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ЗМІСТ

<i>Denysova Lolita, Lavrov Vitaliy</i>	Esports and cybersecurity: modern digital solutions	5
<i>Nagorna Viktoriia, Mytko Artur, Borysova Olha, Shlyapnikova Iryna, Zhyhailova Liubov</i>	Characteristics of Modern Technologies in the Training and Competitive Process of Elite Athletes in Sports Games	14
<i>Savchenko Valentyn, Tymchuk Olesia, Nevedomsjka Jevgenija, Omeri Iryna, Buriak Olga, Kharchenko Halyna, Yatsenko Svitlana</i>	Health motivation and its relation to functional state of the cardiorespiratory system, statistical balancing and muscle strength in sick and healthy people	26
<i>Борисова Ольга, Дутчак Мирослав, Шльонська Ольга</i>	Аналітичний огляд сучасних наукових досліджень за проблемою підготовки спортсменів різного ігрового амплуа в командних ігрових видах спорту	39
<i>Волощенко Юрій</i>	Академічна стійкість здобувачів вищої освіти. Перевірка адаптації української версії шкали академічної стійкості (ars-30ukr) серед студентів першого курсу Київського столичного університету імені Бориса Грінченка	58
<i>Дорошенко Едуард, Михалюк Євген, Алипова Олена, Марамуха Євгеній, Циганок Владислав, Черепок Олександр</i>	Профілактико-реабілітаційні технології первинних функціональних порушень склепіння стопи у дітей 3-5 років на основі ігрових вправ з елементами футболу	81
<i>Дяченко Андрій, Ван Цянь, Ніконов Димитрій, Го Женхао</i>	Контроль енергетичних реакцій веслувальників на каное на етапі підготовки до вищих досягнень	97



ЗМІСТ

<i>Квасниця Олег, Тищенко Валерія, Латишев Микола, Квасниця Ірина, Омельчук Микола, Кірсанов Микола</i>	Аналіз змагальної діяльності команд з врахуванням результату гри на чемпіонаті Європи з регбі-15	108
<i>Кіндзерська Анастасія, Шинкарук Віктор, Мельніков Андрій</i>	Перспективи використання інформаційних технологій у фізичній підготовці та спорті військовослужбовців	116
<i>Мазін Василь, Оржицький Роман</i>	Використання засобів боксу у процесі фізичного виховання у закладах загальної середньої освіти Європи та України	126
<i>Мітова Олена</i>	Система засобів контролю підготовленості у командних спортивних іграх з позиції системного підходу	139
<i>Приймак Марія, Калита Лариса</i>	Інструментальний PR-портфель фізкультурно-спортивної організації (на матеріалах діяльності НОК України)	152
<i>Сова Володимир</i>	Оцінювання сили нервових процесів (працездатності головного мозку) юних тхеквондистів в процесі тренувальних занять	164
<i>Тищенко Денис, Соколова Ольга, Тищенко Валерія</i>	Функціональні можливості гандболісток високої кваліфікації у підготовчому періоді підготовки	176
<i>Шинкарук Оксана</i>	Розвиток екосистеми кіберспорту на сучасному етапі	188
<i>Ярмоленко Максим, Шинкарук Оксана, Ординський Володимир</i>	Чинники, що впливають на ефективну діяльність тренера в кіберспорті	201



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CHARACTERISTICS OF MODERN TECHNOLOGIES IN THE TRAINING AND COMPETITIVE PROCESS OF ELITE ATHLETES IN SPORTS GAMES

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C – Statistical analysis; D – Manuscript preparation;

E – Manuscript editing; F – Final approval of manuscript

Abstract

Introduction. The integration of modern technologies is crucial for enhancing elite athlete training, offering cutting-edge tools for performance optimization. The widespread use of technology in elite sports, including video assistant referees and wearable sensors, providing real-time biomechanical oversight, challenges related to ethics, data protection, and regulatory frameworks require resolution for widespread implementation.

This study *aims* to conduct a thorough assessment of the integration of modern technologies, specifically examining their efficacy in optimizing the training performance and competitive outcomes of elite athletes in sports games.

Material and Methods. Bibliometric techniques and expert evaluations were used to determine the modern trends in innovative technologies to improve the effectiveness of elite athletes' preparation. A thorough biomechanical analysis utilizing diverse methods was performed on 41 elite athletes in sports games.

