VIRTUAL REALITY IN SPORTS: A BIBLIOMETRIC AND SCOPING REVIEW OF GLOBAL TRENDS, KEY AUTHORS, AND FUTURE PERSPECTIVES

LA REALIDAD VIRTUAL EN EL DEPORTE: UNA REVISIÓN BIBLIOMÉTRICA Y DE ALCANCE SOBRE TENDENCIAS GLOBALES, AUTORES CLAVE Y PERSPECTIVAS FUTURAS

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Abstract

Virtual reality (VR) in sports has gained increasing attention in recent scientific literature. However, the combined use of bibliometric analysis and scoping review to explore this topic remains limited. This study aims to: (i) identify global publication trends, key contributors, and leading countries in the application of VR in sports between 2015 and 2024; (ii) examine the types of sports in which VR technologies are implemented; and (iii) explore future research perspectives to advance the integration of VR in sport science and practice. Using data from two major databases, Scopus and Web of Science, this study employs a dual-method approach that combines bibliometric analysis with a scoping review. The results show a clear upward trend in scholarly output, driven by contributions from influential researchers and a growing interest across countries and disciplines. VR has been widely applied in both team and individual sports, particularly for enhancing motor learning, supporting cognitive training, and facilitating physical rehabilitation. Despite this progress, there remain notable gaps in longitudinal research, studies on high-precision sports, and the integration of neurocognitive assessments. Future investigations should adopt more advanced methodologies, address current technological limitations, and expand geographic diversity in research. Overall, this study offers valuable insights and a comprehensive roadmap to guide future innovations in immersive sport technologies.

Keywords: Sports performance, Scientopy, virtual reality, technological innovation, trend analysis.

Resumen

La realidad virtual (RV) en el deporte ha ganado una atención creciente en la literatura científica reciente. Sin embargo, el uso combinado del análisis bibliométrico y la revisión de alcance para explorar este tema sigue siendo limitado. Este estudio tiene como objetivos: (i) identificar las tendencias globales de publicación, los principales contribuyentes y los países líderes en la aplicación de la RV en el deporte entre 2015 y 2024; (ii) examinar los tipos de deportes en los que se implementan tecnologías de RV; y (iii) explorar perspectivas de investigación futura para avanzar en la integración de la RV en la ciencia y la práctica deportiva. Utilizando datos de dos bases de datos principales, Scopus y Web of Science, este estudio emplea un enfoque de método dual que combina análisis bibliométrico con una revisión de alcance. Los resultados muestran una clara tendencia ascendente en la producción académica, impulsada por las contribuciones de investigadores influyentes y un interés creciente en diversos países y disciplinas. La RV se ha aplicado ampliamente tanto en deportes de equipo como individuales, especialmente para mejorar el aprendizaje motor, apoyar el entrenamiento cognitivo y facilitar la rehabilitación física. A pesar de estos avances, persisten lagunas significativas en investigaciones longitudinales, estudios sobre deportes de alta precisión y la integración de evaluaciones neurocognitivas. Las investigaciones futuras deben adoptar metodologías más avanzadas, abordar las limitaciones tecnológicas actuales y ampliar la diversidad geográfica en la investigación. En conjunto, este estudio ofrece conocimientos valiosos y una hoja de ruta integral para guiar futuras innovaciones en tecnologías deportivas inmersivas.

Palabras clave: Rendimiento deportivo, Scientopy, realidad virtual, innovación tecnológica, análisis de tendencias.

Introduction

Virtual reality (VR) is a computer-generated environment with realistic-looking images and objects that make users feel completely immersed in their surroundings (Putranto et al., 2022; Rahmadani et al., 2025). A head-mounted display (HMD) in a VR environment tracks the user's head movements, conveys information to the VR simulation, and simultaneously adjusts the viewing angle, changing the user's perspective and enhancing the sense of full immersion in reality (Lai, 2024; Slater & Sanchez-Vives, 2016; Zaman et al., 2023). Additionally, the virtual environment displays stereoscopic images (Selzer et al., 2020), enhancing the user's experience in both virtual and real-world environments (Wu, 2024). Virtual reality (VR) technology basically relies on two main components: hardware (head-mounted display (HMD), input devices, positioning and tracking systems, audio and haptic feedback), and software (3D computer graphics and rendering, audio processing and sound simulation, interaction mechanisms, biometric and sensor data integration) (Gazali et al., 2026; Lai, 2024).

In recent years, VR has become a useful tool in learning tutorials, dangerous#situation simulations, sports, and other fields (Pastel, Marlok, et al., 2023). In sport specifically, VR was first applied in the 1990s, with research interest resurging in recent years (Neumann et al., 2018). Studies have used VR for anxiety regulation (Harrison et al., 2021; Huang et al., 2022; Sanz et al., 2015), motor#skill learning (Michalski, Szpak, & Loetscher, 2019; Pastel, Petri, et al., 2023), and performance analysis (Faure et al., 2020; Mascret et al., 2022; Richlan et al., 2023). VR has been implemented across sports—from basketball and football to archery and rowing—to enhance technical, tactical, and psychological aspects of performance. These applications support cognitive decision#making, motor#skill development, and personalized training scenarios while minimizing injury risk. VR also allows athletes to train complex skills in safe, immersive environments, unconstrained by space, time, or participant limitations (Farley et al., 2020; Bird, 2020). Additionally, VR helps athletes manage mental and emotional challenges such as performance pressure (Tayal et al., 2023; Wu et al., 2023), provides real#time feedback for technique correction (Li et al., 2024; Liu & Xie, 2024), and supports rehabilitation—e.g., ACL recovery (Almansour, 2024). Despite these benefits, adoption is limited by high costs, learning curves, and uncertain long#term effectiveness (Chiang, 2021).

In recent years, the use of virtual reality (VR) technology in sport has emerged as a rapidly expanding area of scholarly interest. A wide range of studies have investigated its applications, including promoting physical activity and structured training in healthy individuals (Kuleva, 2023), enhancing motor skill acquisition (Michalski, Szpak, & Loetscher, 2019), improving decision-making abilities (Yunchao et al., 2023), optimizing athletic performance (Richlan et al., 2023), and incorporating interactive VR experiences in sport-specific contexts (Neumann et al., 2018). Despite this growing body of literature, no study to date has adopted an integrated approach that combines bibliometric analysis with a comprehensive scoping review to systematically examine the development of VR in sport. Existing bibliometric analyses have primarily addressed broader extended reality (XR) technologies (Zhao et al., 2022), while scoping reviews have focused on more specific topics such as team performance training (Faure et al., 2020) or psychological dimensions like motivation, affect, enjoyment, and engagement (Mouatt et al., 2020). This lack of integration has left research trends, key contributors, and thematic developments within the VR and sport domain insufficiently mapped, presenting a significant research gap and an opportunity for further exploration through a dual-method synthesis.

