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# Application of Artificial Intelligence in rehabilitation science: A scientometric investigation Utilizing Citespace

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ABSTRACT

This study presents a scientometric analysis of the intersection between rehabilitation science and artificial intelligence (AI) technologies, using data from the Web of Science (WOS) database from 2002 to 2022. The analysis employed a comprehensive search query with key AI-related terms, focusing on a wide range of publications in rehabilitation science. Utilizing the Citespace tool, the study visualizes and quantifies the relationships between key terms, identifies research trends, and assesses the impact of AI technologies in rehabilitation science. Findings reveal a significant increase in AI-related research in this field, particularly from 2017 onwards, peaking in 2021. The United States has been a leading contributor, followed by countries like England, Australia, Germany, and Canada. Major institutional contributions come from Harvard University and the Pennsylvania Commonwealth System of Higher Education, among others. A keyword co-occurrence network constructed through Citespace identifies nine distinct hot topics and various research frontiers, highlighting evolving focus areas within the field. Burst analysis of keywords indicates a shift from performance and injury-related research to an increasing emphasis on AI and deep learning in recent years. The study also predicts the potential impact of papers, spotlighting works by Kunze KN and others as significantly influencing future research directions. Additionally, it examines the evolution of knowledge bases in AI-related rehabilitation science research, revealing a multidisciplinary core that includes neurology, rehabilitation, and ophthalmology, extending to complementary fields such as medicine and social sciences. This scientometric analysis provides a comprehensive overview of AI's application in rehabilitation science, offering insights into its evolution, impact, and emerging trends over the past two decades. The findings suggest strategic directions for future research, policy-making, and interdisciplinary collaboration in rehabilitation science and AI.

## 1. Introduction

Artificial Intelligence (AI), a multidisciplinary field drawing from computer science, control theory, information theory, systems science, and philosophy, has become a cornerstone in the evolution of modern technology [1,2]. Since its conceptualization at the Dartmouth Conference in 1956, AI has aimed to emulate and enhance human cognitive processes by developing "intelligent agents" capable of problem-solving and learning [3]. The rise of AI signifies a crucial juncture in our efforts to understand and reshape the world around us, with branches such as cognitive AI, machine learning, and deep learning playing central roles in this pursuit [4]. In rehabilitation science, the integration of AI has transformed patient care, therapy customization, injury prevention, and rehabilitation methods. AI technologies, including machine learning and deep learning, have introduced precision and efficiency to rehabilitation procedures, leading to improved patient outcomes and recovery processes. For example, deep learning algorithms can analyze motion data from sensors or imaging modalities like motion capture systems, accelerometers, or cameras, identifying patterns related to movement disorders, gait abnormalities, or motor function impairments. This aids in diagnosis and treatment planning. However, while the study identifies these trends, establishing more explicit connections between these trends and their practical implications could be advantageous. Certain sections lack specific examples or detailed case studies to validate these

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assertions.

Wearable technologies equipped with sensors and AI capabilities collect critical health data, which therapists and healthcare providers use to create personalized rehabilitation programs, optimizing recovery trajectories for patients [5]. AI's ability to process and analyze extensive biomechanical and physiological data has facilitated a deeper understanding of patient conditions, aiding in the development of more effective rehabilitation techniques. Research, such as that by Biró et al. [6], has shown how AI-assisted analyses can pinpoint areas for improvement in rehabilitation, leading to better patient outcomes. The emergence of AI marks a pivotal moment in our quest to understand and reshape the world. Its various branches, such as cognitive AI, machine learning, and deep learning, play crucial roles in this pursuit [4]. AI's development reflects an ongoing effort to emulate human-like abilities in reasoning, learning, and adapting. In rehabilitation science, the integration of AI has been transformative, revolutionizing aspects like patient care, therapy customization, injury prevention, and rehabilitation methodologies. AI technologies, notably machine learning and deep learning, have brought unprecedented precision and efficiency to rehabilitation practices, significantly improving patient outcomes and the efficacy of recovery processes. Wearable technologies equipped with sensors and AI capabilities are pivotal in this transformation. They collect vital health data, enabling healthcare professionals to design personalized rehabilitation programs that better align with individual recovery paths [5]. This tailored approach is critical in rehabilitation, where patient-specific factors significantly influence recovery. Furthermore, AI's capacity to process and interpret extensive biomechanical and physiological data has led to a more profound comprehension of patient conditions. This capability is instrumental in devising more effective rehabilitation techniques. The research conducted by Biró et al. [6] exemplifies this, demonstrating how AI-assisted analysis can identify specific areas for improvement in rehabilitation protocols, thereby enhancing patient outcomes. Their work highlights the role of AI in generating personalized insights into patient rehabilitation needs, which can significantly influence treatment efficacy.

The literature also suggests a growing trend in using AI for predictive analysis in rehabilitation. For example, studies have explored the use of machine learning algorithms to predict patient outcomes based on initial assessments and ongoing progress data [7–10]. This predictive capability is crucial for anticipating potential complications or determining the most effective treatment approaches, thus optimizing the rehabilitation process. Additionally, AI's role in injury prevention and management in rehabilitation science has been a focal point of recent research. Innovative AI applications have been developed to analyze movement patterns and predict the risk of injuries, enabling more effective preventative measures [11–14]. This proactive approach to injury prevention is particularly beneficial in rehabilitation, where the goal is not only to treat existing conditions but also to prevent future occurrences.

