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Review Article

Global trends and research directions of augmented reality in sports: A bibliometric and scoping review

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ABSTRACT

Background: Advances in digital technology have accelerated the adoption of augmented reality (AR) in sports, enhancing training quality, performance analysis, and learning experiences. However, comprehensive studies that systematically map global research trends and sport-specific applications remain limited. Objective: This study aims to analyze global trends and applications of augmented reality (AR) in sports using a mixed-method approach combining bibliometric analysis and a scoping review. Methods: Bibliographic data were retrieved from Scopus and Web of Science (WoS) databases, covering the period 2016–2025. Following a PRISMA-ScR-based selection process, a total of 520 articles were included. Bibliometric analysis was conducted using VOSviewer and ScientoPy to identify publication trends, leading contributors, sources, and keyword networks. A scoping review was performed to examine AR applications across different sports and identify emerging research directions. Result: The findings show a substantial increase in AR-related publications in sports, with a sharp growth observed after 2020. China, the United States, and Japan emerged as the most productive countries. Keyword analysis indicates strong integration between AR and emerging technologies such as artificial intelligence, computer vision, and wearable sensors. The scoping review identified nine sports adopting AR, with climbing and football being the most frequently studied. Conclusion: AR research in sports is rapidly evolving toward intelligent, data-driven training systems. In practice, these findings suggest that coaches and educators can utilize AR to enhance real-time feedback, skill acquisition, and decision-making. At the same time, developers can design more adaptive, sport-specific training systems. Future research should focus on expanding AR applications across underexplored sports and developing integrated systems that combine artificial intelligence, sensor technologies, and immersive environments.

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Augmented reality; bibliometric analysis; digital sports training; scoping reviews; sports technology.

Introduction

Augmented reality (AR) is a digital technology that integrates virtual objects into the real world in real time through computer-generated elements, including audio, video, graphics, and location data (Soltani & Morice, 2020). This technology has gained significant popularity across various applications over the past few decades (Silva et al., 2021). The principle of AR is to enhance real-world environments by providing enriched contextual experiences (Cossich et al., 2023; Le Noury et al., 2022; Pato & Remillard, 2018). AR enhances user experience by interactively integrating virtual elements with the real environment, offering richer contextual information than traditional digital media (Dargan et al., 2023;

de Amorim et al., 2022). As a result, AR is increasingly utilized across diverse sectors, including education, healthcare, industry, digital entertainment, and sports.

An AR system consists of several essential components, including interrelated hardware and software (Arena et al., 2022; Dargan et al., 2023). The hardware generally comprises cameras, motion sensors, display devices, and tracking systems that determine the user's position and orientation in real time (Intan et al., 2023). Meanwhile, AR software uses computer vision, image processing, and 3D modeling to render virtual objects within real-world environments accurately. The integration of these components enables AR to create interactive experiences for learning, training, and simulation purposes (Choi & Li, 2026; Uçar, 2024).

In recent years, AR technology has rapidly developed across multiple domains, including sports and physical exercise (Michalski et al., 2019). AR can effectively overlay digital information onto real athletic contexts, enabling interactive platforms that provide real-time performance feedback (Greenhough et al., 2021). It serves as an effective tool to improve the quality of sports training (Soltani & Morice, 2020), facilitate motor skill acquisition (Chang et al., 2020), enhance motivation in physical education (Liang et al., 2023; Omarov et al., 2024), simulate sport scenarios (Al-Sinani & Taher, 2023), and analyze athlete performance (Cossich et al., 2023). As a result, AR creates more engaging training environments and enhances athletes' motivation and participation (He & Wei, 2025).

Despite ongoing research on AR in sports, existing studies remain fragmented across multiple disciplines, including sports science, computer science, and educational technology (Minaya-Isique et al., 2024). Most studies focus on specific applications, such as improving technical skills or training motivation, without providing a comprehensive understanding of the overall development of AR research in sports (Soltani & Morice, 2020). Moreover, several review studies examine AR within broader contexts, such as sports and health (Minaya-Isique et al., 2024), sport event management, and the integration of AR with artificial intelligence (AI) in physical activity (Solas-Martínez et al., 2023).

In contrast, several review studies have examined immersive technologies, integrating virtual reality (VR), augmented reality (AR), and mixed reality (MR) in sports and training (Dhillon et al., 2025; Le Noury et al., 2022). Some studies also explore the integration of AI, VR, and AR for sports performance analysis (Cossich et al., 2023). While these studies provide valuable insights into digital technology in sports, their broad scope limits the ability to analyze the development of AR research specifically in this domain. To date, no study has systematically mapped global publication trends, identified key contributors, and examined sport-specific applications of AR within a single framework. Therefore, a comprehensive investigation is needed to understand better the evolution and future directions of AR research in sports.

Bibliometric analysis is a widely used approach for understanding research developments within a specific field. It enables the systematic mapping of publication trends, collaboration networks, influential sources, and emerging research topics (Gazali et al., 2023; Nurhuda et al., 2023; Donthu et al., 2021; Gazali & Saad, 2023; Larassary, 2026). This method has been extensively applied in sports technology research to examine the evolution of the literature and identify future research directions (Tang et al., 2022; Xu et al., 2024). However, it primarily focuses on publication structures and relationships, offering limited insight into the practical implementation of technology in sports contexts.

To address this limitation, a scoping review approach can be applied to identify key concepts, research characteristics, and knowledge gaps within an emerging field (Mak & Thomas, 2022; Pollock et al., 2024). This approach is effective for mapping existing research and guiding future studies (Tricco et al., 2018), particularly in explaining how technologies such as augmented reality are applied across different sports disciplines (Dowling et al., 2018, 2020). Therefore, this study adopts a mixed-method approach combining bibliometric analysis and a scoping review to examine AR research in sports. Specifically, it aims to: (i) analyze global publication trends, (ii) identify leading authors, sources, and

countries, and (iii) examine which sports disciplines have implemented AR technology in research and training contexts.

This study offers a novel contribution by integrating bibliometric analysis and a scoping review within a unified framework to examine AR as a distinct research domain. Unlike prior studies that focus on specific applications or combine AR with other immersive technologies, this study offers a more focused, systematic analysis. It contributes by: (i) mapping the global research landscape, (ii) identifying key contributors and sources, and (iii) examining sport-specific applications, thereby addressing a critical gap in the literature. To address these objectives, the following research questions are proposed:

RQ1: What are the global research trends, key contributors, journal sources, and the most influential countries in AR research in sports?

RQ2: Which sports have adopted AR technology in their research and practice?

RQ3: What are the emerging directions for future research in the literature on the use of AR in sport?