Results. The examination of sports science literature and expert assessments unveils predominant trends in the utilization of innovative technologies in elite sports, with a particular emphasis on the widespread adoption of wearable technology, biomechanics and motion analysis, and recovery and regeneration techniques. The outcomes from OpenCap biomechanical analysis show a high correlation ($r=0.99$, $\alpha = 0.05$) between the symmetry of knee joint angles during barbell squats by elite athletes, confirming the efficacy of real-time monitoring exercise techniques. The Romberg coefficient of $194.5\% \pm 2.47$ indicates a notable degree of stability among elite athletes.

Conclusions. This study enhances the comprehension of innovative technologies, exemplified by OpenCap biomechanical analysis, and their effectiveness in optimizing the training performance and competitive outcomes of elite athletes in sports games. The findings provide valuable insights for coaches, sports scientists, and researchers aiming to optimize training methods and elevate athlete performance in sports games.

Key words: sports games; innovational technologies; OpenCap; wearable sensor technologies; artificial intelligence.



ХАРАКТЕРИСТИКА СУЧАСНИХ ТЕХНОЛОГІЙ У НАВЧАЛЬНО-ТРЕНУВАЛЬНОМУ ТА ЗМАГАЛЬНОМУ ПРОЦЕСІ ВИСОКОКВАЛІФІКОВАНИХ СПОРТСМЕНІВ У СПОРТИВНИХ ІГРАХ

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C – аналіз і інтерпретація даних; D – написання статті;

E – редагування статті; F – остаточне затвердження статті.

Анотація

Актуальність. Інтеграція сучасних технологій має вирішальне значення для покращення підготовки висококваліфікованих спортсменів, пропонуючи передові інструменти для оптимізації результативності. Широке використання технологій в спорті вищих досягнень, включно з відео помічниками суддів і переносними датчиками, забезпечення біомеханічного нагляду в режимі реального часу, проблеми, пов'язані з етикою, захистом даних і нормативними засадами, потребують вирішення для широкого їх впровадження.

Мета дослідження – проведення ретельної оцінки інтеграції сучасних технологій, зокрема вивчення їх ефективності в оптимізації результатів тренувань і змагальних результатів висококваліфікованих спортсменів у спортивних іграх.

Матеріал і методи. За допомогою бібліометричних методик та експертних оцінок визначено сучасні тенденції інноваційних технологій для підвищення ефективності підготовки високо-кваліфікованих спортсменів. Ретельний біомеханічний аналіз із застосуванням різних методів був проведений на 41 висококваліфікованому спортсмені в спортивних іграх.

Результати. Вивчення спортивної наукової літератури та експертних оцінок розкриває переважаючі тенденції у використанні інноваційних технологій у спорті вищих досягнень, з особливим наголосом на широкому впровадженні мобільних технологій, біомеханічного та рухового аналізу, а також методів відновлення та регенерації. Результати біомеханічного аналізу OpenCap показують високу кореляцію ($r=0,99$, $\alpha=0,05$) між симетрією кутів колінного суглоба під час присідань зі штангою висококваліфікованими спортсменами, що підтверджує ефективність методів моніторингу вправ у реальному часі. Коефіцієнт Ромберга $194,5\% \pm 2,47$ вказує на помітний ступінь стійкості пози висококваліфікованих спортсменів.

Висновки. Це дослідження покращує розуміння інноваційних технологій, прикладом яких є біомеханічний аналіз OpenCap, і їх ефективності в оптимізації результатів тренувань і змагальних результатів елітних спортсменів у спортивних іграх. Отримані результати дають цінну інформацію для тренерів, спортивних науковців і дослідників, які прагнуть оптимізувати методи тренувань і підвищити результативність спортсменів у спортивних іграх.

Ключові слова: спортивні ігри; інноваційні технології; OpenCap; мобільні сенсорні технології; штучний інтелект.



Introduction

The utilization of modern technologies is pivotal in the training and development of elite athletes in sports games, offering innovative tools and methods to enhance performance, optimize training, and gain a competitive edge [2, 16, 20, 30].

This scientific research delves into the dynamic landscape of technological advancements in elite sports, focusing on wearables and biomechanical control systems.

