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WEARABLE DEVICES IN SPORTS A REVIEW ARTICLE

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Abstract
Wearable devices in sport - IMUs, GPS, heart-rate wearables, smart textiles, and hybrid systems - have matured rapidly from 2020–2025. Research in this period concentrated on validation and accuracy of sensors during sport-specific movements, integration of smart textiles and embedded sensors for comfort/continuous monitoring, as well as advanced analytics and machine learning for performance and injury risk prediction, and implementation issues such as data quality, privacy, and real-world adoption. The authors reviewed topic-related articles between 2020 and 2025 and analyzed the found data by using Vosviewer software. The findings show an increasing research trend in various aspects of the topic.

1 Introduction

In recent years, wearable devices have become one of the biggest innovations in the world of fitness and sports.

From smartwatches and fitness bands to earbuds with biofeedback and even sensor-embedded clothing. With the help of these tools, athletes and fitness enthusiasts can monitor data while working out. They can measure heart rate, motion, oxygen saturation, muscle fatigue, sleep quality, and hydration. All these important factors can be tracked and assessed in real time with the help of smart wearable devices, which all contribute to optimizing an athlete's performance.

Essentially, these AI-based devices do three things: measure, inform, and adapt. By continuously measuring our body's physical and biological condition, they inform us how our body is responding. It can be monitored during workouts and even during recovery. Furthermore, artificial intelligence algorithms can adapt training plans: for example, suggesting more rest if recovery is weak. [1]This not only improves performance but also lowers the risk of injury, burnout, and overtraining. In sports settings, proper execution of exercises and safety are often not ensured. Even small displacements, poor rest, or too much load can lead to long-term harm and serious injuries. Wearables help intervene in time.[2]

Some gyms incorporate AI in various ways, such as AppInGym [3] in Budapest. It is an innovative facility with modern equipment and 24/7 access. Its app allows membership management, entry, and workout tracking. Although there is no direct evidence of AI in use, the combination of modern equipment and the app contributes to a more effective training experience.

In these gyms nowadays, various applications and methods powered by artificial intelligence are emerging, for example, AI-driven apps for personalized workout plans. These are adjusting sets, load-based on user feedback or tracked results. There are also tools for virtual coaching and motion detection. These video-based or sensor-based systems can count repetitions, check form, and give corrective feedback. Considering the cost of wearables, they can vary widely. Basic fitness trackers cost tens of euros, while premium smartwatches with lots of sensors run into hundreds. For a gym

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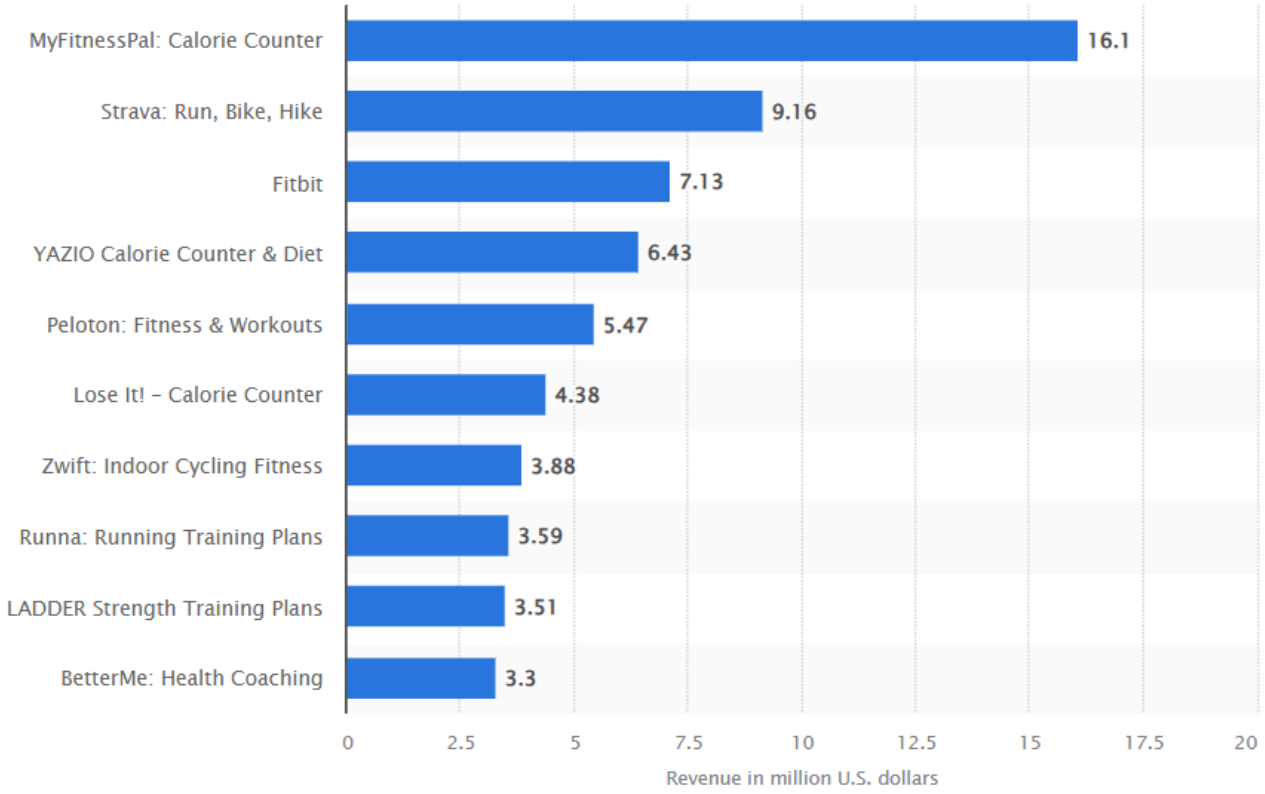
like Life1[4] to deploy gym-wide AI systems, like sensor installation or video-based feedback, it means huge investments. Including hardware, software licenses, and staff training. However, overtime investments are paying off: lower injury complaints, better satisfaction of the members, and premium memberships. Also, as technology matures, costs are coming down, which means more affordable devices and AI tools are available even to smaller gyms or individual users.