Method

Study Design

This study uses a mixed-method approach combining bibliometric analysis and a scoping review to provide a comprehensive understanding of the development of augmented reality research in sports. The integration of bibliometric analysis and scoping reviews is increasingly used in literature studies, as it provides a more comprehensive understanding of research developments within a field (Adegoke & Abidoye, 2024; Liu et al., 2024). Bibliometric analysis facilitates the identification of publication patterns, collaboration networks, and trends in research topics (Gazali et al., 2023; Gazali & Saad, 2023), whereas scoping reviews assist in mapping essential concepts and research attributes within nascent fields (Dowling et al., 2020) and are especially beneficial for synthesizing findings in research areas marked by diverse knowledge (Tricco et al., 2018).

Bibliometric Analysis

Data Sources

Bibliographic data were obtained from two major scientific databases: Scopus and Web of Science (WoS). These databases were selected for their extensive coverage of high-quality international publications and their widespread use in bibliometric studies to analyze global research trends (Nurhuda et al., 2023; Santamaria-Granados et al., 2021). In addition, both databases provide comprehensive citation data, which supports reliable bibliometric analysis (Pranckut, 2021).

Search Strategy

The literature search was conducted in March 2026 using a combination of keywords related to augmented reality and sports, connected through Boolean operators (AND, OR) (Table 1). Boolean operators were used to combine relevant keywords and their synonyms to construct comprehensive search queries (Turnbull et al., 2023). The search was limited to publications from the last ten years (2016–2025) to capture recent developments in the field. This approach enhances both the precision and comprehensiveness of the search strategy by ensuring that relevant studies are retrieved while minimizing the risk of omitting important publications. The search was limited to publications from the last ten years (2016–2025) to capture recent developments in the field.

Inclusion and Exclusion Criteria

The identified publications were screened according to predefined inclusion and exclusion criteria to ensure a consistent, transparent selection process. These criteria were designed to minimize bias by applying objective standards related to research focus, publication type, and data completeness (Adegoke & Abidoye, 2024). Table 2 summarises the criteria used in this study.

Table 1. Keywords and search strings

Database	Search Field	Search String
Web of Science	TS= (Topic)	TS= (("augmented reality" OR "AR-based" OR "mobile augmented reality" OR "marker-based AR" OR "markerless AR" OR "location-based AR") AND ("sport" OR "athletic" OR "competitive sport*" OR "elite sport*" OR "team sport*" OR "individual sport*" OR "physical education" OR "PE" OR "school sport*" OR "physical education class*" OR "physical education lesson*" OR "sport training" OR "athletic training" OR "sport performance" OR "athletic performance"))**
Scopus	TITLE-ABS-KEY	TITLE-ABS-KEY (("augmented reality" OR "AR-based" OR "mobile augmented reality" OR "marker-based AR" OR "markerless AR" OR "location-based AR") AND ("sport" OR "athletic" OR "competitive sport*" OR "elite sport*" OR "team sport*" OR "individual sport*" OR "physical education" OR "PE" OR "school sport*" OR "physical education class*" OR "physical education lesson*" OR "sport training" OR "athletic training" OR "sport performance" OR "athletic performance"))**

Table 2. Inclusion and Exclusion Criteria

Criteria	Description
Inclusion	The publication discusses the use of augmented reality in sport The publication is published in a journal indexed in Scopus or Web of Science The publication was published within the last 10 years (2016–2025) The publication is written in English
Exclusion	Publications not directly related to sport Editorials, review articles, book chapters, or non-scientific reports Publications with incomplete metadata

Study Selection

The bibliometric analysis commenced with a systematic literature search in Scopus and Web of Science (WoS), yielding 842 publications from Scopus and 223 from WoS (total n = 1,065). The dataset was then limited to publications from 2016 to 2025, yielding 702 records from Scopus and 198 from WoS (n = 900). Subsequent filtering by document type (journal articles and conference proceedings) reduced the dataset to 533 records from Scopus and 173 from WoS (n = 706). Further restricting to English-language publications yielded 475 records from Scopus and 165 from WoS, for a total of 640 records. The datasets were merged and processed using SciPy to identify and remove duplicate records (Figure 1).

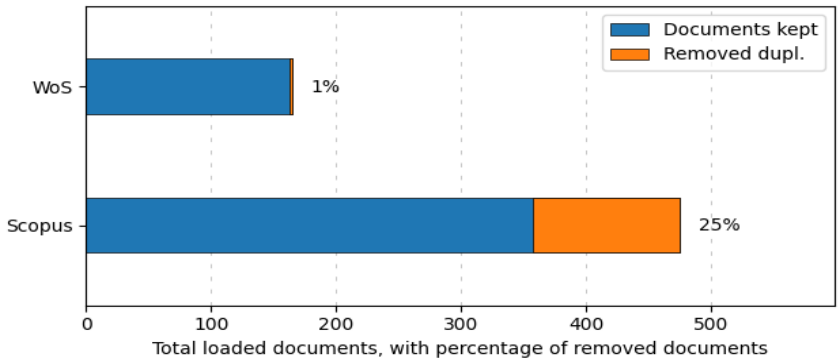

Figure 1. Data Pre-Processing and Duplicate Removal from Scopus and Web of Science (Wos) Databases

A total of 120 duplicate records were removed (2 from WoS and 118 from Scopus), resulting in a final dataset of 520 publications, which meets the recommended threshold for bibliometric studies—typically a minimum of 300 publications—to ensure a representative analysis (Donthu et al., 2021). The study selection process followed the PRISMA-ScR guidelines, including identification, screening, eligibility, and inclusion stages (Figure 2).