AI's strategic application extends beyond data analysis to the creation of personalized therapy plans [15–17]. It uses predictive analytics and modeling to formulate effective rehabilitation strategies, addressing individual patient needs [18]. AI's predictive capabilities are particularly valuable in injury prevention and management. For example, Claudino et al. [19] employed machine learning to anticipate injury risks, which can be adapted to preventive strategies in rehabilitation settings. Similarly, Rigamonti et al. [20] used AI for the early detection of conditions like concussions, crucial in both sports and rehabilitation. Feely et al. [21] demonstrated the use of AI in gait analysis, which is vital for injury recovery and prevention. Citespace offers temporal and spatial analysis tools to explore how AI research evolves over time and across different geographical regions. By tracking changes in citation patterns and research activity, it helps researchers understand the dynamics of AI integration and adoption within physiological rehabilitation and exercise rehabilitation.

The integration of AI in rehabilitation science represents a transformative shift, heralding new breakthroughs and redefining recovery and treatment methodologies [22–25]. Recognizing AI's rapid growth and its profound impact on rehabilitation science, this paper undertakes a scientometric analysis using the Citespace 6.2 Version. This comprehensive approach aims to dissect the expansive literature, mapping the development, trends, and emerging areas in AI research within rehabilitation science. The scientometric method allows us to:

- Chart the progression and intellectual landscape of AI applications in rehabilitation science.
- Pinpoint key research domains, influential scholars, institutions, and nations driving advancements in this field.
- Decipher the complex interactions between various AI technologies and their influences on rehabilitation science.
- Anticipate future trends and potential areas of research in AI-enhanced rehabilitation science.

This scientometric study not only deepens our understanding of AI's current role in rehabilitation science but also guides future research paths and strategic directions in this rapidly evolving arena. By doing so, it contributes significantly to the advancement of rehabilitation science, leveraging the transformative power of AI to improve patient care and therapy outcomes. This exploration reveals the multifaceted nature of AI in rehabilitation science, including its role in enhancing diagnostic accuracy, enabling precision medicine, and improving patient engagement and adherence to rehabilitation programs. AI-driven tools such as virtual reality and gamified therapy platforms have shown potential in increasing patient motivation and engagement, essential for successful rehabilitation outcomes. Additionally, AI's integration into telerehabilitation services has expanded access to care, especially in remote and underserved areas, democratizing healthcare delivery. These developments, coupled with ongoing research and innovation, underscore AI's vital role in shaping the future of rehabilitation science, offering more effective, efficient, and personalized care solutions for patients worldwide.

## 2. Methodology

### *2.1. Data collection*

The study conducted a scientometric analysis within the domain of Rehabilitation Science by utilizing data from the Web of Science (WOS) database. The focus of this analysis was on publications from the years 2002 to 2022, specifically categorized under "Rehabilitation" (WC = Rehabilitation). To identify pertinent literature within this field, a search query was crafted targeting the intersection of physiological rehabilitation and artificial intelligence technologies. This query encompassed a range of keyword terms relevant to both rehabilitation and AI, such as "Computer Vision," "Machine Learning," "Convolutional Neural Networks," "Artificial Intelligence," "Image Processing," "Feature Extraction," "Biomechanical Analysis," "Gait Analysis," "Prosthetics Control," "Neurorehabilitation," "Knowledge Representation," "Automatic Reasoning," "Natural Language Processing," "Intelligent Rehabilitation Systems," and "Robot-assisted Therapy." Inclusion criteria were set to encompass articles published within the specified timeframe, categorized under "Rehabilitation" in WOS, and containing one or more of the specified AI-related terms in their title, abstract, or keywords. Exclusions included duplicate and non-peer-reviewed sources, as well as proceedings articles, retrospective articles, and non-English articles, which could result in mixed data and poor results of software analysis and processing.

Utilizing the scientometric analysis tool Citespace, the study performed data analysis to visualize and quantify relationships between key terms, identify research trends, and assess the impact of artificial intelligence technologies within the Rehabilitation Science domain. The analysis also gathered bibliometric information, such as publication year, authorship, citation counts, and co-citation networks, to track the evolution of research topics and pinpoint influential research clusters. Statistical analyses were conducted to explore trends in publications, collaboration patterns, and the overarching impact of artificial intelligence on Rehabilitation Science research. This systematic approach provided a comprehensive overview of the application and influence of artificial intelligence technology in Rehabilitation Science, offering insights into its development and impact over the study period.

### *2.2. Scientometric tool: CiteSpace*

#### *2.2.1. Timeliness of visualized co-citation networks*

CiteSpace is a software specifically designed for scientific literature analysis. It simplifies complex co-citation networks through visualization techniques, aiding researchers in exploring development trends and research frontiers in academic fields [26]. CiteSpace's core capability lies in revealing research trends of newly published articles, even if these articles have not yet garnered a large number of citations. This is made possible by CiteSpace's burst detection algorithm, which can identify emerging specialized terms in literature, irrespective of how frequently the literature is cited. Therefore, even emerging research themes can be represented in CiteSpace's co-citation network. CiteSpace's timezone view is a unique visualization method that uses bar areas to represent different time periods, thus creating a view arranged in chronological order. These bar areas are aligned from left to right, with each area representing a specific time period. In this view, research frontiers (i.e., the latest research topics and trends) are typically located on the right, while the knowledge base (i.e., the early work and theories that form these research frontiers) is on the left. This layout intuitively displays the evolution and development of research topics over time.

