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Virtual and Augmented Reality Technologies in the Modern Sports Ecosystem: Current Applications, Challenges, and Future Prospects

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Abstract:
This systematic review was designed to examine the current deployment of virtual and augmented reality technologies within the broader sports domain, based on peer-reviewed articles published between 2019 and 2026 across major scientific databases, including Scopus and Web of Science. Adhering to the PRISMA flow diagram and applying strict inclusion and exclusion criteria, we screened and analyzed around 50 relevant studies. The review showcases a range of contemporary VR/AR applications that have proven effective, categorizing them according to sport type and the specific athletic skills they target. Additionally, it outlines the primary challenges spanning economic, technical, health, and psychosocial dimensions that currently restrain their widespread adoption, while also pointing to promising future directions. Crucially, the review recommends that these technologies be integrated as complementary rather than standalone training instruments. Alongside this, sustained investment in further research is urged to address prevailing knowledge gaps, thereby ensuring that future implementation rests on a sound and rigorous scientific footing.
Keywords: Virtual Reality; Augmented Reality; Sports Applications; Athletic Performance; Systematic Review.

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1. INTRODUCTION

In the light of the sweeping technological revolution witnessed across major fields and exact sciences in recent years, sport has not been immune to this transformation. (In the light of the rapid technological revolution that has happened recently in major fields of human life and even in exact sciences as well, sport has not been immune to this transformation) It has been evolved into a complex social phenomenon and a mirror that reflects the development of nations and peoples. The prominent status of sport in advanced societies has positioned it at the intersection of critical sectors such as education, health, and tourism. At the same time it brings sports into a closer convergence with even more significant domains like politics, economics, and commerce.(while also drawing it into closer convergence with even more consequential domains like politics, economics, and commerce.) This technological revolution has radically reshaped the sporting environment. What was once a simple tool , for example (such as the) a stopwatch, has given way to far more sophisticated instruments like sensory sensors, new measurement devices and smart watches and glasses. They were all developed within dedicated laboratories and large-scale research centers. If this shift indicates anything, it is the extent to which sport has come to be regarded as a field of considerable importance, thus making it one of the sciences that has benefited most from the modern technological revolution.

The attainments of the modern technological revolution in sports has reshaped the very form of athletic practice, training, rehabilitation and recovery (Sports embrace of the modern technological revolution has reshaped the very form of athletic practice, training, rehabilitation and recovery) It has touched even the spectacularity of sporting competitions through the emergence of new technologies that introduced an invisible second dimension for athletes, competitors, and coaches alike. Thereby it has transformed the methods and approaches underpinning sport. Among these modern technologies are virtual reality and augmented reality, which integrate the physical world with the digital one, giving rise to new ways of training, analytical, and interactive spaces that would have been inconceivable to the human mind only a few years earlier. These spaces have propelled the applications and platforms they enable to the forefront of the modern tools now demanded across the sporting world, whether by practitioners, coaches, or spectators.

The adoption of these technologies has gone beyond mere option. Being formally embraced by the governing bodies, major federations, and global clubs

alike, they have become an institutional imperative for some in recognition of the substantial benefits these platforms and applications offer. Among the most prominent institutions to have incorporated the latest research-driven tools into their policies is the National Football League (NFL), which was among the first to partner with the virtual-reality platform (STRIVR) to support the players development (Union, 2023). Likewise, the English Premier League (EPL) was among the earliest organizations to establish a partnership with the British virtual-reality company Rezzil, drawing on its training programs and match-analysis capabilities within a supportive digital environment. This partnership grants direct access to Premier League match data, enabling clubs to adapt their training programs and to represent and replay match scenarios using virtual-reality headsets. (Premier League Signs Four-Year Deal with Manchester VR Developer - Prolific North, n.d.)

Based on recent reports and studies, the market for virtual and augmented reality in the sports sector is projected to grow substantially in the coming years. This growth is being driven by the increasing adoption and mainstreaming of these technologies, not only within clubs and sports federations but also across other economic sectors (Ozturk et al., 2025). Such a trajectory clearly signals the emerging direction toward these technologies, especially in the light of the ongoing advancements in digital tools and technological infrastructure.

Reports and studies are pointing toward a significant boom in the virtual and augmented reality market within the sports industry over the next few years. Clubs and sports federations are increasingly embracing these tools, and they're becoming more widespread across other economic sectors too (Ozturk et al., 2025). To us, this trend speaks volumes about where the future is heading, especially when we witness rapid technological advances in hardware and software alike.

Based on the above, this study aims to take a closer look on how virtual and augmented reality applications and platforms are actually being used in modern sport. Our goal is to shed light on these technologies, assess their effectiveness across various domains including training, injury rehabilitation, recovery, and spectators' experiences as well, and to offer a critical perspective grounded on the real-world practice.

In doing so, we conduct a systematic review of recent studies and research published between 2019 and 2026. We also seek to identify the most prominent challenges that limit the widespread adoption of these applications, while exploring what the future might hold for them. Based on this, the central problem of our research focuses on the following question as the main:

To what extent are modern technological tools specifically Virtual Reality (VR) and Augmented Reality (AR) being employed in contemporary sport? And how effective are they in enhancing athletic performance and improving the training process according to current research and studies?

From this overarching question, several sub-questions emerge:

What are the most significant recent applications of VR/AR technologies in the field of modern sport?

How effective are these technologies in improving athletic performance and advancing the training process, based on the latest research and studies?

What are the main challenges and obstacles hindering the integration of VR and AR technologies in the sports sector?

What does the future hold for virtual and augmented reality technologies in modern sport?

2. SEARCH STRATEGY AND STUDY SELECTION

To ensure transparency, maintain rigor in the literature selection process, and minimize bias, the initial search yield was subjected to a multi-stage filtering and screening procedure based on the predefined inclusion and exclusion criteria. We adopted the internationally recognized PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to track the flow of studies through four essential phases: identification, screening, eligibility, and inclusion.

2.1 Phase One: Identification

Using the following keywords "Virtual Reality," "Augmented Reality," "VR Training AND Sports Science," and "Sport" the initial search returned a total of 779 records. The search was restricted to studies published between 2019 and 2025, ensuring that the scientific data remained current and aligned with the rapid technological advancements in this field. The results were distributed across databases as follows: Scopus (n = 251), Web of Science (n = 204), PubMed (n = 159), and Google Scholar (n = 165).

