processing and data analysis were carried out using the computing and graphic capabilities of the computer programs "Statistica" and Microsoft Excel 2010. **Results.** Our analysis of sports science literature and expert assessments has revealed the prevailing trends in the utilization of innovative technologies in elite sports. Wearable technology, encompassing fitness trackers, heart rate monitors, and GPS watches, stands as the most widely adopted category among national team coaches in 20 European countries, particularly for training athletes in sports games. These technologies play a central role in contemporary sports science. Furthermore, our research has highlighted significant disparities in outcomes when comparing cutting-edge sports science and technology with traditional laboratory methods, even under identical experimental conditions. This underscores the essential need for innovative mathematical and statistical approaches to evaluate emerging developments gaining prominence in the field of sports practice. **Conclusions.** The research results obtained by global trends show that technology is increasingly integral in optimizing athlete training and performance in sports games. Staying updated with these innovations is essential for coaches, athletes, and sports organizations aiming for success at the elite level.
Keywords: **elite athletes; sports games; innovational technologies; artificial intelligence.**

Introduction

Today innovative technologies can help athletes optimize their training, prevent injury, improve their technique, and optimize recovery. By leveraging the latest advances in technology, coaches and trainers can help elite athletes reach their full potential and achieve their goals. Current global trends in the direction of the latest scientific developments in elite sports include the following: Artificial Intelligence (AI) is being used in elite sports to analyze data and provide insights that can help athletes and coaches make better decisions. For example, AI can be used to analyze video footage of an athlete's performance and provide feedback on areas for improvement (Hammes et al., 2022; Ha et al., 2024). Sports genomics is a new scientific discipline that focuses on identifying genetic variants that contribute to a greater predisposition to success in certain sports disciplines. This can help with talent identification and development programs in sports (Varillas-Delgado et al., 2022). There is a growing trend of using technology in sports to monitor athlete health, recovery, and injury management, as well as to monitor the achievement of sports performance. For example, wearable technology can be used to monitor an athlete's heart rate, sleep patterns, and other biometric data (Bădescu et al., 2022). There is a huge interest in exploring the relationship between elite athletes' educational development and sporting performance (Dual Career Research). This research can help athletes balance their academic and athletic

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careers (Vidal-Vilaplana et al., 2022; Pérez-Chao et al., 2023). Overall, the latest scientific developments in elite sports are focused on using data, technology, and genetics to improve athlete performance and prevent injury.

In recent years, technology has played a significant role in improving the performance of elite athletes in sports games. The use of technological applications is now widespread across many major sports science disciplines (Giblin et al., 2016). Innovative sports performance analyses that incorporate new technologies to understand individual behaviors within real-based and ecological contexts would provide a greater understanding of how players and teams act and react for greater performance development and application (Smolianov et al., 2018). As examples of innovative technologies that have been used to improve the preparedness of elite athletes in sports games:

Wearable technology such as smartwatches, fitness trackers, and GPS devices can provide real-time data on an athlete's performance, including heart rate, speed, and distance covered (Windt et al., 2020). This data can be used to monitor an athlete's progress and identify areas for improvement. Virtual reality technology can be used to simulate game situations and help athletes prepare for high-pressure situations. For example, a basketball player can use virtual reality to practice shooting free throws in a simulated game environment (Gomez-Ruano et al., 2020). Data analytics can be used to analyze large amounts of data on an athlete's performance, including video footage, physiological data, and performance metrics (Barça Innovation Hub team, 2020). This data can be used to identify patterns and trends that can help coaches and athletes make more informed decisions about training and strategy. Biomechanical analysis involves using technology to analyze an athlete's movements and identify areas for improvement. For example, motion capture technology can be used to analyze a golfer's swing and identify areas where they can improve their technique (Giblin et al., 2016).

Overall, the use of innovative technologies in sports has the potential to improve the preparedness of elite athletes in sports games significantly. By providing real-time data on an athlete's performance, simulating game situations, and analyzing large amounts of data, coaches and athletes can make more informed decisions about training and strategy, leading to better performance on the field.

Despite the large number of the latest developments in the field of fitness and sports, the question of the practical use of innovative technologies by specialists - coaches of national teams, remains. We assumed that by the method of expert evaluations, it would be possible to determine the most popular innovative technologies, which in practice are used by the coaches of the national teams of 20 European countries for the sports training of athletes who specialize in sports games.

Purpose: This study aimed to provide valuable insights into the evolving landscape of innovative technologies in sports games, thereby contributing to the enhancement of sports performance and training methodologies.

Material and methods

Participants. This study received ethical approval from the Institutional Ethics Committee and adhered to the international principles outlined in the Helsinki Declaration of the World Medical Association, as well as the ethical norms and rules stipulated by the Law of Ukraine, specifically the "Fundamentals of Ukrainian Legislation on Healthcare," governing medical research involving human subjects. Before any data acquisition, explicit written consent was obtained from all participants.