Bibliometric analysis plays an important role in mapping knowledge in a field by identifying patterns among sources, authors, affiliations, and relevant documents (Burbano-Fernández et al., 2024; Dendrino & Ghiberdic, 2024). Researchers in physical education and sport technology have widely adopted this approach to understand scholarly landscapes and trends (Calabuig-Moreno et al., 2020; Denche-Zamorano et al., 2023; Gazali, Saputro, et al., 2023; Zhao et al., 2022). On the other hand, scoping reviews are often used as a preliminary step to systematic reviews, aiding in the development of robust analytical frameworks and refinement of research questions (Hadie, 2024). Furthermore, scoping reviews help identify under-researched areas and provide direction for future studies (Puce et al., 2023). Since 2023, some sport-related studies have begun integrating these two methods to create more comprehensive reviews, particularly in adaptive sports such as

para-rowing and para-archery (Puce et al., 2023; Puce et al., 2024). As sport technologies continue to evolve, the application of both bibliometric and scoping approaches will become increasingly vital in mapping innovation and interdisciplinary intersections in the field. This research gap justifies the need for an integrated bibliometric and scoping review approach to systematically map the evolution and impact of VR in sport.

Bibliometric and scoping reviews provide systematic means of analysing research trends and identifying gaps in the literature. Accordingly, the present study aims (i) to map the global research landscape by identifying publication trends, prominent authors, and contributing countries in the field of VR in sport between 2015 and 2024; (ii) to categorise the sports that have adopted VR technologies and the primary purposes for their use; and (iii) to synthesise emerging research perspectives that could enhance the effectiveness, adoption, and innovation of VR in sport training, rehabilitation, and performance development. To meet these aims, we integrate a decade#long bibliometric analysis (2015 – 2024) with a scoping review of empirical work published from 2020 to 2024. Together, the two approaches offer a comprehensive view of publication trends, key contributors, influential sources and countries, and emerging thematic directions, thereby clarifying both the current landscape and future trajectory of VR in sport. In line with this framework, the study addresses three research questions:

Materials and Methods

This study employed a mixedmethod design that combined a bibliometric analysis with a scoping review to examine virtualreality (VR) research in sport. Researchers use bibliometric analysis (Gazali, Sofyan, et al., 2023) to review and analyse voluminous scientific data from various databases. While scoping review is used to map key concepts or existing research, especially for emerging research fields (Dowling et al., 2020), it is particularly useful for summarising findings in research domains characterised by heterogeneous knowledge (Tricco et al., 2018).

A. Bibliometric Analysis

Data Sources and Search Strategy

Records were retrieved from Scopus and the Web of Science Core Collection (WoS)—two citation indexes widely recognised for their comprehensive coverage of peer#reviewed scholarship (Farid et al., 2020) and regularly used in sport#technology reviews (Perdima et al., 2022; Sweileh, 2020; Yang et al., 2021). Guided by previous VR#in#sport syntheses (Kuleva, 2023; Michalski, Szpak, Saredakis, et al., 2019; Neumann et al., 2018; Richlan et al., 2023; Yunchao et al., 2023), we constructed a Boolean query that combined VR terms (e.g., “virtual reality”, “virtual environment*”, VR, “virtual world*”) with sport#related terms (e.g., sport*, exercis*, “physical activit*”). The complete search strings, field tags, and database#specific filters appear in Table 1 to ensure full transparency and reproducibility. Searches were executed on 25 April 2024 and restricted to 2015 – 2024, English language, and empirical research articles or empirical conference papers. Conference proceedings were retained because, in fast#moving technology fields, they constitute an established and independent channel of scholarly communication that enables rapid dissemination of cutting#edge findings before journal publication (Foster et al., 2019; Kim, 2019).

Table 1

Database Specific Search Strategies

Database	Date Run	Complete Query (field tags in bold)	Filters
Scopus	25 Apr 2024	**TITLE-ABS-KEY** (“virtual reality” OR “virtual environment” OR “virtual environments” OR VR OR “virtual world*” OR “virtual system*” OR “virtual partner*”) AND **TITLE-ABS-KEY** (“sport*” OR exercis* OR fitness OR “physical activit*” OR “physical train*” OR “sport performance” OR “sport education” OR athlete* OR football OR soccer OR basketball OR baseball OR volleyball OR badminton OR archery OR handball OR rowing)	Year = 2015–2024; Language = English; Document type = Article OR Conference Paper
Web of Science	25 Apr 2024	**TS** = (“virtual reality” OR “virtual environment*” OR VR OR “virtual world*” OR “virtual system*” OR “virtual partner*”) AND **TS** = (sport* OR exercis* OR fitness OR “physical activit*” OR “physical train*” OR “sport performance” OR “sport education” OR athlete* OR football OR soccer OR basketball OR baseball OR volleyball OR badminton OR archery OR handball OR rowing)	Timespan = 2015–2024; Indexes = SCI-EXPANDED, SSCI; Language = English; Document types = Article, Proceedings Paper

Note. For the scoping review, the same strings were applied with the year filter set to 2020–2024.

Inclusion and Exclusion Criteria

Studies were eligible for inclusion in the bibliometric analysis if they met the following criteria: (i) original empirical research applying virtual reality (VR) in sport-related contexts such as training, performance, rehabilitation, cognition, or fan engagement; (ii) published in English between 2015 and 2024; and (iii) indexed in Scopus or Web of Science as peer-reviewed journal articles or conference proceedings. Studies were excluded if they (i) examined VR technologies without a specific sport-related application; (ii) were not written in English; (iii) were categorized as review articles or non-peer-reviewed literature, including books, book chapters, and editorials, or (iv) were duplicate entries across the two databases.

Selection and Characteristics of Studies

The study selection process began with a thorough search in two major databases, Scopus and Web of Science (WoS), which yielded 1091 titles from Scopus and 2027 titles from WoS. To ensure the relevance and currency of the data, we narrowed our focus to studies published in the last ten years (2015–2024), which reduced the number of titles to 906 from Scopus and 1784 from WoS. We then screened articles and conference papers, resulting in 789 relevant Scopus articles and 462 WoS articles. To ensure more precise coverage, we further screened English-language journal articles, resulting in 772 articles from Scopus and 294 articles from WoS. We used ScientoPy for analysis and removed 261 duplicate articles (Figure 1), resulting in a final dataset of 805 articles offering a comprehensive understanding of VR in sport (Table 2). This meets the requirements of a bibliometric analysis, as at least 300 articles are required (Donthu et al., 2021). To illustrate the complete selection procedure—including bibliometric phases—a consolidated PRISMA flow diagram is provided in Figure 3.

