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The Integrated Application of Virtual and Augmented Reality Technologies in Sports Education

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Abstract: With the rapid advancement of Virtual Reality (VR) and Augmented Reality (AR) technologies, smart sports education is undergoing transformative changes. This paper systematically explores the integrated application of VR and AR in sports education, focusing on practical cases and effectiveness in skill training, tactical rehearsals, and physical fitness assessment. The study demonstrates that VR and AR provide immersive, personalized, and data-driven training environments that significantly enhance athletes' learning outcomes and engagement. Meanwhile, challenges such as hardware costs, interaction experience, instructor training, and data privacy are critically analyzed. The paper further discusses future development trends and promotion strategies, emphasizing the importance of interdisciplinary collaboration and technological innovation to support sustainable advancement in smart sports education.

Keywords: Virtual Reality; Augmented Reality; smart sports education; skill training; data-driven; immersive experience

1. Introduction

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With the rapid advancement of digital technologies, sports education is undergoing a significant transformation. The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies has introduced innovative ways to enhance learning experiences in sports. These immersive technologies enable learners to practice skills, simulate game scenarios, and analyze performance in a highly interactive and controlled virtual environment. In the context of smart sports education—which combines advanced technology, data analytics, and pedagogical innovation—VR and AR provide personalized and adaptive training that improves learning efficiency and deepens student engagement.

Traditional sports education faces many challenges, including limited access to training facilities, constraints due to weather or safety, and the difficulty of offering individualized instruction and real-time feedback. These issues often hinder learners' ability to maximize their training potential. By leveraging VR and AR, many of these limitations can be overcome, providing flexible, immersive, and data-driven approaches to skill acquisition and performance evaluation. However, despite their potential, the widespread adoption of VR and AR in sports education is constrained by factors such as high equipment costs, insufficient high-quality content, and the need for specialized training for educators to effectively utilize these tools.

This study aims to explore the integrated application of VR and AR technologies in sports education, with a focus on advancing smart sports education paradigms. It seeks to analyze current uses, evaluate the benefits and challenges, and propose strategies to

optimize their deployment. The insights from this research are expected to guide educators, developers, and policymakers in harnessing VR and AR technologies to improve sports learning outcomes and foster innovative educational practices [1].

2. The Role and Integration of VR and AR Technologies in Smart Sports Education

2.1. Roles and Advantages of VR and AR in Smart Sports Education

Virtual Reality (VR) technology provides learners with a fully immersive environment by generating comprehensive virtual simulations that facilitate the practice of complex sports skills and tactical strategies without the limitations of physical space or the risk of injury. VR enables the replication of diverse environmental conditions—including weather variations, competitive settings, and opponent behaviors—thereby allowing athletes to adapt and refine their techniques within a controlled and safe context. The immersive nature of VR substantially enhances learner engagement and motivation, which are critical determinants for effective skill acquisition and performance improvement [2].

Conversely, Augmented Reality (AR) superimposes digital information onto the real-world environment, augmenting the learner's perceptual and interactive experience. In the domain of sports education, AR delivers real-time data visualization such as performance metrics, biomechanical feedback, and strategic cues directly within the athlete's field of vision. This immediate and context-sensitive feedback facilitates on-the-spot corrections and informed decision-making during active training sessions. By integrating virtual elements with actual physical practice, AR effectively bridges the gap between theoretical knowledge and practical application.

While VR primarily offers a risk-free simulated environment conducive to the development of cognitive and motor skills, AR enhances real-world training scenarios through supplementary information and guidance. These technologies exhibit complementary characteristics by addressing distinct pedagogical needs and training scenarios. VR is particularly advantageous for immersive skill rehearsal and tactical simulations, whereas AR excels in fostering real-time situational awareness and performance optimization during live practice. The integration of VR and AR within smart sports education frameworks enables personalized, data-driven training approaches tailored to the specific requirements of individual athletes [3].

To elucidate the differentiated yet complementary application domains and functional attributes of VR and AR technologies in smart sports education, Table 1 presents a comparative analysis of their typical application scenarios.

Table 1. Comparison of VR and AR Application Scenarios in Smart Sports Education.