The timezone view in CiteSpace uses an improved spring model algorithm that restricts lateral movement of elements, ensuring they stay within their designated time areas. However, the vertical positioning of elements depends on their associations with elements in other time areas. This layout not only facilitates the identification of research areas within specific time periods but also showcases knowledge transfer and evolution across different time segments. In our study, we utilized CiteSpace's timezone view to explore the progression of artificial intelligence in the field of Rehabilitation Science over time. Through this visualization, we can clearly see how AI technology has gradually been applied and developed in Rehabilitation Science, identifying which themes and concepts have become research hotspots in different time periods. Such analysis is crucial for understanding the history and future directions of AI in Rehabilitation Science. AI is profoundly impacting Rehabilitation Science by revolutionizing various aspects of assessment, treatment, and personalized care delivery. With its capacity to analyze vast amounts of complex data and extract actionable insights, AI enables clinicians and researchers to make more informed decisions, tailor interventions to individual needs, and enhance rehabilitation outcomes.

#### *2.2.2. Calculating and determining keypoints*

In scientometrics, the Burst Detection algorithm is an important method that is widely used to identify research hotspots and emerging frontier areas in academic literature. In analyzing the development of artificial intelligence technology in the field of rehabilitation, this study employed the algorithm to dynamically detect research hotspots in different time periods and discover the bursting pattern of keywords. The Burst Detection algorithm is based on the sudden change in the frequency of occurrence of words or phrases to discover potential research frontiers. Its core formula is:

$$R_u(t) = \frac{B_u(t)}{\frac{1}{n}\sum_{t'=1}^{t'} B_u(t')} \tag{1}$$

Where the calculation method for $B_u(t)$ is as follows:

$$B_u(t) = \sum_{t' \in [t-\Delta, t]} P(u|t') \tag{2}$$

Here, $\Delta$ represents a time window that denotes the time span used to compute bursts. $P(u|t')$ represents the probability of word $u$ occurring at time $t'$. In the context of AI in rehabilitation technology literature, these variables can be redefined using domain-specific terminologies: $u$ denotes rehabilitation technology or related terms like "rehabilitation AI" or "athletic technology." $t$ represents time corresponding to publication dates or specific time intervals to observe the usage trend of specific terms. $n_u(t)$ signifies the frequency or count of a specific term appearing within a certain timeframe. $N(t)$ represents the total occurrences or overall frequency within time segment $t$. $\Delta$ signifies the time window used to identify burst events. Understanding these variables aids in comprehending the frequency or bursts of specific terms in the field of rehabilitation technology, indicating potential surges in prominence or changes in research focus on certain technologies or concepts.

In the initial CiteSpace I version, users relied on visual observation to identify nodes connecting different clusters in the network to determine key points. This method's advantage lies in not requiring additional computation. However, it has a drawback in that it cannot guarantee the identification of all key points unless users devote time to observe all nodes in the entire network. Conversely, the latest version employed in this study, CiteSpace V, encompasses additional functionalities and improvements [27,28]. For instance, it offers enhanced support for large-scale data, stronger data processing capabilities, and exhibits more intuitive visualizations. Its distinct view effects make it easier for users to identify nodes with high intermediary centrality. This version identifies key points through computation and visually emphasizes these key points using purple circles in the visualized network. By employing graph theory to identify these key points, researchers can simplify their study of the entire network by focusing solely on a few key points that hold explanatory significance.

#### *2.2.3. Operational procedures*

The specific operational steps for conducting literature measurement analysis using CiteSpace V in this study are outlined below:

1. Building the search query. Initially, a search query containing AI-related vocabulary was constructed according to the research objectives to collect literature in the target domain, covering keywords like "computer vision" and "machine vision."
2. Literature collection. The search query was applied in the WOS core database to retrieve relevant literature categorized under "Rehabilitation Science" published between 2002 and 2022, excluding duplicates and non-peer-reviewed articles.
3. Data preprocessing. Literature data was extracted, segmented, and subjected to word frequency statistics to construct a frequency matrix, focusing on high-frequency keywords in titles, abstracts, and keywords for analysis.
4. Time zone division. Publication times of literature were segmented into multiple time intervals, set at every 5 years in this study to capture the sequential changes in academic hotspots.
5. Burst detection. Burst strength $B_u(t)$ for words was calculated within each time interval to identify sudden growth in research hotspots. $B_u(t) = \sum_{t' \in [t-\Delta, t]} P(u|t')$, where the goal of burst detection is to identify suddenly growing research hotspots in different time periods. The term $B_u(t)$ in the formula represents the burst strength of word $u$ at a specific time $t$, obtained by summing the conditional probability $P(u|t')$ of word $u$ within the time window $[t - \Delta, t]$.
6. Plotting the burst word evolution graph to display research hotspots at different periods. Specifically, line graphs showing the variation of burst strength $B_u(t)$ over time dynamically exhibit the burst patterns

of different keywords. This illustrates which keywords became hotspots in different eras.
7. Performing cluster analysis to detect word co-occurrences and identify disciplinary hotspots. The study set a threshold for cluster analysis to obtain several clustering categories, representing major AI hotspots in Rehabilitation Science research, such as physical training and musculoskeletal injuries.
8. Generating keyword network diagrams, representing frequency through node size and color indicating clusters. The network diagrams visually display word associations, with larger nodes representing higher frequencies and colors differentiating research themes.
9. Validating key points to confirm genuine research frontiers. Initially, influential literature was identified based on the Δ indicator, followed by validation through literature content review or expert consultation to ascertain if these publications represent research frontiers. This aids in pinpointing genuinely valuable research outcomes.