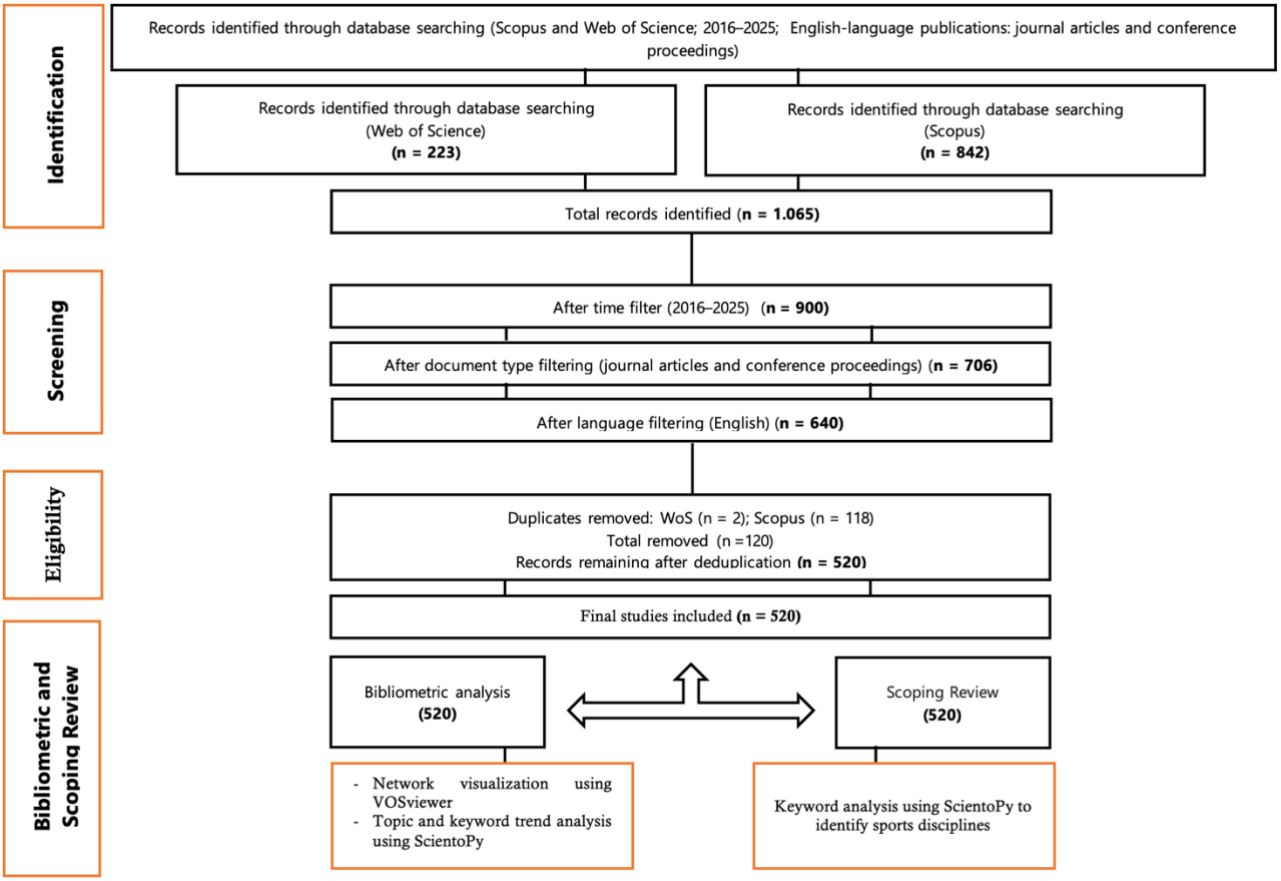

Figure 2. Study Selection Process Following PRISMA-ScR Guidelines

Data Analysis Tools

This study employed two software tools for bibliometric analysis, namely VOSviewer and ScientoPy. VOSviewer was used to visualize bibliometric networks, including co-authorship, co-citation, and keyword co-occurrence, enabling the identification of research collaboration patterns and thematic structures within the field (Van Eck & Waltman, 2019). ScientoPy was used to analyze publication trends, including the growth of scientific output, keyword evolution, and topic development over time (Ruiz-Rosero et al., 2019). The analysis focused on key bibliometric indicators such as publication frequency, annual growth rate, and keyword distribution to interpret the development and emerging directions of AR research in sports.

Scoping Review

Scoping Review Framework

This study follows the scoping review framework proposed by Arksey & O'Malley (2005) and further refined by Tricco et al. (2018), which consists of five stages: (i) identifying research questions, (ii) identifying relevant studies, (iii) study selection, (iv) data extraction, and (v) synthesis and reporting of results. This scoping review also follows the PRISMA-ScR reporting guidelines to ensure transparency and methodological rigor in the study selection and reporting process. This framework is widely applied

in sports science research to map research characteristics and identify knowledge gaps in emerging fields (Dowling et al., 2018, 2020; Robertson et al., 2022).

Identifying the Research Question

The scoping review was guided by clearly defined research questions to ensure alignment with the study objectives (Arksey & O'Malley, 2005; Tricco et al., 2018). This study generated research questions to investigate the application of augmented reality technology in sports and to discover upcoming research directions in the scientific literature. The scoping review stage centers on two primary questions: (i) which sports disciplines have integrated augmented reality technology in research and practice? Moreover, (ii) what future research directions are indicated by the literature concerning the application of augmented reality in sports? These inquiries serve as the foundation for identifying, selecting, and analyzing pertinent studies.

Study Selection

The scoping review utilized the same dataset obtained from the bibliometric selection process (n = 520), as illustrated in Figure 2. This dataset had already undergone a rigorous screening procedure based on predefined inclusion and exclusion criteria during the bibliometric phase. Therefore, no additional screening was required at this stage. The dataset was analyzed to identify sport-specific applications of AR technology. Keyword analysis using SciPy was conducted to extract sport-related terms, which were then used to classify publications by sport discipline.

Data Extraction and Analysis

Publications that met the inclusion criteria were systematically analyzed to extract key research characteristics relevant to the objectives of this study. The extracted data included information on authorship, publication year, country of origin, sport discipline, type of AR technology, application purpose, research design, and main findings. To ensure data validity and reliability, the extraction and classification processes were systematically cross-checked, and any inconsistencies were carefully reviewed and resolved. This procedure minimized potential bias and ensured the accuracy and consistency of the dataset used in the analysis.

The extracted data were then analyzed using a thematic classification approach to categorize AR applications across different sports disciplines. This process involved grouping studies based on similarities in research focus, sport type, and technological implementation. In addition, a keyword frequency analysis was conducted to identify dominant topics and emerging trends in the literature. Through this analytical approach, patterns in the implementation of AR technology across various sports contexts were identified. Furthermore, the analysis enabled the identification of underexplored sports disciplines, thereby highlighting gaps in the existing literature and providing a foundation for future research.

Results and Discussion

Results

Bibliometric Analysis

Global Publication Trends

Global publication trends indicate a substantial and sustained increase in research on AR in sports over the period 2016–2025 (Figures 3 and 4). While publication output fluctuated during the early phase (2016–2019), a clear and consistent growth trend emerged after 2020, culminating in a sharp rise to 100 publications in 2025. This pattern suggests that AR research in sports has transitioned from an exploratory phase to a stage of accelerated development and consolidation.