From video assistant referees in football to advanced pitcher performance analysis in baseball and foot-worn inertial sensors for running economy in distance running, the integration of technology is becoming increasingly prevalent in elite sports [9, 18, 22].

The rapid evolution of these technologies necessitates continuous updates to safety, fair play, and competition integrity regulations to prevent unfair advantages.

Wearable sensor technologies, capable of monitoring, analyzing, and transmitting real-time data, are gaining attention across various industries [3, 8, 10, 14, 17, 18].

This abstract introduces innovative technologies, such as OpenCap [28], for effective biomechanical control in the preparation of elite athletes. The implementation of OpenCap provides real-time data, aiding in identifying technical issues during training and influencing crucial medical decisions for athletes' continued participation.

However, significant technological and regulatory developments are required before widespread adoption for athlete safety. Overcoming ethical and data protection concerns is crucial for wearable

technologies to be backed by quality science.

This manuscript aims to analyze the implementation process of real-time monitoring technology in elite sports, presenting early data collected through Open Cap. Additionally, it guides athletes, coaches, engineers, and administrators for future technological applications in training and major sporting events.

Through a comprehensive review, we emphasize the importance of ethical considerations and the potential for transferring performance-enhancing technologies from elite athletes to broader populations, including recreational athletes, the wellness industry, patients, and emergency services.

Connection with scientific plans, programs, and themes. The study was conducted according to the Plan of scientific research work of the National University of Ukraine on Physical Education and Sport for 2021-2025 under topic 2.2 "Improving preparation for the main macrocycle competitions of Ukrainian national teams in sports games" (state registration number 0121U108185).

The Swiss National Foundation SNF partially supported this study with the project funding of project 192289, "My digital twin is revealing the biomechanics of safe and efficient strength training."

Aim of the study

This study aims to conduct a thorough assessment of the integration of modern technologies, specifically examining their efficacy in optimizing the training performance and competitive outcomes of elite athletes in sports games.

Material and methods

This study granted ethical approval



by the Institutional Ethics Committee, aligns with the ethical guidelines of the Helsinki Declaration and Ukrainian healthcare legislation. All participants provided explicit written consent before data acquisition.

Bibliometric methodologies were employed to systematically retrieve highly cited papers in the field of sports sciences and innovative technologies, encompassing the period from 2003 to 2024.

A panel of 20 sports science specialists and national team coaches aimed to identify prevalent innovative technologies enhancing elite athletes' preparation in sports games.

The biomechanical analyses 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.

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 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.

For mathematical statistics, the degree of agreement between experts' answers was determined using Kendall's concordance coefficient (W). Determination of the normative coefficient of significance, which is the reciprocal of the number of ranked factors.

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 integration of modern technologies in sports training and performance provides unparalleled opportunities for elite athletes. These technologies, ranging from player tracking systems to wearable devices, contribute to optimizing performance, preventing injuries, and gaining a competitive edge. However, their application should be individualized based on athlete needs, guided by qualified coaches and sports scientists [2, 16, 20, 23, 27, 30].

In basketball, various cutting-edge technologies are employed to train elite athletes:

✚ Player Tracking Systems – Utilizing wearable sensors or arena-installed cameras, these systems capture real-time data on player movements, including speed, acceleration, distance covered, and positioning. Examples include SportVU and Second Spectrum.

✚ Virtual Reality (VR) Training – VR technology immerses players in simulated game scenarios, allowing them to practice specific skills, decision-making, and defensive techniques.

✚ Video Analysis Software – Platforms like Sportscode, Hudl, and Synergy Sports offer detailed playback and analysis of basketball footage, aiding in skill refinement and game plan development.

✚ Shooting Analysis Systems – Utilizing sensors or cameras, these systems analyze shooting mechanics, tracking accuracy, release speed, and shooting form. Examples include Noah Basketball and ShotTracker.

✚ Wearable Technology – Devices like smartwatches and fitness trackers monitor metrics such as heart rate, speed, and distance, helping athletes optimize training and recovery. Brands like Whoop

and Garmin are popular in basketball.

✚ Cognitive Training Platforms – These platforms focus on improving decision-making and reaction time through gamified exercises. Examples include FITLIGHT Trainer and NeuroTracker.

✚ Biomechanics Analysis – Systems like KinaTrax, OpenCap and Qualisys use motion capture technology to analyze player movements, optimizing techniques such as shooting form and jumping mechanics.