2.2 Phase Two: Screening

Before commencing the screening process, 193 duplicate records were removed using Zotero, which was also employed for citation management

throughout the review. Subsequently, 586 records were screened by examining their titles and abstracts. Of these, 316 studies were excluded for failing to meet the inclusion criteria, for the following reasons:

- Studies published in languages not eligible for inclusion (n = 65).
- Opinion pieces, editorials, and non-peer-reviewed commercial reports (n= 63).
- Studies published prior to 2019 (n = 87).
- Full-text unavailability (n = 101).

2.3 Phase Three: Eligibility

- A total of 270 full-text studies were assessed for eligibility. Following complete reading, 218 studies were excluded for specific reasons, including:
- Full-text still unavailable (n = 74).
- Insufficient outcome data to address the research questions (n = 59).
- Studies focusing exclusively on medical or educational applications (n = 39).
- Studies not directly related to the sports domain (n = 46).

2.4 Phase Four: Inclusion

Following the full eligibility assessment, 52 studies were ultimately deemed suitable for inclusion in the final analysis

Inclusion and Exclusion Criteria: A set of key criteria was relied upon in the selection of studies:

Inclusion Criteria	Exclusion Criteria
• Peer-reviewed scientific papers published in recognized academic journals or indexed conference proceedings. • Research addressing virtual and augmented reality technologies within the broader sports domain. • Studies published within the period spanning 2019 to 2026, ensuring the recency and relevance of the scientific evidence. • Studies written in English, French, or Turkish. • Studies available in full text or, at minimum, with substantial content accessible for meaningful analysis.	• Non-peer-reviewed publications, including commercial reports, blogs, journalistic articles, and unverified industry reports. • Studies addressing virtual or augmented reality solely within non-sports contexts, such as education or medicine, with no clear connection to sports. • Studies published prior to 2019, owing to their lack of timeliness relative to the rapid technological evolution in this field. • Studies available only as brief abstracts, or those published in languages not comprehensible to the research team.

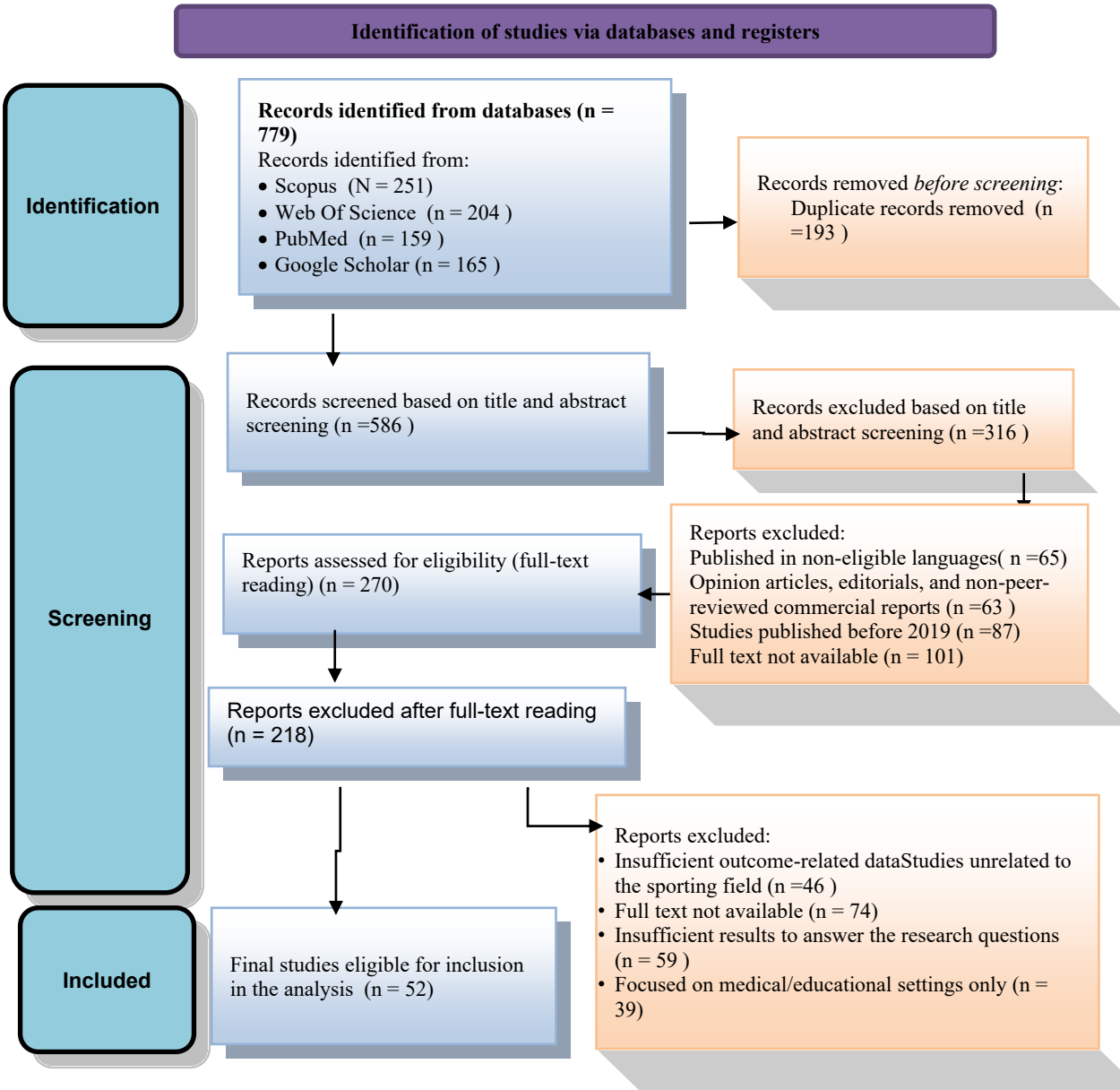


Fig.1. Illustrates the PRISMA flow diagram for the study selection and screening process of scientific papers (2019–2026)

3. OVERVIEW OF VIRTUAL REALITY AND AUGMENTED REALITY TECHNOLOGIES

3.1 Virtual Reality (VR)

Virtual reality (VR) can be defined as a modern technology in which computer-generated simulations are used to create a digital environment that closely approximates the real world. This simulation is experienced through assistive devices such as head-mounted displays and screens that allow users to become fully immersed in a virtual environment and interact with it in ways that closely mimic real-life physical engagement. Initially, this technology was utilized primarily in gaming and entertainment; it has since expanded into other domains, including education, training, and therapy (Yang & Hu, 2024).

VR offers a wide range of advantages, but four stand out as particularly central: immersion, interactivity, presence, and togetherness. A brief explanation of each is provided below:

Immersion: refers to the user's sense of being entirely part of the virtual world. This is achieved through advanced audiovisual technologies that engage the senses, creating a realistic experience that captures attention and diminishes awareness of the external physical environment.