The cumulative growth in publications further reinforces this trend, with Scopus and Web of Science showing a steady increase in the number of indexed studies. Notably, approximately 35–40%

of all publications were produced during 2024–2025, indicating that the field is currently experiencing rapid expansion. This surge reflects the increasing integration of AR with emerging technologies such as artificial intelligence, computer vision, and wearable systems, which are driving innovation in sports training and performance analysis. Collectively, these findings highlight the growing importance of AR as a transformative technology within the digitalization of sports science.

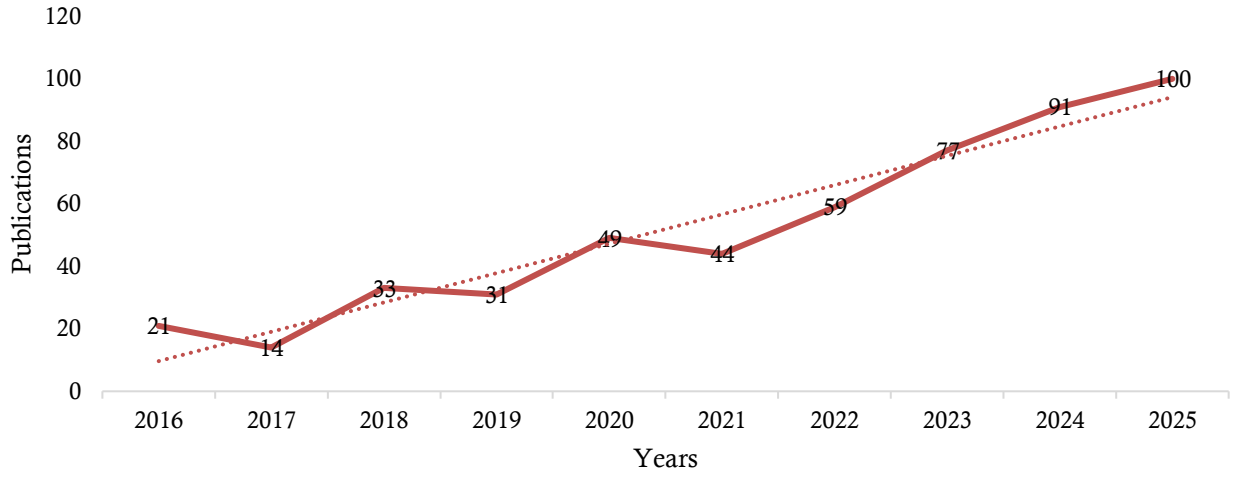

Figure 3. Annual Publication Trends of Augmented Reality Research in Sports (2016–2025)

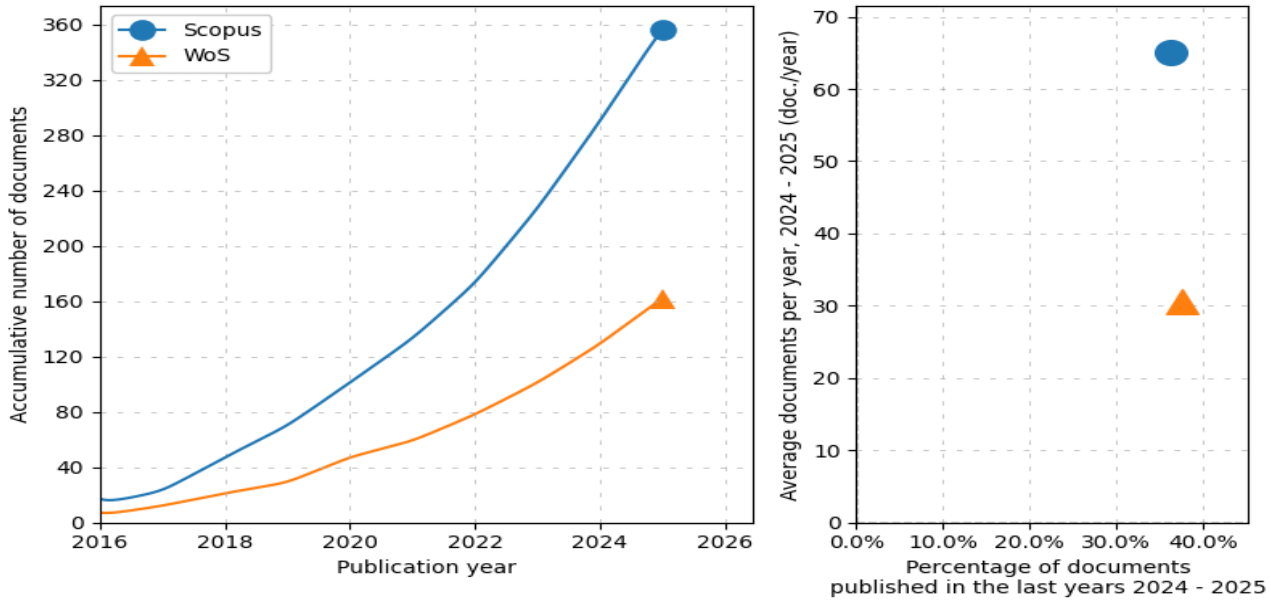

Figure 4. Growth of Cumulative Publications on Augmented Reality in Sports across Scopus and Web of Science

Key Contributors

An analysis of the leading contributors to AR research in sport was conducted using multiple bibliometric indicators, including total publications, average growth rate (AGR), average documents per year (ADY), percentage of documents in the last year (PDLY), and h-index (Table 3). The results indicate that Zollmann S. is the most productive author, followed by Lo W.H. and Regenbrecht H. However, the presence of duplicate author entries (e.g., Zollmann S. and Zollmann, S.) suggests minor inconsistencies in author name indexing within the database, which may affect the accuracy of author-level metrics.

Despite the identification of several productive authors, the relatively low publication counts across contributors (maximum = 8 publications) indicate that the field of AR in sport remains

fragmented, with no single author or research group dominating the literature. This suggests that the research domain is still emerging and characterized by distributed contributions across multiple scholars. This pattern is characteristic of emerging research fields, where knowledge production is distributed rather than centralized. In terms of research impact, Wang J. demonstrates the highest h-index, indicating a relatively stronger citation influence despite a moderate number of publications. Furthermore, recent publication activity (PDLY) highlights emerging contributors such as Omarov B., Jalal A., and Koike H., whose work is concentrated in the most recent period. Collectively, these findings suggest that the development of AR research in sport is driven by a diverse group of researchers, reflecting a dynamic and evolving research landscape.