Application Dimension	Virtual Reality (VR)	Augmented Reality (AR)
Key Features	Fully immersive experience creating a complete virtual environment	Real-time overlay of virtual information onto the real world, enhancing reality perception
Typical Use Cases	Skill training simulation (motion reproduction, technical detail practice)	Real-time tactical guidance on the sports field, data overlay display
User Interaction	Body motion capture, controller input, immersive interaction	Gesture recognition, touch control, voice commands interacting with the real environment
Advantages	High immersion, suitable for complex skills and tactical training	Real-time environmental awareness, enhanced auxiliary information display during training

Limitations	Heavier equipment, limited wearing time, potential fatigue	Virtual information affected by lighting and spatial limitations, complex interactions
Typical Application Examples	VR boxing training systems, virtual skiing simulators	AR football tactical training assistance systems, augmented basketball training glasses

2.2. Integrated Application of VR and AR: Case Studies and Practical Insights

The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies in sports education is gaining momentum, with various practical applications demonstrating significant benefits. These cases highlight how combining VR and AR creates immersive and interactive learning environments that enhance athlete training and performance.

One notable example is the use of VR and AR by the U.S. Ski and Snowboard Team. They employ VR simulations to recreate downhill ski courses, allowing athletes to virtually "ski" the course multiple times before competing. This immersive training helps athletes memorize routes, improve reaction times, and mentally prepare for different terrain challenges. Augmented Reality supplements this by providing real-time biomechanical feedback during physical training sessions, enabling coaches to make immediate corrections and optimize athletes' form [4].

In basketball, companies like STRIVR Labs have developed VR training platforms used by NBA teams such as the Dallas Mavericks. Their system combines VR scenarios with AR overlays to simulate in-game situations, enhancing players' decision-making skills under pressure. Players can practice offensive and defensive plays in a virtual environment while receiving augmented cues and stats displayed in real time. This integration helps bridge the gap between theoretical tactics and real-court execution.

Another example is the application of VR and AR in rehabilitation and injury prevention. The Australian Institute of Sport uses VR environments to simulate dynamic sports scenarios that safely challenge injured athletes' balance and coordination. AR devices, meanwhile, provide therapists with data overlays showing muscle activation and movement patterns during therapy, allowing personalized adjustments to recovery programs.

These cases illustrate the practical benefits of integrating VR and AR in sports education: improving cognitive and physical skills, enabling safe and repetitive practice, and facilitating data-driven, individualized coaching. They also highlight the need for continued development of hardware compatibility and software content to fully harness the potential of these technologies in diverse sports disciplines [5].

2.3. Smart Sports Education: Definition, Core Elements, and Technological Framework

Smart sports education refers to the integration of advanced technologies-including Virtual Reality (VR), Augmented Reality (AR), artificial intelligence (AI), big data analytics, and wearable devices-into traditional sports teaching and training processes. Its primary goal is to create intelligent, personalized, and data-driven learning environments that optimize athlete performance and enhance educational outcomes.

The core elements of smart sports education include:

- 1) Intelligent Systems: Utilization of AI algorithms to analyze athletes' performance data, predict injury risks, and provide customized training plans.
- 2) Data-Driven Decision Making: Collection and real-time analysis of various physiological and biomechanical data through sensors and wearable devices, enabling evidence-based coaching.
- 3) Personalization: Adaptive training programs tailored to individual athletes' strengths, weaknesses, and learning progress, facilitated by interactive technologies like VR and AR.

- 4) Interactivity and Immersion: Use of immersive VR environments and AR overlays to engage learners actively and simulate real-world sports scenarios for effective skill acquisition.

The technological framework of smart sports education integrates hardware and software components, including motion capture systems, VR headsets, AR glasses, sensor networks, and cloud computing platforms. These components work synergistically to collect, process, and visualize data, enabling seamless interaction between athletes, coaches, and digital systems.

Emerging trends in smart sports education emphasize greater connectivity through the Internet of Things (IoT), enhanced AI-driven analytics, and the expansion of mixed reality environments combining VR and AR. Such developments promise to further improve the precision, accessibility, and scalability of sports training and education.

3. Current Status and Practical Applications of VR and AR Technologies in Sports Education

3.1. Technical Application Case Studies

3.1.1. Skill Training and Motion Simulation

The Canadian National Football Team leverages the VR training platform developed by EON Sports VR to simulate complex on-field scenarios. This system immerses athletes in high-fidelity virtual environments that replicate actual game conditions, including dynamic opponent behaviors and weather variations. By allowing quarterbacks and receivers to rehearse plays repeatedly, the platform enhances their decision-making speed and spatial awareness without the risk of physical fatigue or injury. EON Sports VR also incorporates motion tracking and biomechanical analysis, enabling coaches to provide precise feedback on athletes' techniques.