In January 2025, Statista conducted research about fitness and sport apps worldwide. Their findings and results can be seen in the table below. MyFitnessPal was the leading fitness and sports mobile app, generating in-app revenues of more than 16 million U.S. dollars. Strava ranked second, with roughly nine million U.S. dollars in combined revenues via Google Play and Apple App Store. Fitbit, the mobile app eponymous of popular wearable fitness and health tracking devices, generated seven million U.S. dollars from its Google-powered app. [5]



1. Figure Leading fitness and sports apps worldwide in January 2025, by revenue (Statista 2025)

2 Literature review

From 2020–2025, wearables transitioned from promising prototypes to widely used tools in sport science. IMUs, GPS, and HR wearables now support everyday athlete monitoring, while smart textiles are moving toward practical deployment. The field's next steps are stronger sport-specific validation, standardized reporting, longer longitudinal trials linking wearable use to outcomes, and clearer regulatory/ethical standards. [6] If these gaps are addressed, wearables will better translate into performance gains and injury prevention in real sporting environments.

Wearable devices have become central to applied sport science, offering real-time insights into how athletes train, perform, and recover. Over the past five years, research has expanded beyond simple activity tracking to explore targeted applications that directly support coaching and performance decision-making. [7] Studies have primarily examined how wearables quantify training load, monitor technique and biomechanics in the field, identify injury risks, and track recovery and wellbeing. These applications reflect the shift from laboratory-based assessments to continuous, ecologically valid monitoring in real sporting environments, where data can inform individualized training strategies and injury prevention approaches.[8]

One of the most common uses of wearable devices in sport is tracking training and competition loads. GPS, IMUs, and physiological sensors provide data on distance, speed, acceleration, and internal load measures such as heart rate or perceived exertion. [2] Researchers use these insights to optimize training intensity, reduce fatigue, and enhance overall performance planning.

Athlete monitoring & wellbeing: Sleep, recovery, and autonomic markers via HRV and wearable sensors are used for athlete readiness models; interventions based on wearables show promise for change but mixed results for hard performance outcomes.[9]

IMUs enable field biomechanics (jump height, joint angles, limb asymmetries), particularly when optical capture is impractical, validation studies show promise but indicate limits for very high speed or multi-plane tasks.

Wearables provide longitudinal load and asymmetry data; studies explore algorithms to flag deviations linked to injury risk and to monitor rehabilitation progress. Evidence of wearable-driven injury prevention is still emerging and largely correlational.[10]