A panel of experts comprising 20 specialists in sports science and national team coaches was assembled. Their primary objective was to identify the most prevalent innovative technologies aimed at enhancing the preparation of elite athletes in sports games.

The experts undertook the task of determining model characteristics crucial for delineating the optimal psychophysiological and biomechanical parameters of elite athletes engaged in sports games. The study encompassed a cohort of 17 women and 24 men participating in physical activities associated with basketball, handball, and volleyball. Various indicators were meticulously examined to ascertain the defining features of the athletes' psychophysiological states and biomechanical profiles.

Procedure. We collected primary information based on a sociological survey as the key source of research. The survey in our study was used as a method of collecting sociological information about the level of theoretical and practical knowledge of sports professionals (m=160) regarding the specifics of elite sports (oral and written survey, interviews) communication with representatives of various sports and countries during 2021-2023. Expert survey is a method of obtaining information using the knowledge of competent persons, qualified, experienced specialists who express their point of view on certain issues. From 160 respondents after the initial survey, we selected an expert group of sports scientists, and coaches of national teams (m=20) with demonstrated experience working with innovative technologies to improve the effectiveness of elite athletes` preparation in sports games. The task of the experts was to determine the more popular innovative technologies to improve the effectiveness of elite athletes` preparation in sports games. The degree of agreement between experts' answers was determined using Kendall's concordance coefficient (W). Determination of the normative coefficient of significance (K_N), which is the reciprocal of the number of ranked factors.

To ascertain the model characteristics defining the optimal psychophysiological state of 17 women and 24 men, elite athletes from sports games such as basketball (women, n=10 and men, n=14), handball (women, n=3

and men, n=5), and volleyball (women, n=4 and men, n=5) during physical activity, various indicators were considered. These included balance function quality with and without visual control, attention efficiency, voluntary attention volume, productivity, motivational, volitional, and typological components, as well as stress resistance. Attention span was evaluated using standard techniques, measured by the number of objects perceived by the athlete in less than 1 second while completing specific tasks.

Operational thinking was assessed through a computer-based psychophysiological diagnostic test, with the operational thinking coefficient (COT) calculated as $COT = Nr / T \cdot 100$, where T represented the average time to complete the test task (in milliseconds). Short-term visual memory was evaluated following Makarenko's method, where subjects were presented with a table containing randomly arranged two-digit numbers. Subjects were required to write down the memorized numbers in random order within 1 minute. Results were converted into points on a 9-point scale using Makarenko's table.

Assessing the quality of the balance function was of paramount importance, with higher values indicating superior balance maintenance. This assessment was performed using standard and complex Romberg tests, both with open and closed eyes, utilizing the "Stabilan-01" stabilographic system. Assessment of body kinetics involved evaluating parameters such as center of pressure displacement, spread along axes, statokinesigram curve length, movement assessment, balance function quality, area of deviation zone, number of points scored, and errors with visual and verbal stimuli. The VICON system, comprising 10 cameras (200Hz, Oxford Metrics Group, Oxford, UK), was employed for 3D motion analysis.

The study employed anatomically-based fitting to subject-specific data derived from 3D body scanning, validated against magnetic resonance imaging to create a personalized multi-body dynamics model. This model enabled the analysis of specific training interventions and incorporated innovative techniques such as "OpenCap" and specialized smartphone applications.

The "OpenCap" analysis process included camera calibration, video collection and processing, marker position estimation, kinematics estimation, and physics-based dynamic simulations of movements. This comprehensive pipeline was executed using Python (v3.7.10), with web applications guiding users through each step. Cloud-based computing resources were utilized for efficient data processing.

Statistical analysis. Spearman's rank correlation coefficient ρ was calculated to study the interdependence between the conclusions of sports experts and indicators of the level of scientific developments in the specified topic, and its statistical significance was assessed using the t-criterion. Subsequently, the coefficient of determination was calculated to determine the impact of a single cause on the final result, which could take values from 0% to 100%. Finally, all statistical hypotheses were tested at the $\alpha = 0.05$ significance level ($p < 0.05$), and mathematical and statistical processing and data analysis were conducted using Statistica (Statsoft, version 7.0), SPSS, and Microsoft Excel 2010.

Results

The present work will serve as the basis for studying the specifics of optimization competitions and the training process of elite athletes in sports games, taking into account new achievements in sports science for the further development of practical recommendations.