In baseball, HitTrax combines sensor technology with VR to revolutionize batting practice. Players use real bats equipped with sensors that capture swing speed, angle, and contact point. This data is then visualized within a virtual ballpark environment, enabling athletes to analyze their swing mechanics and adjust in real time. The immersive experience helps players maintain focus and replicates the pressure of actual games, fostering skill refinement under simulated competitive conditions [6].

3.1.2. Sports Scene Reproduction and Tactical Drills

FC Barcelona has pioneered the use of Augmented Reality to enhance tactical understanding during training. Through AR headsets like Microsoft HoloLens, coaches overlay virtual formations, movement paths, and strategic annotations directly onto the pitch. Players interact with these augmented elements while executing drills, deepening their comprehension of team tactics and spatial positioning. This approach not only accelerates learning but also facilitates real-time tactical adjustments during practice.

Similarly, the Chicago Blackhawks employ VR simulations to prepare for upcoming opponents. Their system recreates specific game scenarios based on opponent tendencies and strategies. Players navigate these virtual simulations to practice situational plays, improving reaction times and communication under pressure. This method reduces physical strain while allowing frequent repetition of critical tactical moments.

3.1.3. Physical Fitness Assessment and Feedback

The U.S. Olympic Training Center integrates AR with wearable sensor technologies to enhance athlete evaluation and rehabilitation. Sensors capture detailed biomechanical data, including joint angles, muscle activation, and balance metrics during exercises. Coaches and medical staff use AR devices to visualize this data superimposed on the athlete's body in real time, enabling immediate identification of movement inefficiencies or injury risks. This real-time feedback loop supports personalized training adjustments and accelerates recovery.

NeuroTracker, a cognitive training system utilized by multiple professional sports teams, employs VR-based multi-object tracking exercises to improve athletes' visual attention and processing speed. The system tracks athletes' progress quantitatively, and research shows improvements in both cognitive function and physical performance metrics such as reaction time and decision-making accuracy. This fusion of cognitive and physical training represents an innovative frontier in sports education technology [7].

3.2. Teaching Model Transformation

The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies is fundamentally transforming traditional sports education models. Conventional methods, often limited by physical space, equipment, and instructor availability, are evolving into dynamic, technology-enhanced learning environments that emphasize interactivity, personalization, and data-driven feedback.

One significant change is the shift from instructor-centered teaching to learner-centered, experiential learning. VR and AR provide immersive platforms where learners actively engage in simulated sports scenarios rather than passively receiving instructions. This experiential approach enhances motivation and deepens understanding by allowing repeated practice in varied contexts, promoting skill acquisition and retention.

Moreover, VR and AR facilitate real-time feedback and performance analysis. Sensors and motion tracking integrated with these technologies collect precise data on athletes' movements and physiological responses. This data is immediately processed and visualized through VR/AR interfaces, enabling learners and coaches to identify technical flaws and adjust training strategies promptly. Such immediacy and precision in feedback were difficult to achieve in traditional settings.

The teaching model also becomes more flexible and accessible. Virtual environments remove constraints related to weather, location, and safety, allowing athletes to train anytime and anywhere. This flexibility supports differentiated instruction tailored to individual learner needs, an essential feature of smart sports education.

Furthermore, collaborative learning is enhanced as VR and AR enable remote team training and tactical rehearsals. Athletes and coaches can connect through shared virtual spaces to conduct joint sessions despite geographical barriers, fostering communication and teamwork [8].

In summary, VR and AR technologies are driving a paradigm shift in sports education from rigid, uniform instruction to adaptive, interactive, and learner-focused models. This transformation aligns with the broader goals of smart sports education by leveraging technology to optimize training effectiveness and learner engagement.

3.3. Learning Outcomes and User Experience Evaluation

Evaluating the impact of VR and AR technologies in sports education involves assessing both objective learning outcomes and subjective user experiences. Objective measures typically include improvements in athletes' skill proficiency, reaction times, accuracy, and physical performance metrics. These data are often collected through sensors, motion capture systems, and performance tracking software embedded within VR/AR platforms. For example, motion sensors can quantify changes in movement precision or speed, while heart rate monitors and other physiological devices track endurance and fatigue levels. These metrics provide concrete evidence of skill development and physical improvements resulting from immersive training.