## 3. Results

### 3.1. Trends in output

Analyzing the temporal trends of research papers over a specific period can yield deep insights into the scholarly focus and developmental trajectory of a particular field. In this study, we conducted a comprehensive search within the Web of Science (WOS) Core Collection to identify scholarly works related to the application of artificial intelligence (AI) in the field of Rehabilitation Science. The formulated search query encompassed a range of AI-related terms and focused on publications from 2002 to 2022. The query was structured as follows: "(WC=(Rehabilitation Sciences) AND (TS=(Computer Vision) OR TS=(Machine Vision) OR TS=(Convolutional Neural Network) OR TS=(Artificial Intelligence) OR TS=(Image processing) OR TS=(Feature-extraction) OR TS=(Image preprocessing) OR TS=(Target detection) OR TS=(Image segmentation) OR TS=(Knowledge representation) OR TS=(Automatic reasoning and search methods) OR TS=(Machine learning and knowledge acquisition) OR TS=(Knowledge processing system) OR TS=(Natural language understanding) OR TS=(Intelligent robot) OR TS=(Intuitive program design))) AND (Date = 2002–2022)." This search within the WOS database yielded a total of 1499 papers. Our analysis of these AI-related publications in Rehabilitation Science uncovered a distinct growth pattern. From 2002 to 2016, the field saw relatively modest growth, averaging about 50 publications per year. However, a significant acceleration in research activity was observed from 2017 through 2021, characterized by an exponential increase in publications. This upsurge reached its peak in 2021 with a record of 178 documents, as depicted in Fig. 1. This trend indicates a growing interest and investment in integrating AI technologies within the domain of Rehabilitation Science.

The global landscape of artificial intelligence (AI) research in Rehabilitation Science is marked by significant contributions from various countries, with the United States leading in terms of publication volume. Analyzing data from the Web of Science, the United States emerges as the foremost contributor, having authored 512 papers, which constitute 34.16 % of the global literature in this niche. This dominant position underscores the country's pivotal role in advancing AI applications within Rehabilitation Science. In comparison, England, another significant contributor, has produced 133 papers, representing 8.87 % of the global discourse, followed by Australia with 128 papers (8.54 %) (Fig. 2).

Germany's contribution to AI research in Rehabilitation Science is also notable, with 122 papers accounting for 8.14 % of the worldwide literature. Canada, not far behind, has generated 103 papers (6.87 %), reflecting its active engagement in this field. Italy, with its 80 papers (5.34 %), and France, with 60 papers (4.00 %), further demonstrate Europe's robust involvement in AI Rehabilitation Science research. Additionally, the Netherlands and Brazil have made significant contributions, producing 53 (3.54 %) and 51 (3.40 %) papers, respectively, underlining the global reach of this research area.

At the institutional level (Fig. 3), Harvard University and the Pennsylvania Commonwealth System of Higher Education (PCSHE) are prominent, each with 35 publications, accounting for 2.34 % of the total literature. Their contribution signifies a strong academic interest and capacity in AI Rehabilitation Science research. The University of California System, with 29 publications (1.94 %), is another key player. Noteworthy too is the role of specialized institutions like HOSP SPECIAL SURG, contributing 26 papers (1.73 %), and French Research Universities, with 25 papers (1.67 %).

Other influential institutions include Harvard Medical School, Mayo Clinic, the University of Minnesota System, University of Minnesota Twin Cities, and the University of Pittsburgh, each producing 23