Interactivity: denotes the user's capacity to engage with and influence the virtual environment.

Presence: refers to the genuine feeling of actually existing within a multi-dimensional virtual space.

Togetherness describes the ability for one or more users to enter the same digital environment simultaneously and communicate with one another through voice and visual channels.

In addition to the customizability inherent in virtual reality environments, these combined features render VR as a uniquely rich and versatile technology for users (Elsholz et al., 2024).

3.1.1 How Virtual Reality (VR) Works:

Virtual reality operates by constructing a parallel digital space that mirrors the real world, typically through a sequence of interconnected steps:

First: Creating the Digital Environment

The process begins with the development of three-dimensional scenes designed to replicate the target reality. This involves the use of sophisticated algorithms to generate digital shapes, textures, and materials, while carefully applying lighting effects that enhance the sense of authenticity and bring the virtual world closer to real-life perception (Yang & Hu, 2024).

Second: Display and Immersion

Through the use of head-mounted displays or specialized screens, users are provided with a wide field of view and high-resolution imagery. This minimizes pixelation, reduces visual strain, and significantly enhances the sense of immersion within the digital environment.

Third: Tracking

To accurately detect head orientation and movement, precise sensors are employed. Based on the data captured, the virtual scene is updated in real time or entirely new perspectives are generated according to two primary tracking modes:

3DoF (Three Degrees of Freedom): This mode tracks rotational head movements only (such as looking left, right, up, or down) from a fixed point in space.

6DoF (Six Degrees of Freedom): This mode tracks both rotational and translational movements (forward, backward, sideways, up, and down), allowing users to walk and physically navigate through the virtual environment (Wang et al., 2026).

Fourth: Interaction

Using input devices such as handheld controllers or motion-tracking sensors for hands and body, users are able to grasp virtual objects, manipulate their surroundings, and actively influence the course of events within the virtual space.

3.2 Augmented Reality (AR)

Augmented reality (AR) is a contemporary technology that fundamentally builds upon real-world scenes by enhancing them with digital media such as images, texts, and animations to create a new, enriched environment. Unlike virtual reality, which isolates users from their external surroundings, AR supplements physical reality with virtual technological overlays that appear to exist tangibly within the user's actual environment (Peng et al., 2026). This is achieved through the use of advanced cameras to capture images from the real world, which are then processed using complex algorithms to integrate new digital media while ensuring precise spatial placement (Yang & Hu, 2024) .The AR experience is delivered through a range of technological devices, including smartphones, screens, and specialized headsets (Modlin & Kuo, 2025).

3.2.1 How Augmented Reality (AR) Works

The fundamental principle of AR is to augment and enhance real-world reality with digital media, rather than constructing an entirely new environment from scratch. This process operates through the following mechanisms:

First: Image Capture and Processing

A live image of the physical world is captured using high-quality imaging devices such as smartphones, screens, or cameras.

Second: Recognition and Spatial Localization

Using complex algorithms, the captured image is analyzed to identify surfaces and physical objects within the scene (Yang & Hu, 2024)

Third: Compositing

Once the images have been acquired and analyzed, digital media are inserted into them, with careful attention to correct spatial positioning that aligns with the needs of the new augmented reality context. (Modlin & Kuo, 2025)

Fourth: Real-Time Spatial Registration

Through the use of large-capacity storage systems that retain image data, continuous spatial registration is maintained to ensure that the augmented digital environment remains accurate even as the scene changes or the camera's position shifts (Wang et al., 2026)

Fifth: Display

Similar to virtual reality, AR content is displayed, but with greater flexibility. This can be achieved through smartphone screens or smart glasses, which allow users to perceive the physical world alongside the digital information overlaid upon it (Yang & Hu, 2024)

3.3 Key Differences Between Virtual Reality and Augmented Reality

The fundamental distinction between virtual reality (VR) and augmented reality (AR) lies in how each technology engages with the real world and the extent to which users are immersed in the digital environment. These differences can be outlined as follows:

3.3.1 Environment and Technical Objective

- **Virtual Reality (VR):** This is a contemporary technology in which a computer-generated environment is created to fully replicate the real world. Users are entirely isolated from their physical surroundings and placed within a fully three-dimensional virtual space (Peng et al., 2026)
- **Augmented Reality (AR):** This is a more recent development than VR. It works by enhancing the real-world environment with new digital media and information such as images, text, or animations overlaid onto live real-world

scenes in real time. AR complements reality rather than replace it (Modlin & Kuo, 2025) .

3.3.2 Degree of Immersion and Connection to Reality

- **In VR:** Users experience complete immersion, as display devices completely block out the physical world, generating a strong sense of presence within the new digital space (Le Noury et al., 2022).
- **In AR:** Users remain connected to their physical reality; the technology merely enhances it with virtual elements, resulting in a comparatively lower level of immersion Elsholz et al., 2024) .

3.3.3 Devices Used

- **VR Devices:** These rely primarily on head-mounted displays (HMDs) that fully cover the eyes, such as the HTC Vive or Oculus Rift.
- **AR Devices:** These depend on a diverse range of tools, including smartphones, tablets, or specialized smart glasses such as Google Glass or Microsoft HoloLens (Le Noury et al., 2022).

3.3.4 Mechanism of Interaction with Elements

- **In VR:** Users can physically interact with virtual objects and directly influence the course of events within the digital environment.
- **In AR:** Physical interaction with digital objects or the ability to alter their position is often limited. When such interaction does become possible, the technology begins to resemble what is known as Mixed Reality (MR) (Le Noury et al., 2022).

In essence, the core difference between AR and VR can be summarized in terms of the degree of reality displacement: VR creates a completely virtual environment that entirely obscures the real world, whereas AR keeps users connected to their actual surroundings while superimposing a partial virtual layer upon them. This makes AR a powerful interactive medium that merges reality with imagination without losing the sense of physical place (Le Noury et al., 2022).

3.4 Applications in Sport and Athletic Training

- **Uses of VR:** VR is employed to create immersive training environments that simulate complex or hazardous scenarios that would be difficult to reproduce in real life such as mountain training, high-risk environments, or decision-making practice in football.
- **Uses of AR:** AR is more commonly used to display real-time performance data such as speed or heart rate directly within the athlete's field of view

during actual on-field practice, or to provide immediate feedback on movement techniques (Ji et al., 2026).