Figure 1

Data Pre-Processing From WoS and Scopus Databases (Bibliometric Analysis)

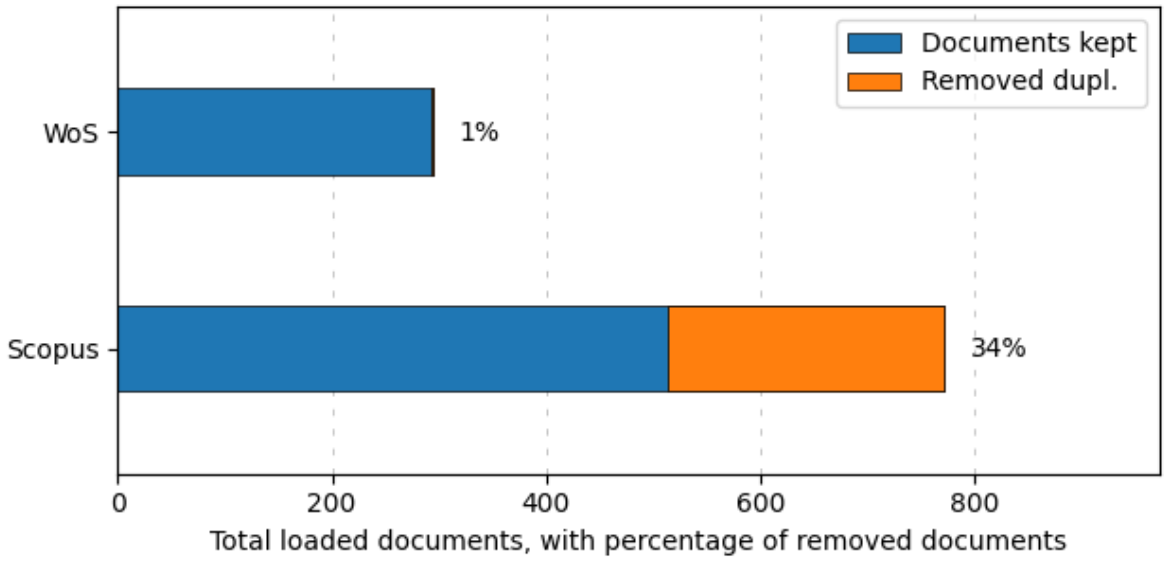


Table 2

The Selection Process and Characteristics of Studies Included in Bibliometric Analysis

Database	Initial Titles	2015-2024	Conference & Article	English	Duplicate(Remove)	Final Selection
Scopus	1091	906	789	772	259 (33.5%)	513
Web of Science	2027	1784	462	294	2(0.7%)	292
Total	**3.096**	**2.690**	**1.251**	**1.066**	**261**	**805**

Data Analysis

We will analyse the collected data using the bibliometric software ScientoPy. Scientopy enables the tracking of research results over time, revealing growth rates and trends in a particular field (Barui & Mazumder, 2023). The tool also highlights prolific authors and influential journals, helping to identify key contributors in a field (Ruiz-Rosero et al., 2019). We will

integrate the results of this bibliometric analysis with the findings from the scoping review to provide a comprehensive understanding of the development and future direction of research in this field.

B. Scoping Review

Protocol

This study used the scoping review approach established by Arksey and O'Malley (2005) and also adopted it from previous researchers in the field of sport to improve the overall quality of the review (Orr et al., 2022; Robertson et al., 2022; Sabiston et al., 2019; Teare & Taks, 2021). The scoping review method has six distinct stages: (i) identifying the research question, (ii) identifying relevant studies, (iii) study selection, (iv) charting the data, (v) collating, summarizing, and reporting the results, and (vi) consultation with relevant stakeholders.

Identifying the Research Question

Research questions should be derived to guide the search strategy. Research questions should not be so narrow that they limit the analysis process and should be broad enough to generate a wide scope and identify all relevant literature (Arksey & O'Malley, 2005). Therefore, aligning with our objectives, we formulated the following research questions to guide this study: (i) Which types of sports utilize VR technology? (ii) What are the future research directions required to optimise the use of VR technology in sports?

Identifying Relevant Studies

Both the bibliometric analysis and the scoping review used Scopus and Web of Science as primary databases. The same keyword strategy was applied, with methodological adaptations for each approach. For the bibliometric analysis, we examined publications from 2015 to 2024 to capture the evolution of the research field over the last decade, providing both early foundations and recent advancements. Meanwhile, the scoping review was limited to 2020–2024 to ensure relevance and recency. Research that considers literature from the last five years can ensure that the data captured reflects the latest trends, latest innovations, and applications that are most relevant to the current situation (Snyder, 2019). More recent literature is also likely to offer more significant and relevant findings due to rapid technological and methodological developments (Boell & Cecez-Kecmanovic, 2015). Our next step is to assess the articles' titles for relevance. We will then analyze the relevant articles in full text. One author (*NG*) conducted a search and screening to exclude out-of-scope articles using predefined eligibility criteria. A second, third, and sixth reviewers (*SK*, *MFM*, and *RLT*) conducted the title review. No formal methodological quality appraisal was performed, in accordance with the standard practice of scoping reviews. However, article selection followed the PRISMA-ScR framework to ensure transparency and rigor. We resolved author disagreements through discussion and iterative discussion.

Study Selection

To ensure a systematic and transparent selection process, we established explicit inclusion and exclusion criteria prior to the screening phase. Studies were included if they (i) were empirical research articles applying virtual reality (VR) in sport-related contexts such as training, performance, rehabilitation, cognition, or fan engagement; (ii) were published between 2020 and 2024; (iii) were written in English; and (iv) were indexed in Scopus or Web of Science as peer-reviewed journal articles or conference proceedings. Studies were excluded if they (i) examined VR technologies without a specific sport-related application; (ii) were not written in English; (iii) were categorized as review articles or non-peer-reviewed literature, including books, book chapters, and editorials, or (iv) were duplicate entries across the two databases. The initial search identified 1,091 titles from Scopus and 2,027 from Web of Science. After filtering by publication year, 693 and 1,199 records remained, respectively. Screening for document type reduced the pool to 597 Scopus and 518 WoS items. Further screening of English-language journal articles yielded 400 from Scopus and 393 from WoS. After removing 231 duplicates using ScientoPy, a final dataset of 562 eligible studies was obtained for analysis (see Figure 2 and Table 3). Figure 3 provides a consolidated PRISMA flow diagram to illustrate the entire selection procedure, including the scoping review phases.

Figure 2

Data Pre-Processing From WoS and Scopus Databases (Scoping Review)

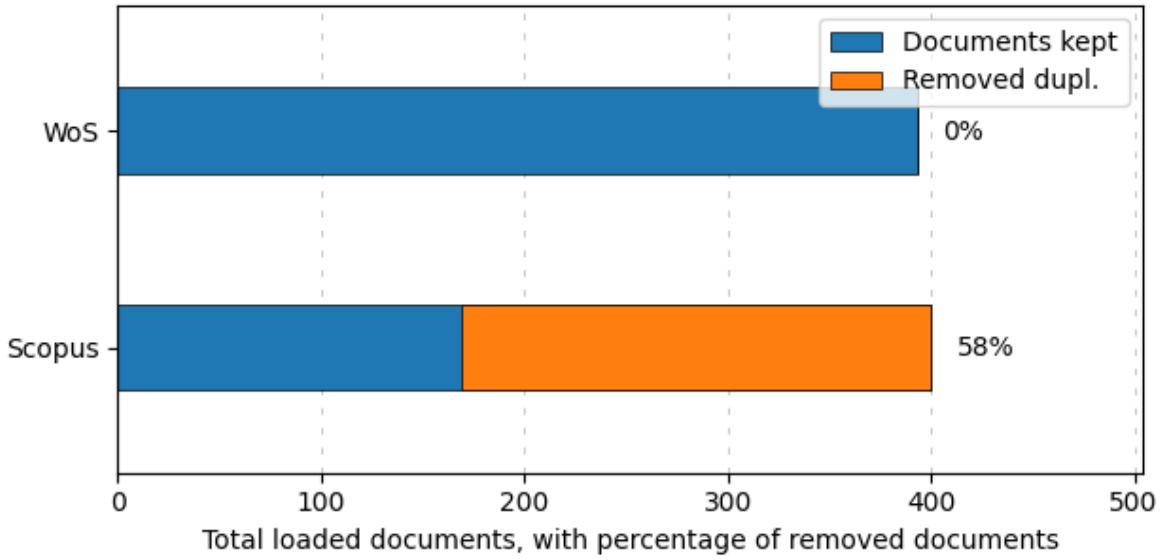


Table 3

The Selection Process and Characteristics of Studies Included in the Scoping Review