**Fig. 1.** Literature output distribution, 2002–2022.

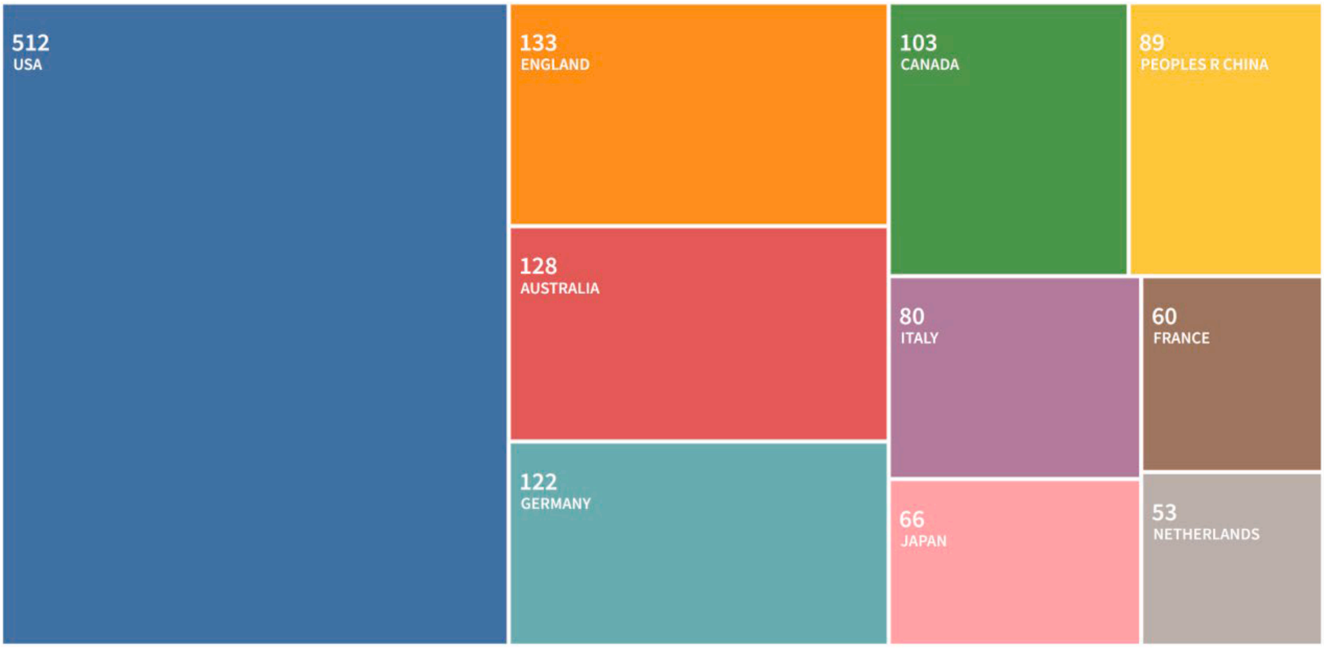


**Fig. 2.** Distribution of literature output by country or region, 2002–2022.

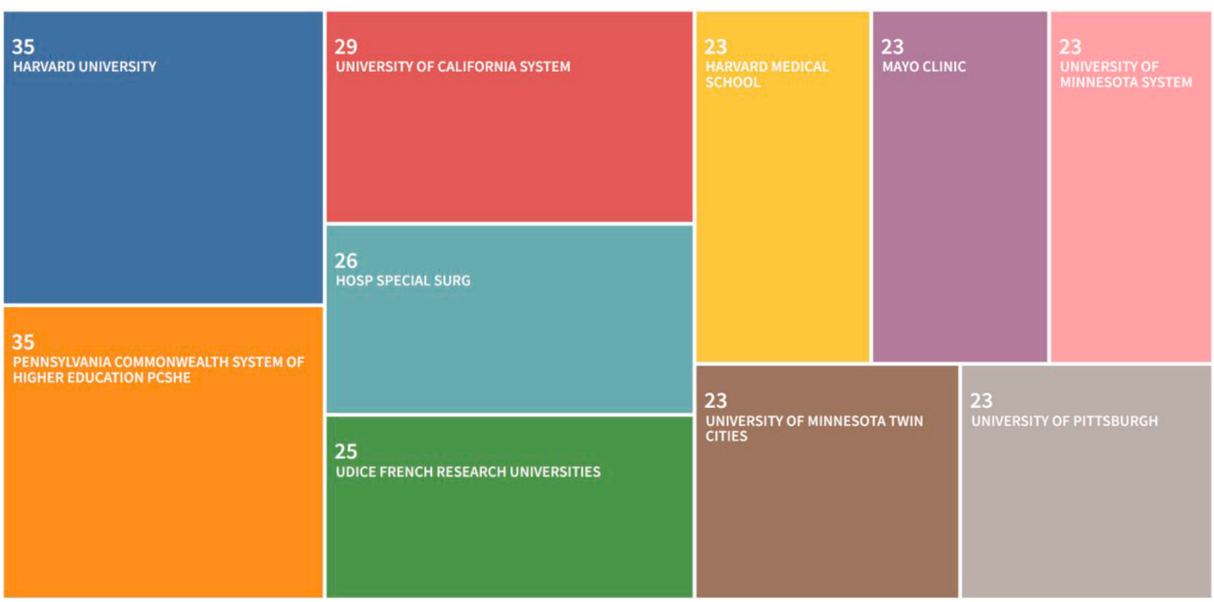


**Fig. 3.** Institutional distribution of literature output, 2002–2022.

publications and collectively contributing 1.53 % to the global body of literature. These figures, as represented in Fig. 3, reflect a diverse and geographically widespread academic involvement in AI research within Rehabilitation Science, highlighting the interdisciplinary and international nature of this evolving field.

### 3.2. Research hotspot analysis

In this comprehensive analysis of artificial intelligence in Rehabilitation Science, the CiteSpace visualization software was employed to construct an intricate keyword co-occurrence network. This network, visualized in Fig. 4, features 606 nodes and 2826 lines, representing the interconnected research themes over two decades (2002–2022). The network's complexity, governed by the g-index $K = 25$, reveals the depth and breadth of AI research within this field.

The analysis identified the top 20 keywords based on their frequency of co-occurrence in the literature, as detailed in Table 1. These keywords provide a snapshot of the dominant research topics, illustrating the focus areas that have captivated scholars' interests.

The clustering functionality of CiteSpace revealed nine distinct research themes, each characterized by a group of related keywords. These themes, visualized in Fig. 5, represent the diverse applications and research angles of AI in Rehabilitation Science. The following are the identified themes and their associated keywords:

1. **Physical Activity**: This theme, centered around keywords like "performance," "sport," "exercise," and "physical activity," highlights