Subjective evaluation focuses on users' perceptions of the technology, including usability, engagement, motivation, and overall satisfaction. Standardized questionnaires, such as the System Usability Scale (SUS) and Presence Questionnaire (PQ), are frequently employed to gauge how intuitive and immersive the VR/AR systems feel to athletes. Additionally, interviews and focus groups help capture qualitative feedback on user comfort, perceived benefits, and challenges experienced during training [9].

Combining these quantitative and qualitative approaches provides a comprehensive understanding of how VR and AR tools influence both performance and learner acceptance. Studies consistently find that immersive technologies enhance motivation and engagement, which correlate with improved learning outcomes. However, user discomfort, such as motion sickness or hardware weight, can negatively affect experience and should be addressed in system design.

Continuous evaluation and iteration based on user feedback and performance data are critical to optimizing VR/AR applications in sports education, ensuring they meet the needs of diverse athletes and training goals.

Table 2 summarizes common evaluation dimensions, specific indicators, and typical assessment methods used in the study of user experience and learning outcomes for VR/AR-based sports education systems:

Table 2. User Experience Evaluation Indicators.

Evaluation Dimension	Specific Indicators	Assessment Methods	Description
Learning Outcomes	Skill proficiency, accuracy, reaction time	Experimental measurement, motion capture analysis	Assess skill improvement and movement quality
User Satisfaction	Satisfaction rating, recommendation willingness	Surveys, interviews	Reflect overall system acceptance
Usage Frequency	Weekly usage frequency, session duration	Usage logs, self-report	Measure user engagement and retention
Interaction Experience	Ease of operation, system responsiveness	Usability testing, observation	Evaluate smoothness of user-system interaction
Physical Comfort	Fatigue, incidence of motion sickness	Self-reported questionnaires	Assess comfort during device use
Motivation and Engagement	Learning enthusiasm, training willingness	Interviews, behavioral observation	Reflect user's psychological acceptance and drive

4. Challenges Faced by VR and AR Technologies in Sports Education

4.1. Technical and Equipment Limitations

Virtual Reality (VR) and Augmented Reality (AR) technologies face several technical and equipment limitations that restrict their effectiveness in smart sports education.

The high cost of VR headsets, AR glasses, and motion capture devices limits accessibility for many institutions and sports teams, especially at grassroots levels. These expenses pose significant challenges for widespread implementation.

Current VR/AR devices tend to be bulky and uncomfortable for extended wear. Users often experience fatigue in the head and neck during training, which affects the duration and quality of practice sessions. Moreover, device designs lack sufficient adaptability for different sports and individual body types, restricting their versatility.

Interaction accuracy and system latency also affect training quality. Precise and timely motion tracking is essential for effective sports training. Any delay or inaccuracy in capturing movements can lead to distorted feedback and improper technique correction. Sensor limitations, processing speed, and wireless transmission constraints contribute to these issues.

These technical and hardware challenges need to be addressed to enhance VR and AR usability and adoption in sports education.

4.2. Challenges in Education and Training

The integration of VR and AR technologies into sports education introduces several challenges in the educational and training processes. One major issue is the shortage of instructors who are adequately trained to utilize these advanced technologies effectively. Many educators lack experience with VR/AR tools, which hinders their ability to design and implement effective training programs.

Additionally, there is a scarcity of high-quality, sport-specific VR and AR content tailored to different disciplines. Developing such content requires significant expertise and resources, and the current lack limits the versatility and appeal of these technologies across various sports.

Resistance to adopting new teaching models also presents a challenge. Traditional sports education often relies on in-person, hands-on coaching methods, and both coaches and athletes may be reluctant to shift to technology-driven approaches. This resistance slows down the integration of VR and AR into established training regimes.

Moreover, integrating VR and AR systems into existing curricula and training schedules is complicated. Ensuring that immersive technology complements rather than disrupts traditional practices requires careful planning and adjustment.

These educational and training challenges must be addressed to fully harness the potential of VR and AR in advancing sports education.

4.3. Data Privacy and Security Challenges

The use of VR and AR technologies in sports education involves extensive collection and processing of athletes' personal and performance data, raising significant concerns about data privacy and security. Sensitive biometric data, movement patterns, and health information are continuously gathered through sensors and wearable devices during training sessions.