4. CURRENT APPLICATIONS:

These technologies are no longer confined to the world of gaming and entertainment; their scope has expanded far beyond that to encompass more consequential domains, including education, athletic training, physical fitness, and medical rehabilitation. At the time of writing this article, and drawing upon the scientific papers identified through the PRISMA flow diagram, a diverse array of applications has demonstrated clear efficacy and effectiveness.

Based on our review of literature, approximately fifty applications, programs, or platforms were identified which derived from the articles examined spanning multiple categories. These include: sports training, physical fitness, research-oriented applications, exergames (physical activity games), medical programs dedicated to rehabilitation and recovery, and educational tools (such as those used in anatomy instruction, among others).

In the present study, these applications were classified according to the sport type and intended purpose, through the analysis of over 50 recent studies published between 2020 and 2026 all of which focused on the sports domain or one of its various branches and sub-disciplines.

Application	Description	Category
Rezzil Player	An application designed to enhance response speed and reaction time, specifically tailored for football goalkeepers.	Football
Rezzil Player 22	An application focused on developing heading technique without exposure to real physical collisions.	Football
Clean Sheet Soccer	A dedicated training application designed to help goalkeepers maintain a clean sheet.	Football
2MD: VR Football	Allows football practitioners to perform passing drills across various positions and timings, with simulated match scenarios at differing intensities.	Football
CortexVR	An application tailored for reaction training in football players, with the added capability of measuring certain vital physiological indicators.	Football
BeTheGladiator	Enables the training of cognitive and motor skills without the need for a full pitch or a large number of players.	Football
VR Goalkeeping	An application designed specifically for goalkeepers through the simulation of real game situations.	Football
Gym Class - Basketball VR	Relies on tracking hand and body movements to develop shooting, passing, and dribbling skills in an experience that closely mirrors real-game basketball performance.	Basketball

VisionCoach	A specialized training application focused on developing visual and cognitive skills in basketball, aimed at enhancing performance by cultivating the visual abilities associated with decision-making and response speed in various sporting situations.	Basketball
WIN Reality Baseball	A training application designed for baseball hitters to refine their batting skills.	Baseball
Ib Cricket	An application aimed at training most of the foundational skills in the sport of cricket.	Cricket
Eleven Table Tennis	A simulation application for table tennis that helps develop foundational skills and techniques.	Table Tennis
First Person Tennis	An application dedicated to the use of virtual reality in tennis, offering both singles and doubles match experiences.	Tennis
Racket: Club	An application designed for racquet sports including tennis, padel, squash, and badminton offering various court dimensions that contribute to the development of a range of physical attributes and skills.	Racquet Sports
Beat Saber	A popular rhythmic application that has been used in several studies to improve hand-eye coordination and reaction time.	Rhythm Fitness
Synth Riders	The program features varying difficulty levels tailored to individual user capabilities, offering an interactive training experience that combines physical fitness with entertainment as players perform movements synchronized with musical rhythm.	Rhythm Fitness
Supernatural	A comprehensive and diverse fitness platform that provides intensive workouts across a variety of immersive virtual environments.	Immersive Fitness
BlackboxVR	Focuses on increasing strength by integrating virtual reality with resistance devices and cables to achieve effective training outcomes.	Strength Training
Holofit by Holodia	Connects various cardio equipment (such as stationary bikes or rowing machines) to immersive virtual environments.	Cardio Fitness
Zwift	Widely used, particularly during the COVID-19 pandemic, this platform allows users to train within three-dimensional virtual worlds. Athletes can perform individual training sessions or participate in group rides and races, with real-time performance data tracking.	Cycling / Cardio
Nike+ Kinect Training	A relatively older system that builds training programs tailored to individual body needs and capabilities.	Home Fitness
YogaXR	An application for training various yoga postures, allowing users to view their own body to ensure movement accuracy and proper alignment.	Yoga / Mind-Body
Virtual Fitness Trail	An application designed specifically for older adults to engage in safe, home-based physical activity.	Senior Fitness
Dance Dash	An application that focuses on rhythmic dance movements within a virtual environment, aimed at developing physical fitness and motor abilities.	Dance Fitness
Zombies, Run	An application primarily dedicated to running, designed to increase engagement through an interactive narrative. Users complete missions accompanying the story such as escaping from zombies or collecting supplies while intensity is adjusted according to	Running / Gamified Fitness

	experimental needs, all within an entertaining, game-like training atmosphere.	
Daily Roping (Tiantian Tiaosheng)	A fitness application that leverages artificial intelligence and computer vision technologies to monitor jump rope performance. It utilizes either a smartphone camera or a smart rope to count jumps and analyze performance without the need for complex or specialized equipment.	Jump Rope / Cardio
Wii Sports Resort / Nintendo Wii Fit	Two interactive sports gaming applications, among the earliest trailblazing systems to employ active gaming. They rely on motion-sensing technology to transform physical activity into an interactive, engaging training and entertainment experience.	Exergaming
Pokémon GO	Utilizing augmented reality, this application encourages participants to move and run within their real-world environment in search of virtual characters (Pokémon), which they capture using their smartphone.	AR Walking / Running
Dragon Hunter	An augmented reality application designed to study the effect of "loss aversion" on increasing physical activity levels.	AR Fitness / Research
VR Regatta	A simulation for sailing and yachting, offering an immersive environment with realistic sporting scenarios designed to mitigate real-world risks.	Sailing
Golf+	A simulation application for the sport of golf.	Golf
Punchpulse	An interactive training system that simulates boxing and certain combat sports, relying on precision devices to measure punching performance and develop physical skills.	Boxing / Combat
LES MILLS BODYCOMBAT	A simulation application for combat sports that helps raise fitness levels among athletes.	Combat Fitness
The Climb	Used in climbing and mountaineering sports, this application simulates a variety of natural environments and locations, requiring users to grasp different points while ascending.	Climbing
ARpenSki	A ski training application that tracks and records physical posture to improve body positioning during flight and descent.	Skiing
Carve Snowboarding	Offers an interactive experience that simulates snowboarding, where users control direction and speed through body tilting and the use of handheld controllers.	Snowboarding
Power-VR	An interactive system designed to simulate the atmosphere of official powerlifting competitions, aiming to boost athlete motivation and reduce competition-related anxiety.	Powerlifting / Strength
traiNreal	A platform adopted across a range of different sports, with a specific focus on developing visuomotor coordination and reaction speed.	Cognitive-Motor Training
RehabMaster ™	An application dedicated to individuals with cerebral palsy, providing real-time feedback for upper limb movements during activity.	Neurological Rehab
RGS (Rehabilitation Gaming	A system designed for rehabilitation and upper limb monitoring, offering immediate feedback to guide and track patient progress.	Upper Limb Rehab