Table 3. Top Contributing Authors in Augmented Reality Research in Sports

Rank	Author	Total	AGR	ADY	PDLY	h-index
1	Zollmann S.	8	-0.5	0.5	12.5	4
2	Lo W.H.	7	-0.5	0.5	14.3	4
3	Regenbrecht H.	7	-0.5	0.5	14.3	4
4	Zollmann, S.	7	0.0	1.0	28.6	3
5	Zhang H.	6	0.0	0.5	16.7	4
6	Jalal A.	5	-0.5	1.5	60.0	3
7	Koike H.	5	1.0	1.0	40.0	3
8	Wang J.	5	-1.0	0.0	0.0	5
9	Liu Y.	4	0.0	0.5	25.0	3
10	Omarov, B.	4	-0.5	1.5	75.0	4

Note: AGR = Average Growth Rate; ADY = Average Documents per Year; PDLY = Percentage of Documents Published in the Last Years; h-index = Hirsch index.

Influential Sources

An analysis of publication sources indicates that research on AR in sport is disseminated across a wide range of outlets, including both conference proceedings and peer-reviewed journals (Table 4). The dominance of the ACM International Conference Proceedings Series, which accounts for the most publications, underscores the strong orientation of this research field toward technology-driven venues. This pattern suggests that AR in sport remains closely aligned with advances in computer science and interactive technologies, with conference dissemination playing a central role in the rapid exchange of emerging findings.

In contrast, journal-based publications, such as IEEE Access, demonstrate increasing recent activity, as reflected by a high PDLY value. Additionally, multidisciplinary journals such as Scientific Reports show the highest growth rate (AGR = 1.5), indicating that AR research in sport is expanding beyond its technological origins into broader scientific domains. This transition suggests a gradual maturation of the field, with increasing integration into disciplines such as sports science, education, and human performance. Overall, the distribution of publication sources reflects the multidisciplinary nature of AR research in sport, characterized by the convergence of computer science, interactive technology, physical education, and sports psychology. This pattern also indicates an ongoing shift from conference-dominated dissemination toward more stable journal-based publication, signaling the field's progressive consolidation.

Table 4. Most Productive Sources in Augmented Reality Research in Sports

Rank	Source Title	Total	AGR	ADY	PDLY	H Index
1	ACM International Conference Proceeding Series	23	-1.5	1.0	8.7	9
2	IEEE Access	8	0.5	3.0	75.0	3
3	Retos-Nuevas Tendencias En Educacion Fisica Deporte Y Recreacion	6	-1.0	2.0	66.7	3
4	CEUR Workshop Proceedings	5	0.0	0.0	0.0	4
5	Computers in Human Behavior	5	0.5	0.5	20.0	4
6	Conference on Human Factors in Computing Systems - Proceedings	5	0.0	0.5	20.0	5
7	Revista de Psicologia del Deporte	5	-1.5	0.5	20.0	3
8	Sustainability	5	0.0	0.5	20.0	4
9	AIP Conference Proceedings	4	-1.0	1.0	50.0	2
10	Scientific Reports	4	1.5	2.0	100.0	2

Note: AGR = Average Growth Rate; ADY = Average Documents per Year; PDLY = Percentage of Documents Published in the Last Years; h-index = Hirsch index.

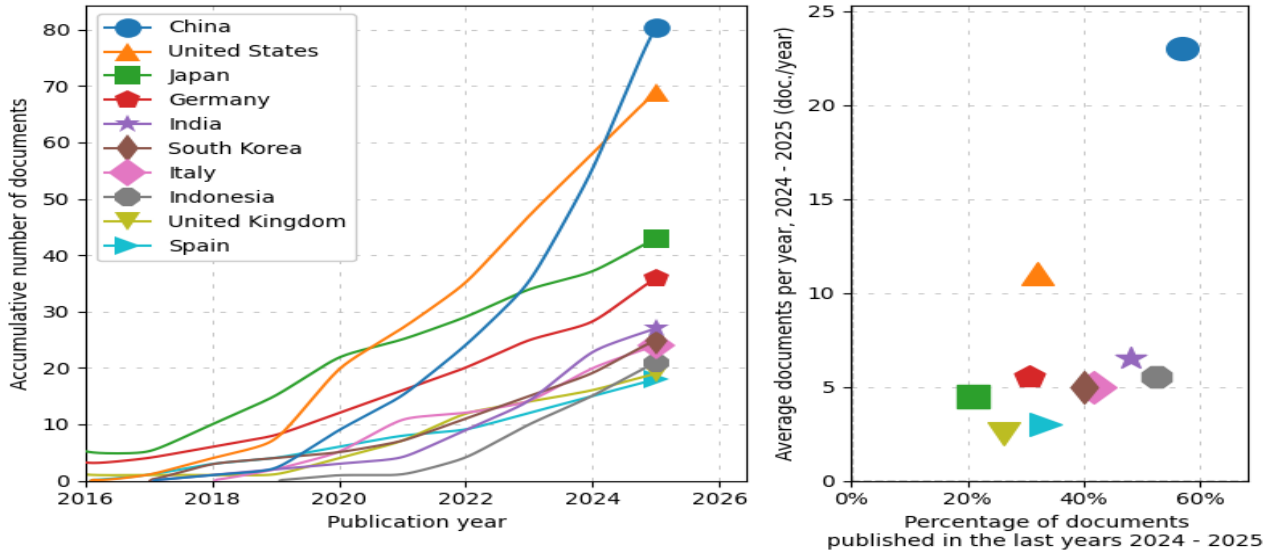

Figure 5. Cumulative Publication Trends and Average Documents Per Year by Country in Augmented Reality Research in Sports

Influential Sources

An analysis of country contributions reveals a clear concentration of AR research in sport within a limited number of technologically advanced nations (Figure 5). China leads in total publications, followed by the United States and Japan, indicating a geographical clustering of research activity in Asia and North America. Beyond publication volume, this pattern reflects differences in technological infrastructure and research capacity, which underpin the development of AR-based sport research. Countries such as China and the United States exhibit both high output and sustained productivity over time, as indicated by their average documents per year (ADY).

In contrast, countries including India, Germany, and South Korea demonstrate stable but comparatively moderate levels of research activity. This distribution suggests that AR research in sport is closely linked to broader national innovation systems, where access to advanced technologies, funding, and interdisciplinary expertise enables higher productivity. Moreover, the uneven geographical distribution indicates that the diffusion of AR technology in sport remains limited in several regions,

highlighting opportunities for expansion in underrepresented contexts. Collectively, these findings underscore the importance of technological ecosystems in shaping the global development of AR research in sport.