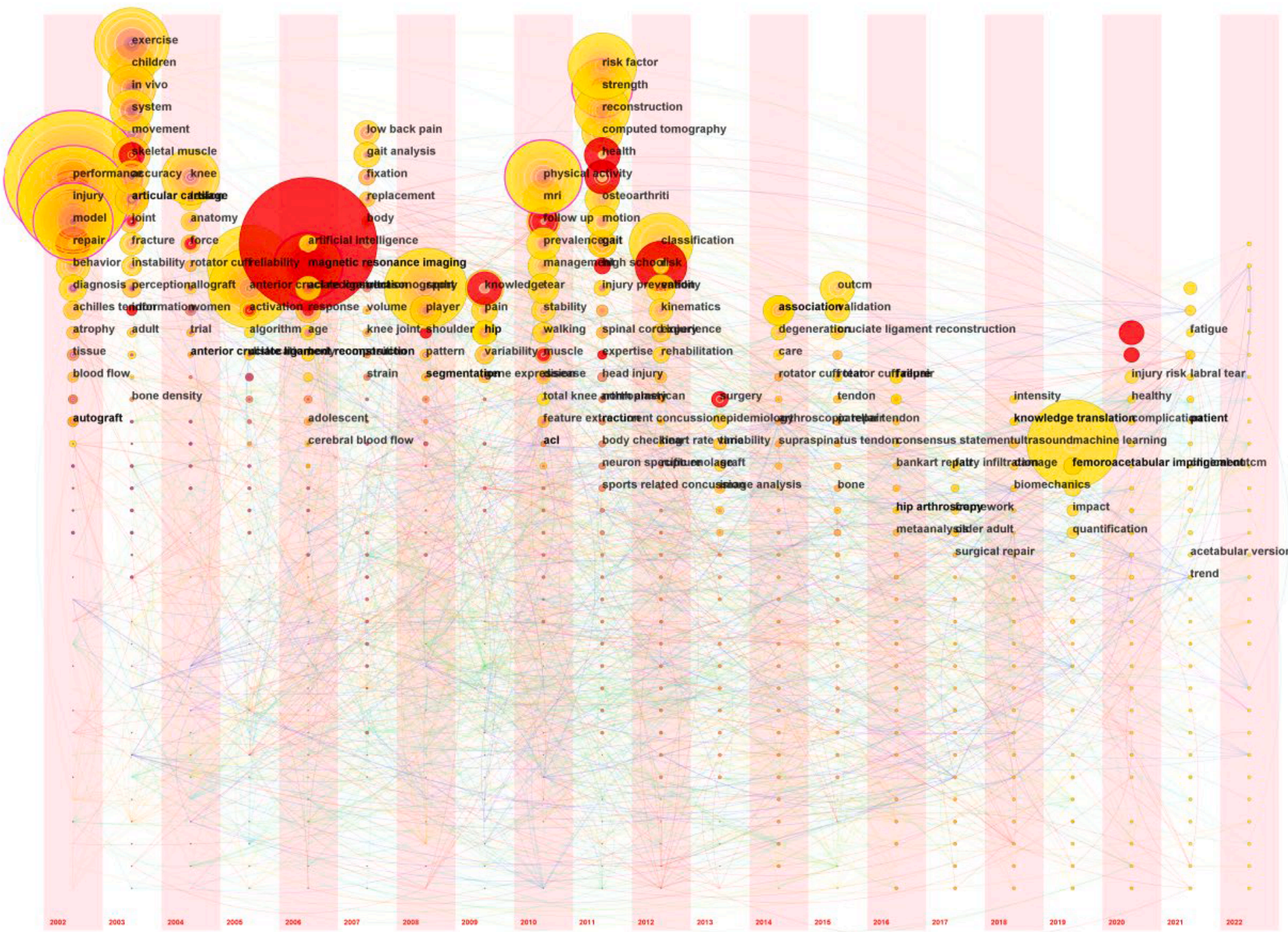


**Fig. 4.** Timezone view of keyword co-occurrence network.

**Table 1**
Information table of main keywords.

| No. | Keyword | Frequency | Centrality | Affiliation Clustering |
|---|---|---|---|---|
| 1 | performance | 75 | 0.15 | 0 |
| 2 | artificial intelligence | 74 | 0.02 | 6 |
| 3 | injury | 62 | 0.13 | 1 |
| 4 | machine learning | 49 | 0.01 | 6 |
| 5 | reliability | 47 | 0.07 | 5 |
| 6 | anterior cruciate ligament | 46 | 0.06 | 4 |
| 7 | sport | 46 | 0.06 | 0 |
| 8 | model | 45 | 0.13 | 3 |
| 9 | exercise | 42 | 0.09 | 0 |
| 10 | physical activity | 42 | 0.1 | 0 |
| 11 | magnetic resonance imaging | 39 | 0.13 | 3 |
| 12 | risk factor | 37 | 0.08 | 7 |
| 13 | classification | 35 | 0.05 | 1 |
| 14 | strength | 34 | 0.11 | 8 |
| 15 | knee | 33 | 0.05 | 1 |
| 16 | reconstruction | 31 | 0.05 | 4 |
| 17 | risk | 28 | 0.04 | 0 |
| 18 | in vivo | 27 | 0.04 | 3 |
| 19 | children | 27 | 0.05 | 2 |
| 20 | system | 25 | 0.05 | 2 |

the role of AI in enhancing athletic performance and tracking physical activity metrics.

2. **Rotator Cuff**: Keywords such as "injury," "classification," and "knee" define this theme, focusing on injury analysis, rehabilitation, and AI's role in diagnosing and treating rotator cuff injuries.
3. **Cerebral Palsy**: This theme, encompassing keywords like "children," "system," and "movement," reflects the application of AI in managing and understanding cerebral palsy, particularly in sports and physical activity contexts.
4. **Skeletal Muscle**: Keywords including "model," "magnetic resonance imaging," and "skeletal muscle" signify the focus on AI's application