System)		
Mitii (Move it to Improve it)	A training and rehabilitation program that integrates physical exercises with cognitive tasks within an interactive digital environment, aimed at enhancing both motor and cognitive abilities.	Motor-Cognitive Rehab
RAPAEL Smart Kids	Focuses on using virtual games that target the limbs of younger individuals, making therapy engaging and age-appropriate.	Pediatric Rehab
UINCARE / UINCARE Home+	A home-based application that facilitates the rehabilitation process through simple, user-friendly exercises.	Home-Based Rehab
TheraGame	Utilizes both virtual and augmented reality technologies to train and rehabilitate athletes through therapeutic games that improve motor and cognitive skills in an enjoyable, interactive manner.	Athlete Rehab
ARkanoidAR	An augmented reality-based rehabilitation application that employs motion-tracking sensors to monitor and guide body movement.	AR-Based Rehab
ARTESH	An augmented reality rehabilitation system that provides haptic feedback, creating an interactive training environment designed to enhance both motor performance and cognitive function.	Haptic Rehab

4.1 Analysis of the Reviewed Literature

Most studies point to the effectiveness of modern sports technologies in developing both the motor and cognitive dimensions of athletes. With the significant evolution in sports and the intensification of competition, physical attributes such as speed, strength, and endurance alone are no longer sufficient to make a difference. Instead, greater emphasis is now placed on secondary yet decisive aspects like reading the game and spatial awareness, speed of reaction, anticipation of opponents' movements, and making the right decision in fractions of a second.

Here, we return to the role of modern technologies. The study by (Paludo et al., 2026) highlights a growing revolution in the adoption of virtual and augmented reality technologies as contemporary tools for football players. Similarly, (Yang & Hu, 2024) focused on the capacity of such technologies to construct realistic training environments that allow athletes to refine their technical skills, understand tactical plans, and analyze movement with precision. They also underscored the role of algorithms in monitoring both physical and tactical performance, thereby equipping coaches with the ability to make strategic decisions grounded in accurate data.

Through our analysis of the reviewed literature, we were able to trace various thematic pathways pursued by researchers. Some studies concentrated specifically on the effects of virtual and augmented reality on particular sports such as football or basketball while others adopted a broader focus on training in general, without delving deeply into any single discipline.

We found that football emerged as the most prominent sport among those in which researchers applied these technologies. Notable examples include the works of (Yang & Hu, 2024), (Paludo et al., 2026), (Marshall et al., 2023), and (Gürbüz & Taş, 2025), all of which examined distinct aspects of football ranging from reaction speed to passing and shooting skills.

Other investigations directed their attention toward basketball, another widely popular sport. For instance, the study by (Günar & Bavlı, 2025) explored how virtual reality games influence specific basketball skills namely dribbling and free-throw shooting among adolescent players. Likewise, (Panchuk et al., 2018) investigated decision-making training among basketball players using interactive video-based tools.

4.1.1 Studies Focusing on Combat Sports

Within the field of combat sports, **(Usra1 et al., 2024)** employed a training program comprised of 50-minute practical sessions. Throughout these sessions, participants executed physical conditioning drills, including squat jumps, alongside offensive techniques such as punches and kicks. These activities were conducted in an interactive, augmented-reality environment. The findings indicate that integrating AR into combat training yields substantial improvements in both the fitness levels and technical proficiency of young self-defense athletes.

Furthermore, (Petri, et al., 2019) explored response behavior in karate. Their work assessed the extent to which smartphone-based virtual reality tools could enhance core karate movements. The researchers utilized observational learning as their primary method in approach that enables trainees to carefully watch specific techniques before practicing them, thereby boosting overall learning efficiency.

4.1.2 Studies Focusing on Muscular Strength Training

In the context of muscular strength development, (Wang et al., 2026) conducted a narrative review encompassing 38 studies published up to the end of 2025. The review examined the application of virtual and augmented reality in strength training contexts. Among the key addressed themes were exercise adherence and the integration of physical and psychological dimensions to enhance muscle development and boost motivation. The review concluded that VR/AR-based exercises increase commitment to training routines, largely due to the motivational elements embedded within these programs. However, the authors

noted a significant limitation: these technologies are currently confined to bodyweight exercises, while the incorporation of external weights and resistance training within virtual environments remains unfeasible due to technical integration challenges.

On a different note focusing on learning rather than strength development (Xiao et al., 2017) investigated user's satisfaction with a VR-based instructional system designed to assist beginners in mastering proper weightlifting techniques. Targeting novice practitioners, the study aimed to teach fundamental lifting movements. The findings suggested that VR can function as an interactive pedagogical tool, reducing the initial difficulty associated with sports requiring high movement precision, such as weightlifting. This, in turn, may help lower the risk of injury stemming from improper form among beginners.

In a similar vein, (Popielski et al., 2023) addressed the issue of incorrect motor performance in powerlifting exercises. Their study developed a VR application capable of tracking the head, hand, and body movements of athletes within a virtual space, comparing these against an "ideal" movement model. Motivated by the premise that improper lifting technique significantly increases injury risk, the research demonstrated that VR could serve not merely as an entertainment tool, but as a virtual personal trainer. By analyzing joint angles and spinal alignment during simulation before the athlete ever touches a real barbell the system offers a protective function against injury.

Another notable contribution comes from (Viana et al., 2021), which provided robust evidence regarding the relationship between interactive exergames and physical strength. The study sought to determine whether active video gaming could serve as an alternative or complement to traditional exercise for improving limb strength. The authors recommended that interactive video games represent an appealing and effective option particularly for younger populations for increasing muscular strength in the limbs. Nevertheless, they cautioned that such games do not fully replace conventional strength training for athletes aiming to develop maximal muscular power.

A recurring concern among athletes, especially in individual sports, is the psychological gap between quiet daily training and the high-intensity atmosphere of official competitions. (Gulec et al., 2023) designed a study to bridge this gap by constructing a fully interactive environment that simulates cheering crowds, observing referees, and platform assistants. Using VR headsets alongside audiovisual effects, the system enables crowd reactions to correct or incorrect

athlete performance. The study's outcomes indicated a reduction in competition-related anxiety and a notable increase in motivation levels among participants.

4.1.3 Applications in Health and Sports Rehabilitation

The domain of sports and medical rehabilitation has likewise attracted considerable scholarly attention. Studies in this area span a broad spectrum, encompassing the rehabilitation of sports injuries, neurological conditions, and elderly care, among other applications.