Keyword Co-occurrence Analysis

The keyword co-occurrence analysis reveals that AR research in sport is strongly interconnected with a broader ecosystem of immersive and intelligent technologies (Table 5 and Figure 6). The prominence of keywords such as virtual reality, computer vision, artificial intelligence, and machine learning indicates that AR is typically studied not as a standalone technology but as part of an integrated digital framework supporting advanced sports applications. The strong association with virtual reality highlights the growing role of immersive environments in training, simulation, and technology-enhanced learning. In parallel, the presence of wearable, motion capture, and motion tracking reflects a clear emphasis on performance monitoring and movement analysis, signaling a broader shift toward data-driven approaches in sport.

Table 5. Most Frequent Author Keywords in Augmented Reality Research in Sports

Rank	Author Keywords	Total	AGR	ADY	PDLY	h-index
1	Virtual Reality	70	3.0	13.5	38.6	18
2	Computer Vision	22	-2.5	4.5	40.9	7
3	Artificial Intelligence	18	0.5	4.0	44.4	7
4	Machine Learning	16	0.0	4.5	56.2	4
5	Wearable	8	0.5	0.5	12.5	6
6	Motion Capture	5	0.0	1.0	40.0	4
7	Motion Tracking	5	0.0	0.0	0.0	4
8	Mobile Learning	3	0.5	0.5	33.3	3
9	Sensors	2	0.5	0.5	50.0	2
10	Eye Tracking	1	0.0	0.0	0.0	1

Note: AGR = Average Growth Rate; ADY = Average Documents per Year; PDLY = Percentage of Documents Published in the Last Years; h-index = Hirsch index.

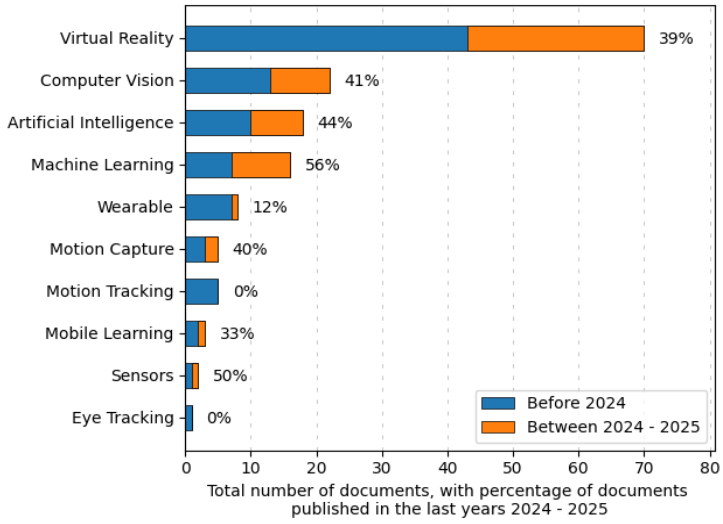

Figure 6. Temporal Distribution of Author Keywords in Augmented Reality Research in Sports

The temporal analysis further shows a rapid increase in research activity related to machine learning, artificial intelligence, and computer vision, with a substantial proportion of publications emerging in the most recent period (2024–2025). This trend indicates a transition toward more

intelligent and adaptive AR systems capable of automated performance analysis and decision support. Additionally, emerging keywords such as sensors and eye tracking, although still infrequent, point to new directions focused on perception, cognition, and human–technology interaction in sport contexts. Collectively, these findings demonstrate that AR research in sport is evolving toward a convergence of immersive, intelligent, and sensor-based technologies, forming the foundation for next-generation sport training systems that are interactive, adaptive, and data-driven.

Scoping Review

Types of Sports Using Augmented Reality

The scoping review identified that the application of AR in sports research is concentrated within a limited number of disciplines, including climbing, football, basketball, martial arts, cricket, karate, volleyball, hockey, and judo (Figure 7). Among these, climbing and football emerge as the most frequently studied sports, followed by basketball and martial arts. Rather than merely reflecting research frequency, this distribution suggests that AR adoption is more prevalent in sports that involve complex motor skills, spatial awareness, and dynamic movement patterns, where real-time feedback and visual augmentation can significantly enhance training effectiveness.

The temporal distribution further indicates that research activity has increased in several sports, particularly football, martial arts, cricket, volleyball, and climbing during the 2024–2025 period. In contrast, other sports such as basketball, karate, hockey, and judo show limited or stagnant research development in recent years. This uneven distribution suggests that AR implementation in sport remains selective and context-dependent, influenced by the technology's suitability for specific training environments and performance requirements. Importantly, these findings highlight a clear research gap: many sports remain underexplored despite the potential benefits of AR technology, suggesting substantial opportunities for future research across a broader range of sports disciplines.

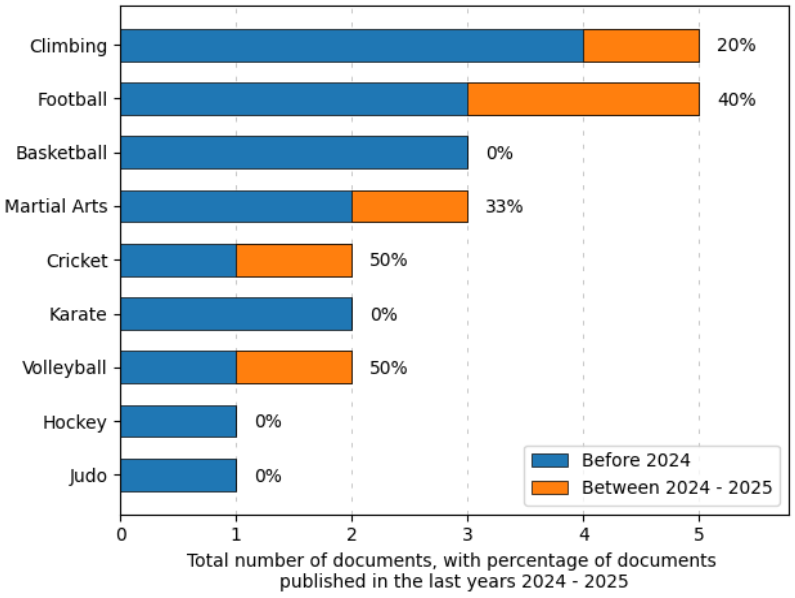

Figure 7. Temporal distribution of sports adopting augmented reality in sports research

Future Research Directions

The analysis of keyword relationships and thematic evolution indicates that future research on AR in sport is increasingly focused on integrating intelligent and immersive technologies (Figures 7 and 8). The strong interconnections among keywords such as artificial intelligence, machine learning, computer vision, and motion capture demonstrate a clear shift toward data-driven, intelligent training systems. In addition, emerging themes such as human–computer interaction, gamification, and immersive learning

highlight the growing importance of user experience and engagement in AR-based sport applications. Collectively, these patterns suggest that future AR research will focus on developing more adaptive, interactive, and personalized training environments.