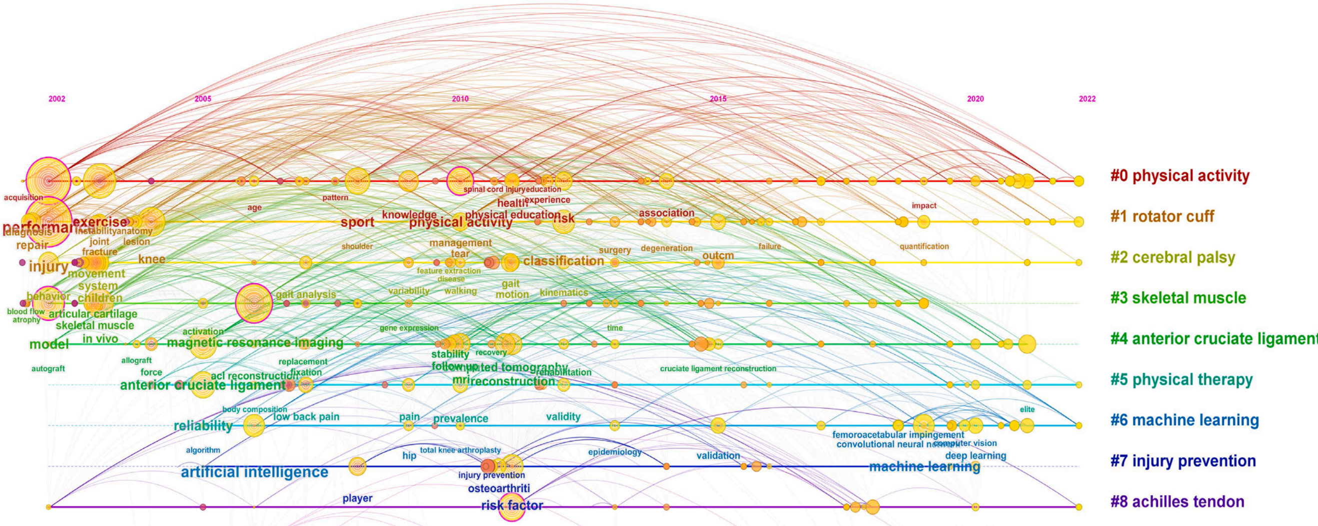


**Fig. 5.** Keyword co-occurrence clustering mapping.

in muscle imaging and modeling, crucial for training and injury prevention.

5. **Anterior Cruciate Ligament (ACL)**: Central to this theme are keywords like "ACL," "recovery," and "surgery," pointing to AI's role in ACL injury analysis, surgical planning, and rehabilitation.
6. **Physical Therapy**: This theme, with keywords like "ultrasonography," "reliability," and "prevalence," indicates the integration of AI in physical therapy, enhancing techniques and outcomes.
7. **Machine Learning**: Keywords such as "algorithm," "data analysis," and "prediction" suggest the use of machine learning techniques in sports analytics and performance prediction.
8. **Injury Prevention**: Focusing on "prevention," "risk assessment," and "training," this theme highlights AI's preventive role in sports injuries, risk assessment, and training optimization.
9. **Achilles Tendon**: This theme, including keywords like "tendon injury," "rehabilitation," and "biomechanics," showcases AI's application in understanding and treating Achilles tendon injuries.

The TimeZone view of the keyword co-occurrence network (Fig. 4) offers a dynamic representation of how academic interests have shifted over time, with the themes shifting in prominence. Notably, "performance" and "artificial intelligence" emerged as significant keywords with high frequencies and centralities, indicating their central role in the field. This reflects the continuous focus on enhancing performance and integrating AI technologies in Rehabilitation Science.

In sum, the analysis through CiteSpace reveals a rich tapestry of research themes, from injury analysis and prevention to performance enhancement and rehabilitation, underpinned by AI technologies. These themes not only encapsulate the current state of AI research in Rehabilitation Science but also hint at future directions and potential areas for further exploration.

### 3.3. Research frontier analysis

Our analysis identified 24 keywords with notable burst strength (Table 2). In the initial period from 2002 to 2010, the research frontier was dominated by keywords such as "performance," "information," "joint," "movement," "force," "activation," "response," and "magnetic resonance imaging." This selection of keywords suggests a focus on biomechanics, physiological responses, and imaging technologies in Rehabilitation Science, reflecting an era where foundational research in these areas was gathering momentum.

In the subsequent phase from 2011 to 2019, there was a noticeable shift in scholarly attention. New frontier keywords emerged, including "skeletal muscle," "high school," "expertise," "strength," "surgery," "follow-up," "repair," "knowledge," and "physical education." This shift indicates a broadening of research scope to encompass educational aspects, surgical interventions, and muscle physiology within Rehabilitation Science. These topics point to a deeper integration of multidisciplinary approaches in Rehabilitation Science, merging educational theories, clinical practices, and physical training methodologies.

The most recent period, from 2020 to 2022, marked another significant shift with an increased focus on "artificial intelligence," "deep learning," "risk," "health," and "computer vision." The prominence of these keywords underscores the escalating integration of advanced AI technologies in Rehabilitation Science. This trend reflects a paradigm shift towards more sophisticated, data-driven approaches in sports analytics, injury risk assessment, and health management. The emergence of 'deep learning' and 'computer vision' as frontier keywords indicates a growing reliance on these AI technologies for complex tasks such as motion analysis, performance tracking, and predictive analytics in sports.

These evolving trends captured through burst analysis indicate the dynamic nature of Rehabilitation Science research, continually adapting to technological advancements and emerging scientific inquiries. This progression is not only a testament to the field's resilience and adaptability but also highlights the increasing importance of AI as a transformative tool in Rehabilitation Science. As AI technologies continue to evolve, they are expected to further revolutionize research methodologies and applications in Rehabilitation Science, shaping the future trajectory of the field.