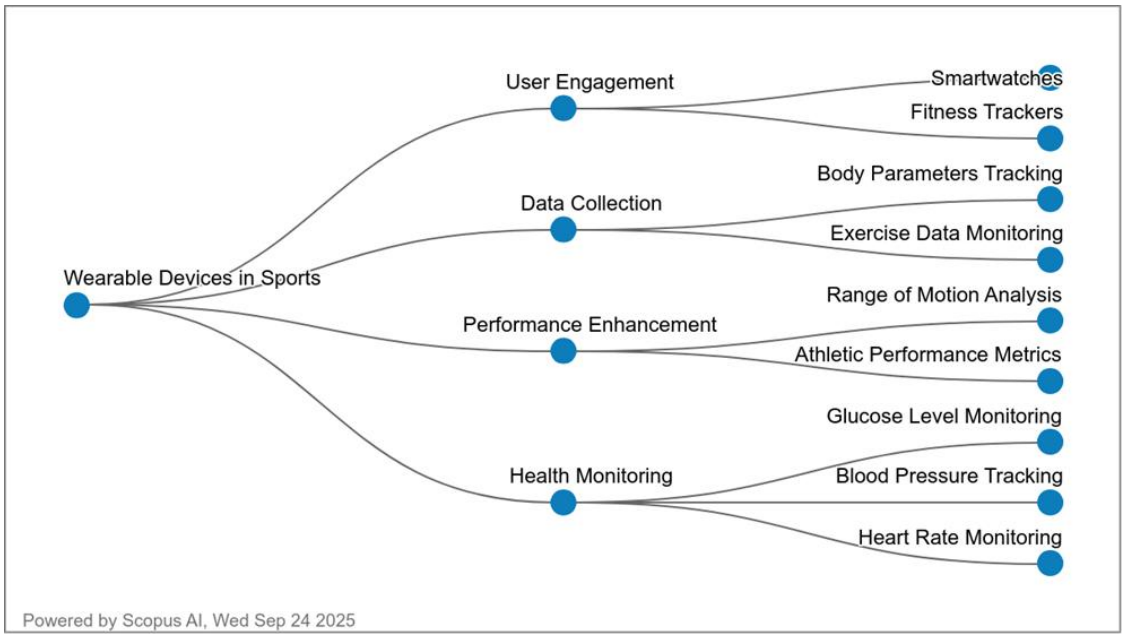
3 Data and method

In recent years, wearable technologies have transformed the landscape of sports and exercise sciences. Devices such as smartwatches, GPS trackers, heart rate monitors, and inertial measurement units are increasingly embedded in both professional and recreational athletic practices. Their ability to capture real-time physiological, biomechanical, and environmental data offers new possibilities for monitoring training loads, optimizing performance, and reducing the risk of injury.[11]

The relevance of wearables extends beyond elite sports. In fitness and recreational contexts, they contribute to health promotion, personalized exercise programs, and long-term well-being, making their study pertinent not only to athletes but also to the wider public. From a research perspective, the field is inherently multidisciplinary, connecting sports science with engineering, computer science, and data analytics. Innovations such as machine learning, Internet of Things (IoT) integration, and advanced biometric sensing are expanding the scope and applications of wearable devices. [12]

Given this rapid growth and diverse set of applications, it is important to map the research trends, thematic clusters, and collaboration networks driving this field. Bibliometric analysis provides a structured method for achieving this goal by identifying the most influential publications, sources, and keywords, as well as the leading authors, institutions, and countries contributing to the topic.

The present study applies a bibliometric approach using Scopus (Elsevier) data from 2020 to 2025, focusing on the keyword combination “wearable devices” AND “sports.”



2. Figure Research topic (generated by Scopus AI)

The analysis employs VOSviewer to visualize networks of co-authorship, keyword co-occurrence, and citation structures. In doing so, this article aims to provide a comprehensive overview of the intellectual landscape of wearables in sports research, highlighting emerging hotspots, influential actors, and potential avenues for future investigation. [13]

Further to the research, a Scopus AI-based methodology has been carried out to see how a deeper focus can enhance the articles' relevance to the topic searched. The figure below shows each topic and its engagements.

A total of 2027 publications were retrieved after applying the inclusion criteria (peer-reviewed journal articles, conference papers, and reviews), and thematically, all articles were excluded that did not specifically relate to the research topic. (e.g., wearable medical devices, the development process as far as algorithm and textile design are concerned, older than 2020 articles). Duplicates and irrelevant records were manually screened and excluded, resulting in a final dataset of 1986 documents.

3.1 Data Processing

The bibliographic data were exported in the RIS and CSV formats, including information on titles, authors, abstracts, keywords, affiliations, sources, and citations. These files were subsequently cleaned and standardized to merge variations in author names, institutional affiliations, and keyword spellings (e.g., "wearable technology" vs. "wearables").

This study employed a bibliometric approach to examine the research landscape of wearables in sports. Data were retrieved from Scopus (Elsevier), one of the largest abstract and citation databases of peer-reviewed literature. The database was selected for its comprehensive coverage of journals, conference proceedings, and book chapters across disciplines. [14]

3.2 Analytical Approach

To map the intellectual structure and emerging themes in the field, the data were analyzed using VOSviewer (version 1.6.20), a widely used software tool for bibliometric visualization. VOSviewer was chosen for its ability to construct and visualize networks of co-authorship and co-occurrence of keywords. [15]

4 Findings

Descriptive statistics of the dataset were produced to provide context. The search was conducted for the period from January 2020 to September 2025, reflecting the most recent five-year span to capture current developments and research trends. The following search string was applied to the Title, Abstract, and Keywords fields: wearable devices in sports. This query ensured the inclusion of literature that explicitly addressed wearable technologies in the context of sports. Only documents in English were considered to maintain consistency and comparability.