A. **Orthopedic and Sports Injury Rehabilitation**

Among the notable contributions in this area is the work of (Lim et al., 2024), which centered on the home-based rehabilitation of patients and athletes following anterior cruciate ligament (ACL) reconstruction surgery. The study involved 56 participants, divided into two groups. The first group performed their rehabilitation exercises at home using an augmented-reality system. This program displayed correct movement patterns and tracked patient performance, delivering real-time corrective feedback. The second group (the traditional cohort) carried out the same exercises at home but relied on conventional materials such as printed instructional booklets and brochures. The findings revealed that the AR-guided group experienced faster recovery in knee extensor strength compared to the control group. Moreover, the AR system achieved functional improvements in the knee that were on par with conventional rehabilitation, while offering the added advantages of enhanced patient motivation, greater exercise enjoyment, and higher adherence to the daily schedule.

Similarly, (Shim et al., 2023) demonstrated that home-based rehabilitation using an AR system constitutes a safe and effective alternative to traditional approaches following total knee arthroplasty (TKA). The study reported outcomes comparable to conventional rehabilitation in terms of knee mobility improvement and pain reduction, yet with notably higher patient compliance. The authors concluded that such digital systems provide high-quality care while reducing the burden on both patients and healthcare systems thanks to guided, home-based exercise regimens.

Equally noteworthy is the study by (Peng et al., 2026), which provided compelling clinical evidence regarding the superiority of AR-guided rehabilitation in the sports and therapeutic domain. Focusing on the post-recovery phase and the

prevention of recurrence, the research demonstrated a 27% reduction in ankle re-injury rates, alongside real-time postural correction capabilities.

B. **Neurological Rehabilitation**

(Calabrò et al., 2026) concluded that sports simulation within virtual environments represents a promising and effective tool for enhancing fitness and motor functions among Paralympic athletes and individuals with neurological disabilities. Their study reported improvements in cardiorespiratory efficiency, balance, and psychological motivation among participants. The authors recommended the development of specialized medical simulation software to ensure both training accuracy and safety.

In a related context, (Tobaiqi et al., 2023) explored the integration of virtual reality technologies with physical activities as a contemporary therapeutic approach. Their findings indicate that VR offers advantages over conventional rehabilitation in improving daily living activities, upper and lower limb movement, and cognitive functions in children with cerebral palsy. Given its potential effectiveness, ease of application, absence of side effects, and entertaining nature, the approach may be regarded as a promising complementary strategy to traditional physiotherapy.

Meanwhile, (Guinet et al., 2022) investigated gait training for the same population using augmented video games. Their preliminary results revealed a highly positive response. However, the study was conducted on a limited sample of only 14 patients; accordingly, the research team plans to expand the investigation to include 40 participants to further validate their initial observations.

C. **Elderly Care and Rehabilitation**

(Chitjamnogchai et al., 2025) directed their attention toward older adults, examining the effects of a home-based virtual-reality exercise program combining aerobic and resistance training on cardiorespiratory fitness among community-dwelling seniors with sarcopenia.

Similarly, (Lee et al., 2017) aimed to evaluate the impact of the Otago exercise program, a well-known home-based regimen, for fall prevention when delivered through augmented reality technology. They compared this AR-based delivery with a yoga program and conventional self-administered exercises in terms of balance improvement and fall prevention among elderly women. The study concluded that AR-delivered Otago exercises constitute an effective means

of enhancing muscle strength, balance, and other physical factors associated with fall prevention in older women.

5. CHALLENGES AND LIMITATIONS

The integration of virtual reality (VR) and augmented reality (AR) technologies into the sports domain is accompanied by a range of challenges and constraints. These obstacles span technical, economic, health-related, and scientific dimensions, and are discussed in detail below, drawing upon the available literature.

5.1. Technical and Hardware Challenges

One recurring issue is the interruption of training due to adverse effects associated with VR/AR use. Among these is cybersickness commonly referred to as motion sickness in virtual environments which affects approximately 25% of VR users, with symptoms including nausea, disorientation, and oculomotor strain. (Peng et al., 2026) reported a statistically significant correlation between cybersickness and training dropout rates, with a correlation coefficient of $r = 0.34$ ($p = 0.01$). These symptoms, as noted by (Y. Ji et al., 2026) , may compromise motor performance quality, reduce adherence to training programs, and diminish the overall appeal of VR/AR technologies.

Another frequently cited concern among both users and coaches is latency, i.e. the delay between a user's physical movement and the system's corresponding response. Even minimal latency can undermine the sense of realism and, more critically, may lead to the adoption of incorrect movement patterns or flawed tactical decisions. According to (Le Noury et al., 2022) , this issue impedes the development of reaction speed and weakens the effectiveness of real-time movement correction.

Hardware ergonomics also pose a significant barrier, particularly in sports requiring calm and controlled movements, such as yoga. (Elsholz et al., 2026) documented participant dissatisfaction with the Meta Quest 3 headset, citing its weight and lack of comfort during sessions especially when performing dynamic poses. Participants also reported that the limited field of view (FOV), combined with the headset's bulk, contributed to balance difficulties in certain postures. These ergonomic shortcomings, the study suggests, negatively influence timing-related decisions (e.g., the initiation of strikes) and hinder the accurate simulation of sports that demand high visual precision.

A further point of concern both for athletes and manufacturers is the absence or insufficiency of haptic feedback within virtual environments. Replicating the tactile sensations of real-world interactions, such as striking an opponent or experiencing physical resistance, remains a formidable challenge. (Le Noury et al., 2022) argue that this limitation may impair the acquisition of skills that rely heavily on somatosensory input, while fostering an over-reliance on visual cues. Some researchers have suggested that this constraint may be insurmountable within current VR/AR paradigms, prompting calls for the integration of emerging technologies capable of delivering vibrations or tactile responses thereby enhancing training quality and bringing the experience closer to reality (Marshall et al., 2023).

Finally, despite ongoing advancements in sensor technology, tracking systems do not always capture the full complexity of human movement with sufficient precision. Inaccuracies in motion tracking can result in distorted representations of athletic performance within the virtual space. This issue is particularly pronounced in sports involving compound movements and fine-tuned whole-body adjustments such as gymnastics and karate where current VR/AR technologies struggle to replicate intricate details with the required fidelity (Elsholz, Frank, et al., 2025).