Talent and training have always been the cornerstone of athletic achievement. However, the integration of new technologies is transforming how athletes can maximize their potential, monitor their progress, and prevent injuries. Here are some Israeli inventions in sports tech that can revolutionize athletic performance (10 Technologies that Help Athletes Ramp Up Performance, 2023): Yopi's connected sensor worn on the arm monitors oxygen consumption (VO2) through sweat electrolytes. This technology allows athletes to measure their cardiorespiratory fitness without the need for a mask device, providing valuable insights for training and health; Sency's Movement-OS app uses computer vision to assess users and create customized daily exercise routines. It offers full training programs, mobility exercises, tracking, recording, and AI coaching for athletes; BlazePod is a customizable reaction training system with light-up sensors connected to a smartphone app. It enhances hand-eye coordination, reflex speed, and cognitive abilities for athletes across various sports; Based on an Israel Air Force brain-training system, IntelliGym enhances awareness, decision-making, concentration, and execution in young soccer and hockey players, improving their performance and reducing the risk of injury; Playform is an AI-powered mobile app that captures data points from each drill to provide real-time feedback on an athlete's physical, technical, and mental skills. It offers customized workout routines and insights for players, coaches, or trainers; Physimax uses video capture and AI to assess athletes' physical abilities, endurance, and injury risk. It provides personalized exercise and physical therapy programs based on the user's performance; Lumen measures carbon dioxide in your breath to improve metabolic flexibility. The connected app offers real-time metabolic insights, personalized diet, exercise recommendations, and meal plans to enhance overall health; Playermaker tracks soccer players' technical and physical performance with a small device worn on their cleats. It provides valuable data on ball touches, passes, runs, and interceptions, aiding in progress monitoring and comparison; RSPCT digitizes basketball shots, offering real-time analytics for players, coaches, and scouts. It tracks shot location, origin, arc, and more, providing insights into shooting potential; Track160 offers an

automated data analytics platform for soccer coaches and players. It tracks 3D pose and motion, providing valuable data, video, and events for performance analysis.

These Israeli innovations showcase the potential of sports technology to transform athletic performance, enhance training, and provide valuable insights to athletes and coaches. For those interested in exploring more developments in sports technology, the Sports Tech Nation conference in Tel Aviv offers an opportunity to stay updated on the latest trends and opportunities in the field.

The literature data provided includes studies that analyze modern technologies in psycho-physiological control in sports. The studies use different methods and equipment to measure brain activity and performance in athletes, such as Moscaleski et al. (2022) studied professional female basketball players during free-throw shooting using high-definition transcranial direct current stimulation and EEG with actiCHamp (Moscaleski et al., 2022) studied rifle shooting using EEG with actiCHamp and SynAmps2 from Compumedics (Shuyu et al., 2022; Lange & Osinsky, 2021) studied pistol shooting using EEG with LiveAmp and Analyzer, compared table tennis to cycling using EEG with LiveAmp 64 (Visser et al., 2022), conducted a review of the literature on the use of EEG in sports (Haar & Faisal, 2022), studied brain oscillations in sport and proposed EEG biomarkers of performance (Cheron et al., 2016).

Overall, these studies show that EEG is a useful tool for measuring brain activity in athletes and can provide insights into the mechanisms controlling and regulating elite performance. The studies also suggest that psychological skills such as motivation, self-confidence, and mental toughness are important factors related to performance in most sports. Finally, psychological and psychosocial interventions have been shown to have a moderate positive effect on sports performance. Psychophysiological parameters can differ between individual and team sports due to the nature of the sports and the demands they place on athletes. Modern studies have found that athletes in individual sports tend to have higher levels of introversion, neuroticism, and anxiety compared to athletes in team sports (Forte et al., 2023). Overall, these differences suggest that psychophysiological parameters can vary depending on the type of sport an athlete participates in. Understanding these differences can help coaches and trainers develop more effective training and intervention programs tailored to the specific needs of individual and team athletes. Advancements in technology have revolutionized the field of sports science, enabling researchers to gain deeper insights into the biomechanics of elite athletes' movements (Lorenzetti et al., 2017; Sánchez-Moreno et al., 2020). Among these technological advancements, OpenCap emerged as a powerful tool for biomechanical analysis (Uhlrich et al., 2022; Smith et al., 2020). The integration of OpenCap with other innovative technologies, such as motion capture systems and data analytics, further enhances the understanding of human movement.