Despite these advancements, the application of AR remains concentrated in a limited number of sports, indicating substantial opportunities for expansion into underexplored disciplines. The recent increase in research activity during the 2024–2025 period further suggests that the field is entering a phase of rapid development, driven by advances in artificial intelligence and sensing technologies. Based on these findings, future research should prioritize integrating AR with emerging technologies to support adaptive training systems, automated performance analysis, real-time athlete monitoring, and enhanced decision-making processes. These directions, summarised in Table 6, provide a structured pathway for advancing AR applications across a wider range of sport contexts.

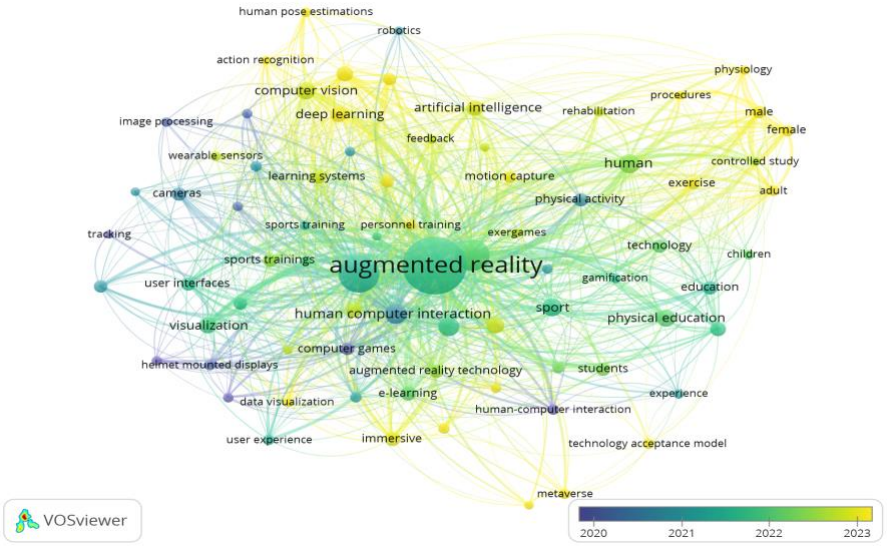

Figure 8. Keyword Co-Occurrence Network with Overlay Visualization in Augmented Reality Research in Sports

Table 6. Future Research Directions of Augmented Reality Applications in Sports

Research Theme	Emerging Technology	Potential Sports Context	Future Research Opportunities
Intelligent sport training	Artificial Intelligence, Machine Learning	Football, Basketball	Development of adaptive training systems
Motion analysis and performance evaluation	Computer Vision, Motion Capture	Martial Arts, Karate, Judo	Automated technique analysis
Athlete monitoring systems	Wearable sensors, IoT	Cricket, Volleyball	Real-time performance tracking
Immersive sport environments	Virtual Reality, Immersive systems	Climbing	Simulation-based training
Visual perception and tracking	Eye tracking, Sensors	Football, Basketball	Decision-making and tactical awareness

Discussion

Global Research Trends in Augmented Reality in Sports

Research on AR in sport has increased significantly, particularly after 2020, reflecting a broader shift toward the digitalization of sports science. From a theoretical perspective, this trend can be interpreted through the diffusion of innovation framework, where AR is transitioning from an emerging technology to a more widely adopted training tool. The growing use of immersive technologies, including AR and virtual reality, indicates that these tools are increasingly applied to enhance training quality, athlete motivation, and cognitive engagement (Temel et al., 2025).

Furthermore, this development aligns with the emergence of data-driven sport, where training processes are supported by real-time data collection and performance analytics (Cossich et al., 2023; Ihsan et al., 2025). In this context, AR is no longer limited to visualization but functions as part of an interactive training system integrating motion analysis, simulation, and immediate feedback, thereby supporting motor skill acquisition and decision-making (Janssen et al., 2023; Soltanabadi et al., 2023; Chang et al., 2020; He & Wei, 2025).

Key Contributors and Publication Sources

The analysis of key contributors indicates that AR research in sport is characterized by a relatively fragmented authorship structure, where no single researcher or group dominates the field. This pattern is typical of emerging research domains and can be explained through bibliometric perspectives on knowledge development, in which a core group of contributors shapes research directions and fosters collaboration networks (Donthu et al., 2021). Such distributed contributions suggest that the field is still evolving, with opportunities for greater consolidation through interdisciplinary collaboration.

In terms of publication sources, the dominance of conference proceedings alongside multidisciplinary journals reflects the technology-driven nature of AR research in sport. Conference venues facilitate rapid dissemination of innovations, particularly in fields linked to computer science and human–computer interaction, while journal publications indicate increasing research maturity. The influence of publication outlets on research visibility and citation impact further highlights the importance of strategic publication choices (Kousha & Thelwall, 2024; Tahamtan et al., 2016). Overall, these findings underscore the field's multidisciplinary character, shaped by the convergence of sports science with digital technologies such as artificial intelligence and sensor systems (Bodemer, 2023; Chidambaram et al., 2022).

Global Research Contributions by Country

The distribution of AR research in sport shows a clear concentration in technologically advanced countries such as China, the United States, and Japan. This pattern reflects the influence of national innovation systems, where robust funding structures, advanced digital infrastructure, and supportive policy frameworks collectively drive higher scientific productivity (Cao et al., 2023; Liu & Xia, 2018). In addition, these countries benefit from extensive international collaboration networks, which play a critical role in enhancing research visibility, knowledge exchange, and publication output in sport technology research.

In contrast, the relatively limited contribution of developing countries highlights structural disparities in access to technology, funding, and global research networks (Kadikilo et al., 2024). The emergence of Indonesia as a contributor suggests a growing regional interest in integrating AR into sport and physical education contexts (Botagariyev et al., 2024; Wintle, 2019). However, the uneven global distribution indicates that the diffusion of AR in sport remains constrained. From a practical perspective, expanding participation will require targeted strategies, including strengthening international collaboration, increasing investment in research infrastructure, and developing human resource capacity to support technology-driven sport innovation. However, this concentration of

research within technologically advanced countries may limit the generalisability of findings across diverse sport contexts, particularly in regions with different resource availability and training environments.