The yearly publication trend (2020–2025) demonstrates a growing trajectory in the field of wearable devices in sports, with publication numbers rising from 233 in 2020 to 354 in 2025 as of September. The increasing trends in publications related to wearable devices in sports between 2020 and 2025 suggest a growing interest and investment in this field. Several factors contribute to this upward trajectory. First, an undeniable technological advancement. Continuous improvements in sensor technology, data processing capabilities, and wireless communication have made wearable devices more accurate, reliable, and user-friendly.

This has spurred researchers and developers to explore new applications in sports. Second, the growing market demand, as Figure 1 shows. The market for wearable devices in sports is expanding rapidly, driven by increasing awareness among athletes, coaches, and sports organizations about the potential benefits of these technologies. This market demand fuels further research and development efforts.

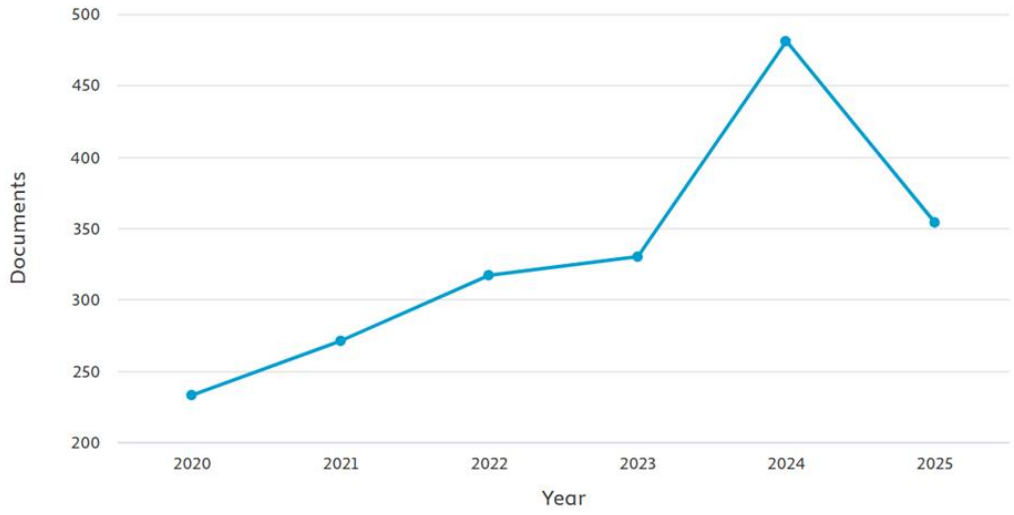
Furthermore, remote monitoring and coaching, especially during and after Covid-19 pandemic, added to the increasing publications. While wearable devices enable remote monitoring of athletes' training and recovery, they also allow coaches to provide personalized guidance and support even

when they are not physically present. As wearable technology becomes more accessible and affordable, it is being adopted by a wider range of athletes and sports organizations. This increased adoption leads to more data being generated and analyzed, which in turn fuels further research and development.

Year ↓	Documents ↑
2025	354
2024	481
2023	330
2022	317
2021	271
2020	233

3. Figure Documents' distribution by years between 2020-2025 (Scopus data)

Based on the data from Scopus Elsevier, most of the relevant articles have been published in 2024 as it was 481. However, it should be noted that by the time of data filtering there were three months remaining in 2025, so the data set might change if we take into consideration the entire year.



4. Figure Documents by year between 2020-2025 (Scopus data)

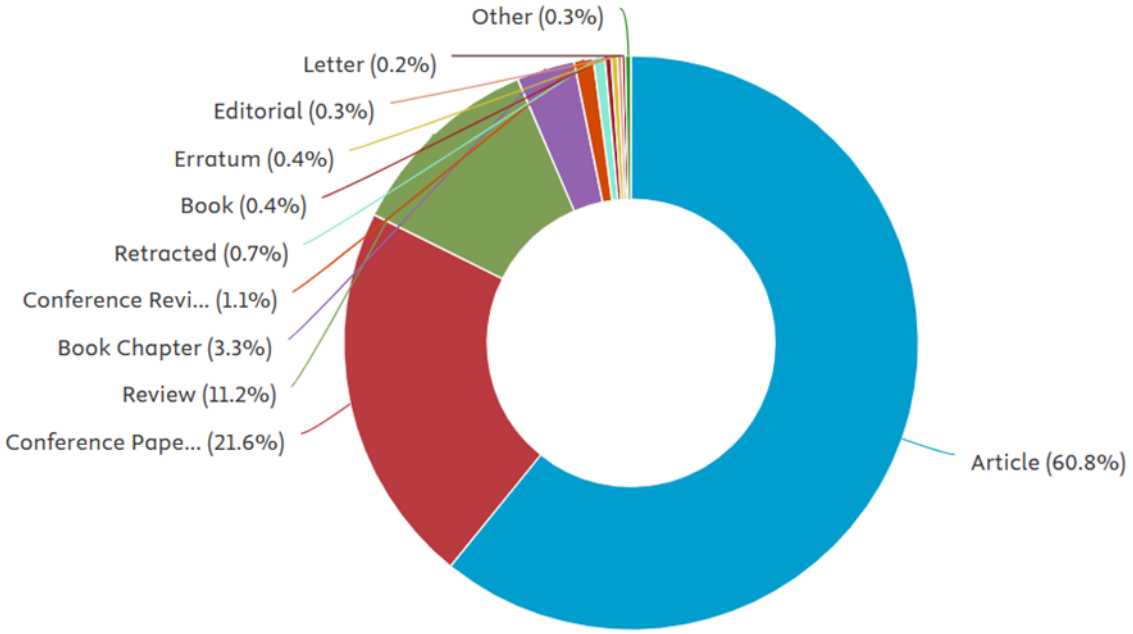
This document analyzes the distribution of document types within a specific research dataset. The analysis reveals a significant prevalence of journal articles, followed by conference papers and review articles, providing insights into the dataset's composition and potential research focus.