The literature and special Internet sources review, helped us to gather special information about using innovative technologies in sports games for elite sportsmen. The current world trends regarding the directions of the latest scientific developments in elite sports are:

- Data analytics and artificial intelligence (AI) are gaining momentum in high-achievement sports. Researchers and sports scientists are utilizing advanced algorithms and machine learning techniques to analyze vast amounts of data, including athlete performance data, biometric data, and competition data. This allows for more accurate performance predictions, injury risk assessment, and personalized training programs based on individual athlete characteristics.
- Wearable technology, such as fitness trackers, heart rate monitors, and GPS watches, is being extensively used in high-achievement sports. These devices provide real-time monitoring of various physiological parameters, training load, and movement patterns. The integration of sensors into sports equipment, such as smart shoes or smart clothing, is also gaining popularity. The data collected from wearables and sensors help in optimizing training, preventing injuries, and improving performance.
- Virtual reality (VR) and augmented reality (AR) technologies are being explored in high-achievement sports for training, skill acquisition, and performance analysis. VR and AR simulations offer realistic training scenarios, allowing athletes to practice in virtual environments that mimic real-world conditions. These technologies also aid in tactical analysis, providing athletes with a better understanding of game situations and enhancing decision-making abilities.
- Biomechanics and motion analysis are crucial areas of research in high-achievement sports. Researchers are utilizing advanced motion capture systems, force plates, and wearable sensors to gather detailed biomechanical data during training and competition. This information helps identify optimal techniques, detect inefficiencies in movement patterns, and enhance athletic performance by improving efficiency and reducing injury risk.
- There is a growing interest in neurofeedback and brain training techniques in high-achievement sports. These methods involve training athletes to enhance cognitive abilities such as attention, focus, and reaction time. Neurofeedback technologies provide real-time feedback on brain activity, allowing athletes to optimize their mental performance and develop strategies for managing stress and pressure.
- Research is focused on optimizing recovery and regeneration techniques to enhance athlete performance and prevent overuse injuries. This includes advancements in cryotherapy, compression therapy, hydrotherapy,

and other modalities. Researchers are investigating the physiological benefits and practical applications of these techniques to expedite recovery and maintain optimal physical condition.

- The field of genetics and genomics is gaining attention in high-achievement sports. Researchers are studying genetic markers associated with athletic performance, injury susceptibility, and recovery. This knowledge can help in personalized training programs, talent identification, and injury prevention strategies based on an athlete's genetic profile.
- Researchers are exploring the impact of environmental factors, such as altitude, temperature, and humidity, on performance in high-achievement sports. Understanding how athletes adapt to different environmental conditions helps develop training strategies to optimize performance in specific settings, such as altitude training camps or hot and humid environments.
- The importance of psychological well-being and mental health in high-achievement sports is gaining recognition. Researchers are focusing on developing interventions and strategies to address issues such as performance anxiety, burnout, and stress management. Enhancing mental resilience, motivation, and well-being is considered essential for optimal performance and overall athlete development.
- Sustainable practices in high-achievement sports are becoming increasingly important. Researchers are investigating the environmental impact of sports events, developing eco-friendly technologies and materials for sports equipment, and promoting sustainable training and recovery practices. This includes initiatives to reduce waste, minimize carbon footprint, and promote sustainable resource management.

These trends represent the current directions of scientific developments in high-achievement sports. Continued research and innovation in these areas have the potential to revolutionize athlete training, performance analysis, and overall sports science practices.

The analysis of the experts' analytical notes made it possible to obtain information about the average situation of innovative technology's practical use in sports of high achievement in Europe.

To identify the general opinion of experts regarding the existing innovative technologies, an analysis of the materials of expert assessments was carried out. For this purpose, we created a matrix of ratings of ranked factors by each expert. The factor numbering is given in Table 1 with the corresponding matrix of ratings in Table 2. Experts chose which tools are, in their opinion, the most significant for their practice work and distributed them in places from 1 to 10 in order of decreasing influence.

So, by the method of expert evaluations, we determined that the most popular innovative technologies used in practice by the coaches of the national teams of 20 European countries for the sports training of athletes who specialize in sports games are: wearable technology, encompassing devices such as fitness trackers, heart rate monitors, and GPS watches, has emerged as a pivotal component in contemporary sports science. These technologically advanced devices offer the capability for real-time monitoring and assessment of diverse physiological parameters, training loads, and movement patterns. Additionally, the integration of sensors within sports equipment, notably smart shoes and smart clothing, is progressively garnering favor within the athletic community. The wealth of data procured through the utilization of wearables and integrated sensors plays a pivotal role in the refinement of training regimens, the mitigation of injury risks, and the enhancement of athletic performance. This technological synergy represents a paradigm shift in the scientific approach to sports training and performance optimization.

Table 1. Numbering (n) of 10 innovation trends in sports according to expert survey

Name of the factor	Factor number (n)
Data analytics and AI	1
Wearable technology	2
Virtual and augmented reality	3
Biomechanics and motion analysis	4
Neurofeedback and brain training techniques	5
Recovery and regeneration techniques	6
Genetics and genomics	7
Altitude training camps or hot and humid environments	8
Performance anxiety, burnout, and stress management	9
Eco-friendly technologies and materials	10

As we can see in Table 2, there are no connected (same) assessments (according to the condition) in the experts' statements, therefore the concordance coefficient (expert agreement) W was calculated according to the standard formula. Since W=0.41, which is ≥0,4, it can be argued that the experts' assessments have been positive. Thus, we accept the hypothesis that there is an agreement between specialists and determine that the results of the expert group's questionnaire can be trusted.