Database	Initial Titles	2020-2024	Conference & Article	English	Duplicate(Remove)	Final Selection
Scopus	1091	693	597	400	231 (57.8%)	169
Web of Science	2027	1199	518	393	0	393
Total	**3.096**	**1.892**	**1.115**	**793**	**231**	**562**

Charting the Data

The next step in the process was to organize data extraction for the 562 articles identified through the initial search. We then integrated the scoping review results with bibliometric analysis, using ScientoPy to extract and review the main keywords used by the authors. Our focus was on keywords related to sports and VR technology over the period 2020–2024. We selected 10 keywords from this analysis, each serving as a significant representation of the important components of this study. This keyword analysis is crucial in understanding the current research landscape and identifying neglected, popular, or emerging topics (Weismayer, 2017).

Collating, Summarizing and Reporting the Results

ScientoPy groups the data according to the most frequently studied sports categories, such as football, basketball, volleyball, and others, to analyse the types of sports based on VR technology. ScientoPy first imports data from the database for filtering and visualisation. We analyse keywords and topic trends in the summarising stage to identify frequently used sports with VR, then categorise them based on popularity or usage trends. In the final stage, we present the results in the form of images to visualise the frequency of discussion for each sport, thereby providing insight into VR research trends across various sports.

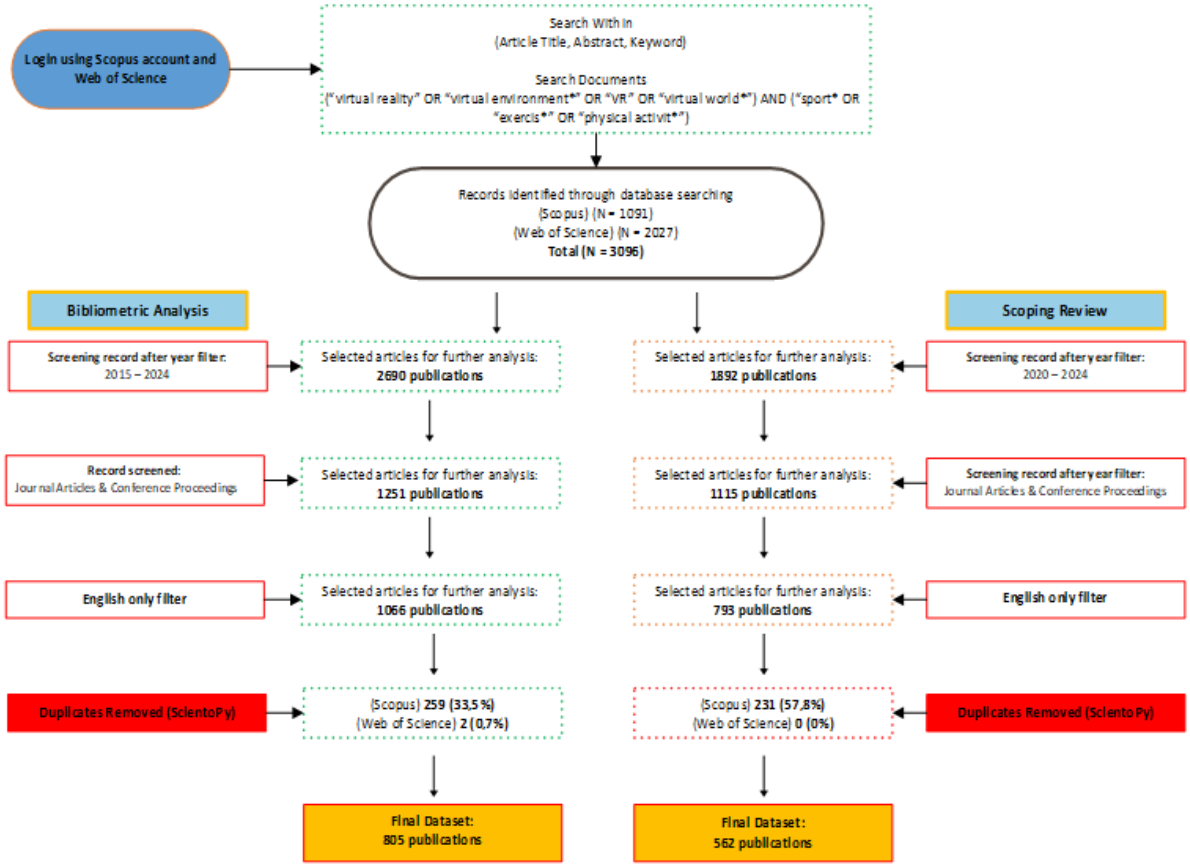
Consultation With Relevant Stakeholders

We conducted consultations with experts and stakeholders in the field of sports and VR technology at this stage. The goal is to gain additional insight into the trends, challenges, and future potential of VR in sports. Stakeholders such as researchers, coaches, VR developers, and sports practitioners offer valuable insights into VR applications that enhance athlete performance, lower injury risk, and enhance the training experience through interviews or panel discussions. This approach enriches the perspective of the article by adding practical and professional experience that can clarify the relevance and impact of the identified trends. Additionally, their input assisted in identifying pertinent research gaps, ensuring that

proposed research directions align with industry needs and the development potential of emerging technologies (Selamat et al., 2022).