Emerging Technologies in Augmented Reality Research

Keyword analysis indicates that AR research in sport is increasingly shaped by the integration of advanced digital technologies, including artificial intelligence (AI), machine learning, computer vision, motion capture, and wearable sensors. This convergence reflects a shift toward intelligent, data-driven training systems, in which AR serves as an interface that connects real-time data, performance analytics, and interactive feedback. From a theoretical perspective, this development aligns with the emergence of intelligent sport ecosystems, where multiple technologies operate synergistically to enhance training effectiveness and decision-making. In particular, the integration of AR with computer vision and motion capture enables precise movement analysis and real-time feedback, thereby supporting motor skill learning and technique optimization (Liu & Xie, 2024), while AI and machine learning enable predictive modeling and personalized training interventions (Cust et al., 2018; Souaifi et al., 2025).

In addition, wearable sensors extend the capabilities of AR by enabling continuous monitoring of physiological and biomechanical data during training and competition (Olsen et al., 2024; Seçkin et al., 2023). This integration supports more evidence-based coaching practices, allowing coaches and athletes to make informed decisions based on real-time performance indicators (Zhu et al., 2025). Collectively, these developments indicate that AR in sport has evolved beyond a visualization tool into a core component of adaptive training systems that combine data analytics, sensor technologies, and interactive simulations to optimize performance and training outcomes.

Applications of Augmented Reality in Sports

The scoping review indicates that the application of AR in sport is concentrated in a limited number of disciplines, particularly those involving structured and spatially oriented movements, such as climbing, football, basketball, and martial arts. This pattern can be explained by the alignment between AR technological capabilities and the demands of perceptual–motor integration, with augmented feedback playing a central role in dynamic sport environments. From a motor learning perspective, AR facilitates the alignment between visual information and movement execution, thereby enhancing skill acquisition and real-time decision-making (Cossich et al., 2023). For instance, in climbing, AR-based route visualization has been shown to support strategic movement planning and anticipatory decision-making during training (Cast et al., 2024).

However, the limited distribution of AR applications across sports highlights a clear research gap, particularly in disciplines characterized by complex tactical dynamics or less structured movement patterns. This uneven adoption indicates that AR implementation remains context-dependent, requiring adaptation to the specific demands of each sport. From a practical perspective, future research should prioritize the development of adaptive, sport-specific AR systems that support motor skill learning, tactical understanding, and training effectiveness across diverse sport contexts. Moreover, integrating AR with complementary technologies such as artificial intelligence and wearable sensors offers significant potential to expand its applications beyond visualization toward fully data-driven, intelligent training systems.

However, the implementation of augmented reality (AR) in sports is also influenced by several external factors, including cost, accessibility, and technological infrastructure. The high cost of AR devices and supporting systems may limit adoption, particularly in developing countries or educational settings with limited resources (Mondal & Mondal, 2026; Souza et al., 2023). In addition, disparities in digital infrastructure and users' technological literacy may affect the effectiveness and scalability of AR-based training systems (Familoni & Onyebuchi, 2024). Therefore, while AR demonstrates significant

potential, its practical implementation requires careful consideration of contextual constraints, including resource availability, institutional support, and technological readiness.

These findings address a key gap in the literature by providing an integrated analysis of both global publication trends and sport-specific applications of AR, which have previously been examined in isolation. By combining bibliometric and scoping approaches, this study offers a more comprehensive and structured understanding of how AR research is evolving across different sport contexts.

Applications of Augmented Reality in Sports

These findings suggest that AR can be effectively integrated into sport training to enhance real-time feedback, movement analysis, and decision-making. Coaches can use AR-based systems to support data-driven training and performance evaluation, while educators can adopt AR to create more engaging, interactive learning environments in physical education. In addition, developers should focus on designing adaptive and sport-specific AR systems that integrate artificial intelligence and sensor technologies to support real-world implementation.

Limitations of Study

This study has several limitations that should be acknowledged. First, the analysis was restricted to publications indexed in Scopus and Web of Science, potentially excluding relevant studies from other databases and limiting the dataset's comprehensiveness. Second, the identification of sports disciplines relied on keyword and metadata analysis, which may be affected by inconsistencies in terminology and classification. Third, this study focused on mapping research trends and did not include a formal assessment of the methodological quality of the included studies, which may limit the interpretability of the findings.

In light of these limitations, future research should expand database coverage to include additional sources such as PubMed, IEEE Xplore, and the ACM Digital Library to achieve a more comprehensive representation of the field. More importantly, future studies should move beyond bibliometric mapping toward evidence-based evaluation, for example, by conducting systematic reviews or meta-analyses to assess the effectiveness of AR in improving performance, motor skill acquisition, and training outcomes. Additionally, further research is needed to develop standardized evaluation frameworks, examine AR applications across underexplored sports, and design adaptive, sport-specific AR systems that integrate artificial intelligence and sensor technologies for real-world implementation.

Conclusions

This study demonstrates that research on AR in sport has grown significantly over the past decade, particularly since 2020. Bibliometric findings indicate that key contributors, multidisciplinary publication outlets, and leading countries such as China, the United States, and Japan shape the field. Keyword analysis further shows an increasing integration of AR with advanced technologies—including artificial intelligence, machine learning, computer vision, motion capture, and wearable sensors—reflecting a shift toward intelligent, data-driven training systems.

The scoping review shows that AR applications remain concentrated in specific sports, indicating opportunities for broader adoption. This study advances the literature by integrating bibliometric and scoping approaches within a single framework, providing a more comprehensive understanding of global research trends and sport-specific applications of AR. In practice, these findings suggest that coaches should adopt AR to enhance feedback and skill development, that educational institutions should strengthen their digital infrastructure and training, that developers should design adaptive and user-centered systems, and that policymakers should support the equitable and strategic implementation of AR in sport contexts.

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Authors' contributions

NG, AR, and RC contributed to the research concept and design. NG, AR, and MFM contributed to the collection and/or assembly of data. NG, RC, and MFM contributed to the data analysis and interpretation. NG and RC contributed to writing the article. SKSA, JL, and ES contributed to the critical revision of the article. All authors contributed to the final approval of the article.

Competing interests

The authors declare no competing interests.

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During the drafting of this manuscript, the author used DeepL (DeepL GmbH) and QuillBot (QuillBot Inc.) to assist with translation, paraphrasing, language refinement, and proofreading, thereby improving the clarity and readability of the manuscript. In addition, Scopus AI (Elsevier) was used to support literature searches and identify articles and research trends relevant to augmented reality in sport. All outputs generated by these tools have been critically reviewed and re-edited by a proofreader and the author to ensure accuracy and compliance with academic writing standards. The author takes full responsibility for the integrity and content of this manuscript.

Data Availability Statement

The data supporting the findings of this study were obtained from the Scopus and Web of Science (WoS) databases. The corresponding author can provide the datasets generated and analyzed during this study upon reasonable request.

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