5.2. Economic Challenges and Accessibility

Economic constraints and unequal access to technology are among the most pressing obstacles hindering the widespread adoption of VR and AR in sports. Despite rapid advancements in these systems, fundamental issues related to economic feasibility, equitable distribution, and accessibility remain unresolved. The high cost of advanced hardware and specialized software continues to pose a significant barrier for small clubs, schools, and families, thereby limiting the diffusion of these technologies. (Ozturk et al., 2025) focused specifically on smaller clubs and individual athletes, pointing out that VR/AR applications are often prohibitively expensive, which may restrict access for lower-income athletes and less affluent sporting organizations. Similarly, (Li, 2024) and (Ayenigbara, 2025)offered more detailed analyses concerning schools and households, emphasizing that the substantial financial outlay required for technology and equipment represents a heavy burden on many educational institutions, communities, and ordinary families further constraining the penetration of VR/AR within the sports sector.

Beyond the issue of cost, this financial disparity gives rise to a secondary concern: inequity among athletes, particularly in competitive settings. As (Ayenigbara, 2025) observed, the cost barrier aggravate the divide between athletes from well-funded backgrounds and those from less privileged circumstances, granting the former an unfair advantage in skill development and training opportunities.

The limited technical literacy among coaches and athletes adds another layer of complexity which is a further obstacle to the effective deployment of VR/AR. (Gunawan Manullang et al., 2025) reported that players encountered significant difficulties during the initial setup phase, struggle to operate the systems smoothly. This resulted in considerable wastage of training session time, as the focus shifted from actual practice to troubleshooting and exploring device functionality. Moreover, interview data revealed a pressing need for technical supervision; participants consistently affirmed that independent training using these systems was nearly impossible without the presence of a technology-savvy expert. This, in turn, opens the door to either expanding the coaching staff to include specialized technology personnel thereby increasing the financial burden on clubs and sports institutions or integrating technical training sessions into the regular schedule for coaches and players, enabling them to use the devices autonomously (Mascret et al., 2025).

5.3. Health and Safety Challenges

The prolonged or improper use of VR and AR devices introduces a range of health and safety concerns that cannot be overlooked. Among the most frequently reported issues are visual strain, physical injury risks, and cognitive overload each of which carries implications for both athlete well-being and training effectiveness.

5.3.1. Ocular Strain and Visual Fatigue

Extended usage particularly in sessions lasting one to two hours or more has been associated with potential adverse effects on vision (Pastel et al., 2023). A primary contributor to this discomfort is the vergence-accommodation conflict (VAC), a phenomenon in which the eyes struggle to maintain proper focus on objects at varying depths within the virtual space. This conflict induces visual fatigue, which may progressively reduce visual acuity and compromise the accuracy of eye-tracking data. Such visual disturbances, in turn, undermine

adherence to training programs, degrade motor performance quality, and dampen athletes' motivation to complete sessions. As a result, (Günar & Bavlı, 2025) emphasize that practitioners are often compelled to limit session durations to mitigate the risk of dizziness and blurred vision.

5.3.2. Physical Injury Risks

A further point of criticism relates to the spatial requirements of VR/AR systems. These devices typically demand open, unobstructed areas and are ill-suited to confined spaces or crowded training environments (Fendrian et al., 2024). Complete immersion may cause athletes to lose awareness of their physical surroundings, leading to collisions with real-world objects or falls. This partly explains why VR/AR applications are more commonly adopted in individual rather than team sports, where movement is more predictable and less prone to interference from other participants.

The physical design of the headsets themselves adds another layer of risk. The weight and bulk of the equipment can interfere with balance, while the restricted field of view (FOV) limits peripheral awareness particularly during certain postures making users more vulnerable to stumbling or falling when fully absorbed in the virtual experience (Elsholz et al., 2026) . Additionally, (Wang et al., 2026) highlighted safety concerns specific to strength and speed training, where impaired peripheral vision prevents athletes from detecting physical obstacles such as cones, barriers, or other equipment within the training space. The authors strongly recommended that VR-based training areas be meticulously cleared of such hazards, and that a supervisor or spotter be present at all times to ensure athlete safety.

Crucially, these physical safety concerns are often compounded by cognitive and perceptual demands, creating a dual burden that can undermine the very purpose of training namely, the refinement of athletic skills.

5.3.3. Mental Fatigue

The interaction between restricted visual input and inefficient system design significantly elevates cognitive load. (Ayenigbara, 2025) argued that the combination of a limited field of view and small display areas within the headsets forces the brain to expend a greater effort in processing the visual information it receives and thus often leads to mental exhaustion. Furthermore, the simultaneous presentation of excessive digital information can result in cognitive overload, where athletes become unable to extract the data most relevant to their

performance, ultimately depleting their mental energy reserves (Pastel et al., 2023) .

5.4. Research and Scientific Gaps

Despite the growing volume of scientific literature devoted to virtual and augmented reality in sports, several research gaps remain insufficiently addressed. Identifying and filling these gaps is not merely an academic exercise but a necessary step toward ensuring the optimal and responsible deployment of these technologies.

5.4.1. Shortage of Longitudinal Studies

A recurring observation across the current body of research is the predominance of short-term experimental designs, with intervention periods typically ranging from four to twelve weeks. Robust evidence regarding the long-term retention of acquired skills, or the potential risks associated with chronic use, remains scarce. Consequently, the sustainability of training gains and their transfer to real-world performance contexts have not been adequately examined (Y. Ji et al., 2026). At the same time, prolonged exposure to these technologies raises legitimate concerns about dependency and ocular health, making the case for longitudinal research both urgent and complex.

The issue of sample size compounds this limitation. Through our examination of the experimental literature, we noted that the average number of participants per study hovers around 30, with some investigations involving as few as four individuals (Elsholz, Frank, et al., 2025). Such small samples inevitably reduce statistical power and limit the generalizability of findings, largely due to the prohibitively high costs of VR/AR equipment.

5.4.2. Skill Transfer and Ecological Validity

This brings us to a second major concern: the transferability of skills learned in virtual settings to real-world athletic performance, a question that lies at the heart of the technology's practical value.

Improvements observed within virtual environments do not consistently translate into tangible gains on the field; in some cases, a negative transfer may even occur, leading to a decline in actual performance (Le Noury et al., 2022). (Drew et al., 2020) offered a compelling illustration of this phenomenon, finding that VR-based training in archery produced a deterioration in real-world accuracy. The authors attributed this outcome to the system's inability to faithfully replicate

the physical mechanics of shooting particularly the forces involved, the release timing, and the trajectory of the arrow which differed markedly from real-world requirements.