The dataset exhibits a clear dominance of journal articles, constituting approximately 61% of the total documents. This suggests a strong emphasis on original research and scholarly publications within the dataset. Journal articles typically undergo rigorous peer review and represent established findings in a particular field. Their high proportion indicates a focus on disseminating validated research outcomes.

Conference papers represent the second largest category, accounting for around 22% of the dataset. Conference papers often present preliminary research findings, novel ideas, or work-in-

progress. Their inclusion suggests the dataset captures ongoing research efforts and emerging trends within the relevant domain. Conference papers can also provide valuable insights into the latest advancements and discussions within the research community.

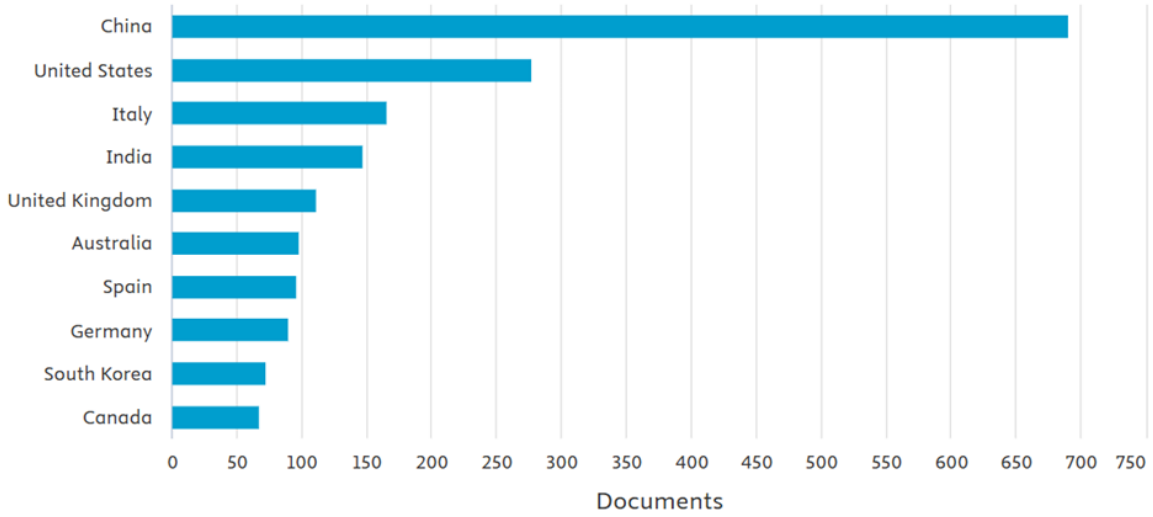
Review articles comprise approximately 11% of the dataset. Review articles synthesize existing research on a specific topic, providing a comprehensive overview of the current state of knowledge. Their presence indicates an effort to consolidate and summarize research findings, offering valuable resources for researchers seeking to understand the broader context of their work. Review articles can also identify gaps in the literature and suggest directions for future research.



5. Figure Documents by type (Scopus data)

Among the top contributing countries, the most publications originated from China, the United States of America, and Italy from the European Union. These were followed by India, the United Kingdom, and Australia, indicating a geographically diverse research base. Spain and Germany also made it to the top ten along with South Korea and canada

The dominance of China, the United States, and Italy in research publications highlights the importance of sustained investments in research and development. These countries have prioritized research and innovation, which has led to significant advancements in various fields.