Table 2. Ratings of the 10 key factors according to each expert (m=20) with the average sore $\bar{x}$ and the coefficient of the significance of each factor (K_j) established as a whole by the group of experts (Matrix of experts' assessments)

Number of the expert (m)	Factor number (n)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**
1.	2	1	5	3	6	7	10	8	4	9
2.	4	2	6	1	4	3	10	9	5	8
3.	4	2	6	1	3	5	9	10	8	7
4.	4	1	5	2	6	3	10	9	8	7
5.	5	1	5	2	4	3	10	9	8	7
6.	1	3	6	4	5	2	9	8	7	10
7.	5	1	6	2	4	3	10	9	8	7
8.	5	1	6	2	4	3	10	9	7	8
9.	4	1	6	3	5	2	10	8	9	7
10.	5	1	7	3	4	2	10	9	8	6
11.	5	2	6	3	4	1	9	10	8	7
12.	5	1	6	2	3	4	10	9	8	7
13.	6	1	5	3	4	2	10	8	9	7
14.	4	1	5	2	6	3	10	9	8	7
15.	6	3	5	1	4	2	10	8	9	7
16.	5	1	6	3	4	2	10	9	8	7
17.	6	2	5	1	3	4	10	9	8	7
18.	6	1	7	2	4	3	10	9	8	5
19.	4	1	6	3	5	2	10	9	8	7
20.	5	2	8	3	4	1	9	10	7	6
x_j	4,55	1,45	5,85	2,3	4,3	2,85	9,8	8,9	7,65	7,15
K_j	0,12*	0,19*	0,1*	0,17*	0,13*	0,16*	0,004	0,02	0,05	0,06

* - the factor is significant, as the value of the coefficient significance is equal to or exceeds the value of the normative coefficient (K_j ≥0,1), because of the normative coefficient of significance $K_N = 0,1$.

That is, the method of expert analysis in modern conditions is one of the most effective means of obtaining and analyzing qualitative information regarding the identification of popular scientific innovations in the practice of elite sports.

At present, laboratory-based motion capture stands as the recognized gold standard for acquiring data related to human biomechanics. However, the state-of-the-art software used to reconstruct motion and kinetics, based on the interpretation of optical marker trajectories and ground reaction forces, demands ongoing iterative refinement. This inherent need for fine-tuning results in increased costs, limited scalability, and reduced reproducibility in the field of motion capture studies (Wade et al., 2022; Werling et al., 2023; Schumperlin et al., 2023).

Quantitative analysis of human movement dynamics and psychophysiological assessment programs have emerged as powerful tools with widespread recognition for evaluating athletes' readiness in sports integration. These innovative technologies facilitate the assessment of assistive devices designed to improve athletes' movement capabilities and monitor their psychophysiological states. Importantly, this analysis can take place not only in controlled laboratory settings but also directly in the competitive arena.

For instance, we conducted an extensive array of measurements to determine the model characteristics defining the optimal psychophysiological state of elite male and female athletes during exercise activities. We considered indicators such as the quality of balance function with and without visual control, attention efficiency, the volume of voluntary attention, productivity, coefficients related to motivational, volitional, and typological components, as well as stress resistance.

During psychophysiological testing, elite athletes from sports like basketball (women, n = 10; men, n = 14), handball (women, n = 3; men, n = 5), and volleyball (women, n = 4; men, n = 5) initially underwent the proposed tests in a training mode. The state of their core mental functions was evaluated using a computer-based psychophysiological diagnostic test. To convert the results into a 9-point scale, we employed the table proposed

by Makarenko. In addition, we evaluated the development of athletes' balance function by employing standard and complex Romberg tests, both with open and closed eyes, utilizing the "Stabilan-01" stabilographic complex. The kinetic stability of elite male and female athletes' bodies was directly assessed during these tests, incorporating universal indicators such as the center of pressure displacement, spread along the axes, statokinesigram curve length, movement assessment, and balance function quality. Special tests, including the area of the deviation zone, number of points scored, and errors with visual and verbal stimuli, were also employed.

This method encompassed both biomechanical and psychophysiological aspects, as the Romberg tests consisted of two segments: 1) with open eyes (involving visual stimulation through alternating-colored circles on a screen) and 2) with closed eyes (involving sound stimulation via tone signals). This setup allowed for a comprehensive qualitative assessment of biomechanical and psychophysiological gender differences among elite athletes specializing in various sports.