5.5. Psychological and Social Constraints

5.5.1. Technology non-acceptance among coaches and athletes

Resistance to technological adoption remains a persistent barrier. Some coaches are reluctant to embrace VR/AR due to skepticism about its efficacy, compounded by a fear that these tools might undermine their traditional roles. This hesitation is often reinforced by a perceived lack of concrete evidence linking virtual training to measurable on-field outcomes, as well as the limited diffusion of these technologies within professional sporting environments (Greenhough et al., 2021). Furthermore, limited technical literacy may breed apprehension about operational failures or the risk of wasting valuable training time on troubleshooting (Usra1 et al., 2024).

5.5.2. Social isolation

Team dynamics including communication, leadership, and direct interaction with teammates and opponents are integral to the social fabric of sport. Yet many VR/AR applications are inherently individualistic in design, thereby curtailing these essential social dimensions (Elsholz, Pham, et al., 2025) . Although some platforms incorporate virtual avatars to simulate opponents or coaches, they fall short of replicating the nuanced human interactions that underpin collective sports. This social disconnect has been cited by coaches as a key reason for their hesitancy to adopt these technologies (Li, 2024; Mascret et al., 2025). (Høeg et al., 2023) further confirmed this, with participants reporting that the absence of meaningful social engagement significantly detracted from their overall experience.

What emerges from these observations is a clear pattern: the technological promise of VR/AR is unlikely to be fully realized unless future developments address not only technical and economic barriers but also the human dimensions of sport: social interaction, trust, and the relational dynamics that define athletic communities.

6. FUTURE PERSPECTIVES

At a time when technology is advancing at an unprecedented pace and innovations are proliferating, ambitious visions are being drawn for the role of

virtual and augmented reality in sport. These technologies are poised to evolve from complementary tools into core pillars across various sporting domains.

6.1. Increasing Integration of VR/AR with Artificial Intelligence

The current era is characterized by rapid technological flourishing, with artificial intelligence assuming a central position at the heart of a scientific research. Interest in AI is no longer confined to specialized technical circles, but has extended across diverse knowledge fields and sectors of a daily life. Studies suggest that the future lies in the integration of VR/AR technologies used in sports with AI and big data, aiming to develop "virtual athletic coaches" capable of delivering professional, customized training content tailored to the actual needs of each individual athlete (Li, 2024). The goal extends beyond simple simulation toward the creation of intelligent, integrated training systems that can understand, analyze, and respond instantaneously thereby refining physical, motor, and technical skills with greater precision (Elsholz, Pham, et al., 2025) .

6.2. Advances in Hardware and Biosensors

Another key focus of ongoing research is the enhancement of device ergonomics and realism. Efforts are directed toward reducing the weight of headsets, improving design to accommodate different athlete populations, increasing screen resolution, and expanding the field of view (FOV) to address issues arising from prolonged use such as visual fatigue and motion sickness (Li, 2024). Emerging technologies also include "smart socks" and sensors embedded within clothing, capable of collecting biomechanical data (e.g., foot pressure and joint angles) and transmitting it wirelessly to VR systems without the need for external power sources. Such innovations could revolutionize athlete tracking and enable the seamless integration of real movements into virtual environments in a sustainable, untethered manner (M. Ji et al., 2025).

6.3. Inclusivity and Expansion

A further forward-looking dimension is the inclusiveness and expansion of VR/AR applications in sport. By inclusiveness, we refer to the comprehensive integration of these technologies across all facets of the sporting ecosystem including warm-ups, training, development, rehabilitation, and spectator experiences. By expansion, we mean the generalization of these tools across a wider array of sports, including aquatic disciplines (swimming and diving), equestrian sports, winter sports such as skiing, as well as ensuring accessibility for

all groups and individuals including people with disabilities, clubs, federations, and individual users alike.

7. CONCLUSION

The present review sought to analyze a collection of peer-reviewed scientific studies (n = 50) addressing virtual and augmented reality technologies within the sports domain, published between 2019 and 2026 across major global databases namely Scopus, Web of Science, PubMed, and Google Scholar.

It is evident from this systematic review that the application of these technologies has moved beyond the early stages of experimentation and exploration; we are now in a phase of validation and practical implementation. The findings reveal a broad diffusion of VR and AR across various areas, including health, athletic rehabilitation, training, and spectator experiences. The accompanying scientific evidence consistently points to substantial effectiveness in most applications, whether targeting physical fitness, strength development, technical and tactical skill enhancement, or recovery from sports injuries and neurological conditions such as cerebral palsy or stroke, as well as in elderly care. On the psychological and social front, the reviewed studies suggest that these technologies also contribute to reducing anxiety, bolstering self-confidence, increasing motivation, and fostering greater engagement within clubs and teams.

Crucially, however, these benefits remain heavily contingent upon a constellation of mediating factors, including the appropriate use of applications and software, the implementation strategies adopted by coaches and users, the quality of the hardware, and the degree to which the virtual or augmented environment faithfully mirrors the realities of the physical world (Fendrian et al., 2024).

Alongside these positive outcomes, the systematic review has equally uncovered a range of challenges and constraints that impede the effective integration of VR and AR in sports. These can be categorized into five principal axes:

1. Technical challenges, including latency issues arising from the difficulty of processing information rapidly, resulting in delayed responses that lag behind real-world requirements; insufficient haptic feedback; the excessive weight of headsets; and restricted fields of view.
2. Health challenges, which constitute perhaps the most prominent concern, encompassing visual fatigue and mental exhaustion induced by prolonged screen use, alongside the risk of physical injury due to improper usage or insufficient familiarity with device operation.
3. Economic and accessibility challenges, where the high cost of hardware and software remains a significant barrier for smaller clubs and athletes,

particularly in developing nations, thereby widening the disparity and creating unfairness in major international competitions.

4. Research gaps, particularly the shortage of longitudinal studies, given that most interventions span only one to three months. This raises legitimate uncertainty regarding the long-term retention of skills and the transfer of training effects to authentic performance contexts.
5. Psychological and social constraints, including technological resistance among athletes and coaches, as well as the social isolation engendered by the predominantly individualistic design of many applications.

Looking toward the future, VR and AR hold considerable promise within the sports sector, as indicated by the present review especially amidst the ongoing digital revolution in artificial intelligence. Enhanced integration with AI is likely to expand the market for these technologies in the coming years. Concurrently, ongoing hardware development encompassing lighter headsets, advanced biometric sensors, and smart textiles promises to improve user experience and expand applicability. Furthermore, efforts to enhance inclusivity and broaden the scope of these technologies across diverse sports and various functional domains represent key trajectories for future growth.

Ultimately, the path forward lies not solely in technological sophistication, but in bridging the divide between virtual potential and human athletic reality ensuring that these tools serve not as substitutes, but as empowered complements to the coach's expertise and the athlete's lived experience.

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