✚ Mobile Applications – Apps like HomeCourt and Shot Science Basketball offer workout plans, skill development exercises, and video tutorials for basketball training.

It's crucial to select technologies aligned with specific training goals, resources, and individual needs. The application of these innovations varies depending on the athletes' level and available resources.

In volleyball, coaches utilize the "VolleyMetrics" application, developed by Data Project, to analyze and enhance player performance, strategy, and team dynamics. Key features include statistical analysis, video analysis, a tactical board, match simulation, and data sharing, fostering collaboration and informed decision-making.

Similarly, in handball, the "Handball Training App" serves as a comprehensive mobile application for coaches and players. It offers skill libraries, training programs, video analysis, a tactical board, performance tracking, and team communication, contributing to customized training, player development, and effective team strategies.

These innovative programs showcase the dynamic role of technology in optimizing training sessions, enhancing



player development, and improving overall team performance in various sports.

The examination of analytical notes from experts has yielded insights into the prevalent application of innovative technology in high-performance sports across Europe. To ascertain a collective expert opinion on existing innovative technologies, an extensive evaluation of expert assessments was conducted.

A matrix of factor rankings, elucidating each expert's prioritization of tools deemed most significant in their practical endeavors, was devised.

Experts were tasked with assigning numerical values (ranging from 1 to 10) to

these tools based on perceived influence, facilitating the comprehensive analysis of their preferences.

Figure 1 illustrates that wearable technology, biomechanics and motion analysis, as well as recovery and regeneration techniques, emerge as the most favored innovations integrated into the sports process. With a calculated coefficient ($W=0.41$) exceeding the threshold of 0.4, it is substantiated that expert assessments lean towards a positive inclination.

Thus, the formulated hypothesis asserting agreement among specialists is upheld, affirming the reliability of the expert group's questionnaire results.