Figure 3

Flowchart of Selected Studies Using PRISMA Guidelines



Results

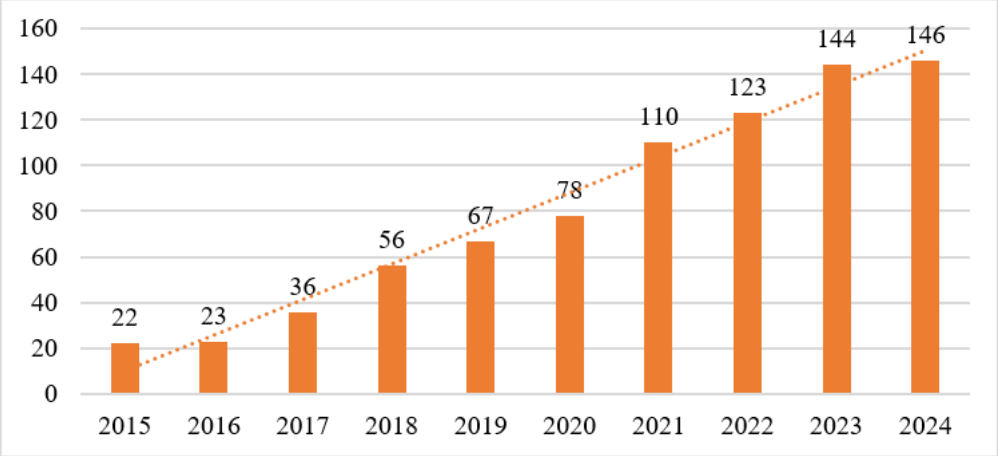
A. Bibliometric Analysis

Global Research Trends

From 2015 to 2024, the number of publications on virtual reality (VR) in sport exhibited a steady and continuous upward trend (Figure 4). The field began with 22 publications in 2015, followed by a noticeable increase from 2018 onward—reaching 56 publications—and culminating in a peak of 146 articles in 2024. This growth illustrates the rising global interest in the application of VR in areas such as athletic performance enhancement, training simulations, and fan engagement, indicating both the technological momentum and the expanding research attention dedicated to immersive solutions in the sport domain.

Figure 4

Global Research Trends VR Publications in Sports

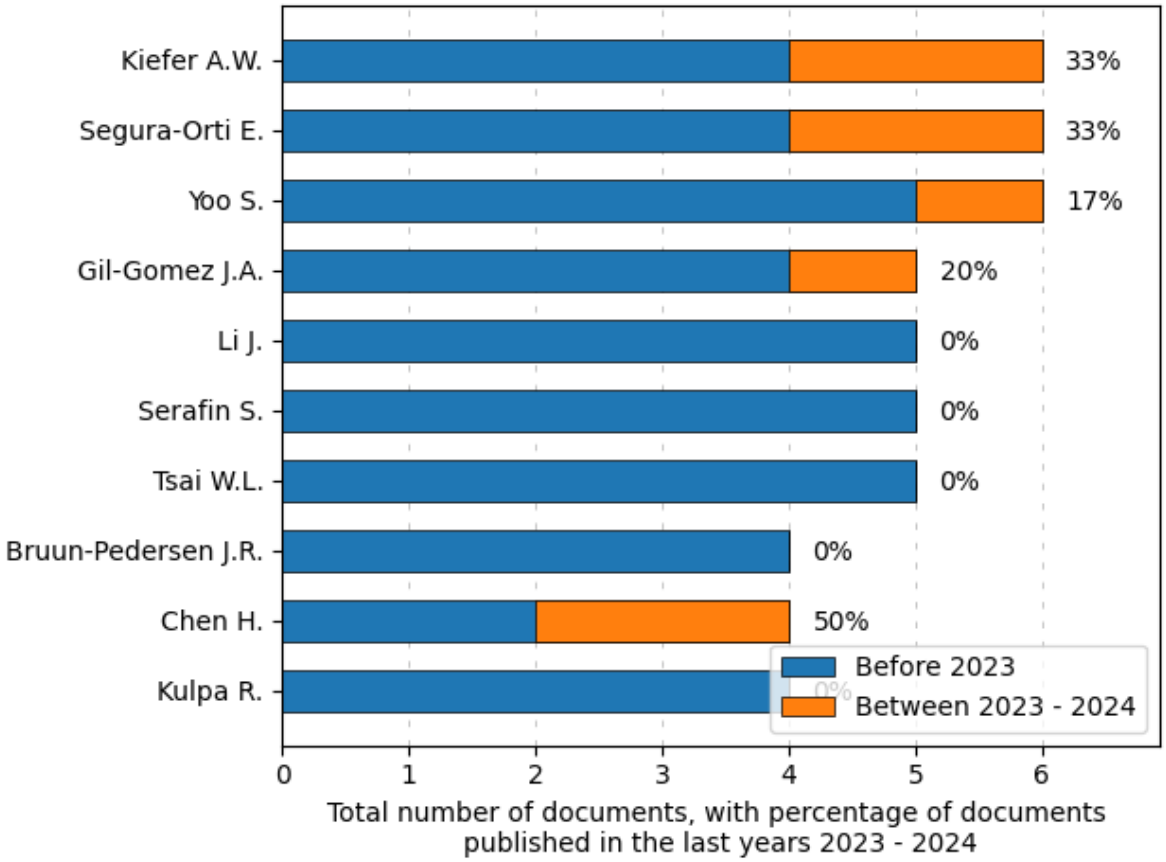


Key Authors

Figure 5 highlights several leading authors in VR-sport research from 2015 to 2024. Adam W. Kiefer stands out with six publications and a high h-index of 42, underscoring substantial scientific impact. Eva Segura-Ortí likewise contributed six publications; although her average growth rate of publications (AGR, the year-on-year change in output) is slightly negative (–0.5), her h-index of 33 indicates sustained relevance. Soojeong Yoo and José-Antonio Gil-Gómez both demonstrate consistent output—six and five publications, respectively—with correspondingly high h-indices (44 and 35), confirming their long-term influence despite modest AGR values. Notably, Hui Chen, with four publications, records the highest percentage of distribution in the last year (PDLY) at 50 percent, signalling a sharp recent surge in scholarly engagement.

Figure 5

Key Contributors VR Publications in Sports



Key Sources

Based on publication data related to the application of VR in sports between 2015 and 2024, several main sources have been identified as highly influential (see Table 4). The source with the highest publications is the ACM International Conference Proceeding Series, with a total of 23 publications and an h-index of 5, indicating a consistent but moderate contribution in its impact. Lecture Notes in Computer Science takes second place with 21 publications, an AGR of 0.5, and an H-index of 6, signaling a greater level of influence and a steady increase each year. The International Journal of Environmental Research and Public Health, with 18 publications and the highest h-index among the list at 8, is the third most influential source, despite a decrease in AGR (-1.5). The Games for Health Journal stands out with an AGR value of 2.0 and a PDLY (Percentage Distribution in the Last Year) of 46.2%, suggesting a rapid increase and significant focus on publications in this field. In addition, Applied Mathematics and Nonlinear Sciences, despite having only 12 publications, shows high growth with an AGR of 6.0 and a PDLY of 100%, indicating intensive engagement in recent years. Overall, these sources became a major reference in the development of VR research in sports, with contributions that included continuous publications and increased influence over the period studied.