Protecting this data from unauthorized access, breaches, or misuse is critical. However, many current systems lack robust security frameworks, making them vulnerable to cyberattacks or data leaks. Additionally, the legal and ethical standards governing the collection, storage, and sharing of such data are still evolving, creating uncertainty for both institutions and users.

Ensuring compliance with data protection regulations, such as GDPR or similar local laws, adds complexity to the deployment of VR/AR technologies in sports contexts. Moreover, athletes and coaches may have concerns about how their data is used, which can affect their willingness to fully engage with these technologies.

Addressing these privacy and security challenges requires the development of stringent data management policies, secure technical architectures, and transparent user consent mechanisms. Only by safeguarding athlete data can VR and AR systems gain trust and wider acceptance in sports education.

4.4. User Acceptance and Usability Issues

The successful implementation of VR and AR technologies in sports education depends largely on user acceptance and system usability. Despite their advanced capabilities, these technologies face several barriers related to how athletes and coaches perceive and interact with them.

Firstly, athletes and instructors may exhibit resistance to adopting new technological tools, often due to unfamiliarity, skepticism about effectiveness, or preference for traditional training methods. This reluctance can limit the frequency and depth of VR/AR integration in training programs.

Secondly, the complexity of VR and AR systems can pose a steep learning curve. Without adequate training and intuitive design, users may find it difficult to navigate the interfaces, reducing engagement and leading to frustration.

Physical discomfort is another significant issue. Some users experience motion sickness, dizziness, or eye strain during VR sessions, which negatively impacts their training experience and limits session duration.

Finally, the portability and setup requirements of current VR/AR hardware may not always align with the dynamic environments typical of sports training, restricting their practical usability.

Overcoming these acceptance and usability challenges requires user-centered design improvements, comprehensive training for both coaches and athletes, and ongoing technical support to ensure smooth and effective use of VR and AR technologies in sports education.

5. Future Development Trends and Strategic Recommendations

5.1. Technological Development Trends

Virtual Reality (VR) and Augmented Reality (AR) technologies are evolving rapidly, offering promising advancements that will further enhance their applications in smart sports education. One key trend is the deep integration of Artificial Intelligence (AI) and big data analytics, which can enable more personalized and adaptive training programs. AI algorithms can analyze vast amounts of performance data to provide tailored feedback, optimize training intensity, and predict injury risks.

The deployment of 5G networks and cloud computing infrastructure is another significant trend. These technologies support real-time, low-latency data transmission and processing, facilitating seamless immersive experiences and enabling remote collaborative training sessions without geographical constraints.

Mixed Reality (MR), which combines elements of VR and AR, is gaining traction as a next-generation platform. MR allows users to interact with both virtual and real-world objects simultaneously, offering richer and more flexible training environments that can simulate complex sports scenarios with high fidelity.

In addition, advancements in hardware design aim to create lighter, more comfortable, and more portable devices, improving usability and allowing longer training sessions without discomfort. Improvements in haptic feedback and multisensory technologies will further increase immersion and realism, enhancing skill acquisition and motivation.

These technological developments collectively promise to expand the scope and effectiveness of VR and AR in sports education, driving the evolution of smarter, more engaging, and accessible training solutions.

5.2. Innovation in Educational Models

The continuous advancement of VR and AR technologies is driving significant innovation in sports education models. Traditional instructor-led, location-bound training is gradually transforming into immersive, learner-centered experiences that emphasize active participation and personalized development.

One emerging model is the integration of adaptive learning systems powered by AI, which adjust training content and difficulty in real time based on the athlete's performance and feedback. This approach maximizes training efficiency by catering to individual strengths and weaknesses, fostering accelerated skill improvement.

Remote and collaborative training environments enabled by VR and AR are also reshaping how teams and coaches interact. Athletes can participate in virtual group sessions regardless of physical location, facilitating tactical rehearsals, peer learning, and enhanced communication [10].

Moreover, immersive simulation-based assessments are becoming integral to evaluating athletes' tactical decision-making, spatial awareness, and motor skills in dynamic, realistic scenarios. This allows for more comprehensive and objective performance evaluations beyond traditional tests.

To fully realize these innovations, sports education institutions need to redesign curricula to integrate immersive technologies effectively and provide comprehensive training for coaches and educators. This paradigm shift requires balancing technological possibilities with pedagogical principles to optimize learning outcomes.