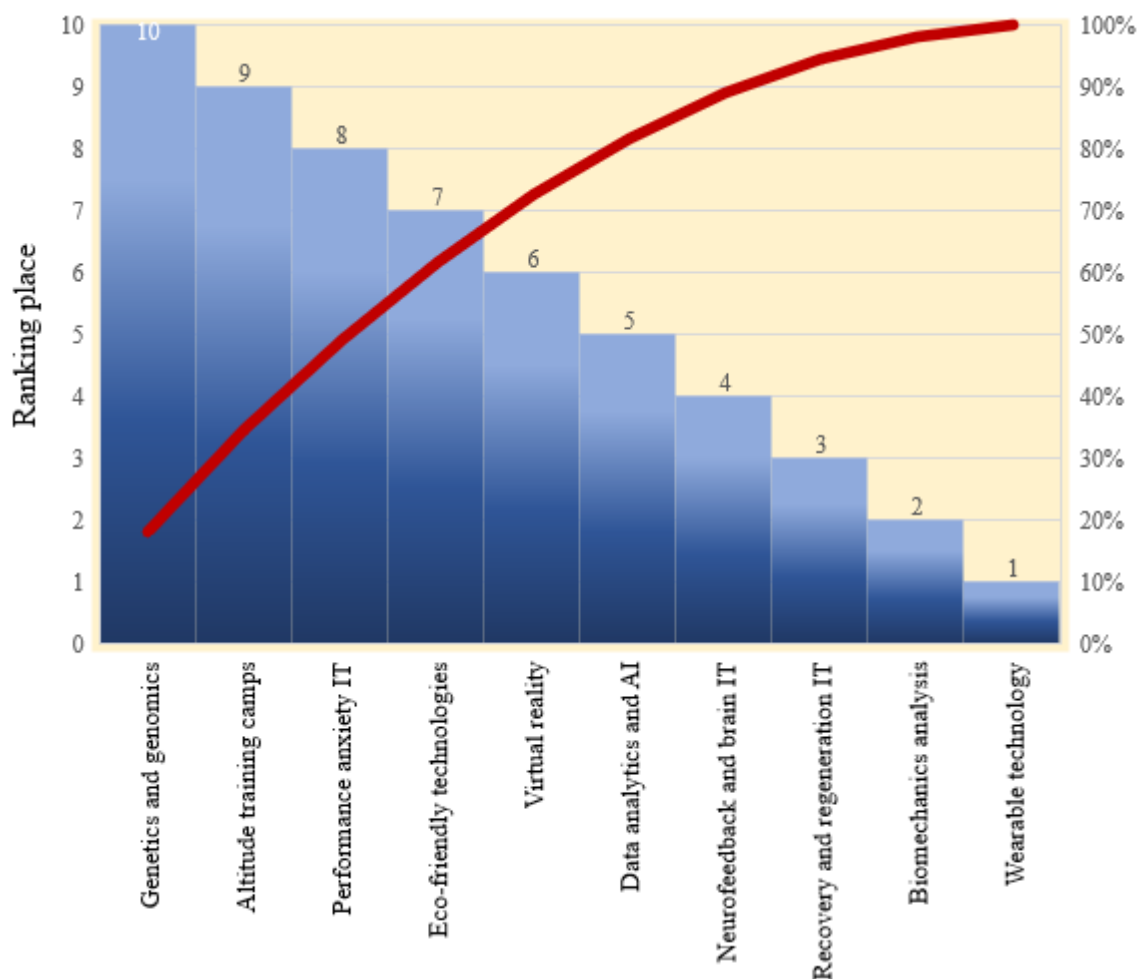


Figure 1 – Ranking of 10 innovation trends in sports according to experts (m=20) survey

Cutting-edge devices enable real-time monitoring of physiological parameters, training loads, and movement patterns, with integrated sensors in smart sports equipment gaining traction.

The wealth of data from wearables aids in refining training, reducing injury risks, and enhancing athletic performance, marking a paradigm shift in sports training.

While laboratory-based motion capture remains the gold standard for biomechanics data, the associated software's reliance on optical marker trajectories and ground reaction forces entails ongoing refinement, leading to increased costs and limited scalability [24,

32, 33].

Through literature analysis, surveys, and expert evaluations, we identified a priority area for applying innovative developments in high-performance sports, with biomechanical analysis playing a crucial role in enhancing sports performance.

The innovative OpenCap in biomechanical analysis sparked our interest, leading to a hypothesis about its efficacy in monitoring athletes' exercise techniques. We focused on the barbell squat exercise, using knee joint angle symmetry as an indicator of effectiveness (Figure 2).

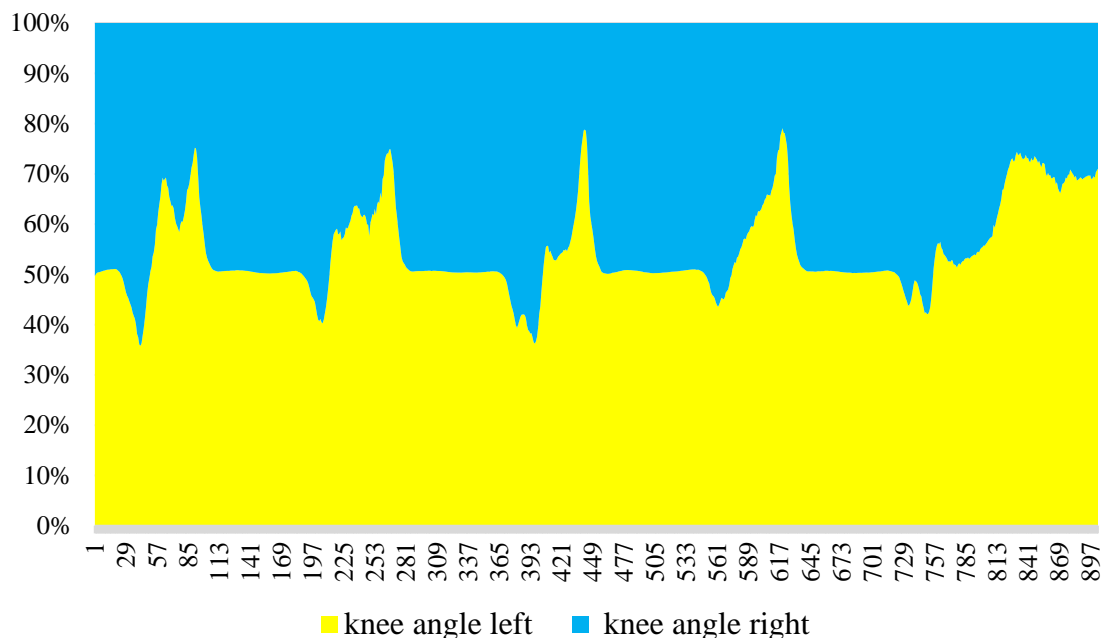


Figure 2 – OpenCap biomechanical analysis of right and left knee angle changes during barbell squats ($r=0,99$)

We determined that the technique of performing squats with a bar by elite athletes is determined by the symmetry of the angle change in the left and right knee joints, which is confirmed by a high correlation at the level of $r=0,99$ at the $\alpha = 0,05$ significance level ($p < 0,05$).