Table 4

Key Sources VR Publications in Sports

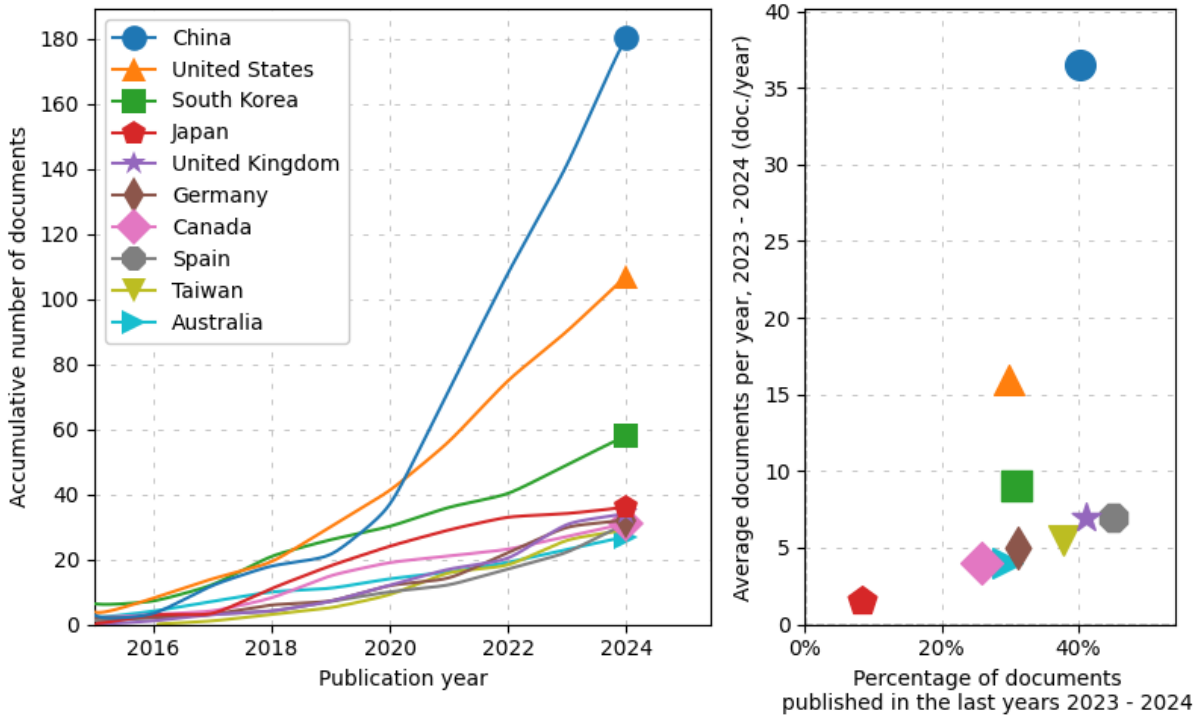
Pos.	Source Title	Total	AGR	ADY	PDLY	h-Index
1	ACM International Conference Proceeding Series	23	0.0	1.5	13.0	5
2	Lecture Notes in Computer Science	21	0.5	2.0	19.0	6
3	International Journal of Environmental Research and Public Health	18	-1.5	3.5	38.9	8
4	Journal of Physics: Conference Series	14	0.0	0.0	0.0	5
5	Games for Health Journal	13	2.0	3.0	46.2	6
6	Applied Mathematics and Nonlinear Sciences	12	6.0	6.0	100.0	2
7	Frontiers in Psychology	9	0.0	1.0	22.2	6
8	PLOS One	9	0.0	1.5	33.3	5
9	Applied Sciences-Basel	8	0.5	2.5	62.5	4
10	Advances in Intelligent Systems and Computing	8	0.0	0.0	0.0	3

Key Countries

Figure 6 illustrates notable national trends in VR-related sport research between 2015 and 2024. China leads the field with 181 publications, showing rapid growth particularly from 2020 onward, including peaks in 2021 (36 publications) and 2024 (40 publications). The United States ranks second with 107 publications and demonstrates a relatively steady output, peaking in 2022 with 19 articles. South Korea follows with 58 publications, exhibiting early momentum and maintaining stable contributions in recent years. Meanwhile, Japan (36 publications), the United Kingdom (34), and Germany (32) also contributed to the global research landscape, albeit with more modest growth. These patterns highlight a strong upward trend in Asian countries, particularly China and South Korea, suggesting the region's growing role as a hub of innovation in applying VR technologies within sport.

Figure 6

Country Evolution Graph in VR Sports Research Publications



B. Scoping Review

Types of Sports

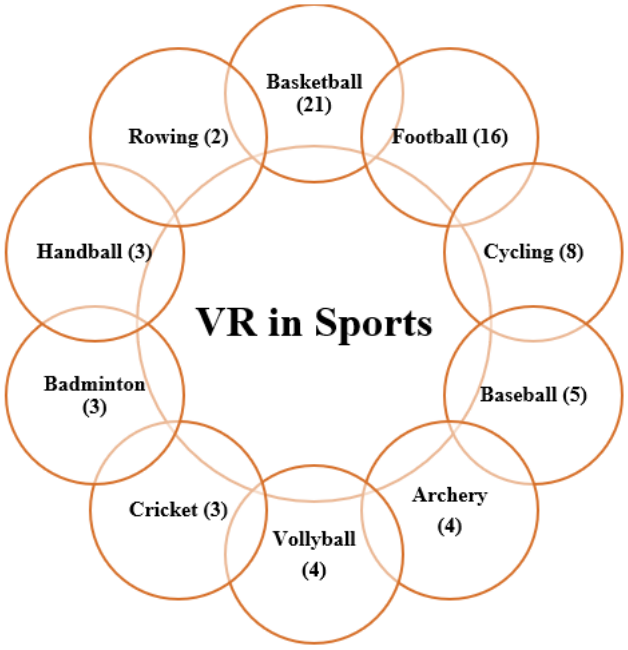
Of the 562 records initially retrieved, 69 studies published between 2020 and 2024 met the inclusion criteria and were analysed through a scoping review using ScientoPy (Figure 7). These studies revealed that team sports dominate VR applications, particularly in basketball (n = 21) and football (n = 16). In these sports, VR is most commonly used for enhancing physical skills, such as passing and shooting (Liu et al., 2024; Wei et al., 2022; Yang & Yi, 2022), and for cognitive skills like tactical awareness and decision-making (Chalmers et al., 2014; Tsai et al., 2021). Football-specific applications further include training for heading (Marshall et al., 2023) and development of perceptual-cognitive and motor coordination skills (Fortes et al., 2021; Krupitzer et al., 2022; Ibrahim et al., 2023; Lozano-Tarazona & Rivera Pinzón, 2023). Similarly, baseball (n = 5) employs VR to support motor performance (e.g., throwing mechanics) and psychological readiness (Ara & Nakamura, 2020; Wilkins, 2024). In volleyball (n = 4), VR facilitates technical and tactical development, particularly in setter awareness and attack precision (Chen et al., 2023; Song, 2023), while handball (n = 3) integrates VR to improve shooting accuracy and speed (Sha'lan, 2023). Cricket (n = 3) simulations focus on psychological and stress management under competitive conditions (Kelly et al., 2022).

In individual and precision-based sports, VR is frequently applied to enhance visuomotor coordination, rehabilitation, and perceptual-cognitive integration. In cycling (n = 8), VR is most often used for rehabilitation purposes, improving motor function and cardiorespiratory fitness (Hasnan et al., 2024; Lesmana et al., 2024). Archery (n = 4) and badminton (n = 3) target fine motor control and visuospatial awareness, using VR to simulate realistic training environments that support head-body coordination and eye-hand synchronisation (Adachi et al., 2020; Esposito et al., 2021; Ishibe et al., 2020). Meanwhile, rowing (n = 2) emphasizes inclusive applications, with VR simulators designed to expand participation for athletes with special needs, offering safe, adaptive training scenarios (Covarrubias et al., 2024).