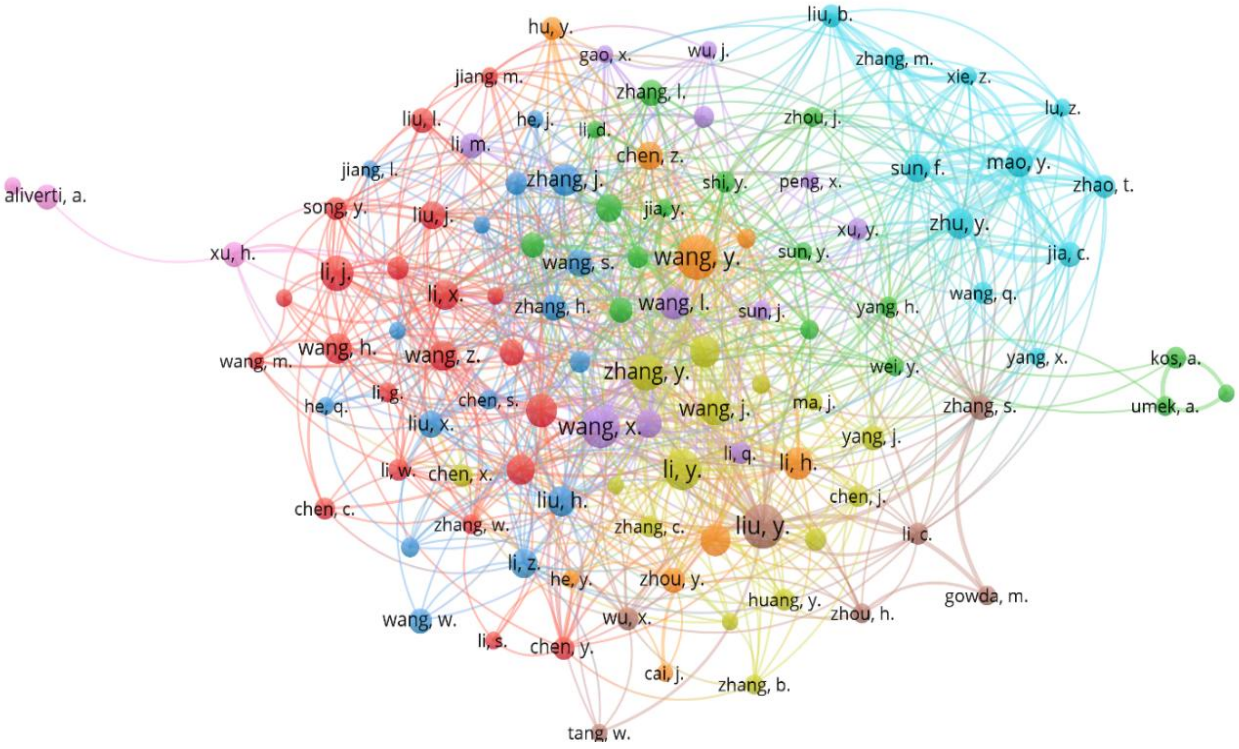
6. Figure Documents by country or territory (Scopus data)

The emergence of India as a major research contributor underscores the potential for developing countries to play a more prominent role in global knowledge production. By investing in research and education, developing countries can contribute to solving global challenges and improving the lives of their citizens.

The continued strength of the United Kingdom and Australia in research publications demonstrates the importance of maintaining a strong research ecosystem, even in countries with relatively small populations. By fostering collaboration, providing adequate funding, and attracting talented researchers, these countries can continue to make significant contributions to global knowledge.