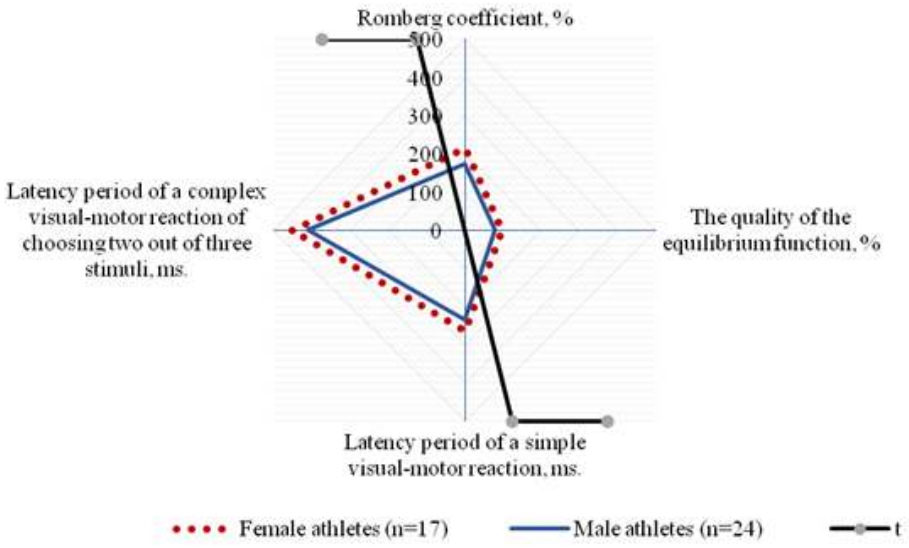

Figure 1. The differences in the values of indicators of neurodynamic and balance functions between elite female athletes (n=17) versus male athletes (n=24).
Note: denotes statistically significant differences $p < 0.01$ between indicators of male athletes compared to the group of women.

These studies were extensive in terms of both time and the number of actions required to obtain results and were conducted in controlled laboratory conditions, simulating competitive stress (Nagorna et al., 2023; Borysova et al., 2020).

Recent technologies such as OpenCap, AddBiomechanics, Brain Activity control technologies, and others enable rapid, precise calculations to be performed in training or competition conditions (Garcia et al., 2016; Haar et al., 2020; Moscaleski et al., 2022).

However, it's important to note that innovative technologies may not always have the necessary validation for seamless integration with established methodologies. The incorporation of these new tools into sports activities requires a strong foundation of scientific support. In the context of optimizing athletes' preparation for the peak competitions of the macrocycle, it's crucial to recognize that, in addition to traditional means and methods of sports activity management, control, and organization, the ever-evolving landscape of technological progress underscores the importance of innovative developments.

In the course of our research, which sought to assess the validity of the latest advancements and applications in comparison to conventional laboratory techniques, we encountered several challenges concerning the statistical analysis of the obtained results. Figure 2 illustrates the disparities in the processing of results from biomechanical analysis, specifically the angle change in the athlete's right knee joint during squatting with a barbell, utilizing two distinct methods - OpenCap and Vicon.

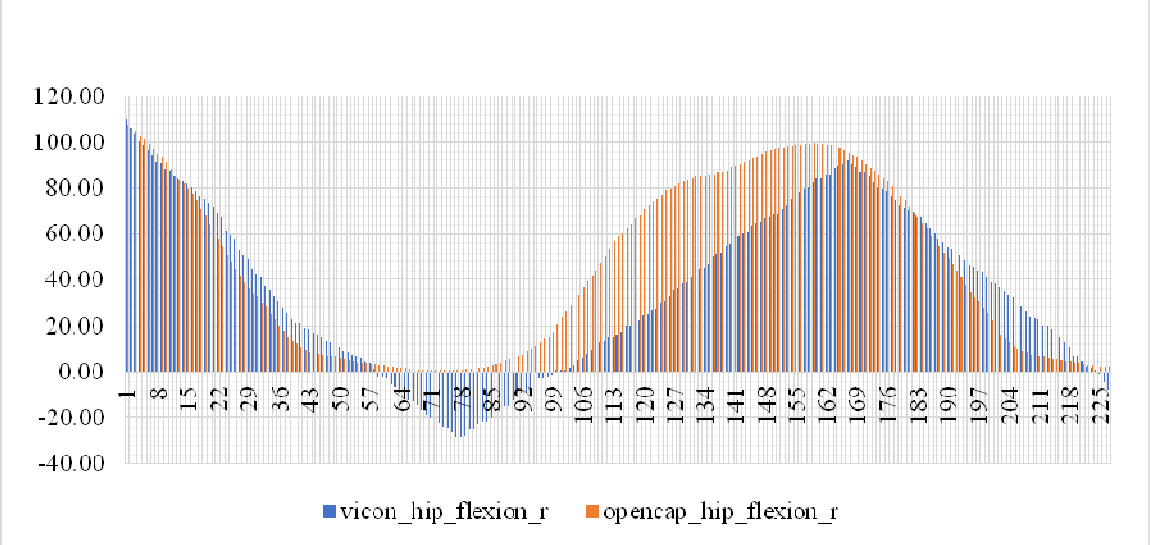

Figure 2. Comparative biomechanical analysis of right hip flexion changes during barbell squats: OpenCap vs. Vicon (r=0,87).