The analysis provided in this section is descriptive in nature. It does not involve thematic coding or qualitative interpretation but instead aims to map the breadth of VR applications across sports by categorizing the purposes and contexts of use reported in the included studies. Overall, this scoping review shows that VR in sports serves multiple functions: (1) developing physical and technical performance, (2) strengthening cognitive and perceptual decision-making, (3) aiding rehabilitation and recovery, (4) supporting psychological adaptation, and (5) promoting inclusive training environments. The findings suggest that VR is not merely a performance-enhancing tool, but also a comprehensive technological intervention adaptable to a wide range of sport-specific goals.

Figure 7

Ten Types of Sports Using VR Technology



Future Perspectives

The findings of the scoping review identified several promising directions for future research to expand the use of virtual reality (VR) in sports contexts (see Table 5). VR technology demonstrates considerable potential in enhancing multiple dimensions of athletic performance, including cognitive functioning, decision-making skills, and reflexive responses—especially within high-intensity or fast-paced sports environments.

Table 5

Key Sources VR Publications in Sports

Future Perspectives	Description
Sports use VR for cognitive and strategy training	Research the effectiveness of VR in improving cognitive skills, such as strategy and decision-making in team sports (e.g., football and basketball), by simulating realistic game situations.
VR in Sports with High Tactical and Reflex Skills	Explore VR to train quick response and high accuracy in sports such as badminton, handball, and archery, especially in high-intensity situations that require precision timing and quick reflexes.
Expansion to Sports with Limited Usage	Develop research to evaluate the benefits of VR in currently underexplored sports, such as cricket and rowing, to train technical skills and mental resilience in the face of difficult environments, or to simulate real competition.
Long-term evaluation of performance enhancement through VR	Conduct longitudinal studies to assess the impact of VR on athlete performance, including psychological aspects, mental fatigue, and increased motivation in training, which will provide a picture of the long-term benefits of using VR in sports.
Research in the underexplored field of sports	Sports that require high concentration and mental endurance, such as golf or table tennis, have not been widely explored. The implementation of VR in these disciplines can test athletes' mental performance and improve focus through simulated matches that demand emotional control and consistency.
VR for increased engagement among beginners and young athletes	VR can be developed for basic training and engagement programs for young athletes in popular sports such as basketball and football. They can train for basic technical skills and understand game tactics early on with VR.

Discussion

In the last ten years, research on VR in the context of sports has shown a significant increase. The advancement of VR technology, which is becoming increasingly affordable, accessible, and applicable in various aspects of sports, from training and rehabilitation to fan engagement, is responsible for this increase. This is due to the decreasing cost of VR hardware and software, which is an important factor in expanding the application of this technology (Panagiotidis, 2021; Wohlgenannt et al., 2020). In the field of sports, VR not only enhances the user experience but also opens up opportunities for athletes to hone skills in a safe and controlled simulated environment (Greig et al., 2024; Staurset & Prasolova-Førland, 2016). Technology companies, seeing the potential of VR as a medium to optimize athlete performance and increase the appeal of sports among the wider community, are also driving this growth (Cossich et al., 2023; Park et al., 2024). According to our bibliometric

data, 2024 records the highest annual output for VR sport publications within 2015–2024. This peak—supported by continual growth in databases such as Scopus and WoS, where sport VR entries rose from fewer than 25 publications in 2015 to over 140 in 2024—is likely driven by sustained academic interest, expanding institutional funding, and rapid advances in motion tracking sensors that make VR more immersive and research-ready (Caserman et al., 2020). Recent studies illustrate the momentum: Chan et al. (2024) reported significant gains in reaction time among elite basketball players after an eight#week VR protocol, while Du et al. (2025) observed improved proprioception and well#being during ACL rehabilitation. Rather than being a speculative projection, this claim is grounded in quantitative publication data observed in this study, though future monitoring is needed to determine whether the upward trend will continue beyond 2024.

Several researchers, such as Adam W. Kiefer, Eva Segura Ortí, Soojeong Yoo, and José Antonio Gil Gómez, have made significant contributions to the development of VR research in sports. Their high h-index reflects widespread scholarly influence. For instance, Kiefer and colleagues have explored VR-based assessments to improve skill transfer and inform injury prevention strategies (DiCesare et al., 2020), while Segura-Ortí has focused on the rehabilitation domain, enhancing physical function and health-related quality of life through VR (Segura-Ortí & García-Testal, 2019). More recent contributors like Hui Chen, identified by high Publication Delay Year (PDLY) scores—which indicate that their impactful work gained recognition relatively late after publication—represent a rising wave of interest in athlete-centric VR research. These include psychological dimensions such as motivation and user engagement (Bai et al., 2021; Chen & Li, 2024). Collectively, this transition marks a broader shift from technology-driven explorations toward more human-focused, interdisciplinary investigations.

This shift in focus is paralleled by an emerging diversification in research methodologies. Most VR#in#sport studies to date have adopted experimental designs, particularly randomised controlled trials (RCTs), which aim to demonstrate causal effects on performance outcomes—for example, Wu et al. (2023) tested VR table tennis and soccer to assess changes in body fat and brain health in adolescents with obesity, whereas Mohammadi et al. (2023) evaluated VR#based balance training for functional ankle instability, reporting modest, yet measurable, improvements in postural control and perceived ankle stability among basketball players. Meanwhile, observational studies add ecological validity by analysing VR use in real#world settings; Anguera et al. (2025) showed that supplementing regular tennis practice with VR#driven cognitive training significantly improved adolescent players' performance ratings. Case studies provide depth for niche contexts—such as Romeas et al. (2022), who implemented a 360° VR temporal#occlusion program during COVID#19 restrictions and found superior decision#making improvements in elite boxers compared with a VR#game control, while also underscoring VR's safety and representativeness for combat#sport training. However, longitudinal mixed-methods studies remain scarce, constraining insight into the sustained effects of VR interventions. Future research should triangulate quantitative metrics (e.g., reaction time, biomechanical outputs) with qualitative feedback from athletes and coaches to capture both performance and experiential impacts over time. To operationalise such work, researchers could adopt validated cognitive batteries (e.g., CANTAB) alongside neuroimaging tools like EEG or fNIRS to map executive#function gains and prefrontal activation patterns during VR#based training, thereby linking theoretical constructs to measurable outcomes.