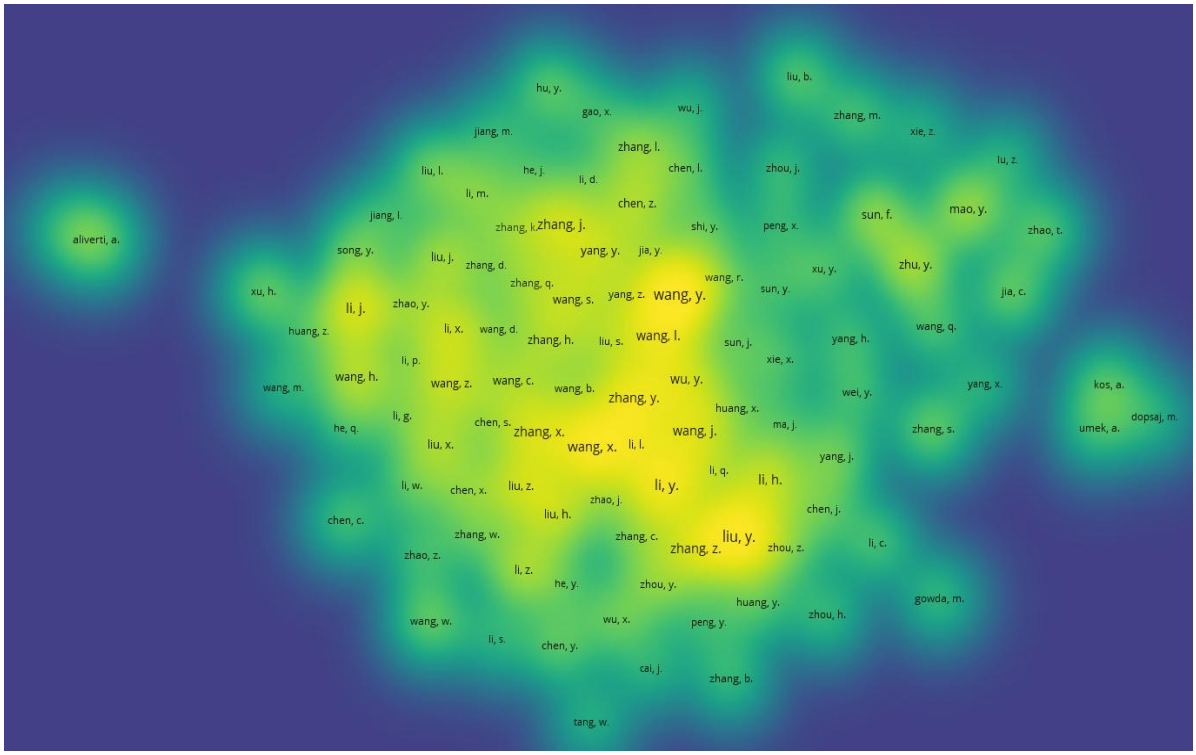
4.1 Vosviewer analysis

Co-authorship analysis – to identify collaboration patterns among authors, institutions, and countries. Co-authorship analysis is a bibliometric method that examines patterns of collaboration among researchers, institutions, and countries based on their joint publications. It treats co-authorship as a form of social connection, where authors who publish together are linked to a network. By analyzing these networks, researchers can gain insights into the structure and dynamics of scientific collaboration.



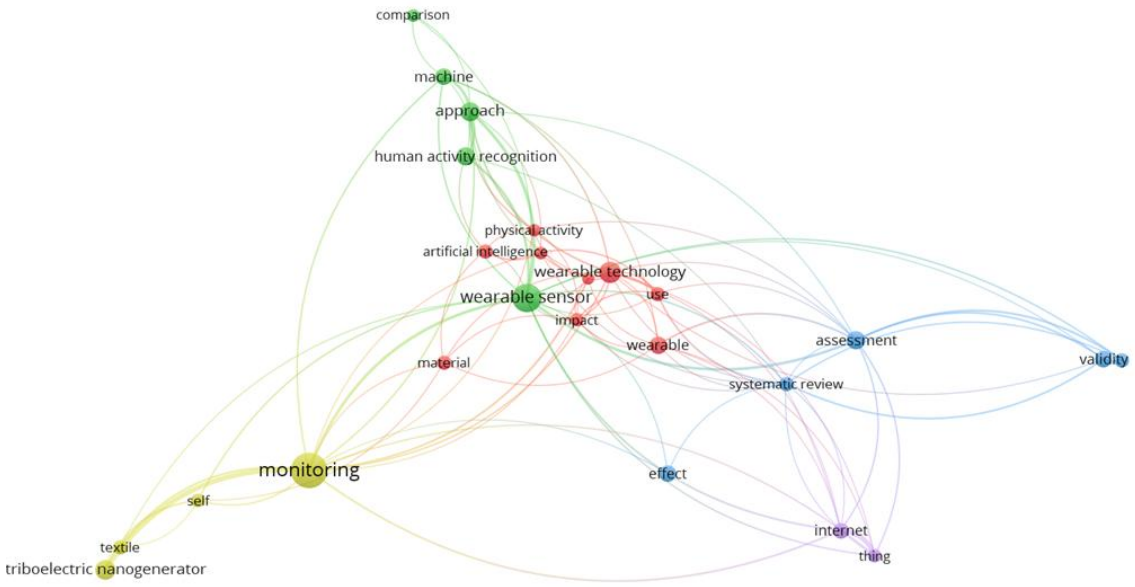
7. Figure Co-author analysis by Vosviewer

Clustering Coefficient is another method to measure the degree to which nodes in a network tend to cluster together. It indicates the density of collaboration within a particular group of authors, institutions, or countries. in our research we measured the density of co-author collaboration as Figure 8. shows.



8. Figure Density of co-author collaboration

Keyword co-occurrence analysis – to detect thematic clusters and research hotspots within wearable sports devices research. Keyword co-occurrence analysis is a text mining technique used to identify relationships between concepts by examining the frequency with which keywords appear together within a corpus of text, such as research articles, abstracts, or conference proceedings. In the context of wearable sports devices research, this method can reveal the dominant themes, emerging trends, and interdisciplinary connections that characterize the field. The underlying principle is that keywords that frequently co-occur are likely to be related and represent a common research focus.



9. Figure Keyword co-occurrence analysis by Vosviewer

Keyword co-occurrence analysis can be applied to address several research questions in the field of wearable sports devices, including:

For example, identifying dominant research themes. By analyzing the most frequently co-occurring keywords, we can identify the major research areas that have attracted the most attention in the field. For example, clusters related to "activity recognition," "heart rate monitoring," and "energy expenditure" may indicate that these are dominant themes in wearable sports devices research.