Remarkably, under identical ascending parameters, we observed varying outcomes, encompassing differences in the number of measurements per unit of time, distinct starting points for angle change calculations, and even mirrored results. These findings underscore the imperative need for innovative mathematical and statistical approaches when gauging the validity of emerging developments, which are progressively gaining prominence in the realm of sports practice. Our forthcoming research endeavors will be dedicated to addressing this pressing concern.

Discussion

Advancements in technology have revolutionized the field of sports science, enabling researchers to gain deeper insights into the biomechanics of elite athletes' movements (Delp et al., 2007; Lorenzetti et al., 2017; Smith et al., 2020; Brown et al., 2019). Among these technological advancements are:

Wearable technology - helps in data capturing and monitoring, such as tracking heart rate, speed, and movement.

Immersive reality - off-field technology like immersive reality can aid in understanding the entire process of a sport. Data analytics - using analytics to prevent injuries is one of the sports science trends receiving prominence over the past few years. Sensors can be used to measure player movement and speed, heart rate, and pressure. Virtual reality can be used to simulate game situations and help athletes train. Computerized scoring has impacted sports like bowling. Goal-line technology has been introduced in football to help referees make accurate decisions. Instant replay has been another technological advancement that has drastically changed how many sports are played and refereed. Video Assistant Referee (VAR) is a system used in football to review decisions made by the on-field referee. Protective equipment like helmets and pads have been developed to help prevent injuries in contact sports. Timing systems have been developed to accurately measure race times in sports like swimming and track and field. Kinetic Energy Recovery System (KERS) is a system used in auto racing to recover energy lost during braking and reuse it to power the car. Brain-computer interfaces are an upcoming technology that could be used to help athletes train and recover from injuries. Biomechanical analysis is an upcoming technology that could be used to analyze an athlete's movements and improve their performance. Nanotechnology is an upcoming technology that could be used to develop new materials for sports equipment. Blockchain is an upcoming technology that could be used to improve the security and transparency of sports transactions.

These are just a few examples of the many technological advancements that are changing the world of sports science nowadays.

Nowadays the integration of quantitative movement analysis is imperative for modern sports optimization. However, the effective implementation of innovative technologies necessitates rigorous scientific validation and a nuanced approach to their comparison with traditional laboratory techniques (Wilson et al., 2018; Zhang et al., 2017; Achermann et al., 2023; Oberhofer et al., 2021).

In the contemporary landscape of scientific engagement with sports, there is an undeniable surge in support and funding, resulting in a wealth of daily contributions worldwide. These contributions encompass a plethora of articles, research works, reports, projects, ideas, and dissertations. This deluge of scientific knowledge in the realm of sports poses a challenge when attempting comprehensive statistical analyses. When

comparing biomechanical analysis results derived from different programs, it is essential to conduct correlation analyses on identical biomechanical parameters generated by diverse models (Jing et al., 2023).

To facilitate such comparisons, the following general steps can be undertaken (Kwok et al., 2021; Li et al., 2022):

• Identify the specific movement patterns, such as concentric, eccentric, or isometric, and the planes in which they occur.

• Determine the involved joints during the athletic activity.

• Identify the recruited muscles and their respective actions.

• Assess the duration of active engagement by the athlete in the sporting event.

• Analyze video recordings of athletes in action.

• Estimate movement velocity during the range of motion's early, middle, and late phases.

• Perform correlation analyses on the results of matching biomechanical parameters obtained from different models.

It is essential to acknowledge that these steps serve as a general framework and may require customization based on the specific nature of the analysis being conducted. Furthermore, ensuring consistency in variables measured and data collection methods across programs is crucial to guarantee accurate comparisons.

One of the primary objectives of our research is to integrate traditional knowledge about the long-term training of athletes in various sports with innovative developments to optimize the training process, improve competitive performance, and prioritize athletes' well-being. Key aspects of this integration should include:

- Mindfulness-Based Interventions (MBIs): Research has demonstrated that MBIs can effectively enhance athletic performance and reduce sports competition-related anxiety (Wang et al., 2023). Incorporating these techniques into training programs can bolster athletes' mental well-being and overall performance.
- Tapering Strategies: Tapering, characterized by a reduction in training load before a competition, has been shown to enhance sports performance in endurance athletes (Wang et al., 2023). Integrating appropriate tapering strategies into training plans can assist athletes in achieving peak performance during competitions.
- Long-term Performance Development: Long-term performance development necessitates a systematic increase in training load over time, coupled with adequate rest and recovery (Haugen et al., 2019). Designing training programs that gradually intensify in both intensity and volume can enable athletes to reach their full potential while minimizing the risk of overtraining and injuries.
- Optimal Mechanics and Technique: While the significance of technique in performance is well-established, there remains a need for further research on achieving optimal mechanics in various sports (Wang et al., 2023; Haugen et al., 2019). Integrating biomechanical analysis and training methods can aid athletes in improving their technique and maximizing their performance potential.
- Technology Integration: The utilization of technology in training and performance optimization is an evolving field. This includes the integration of machine learning systems for tailored training regimens, as well as technology's role in psychological skills training to optimize performance (Pellot et al., 2020; Siekanska et al., 2021).
- Biomechanical Variables for Performance Monitoring and Training Optimization: Monitoring and optimizing specific biomechanical variables, such as the eccentric utilization ratio, force-velocity relationship, and reactive strength index, can contribute to improved sports performance (Pleša et al., 2022). Incorporating these variables into training programs can aid athletes in achieving their performance goals more effectively.

Through the integration of these innovative developments with established training principles, researchers and coaches can enhance the training process, elevate competitive performance, and prioritize the well-being of athletes across various sports. This integration has the potential to yield more effective and efficient training methods, ultimately assisting athletes in reaching their full potential.

Prospects for further research

Our further research will be aimed at improving the programs of elite athletes` sports preparation, taking into account the use of innovative technologies and special devices.

Conclusions:

Identifying global trends in the use of innovative technologies to improve the effectiveness of training elite athletes in sports games is crucial for staying competitive in the world of sports. As a result of our research, we have such notable trends: Athletes are increasingly using wearable devices like fitness trackers, smartwatches, and GPS technology to monitor their performance. These devices track metrics such as heart rate, sleep patterns, and distance covered, allowing coaches and athletes to make data-driven decisions about training and recovery. High-tech motion capture systems and 3D analysis tools are becoming more accessible. These technologies help coaches and athletes analyze an athlete's movements in detail, identifying areas for improvement in technique, posture, and injury prevention.

Virtual Reality (VR) and Augmented Reality (AR) are being used to simulate game situations and scenarios. Athletes can train in a more immersive environment, enhancing decision-making skills and situational awareness. VR is also used for injury recovery and rehabilitation exercises. Advanced data analytics and artificial intelligence are being applied to analyze vast amounts of performance data. Machine learning algorithms can identify patterns and provide insights that help optimize training regimens, predict injuries, and improve overall performance. Nutritional science is advancing rapidly, and athletes are benefiting from personalized diet plans based on their unique needs. This includes the use of genetic testing to determine how an athlete's body responds to different types of diets and supplements. Athletes are using recovery technologies like cryotherapy chambers, hyperbaric oxygen chambers, and advanced massage tools to speed up recovery after intense training sessions or competitions. Cognitive training programs and neurofeedback are being used to enhance mental resilience and decision-making skills in high-pressure situations. This is particularly important in sports games where split-second decisions can make a significant difference. Video analysis software is getting more sophisticated, allowing coaches to break down game footage and provide detailed feedback to athletes. This technology helps athletes understand their performance better and make improvements. Athletes are using biometric monitoring systems to track vital signs like heart rate, oxygen saturation, and body temperature in real time during training and competition. This data can help prevent overexertion and improve performance. Monitoring and adapting to environmental conditions, such as temperature, humidity, and air quality, can give athletes an edge. This is especially relevant for outdoor sports. In some sports, robotic devices are being used to mimic opponent movements, helping athletes practice against specific playing styles. In some cases, blockchain technology is being used to provide transparency and security in areas like athlete contracts, anti-doping efforts, and the management of sports-related data. Remote coaching and telemedicine are becoming more common, allowing athletes to receive guidance from experts regardless of their location.

Our research was centered on the comparative assessment of the latest advancements in the field of sports science and technology when juxtaposed with conventional laboratory methods. We focused on the discrepancies in the data processing derived from biomechanical analysis, specifically honing in on the angle change in the right hip flexion of athletes during barbell squats. We employed two distinct methodologies for this analysis: OpenCap and Vicon.

Remarkably, even under identical experimental conditions, we uncovered significant disparities in the outcomes. These distinctions encompass variations in the frequency of measurements over time, divergent starting points for angle change calculations, and even mirrored results. These findings emphasize the compelling necessity for pioneering mathematical and statistical techniques in assessing the validity of emerging developments. These innovative technologies are increasingly gaining prominence in the field of sports practice. Our forthcoming research initiatives will be dedicated to addressing this pertinent issue and further advancing the domain of sports science and technology.

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Conflict of interest

The authors declare that there is no conflict of interest.

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