Dominant publication outlets—such as the ACM International Conference Proceeding Series—remain a preferred venue for VR-related research, reflecting the field's strong foundation in computing and technological innovation. This preference suggests that the VR research community continues to value platforms with wide dissemination and high relevance in computer science advancement. The Association for Computing Machinery (ACM), as the publisher, spans five key computing domains—computer science, computer engineering, information technology, information systems, and software engineering—making it a central hub for interdisciplinary contributions (Connolly et al., 2016). Meanwhile, journals such as *Games for Health* have shown a notable increase in Average Growth Rate (AGR), indicating growing scholarly interest in VR's applications for health, rehabilitation, and physical performance. Recent empirical studies now document VR-assisted stroke rehabilitation, gait retraining, and anxiety reduction in athletic populations (Kim & Kaneko, 2023; Kim et al., 2025), reinforcing VR's dual utility in both physical and mental health domains (Kuleva, 2023). This evolution points to a paradigm shift in sport science, where VR is no longer viewed solely as a training innovation but also as a holistic intervention for enhancing physical performance, facilitating rehabilitation, and supporting mental well#being. The diversification of publication venues —from technical conference proceedings to health-focused journals—mirrors this broader interdisciplinary integration and underscores the need for more collaborative research frameworks moving forward. Nonetheless, current VR systems still

face limitations—including simulator sickness, high hardware costs, restricted haptic feedback, and safety concerns during high#intensity movements—that must be mitigated before widescale adoption in elite training environments.

Geographically, China and the United States dominate VR-in-sport research output, supported by national innovation policies, institutional collaboration, and robust R&D investment (Pan et al., 2000; Wang & Wu, 2014; Wei, 2022). China emphasizes state-sponsored smart sports initiatives and school-based VR adoption, while the U.S. leverages academic–industry partnerships to develop VR for training, injury prevention, and cognitive performance. South Korea focuses on the application of VR in sports education (Kang & Kang, 2019), developing technologies that enable interactive learning (Bae, 2023). Japan and the United Kingdom have widely explored VR for training systems (Ara & Nakamura, 2020; Marshall et al., 2023; Mikami et al., 2018), while Germany emphasizes the development of VR-based training devices to enhance athlete performance (Stoeve et al., 2022). These national initiatives reflect a growing international ecosystem shaping VR innovation across diverse sport domains. Notably, emerging contributions from countries such as Australia—focusing on post-injury rehabilitation—and Spain—emphasizing youth-oriented VR training programs—are helping to expand the field's global footprint. To further accelerate global progress, strengthening interregional collaboration will be essential for fostering knowledge exchange and culturally adaptive VR sport innovations, supporting more inclusive and context-sensitive technology development, culturally responsive VR sport technologies.

Although the evidence base for VR in sport is growing, several areas remain under#explored. First, there is scant work on VR#enabled cognitive training that targets high#level strategic skills and real#time decision#making in team sports. Integrating game#theoretic scenarios and adaptive AI opponents could elucidate how virtual rehearsal translates into on#field tactics. Second, the psychological dimension of VR interventions—improvements in sustained concentration, stress regulation, and mental resilience—has received limited empirical attention, despite early indications of benefit in collegiate and professional cohorts. Third, high#precision technical sports such as badminton, handball, and archery offer fertile ground for investigating VR's potential to train rapid visuomotor responses and millisecond#level accuracy; yet controlled trials in these disciplines are virtually absent. Addressing these gaps will require interdisciplinary studies that combine neurocognitive assessment (e.g., EEG, fNIRS), biomechanical analytics, and qualitative athlete feedback. Such multimodal designs will trace how skills acquired in immersive environments translate into realworld performance. Recent reviews (Neumann et al., 2018; Richlan et al., 2023) emphasise the need for longitudinal, mixed#methods designs that monitor retention, injury risk, and motivation over entire competitive seasons. Such work would clarify underlying mechanisms, optimise training dose, and inform evidence#based guidelines for coaches and sport psychologists.

Beyond its theoretical value, VR now serves as a versatile platform for the sport industry. It enables realistic athlete#training simulations, collaborative group#learning modules, adaptive rehabilitation programs, and immersive fan#engagement experiences—functioning as a comprehensive tool for performance development, education, and overall well#being. By recreating match#like scenarios, VR allows athletes to refine skills under controlled yet authentic conditions. At the same time, spectators can follow their favourite teams through richly interactive, 360#degree environments. These capabilities highlight VR's potential to transform not only how athletes train and recover but also how fans engage and how learning unfolds in sport settings. To fully harness this potential, sustained investment and interdisciplinary collaboration—uniting sport scientists, technologists, educators, and health professionals—are essential. Such efforts will advance VR#driven innovations, inform best#practice guidelines, and provide a solid foundation for future studies aimed at maximizing athlete performance, enhancing fan engagement, and improving user well#being across sport contexts. Ultimately, the convergence of VR innovation, interdisciplinary scholarship, and practical integration across sporting contexts affirms its growing role as a transformative force in contemporary sport science.

Given the current momentum and identified limitations, the next wave of VR research in sport must strive for greater methodological rigor and global inclusivity. However, this bibliometric and scoping review not only maps the current research landscape of VR in sport but also identifies several areas requiring improvement. Key limitations include the restricted coverage of certain databases and the lack of comprehensive assessment regarding the long-term impact of VR in sports settings. It is recommended that future reviews expand database inclusion beyond Scopus and Web of Science to capture a broader array of relevant literature and regional contributions. Further, international collaboration network analysis could provide deeper insight into cross-country research patterns and foster new opportunities for global partnerships. The adoption of more advanced bibliometric techniques—such as co-word analysis, co-citation analysis, and network analysis —will enable the identification of more specific and emerging research trends. Interdisciplinary approaches that integrate

fields such as psychology, neuroscience, and engineering are also essential to drive innovation and broaden the scope of VR applications in sport. These efforts will enhance understanding of how VR affects both athletes and fans, while supporting the sustained evolution of immersive technologies to elevate both athletic performance and the spectator experience. In summary, the convergence of VR innovation, interdisciplinary scholarship, and applied integration across sporting contexts affirms its growing role as a transformative force in contemporary sport science.

Conclusions

This bibliometric analysis and scoping review provide a comprehensive overview of the research landscape surrounding the use of virtual reality (VR) in sport. The findings highlight rapid publication growth, expanding interdisciplinary interest, and diverse methodological approaches across performance training, rehabilitation, and mental well-being domains. In addition to identifying leading contributors, publication outlets, and global trends, the review also pinpoints underexplored themes such as cognitive enhancement, psychological outcomes, and precision skill acquisition in specific sports. By synthesizing trends and gaps, this review contributes to a more structured understanding of how VR is shaping contemporary sport science. As the field matures, greater methodological refinement, broader database inclusion, and cross-sector collaboration will be essential to strengthen empirical grounding and practical relevance. VR continues to evolve from a niche innovation to an integrated, transformative tool across athletic and educational contexts—positioning it as a critical frontier for future sport technology research and application.

Ethics Committee Statement

Not applicable as the study does not involve human participants, direct intervention, or primary data collection which requires approval from the Ethics Committee.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest that could affect the presentation or interpretation of the results in this study.

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Authors' Contribution

Conceptualization: N.G. & S.K.S. A.; Methodology: E.S.; Software: R.C.; Validation: M.F.M; Formal Analysis: J.L.; Resources: N.G.; Data Curation: S.A.K.; Writing – Original Draft: N.G & E.S.; Writing – Review & Editing: R.C. & M.F.M.; Visualization: N.G.; Supervision: R.J.L.T. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data supporting the findings in this study were obtained from the Scopus and Web of Science databases, accessed through Universiti Utara Malaysia.

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