Secondly, by comparing keyword co-occurrence patterns over time, we can identify emerging trends and shifts in research focus.

1. Table Cluster of keyword co-occurrence edited by the authors

Clusters	
Research trends	**Cluster 1 (9 items)**
AI-enabled wearable technology in physical activity	artificial intelligence
	impact
	material
	physical activity
	role
	scoping review
	use
	wearable
	wearable technology
Human Activity Recognition	**Cluster 2 (5 items)**
	approach
	comparison
	human activity recognition
	machine learning
	wearable sensor
Evaluation	**Cluster 3 (5 items)**
	assessment
	effect
	reliability
	systematic review
	validity
Textile-based triboelectric nanogenerators (T-TENGs)	**Cluster 4 (4 items)**
	monitoring
	self
	textile
	triboelectric nanogenerator
IoT	**Cluster 5 (2 items)**
	internet
	thing

For example, an increase in the co-occurrence of keywords related to "artificial intelligence," "machine learning," and "human activity recognition" may indicate a growing interest in using AI-powered techniques to enhance the performance and effectiveness of wearable sports devices.

5 Summary

Wearable devices have become indispensable tools for athletes and coaches across various sports disciplines. These devices, ranging from smartwatches and fitness trackers to specialized sensors embedded in clothing, provide a continuous stream of data related to an athlete's physiological state, movement patterns, and performance metrics. This data enables a more

objective and personalized approach to training and performance optimization. Beyond physiological monitoring, wearable devices also play a crucial role in analyzing an athlete's biomechanics and movement efficiency.

This information can be used to identify areas of improvement in an athlete's technique, reduce the risk of injury, and enhance overall performance. [16] For example, runners can use wearable sensors to analyze their running form and identify imbalances or inefficiencies that may be contributing to injuries. Injury prevention is another significant benefit of wearable devices in sports. By monitoring an athlete's or private person's physiological state and movement patterns, these devices can detect early signs of fatigue, stress, or biomechanical imbalances that may increase the risk of injury. For example, a heart rate too high can signify slowing down for a runner. [17] [18]

1. Table Summary table edited by the authors

Application	Benefits	Technological Advancements	Challenges
Performance Monitoring	Real-time tracking of metrics like heart rate, speed, and power output	IoT and AI integration for sophisticated analysis	Data quality, reliability, and security
Injury Prevention	Detection of injury risks and monitoring recovery progress	Flexible, non-invasive sensors	High cost and limited accessibility. Proper data validation
Biometric Parameters	Measurement of vital signs and fitness levels	Advanced sensor technologies	Need more research for accurate data
Energy Efficiency	Management of energy use and hydration status	Wearable sensors integrated into clothing	Improving sensor accuracy

6 Conclusion

The findings indicate a consistent and pronounced growth in scientific output, reflecting the increasing relevance of wearable technologies in both applied sports contexts and academic research. This upward trend underscores the maturation of the field and its expanding role in performance optimization, injury prevention, and athlete health monitoring. The prominence of keywords related to sports performance, physiological monitoring, machine learning, and injury prevention demonstrates a shift toward data-driven and predictive approaches, signaling the integration of advanced analytics and wearable textiles into sports and biometric data science research.

Network visualizations reveal a highly interdisciplinary and internationally distributed research structure, with strong contributions from technologically advanced regions and growing collaboration across countries and institutions. The co-authorship and citation networks suggest that while several core research clusters dominate the field, there remains substantial potential for deeper cross-disciplinary integration, particularly between engineering-oriented and sport science–oriented research.

From a methodological standpoint, this study demonstrates the utility of bibliometric analysis as a strategic tool for synthesizing large volumes of scientific literature in rapidly evolving technological domains. The use of VOSviewer enables the identification of latent structures and emerging research fronts that may not be readily apparent through traditional narrative reviews. As such, this work contributes not only substantive insights into wearables in sports but also a replicable methodological framework for future bibliometric investigations in related domains.

Despite its contributions, this study is not without limitations. The reliance on a single database (Scopus) may exclude relevant publications indexed elsewhere, and the restriction to English-language documents could introduce linguistic bias. Furthermore, bibliometric methods primarily emphasize quantitative patterns and do not directly assess the qualitative depth or empirical rigor of individual studies. Future research may benefit from integrating multiple databases, extending the temporal scope, or combining bibliometric techniques with systematic or meta-analytic approaches.

In conclusion, the present analysis confirms that wearable technologies in sports constitute a dynamic, rapidly expanding, and methodologically diverse research domain. By elucidating its structural foundations and emerging directions, this study provides valuable guidance for researchers, practitioners, and policymakers seeking to advance innovation, collaboration, and evidence-based application in sports and exercise science. Continued interdisciplinary engagement and methodological refinement will be essential for translating wearable technology research into meaningful performance and health outcomes.

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