The outcomes derived from the OpenCap biomechanical analysis were substantiated by a notable degree of visual

stability, as indicated by the Romberg coefficient, standing at $194,5\% \pm 2,47$ for elite athletes. A higher percentage in this context signifies superior coordination and training proficiency. Additionally, the assessment of the equilibrium function quality among elite athletes, both with and without visual control, yielded a ratio of $0,88 \pm 0,04$.



Discussion

In the realm of elite sports, contemporary advancements in technology offer unprecedented opportunities for optimizing athlete training, preventing injuries, and enhancing overall performance.

Cutting-edge applications such as Artificial Intelligence (AI) are employed for data analysis, providing valuable insights to athletes and coaches for informed decision-making [13].

Sports genomics, a burgeoning scientific discipline, identifies genetic variants influencing success in specific sports, aiding talent identification and development [29]. The integration of wearable technology, such as heart rate monitors and sleep trackers, has become instrumental in monitoring athlete health, recovery, and performance [4].

Concurrently, research delves into the intersection of athletes' educational development and sporting performance, contributing to a balanced approach in their academic and athletic pursuits [21, 31].

Technological applications have been pivotal in elevating the performance of elite athletes, fostering an understanding of individual behaviors within real-based and ecological contexts [11, 26]. Advances in sports science have revolutionized biomechanical analyses, providing deeper insights into athletes' movements [6, 7, 15, 25].

The integration of quantitative movement analysis is essential for sports optimization, emphasizing the need for scientific validation and nuanced comparisons with traditional laboratory techniques [1, 19, 35].

Innovative technologies, ranging from wearable devices to virtual reality

and data analytics, have transformed athlete preparedness in sports games. Wearable technology provides real-time performance data, including heart rate and distance covered [34].

Virtual reality facilitates simulated game environments for targeted practice and skill enhancement [12]. Data analytics processes vast amounts of performance data to identify patterns and inform strategic decisions [5].

Biomechanical analysis, utilizing motion capture technology, scrutinizes athletes' movements for areas of improvement [11].

This integration of innovative technologies, when aligned with established training principles, holds the potential to revolutionize training methods, enhance competitive performance, and prioritize athlete well-being. By leveraging real-time data, simulating game situations, and analyzing extensive datasets, coaches and athletes can make informed decisions, ultimately propelling athletes to reach their full potential.

Conclusions

This study provides a comprehensive evaluation of the integration of modern technologies, specifically focusing on their impact on optimizing the training performance and competitive outcomes of elite athletes in sports games.

The utilization of diverse technologies, ranging from player tracking systems to biomechanical analysis and cognitive training platforms, exemplifies the dynamic role of technology in enhancing training sessions, player development, and overall team performance across different sports.

The examination of expert assessments and the formulated



hypothesis revealed a prevalent application of innovative technology in high-performance sports, particularly emphasizing the significance of wearable technology, biomechanics, and motion analysis, as well as recovery and regeneration techniques.

Moreover, the study sheds light on the priority area for applying innovative developments in high-performance sports, with biomechanical analysis, exemplified by OpenCap, playing a crucial role in enhancing sports performance.

The detailed analysis of the barbell squat exercise, utilizing knee joint angle symmetry as an effectiveness indicator, demonstrated a high correlation ($r=0.99$) and visual stability, indicating superior coordination and training proficiency among elite athletes.

While the study underscores the potential of modern technologies to revolutionize sports training, it also emphasizes the importance of ethical considerations, data protection, and regulatory frameworks for their widespread implementation.

Overall, the findings contribute valuable insights for coaches, sports scientists, and researchers seeking to optimize training methods and enhance athlete performance in sports games.

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.

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