5.3. Data Security and Privacy Protection Strategies

The increasing use of VR and AR technologies in sports education involves extensive collection of athletes' personal and performance data, making data security and privacy protection essential. Establishing comprehensive data protection policies is crucial to ensure that sensitive biometric and behavioral information is handled responsibly.

Technical strategies such as data encryption, secure authentication, and strict access control should be implemented to safeguard data during collection, transmission, and storage. Additionally, compliance with relevant legal frameworks, such as the General Data Protection Regulation (GDPR) and local privacy laws, must be ensured.

Transparent user consent mechanisms and clear communication about data usage can build trust among athletes and coaches, encouraging broader acceptance of VR and AR systems. Education and training on data privacy awareness are also important components.

By prioritizing data security and privacy, institutions can protect user rights, comply with legal requirements, and support the sustainable development of immersive sports education technologies.

5.4. Application Promotion Strategies

To fully leverage the potential of VR and AR technologies in sports education, a multi-faceted approach to promotion and adoption is necessary. The following strategies can facilitate widespread application and sustainable development:

- 1) Enhancing Teacher Training and Professional Development: Establish systematic training programs and certification courses for coaches and educators to improve their proficiency with VR/AR tools. Encourage knowledge exchange through workshops, seminars, and online platforms, fostering a community of practice around immersive sports education.
- 2) Strengthening Policy Support and Funding Mechanisms: Advocate for targeted policies that incentivize innovation in sports technology. Governments and educational institutions should allocate grants and subsidies to support research, infrastructure development, and pilot projects focused on VR/AR in sports training.
- 3) Encouraging Cross-sector Collaboration: Promote partnerships among technology companies, universities, sports organizations, and healthcare providers to co-develop tailored VR/AR content, share expertise, and integrate multidisciplinary insights, ensuring solutions meet practical training needs and scientific standards.
- 4) Improving User-Centered Design: Involve end-users-athletes, coaches, and students-in the design and testing phases to optimize hardware ergonomics, software interfaces, and interaction modalities. Address common pain points such as device comfort, ease of use, and motion sickness to enhance overall experience.

- 5) Expanding Accessibility and Infrastructure: Invest in affordable, portable VR/AR equipment and develop cloud-based platforms that lower barriers for schools and clubs with limited resources. Explore mobile and wireless solutions to support training in diverse environments, including remote and outdoor settings.
- 6) Raising Awareness and Demonstrating Effectiveness: Launch awareness campaigns highlighting successful case studies and evidence-based benefits of VR/AR in sports education. Organize demonstration events, competitions, and pilot programs to showcase practical applications and build user confidence.
- 7) Establishing Evaluation and Feedback Systems: Implement standardized frameworks to assess training outcomes and user satisfaction continuously. Use feedback to iteratively improve technologies, training protocols, and content relevance.

Through these integrated strategies, VR and AR technologies can achieve broader acceptance, improved effectiveness, and long-term sustainability in transforming sports education.

6. Conclusion

This study systematically examined the integrated application of Virtual Reality (VR) and Augmented Reality (AR) technologies in the field of smart sports education. The analysis demonstrated that VR and AR serve as powerful tools to create immersive, interactive, and personalized learning environments that significantly enhance athletes' skill development, tactical understanding, and physical conditioning. Their ability to simulate realistic sports scenarios, provide immediate feedback, and enable data-driven training interventions marks a transformative shift from traditional sports education methods to a more intelligent and adaptive paradigm.

However, despite the promising advancements, this paper also identified several critical challenges hindering the full-scale adoption of VR and AR in sports education. These include high hardware costs, equipment ergonomics issues, limitations in interaction precision, insufficient professional training for educators, lack of tailored content, and complex data privacy and security concerns. Furthermore, user acceptance and system usability remain key factors that influence the effectiveness of immersive technologies in real-world training contexts.

Looking forward, the convergence of emerging technologies such as artificial intelligence, 5G networks, cloud computing, and mixed reality holds great potential to overcome current limitations. Coupled with strategic efforts in policy support, interdisciplinary collaboration, and user-centered design, these developments will facilitate more scalable, efficient, and engaging applications. Consequently, VR and AR are poised to revolutionize sports education by fostering individualized learning experiences, expanding remote training possibilities, and ultimately contributing to the holistic development and performance enhancement of athletes. Future research should focus on longitudinal empirical studies, standardized evaluation frameworks, and the ethical governance of data to ensure sustainable and responsible integration of these cutting-edge technologies in the sports domain.

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