**Table 2**
Top24 Keywords with the strongest citation bursts.

| Keywords | Strength | Begin | End | 2002 - 2022 |
|---|---|---|---|---|
| performance | 3.71 | 2002 | 2008 | |
| information | 3.67 | 2003 | 2006 | |
| joint | 3.31 | 2003 | 2005 | |
| movement | 3.2 | 2003 | 2011 | |
| force | 3.16 | 2004 | 2010 | |
| activation | 3.36 | 2005 | 2011 | |
| response | 3.26 | 2006 | 2010 | |
| magnetic resonance imaging | 3.17 | 2006 | 2014 | |
| shoulder | 3.21 | 2008 | 2014 | |
| muscle | 3.98 | 2010 | 2013 | |
| skeletal muscle | 4.2 | 2011 | 2015 | |
| high school | 3.3 | 2011 | 2017 | |
| expertise | 3.1 | 2011 | 2014 | |
| strength | 3.14 | 2012 | 2015 | |
| surgery | 3.85 | 2013 | 2018 | |
| follow up | 4.82 | 2015 | 2018 | |
| repair | 4.73 | 2016 | 2018 | |
| knowledge | 3.73 | 2016 | 2019 | |
| physical education | 4.89 | 2018 | 2020 | |
| artificial intelligence | 19.25 | 2020 | 2022 | |
| deep learning | 5 | 2020 | 2022 | |
| risk | 3.84 | 2020 | 2022 | |
| health | 3.66 | 2020 | 2022 | |
| computer vision | 3.21 | 2020 | 2022 | |

### *3.4. Potential impact forecast*

The concept of Structural Variation Analysis (SVA), as introduced by Professor Chaomei Chen in 2012, provides a sophisticated means of assessing the influence of new academic contributions on the existing knowledge network. Within SVA, the Rate of Modal Change (ΔM) stands as a key metric. It essentially measures the degree to which new literature enhances the interconnectedness of the existing knowledge base. A higher ΔM value indicates a more significant potential impact of the cited work on the network's structure, often suggesting that the work lies at the forefront of its field.

Applying this concept to our study of artificial intelligence (AI) in Rehabilitation Science, we calculated the ΔM values for a range of relevant research literature. The results, listed in Table 3, identify the top 20 publications that have made the most substantial contributions to this field, as measured by their ΔM values. Among these, a paper by

**Table 3**
The model change rate of English literature(Top20).

| No. | △M | Title | Author | Publication Date | Journal |
|---|---|---|---|---|---|
| 1 | 100 | Diagnostic Performance of Artificial Intelligence for Detection of Anterior Cruciate Ligament and Meniscus Tears: A Systematic Review | Kunze KN | 2021 | ARTHROSCOPY V |
| 2 | 100 | Application of Machine Learning Algorithms to Predict Clinically Meaningful Improvement After Arthroscopic Anterior Cruciate Ligament Reconstruction | Kunze KN | 2021 | ORTHOP J SPORTS MED V |
| 3 | 100 | Three-Dimensional Quantification of Glenoid Bone Loss in Anterior Shoulder Instability: The Anatomic Concave Surface Area Method | Launay M | 2021 | ORTHOP J SPORTS MED V |
| 4 | 100 | Hip joint space width in an asymptomatic population: Computed tomography analysis according to femoroacetabular impingement morphologies | Nehme A | 2021 | ASIA-PAC J SPORT MED V |
| 5 | 100 | Verification of validity of gait analysis systems during treadmill walking and running using human pose tracking algorithm | Ota M | 2021 | GAIT POSTURE V |
| 6 | 100 | In Vivo Visualization of Tissue Damage Induced by Percutaneous Muscle Biopsy via Novel High-Resolution MR Imaging | PREISNER FABIAN | 2021 | MED SCI SPORT EXER V |
| 7 | 100 | Clinical and Research Medical Applications of Artificial Intelligence | Ramkumar PN | 2021 | ARTHROSCOPY V |
| 8 | 100 | A novel dataset and deep learning-based approach for marker-less motion capture during gait | Vafadar S | 2021 | GAIT POSTURE V |
| 9 | 100 | An exploration of doping-related perceptions and knowledge of disabled elite athletes in the UK and Austria | Weber K | 2021 | PSYCHOL SPORT EXERC V |
| 10 | 100 | Forecasting football injuries by combining screening monitoring and machine learning | Hecksteden A | 2022 | SCI MED FOOTBALL V |
| 11 | 100 | Radiographic findings involved in knee osteoarthritis progression are associated with pain symptom frequency and baseline disease severity: a population-level analysis using deep learning | Kunze KN | 2022 | KNEE SURG SPORT TR A V |
| 12 | 64.4294 | Association Between Preoperative Patient Factors and Clinically Meaningful Outcomes After Hip Arthroscopy for Femoroacetabular Impingement Syndrome: A Machine Learning Analysis | Kunze KN | 2022 | AM J SPORT MED V |
| 13 | 64.4294 | Machine Learning Algorithms Predict Achievement of Clinically Significant Outcomes After Orthopaedic Surgery: A Systematic Review | Kunze KN | 2022 | ARTHROSCOPY V |
| 14 | 64.4294 | A Survey on the Use of Artificial Intelligence for Injury Prediction in Sports | Tedesco S | 2022 | IEEE INTERNATIONAL WORKSHOP ON SPORT TECHNOLOGY AND RESEARCH |
| 15 | 46.6441 | Artificial Intelligence in Elite Sports-A Narrative Review of Success Stories and Challenges | Hammes F | 2022 | FRONT SPORTS ACT LIV V |
| 16 | 46.6441 | Machine learning in knee arthroplasty: specific data are key-a systematic review | Hinterwimmer F | 2022 | KNEE SURG SPORT TR A V |
| 17 | 46.6441 | Artificial intelligence algorithms accurately predict prolonged length of stay following revision total knee arthroplasty | Klemt C | 2022 | KNEE SURG SPORT TR A V |
| 18 | 46.6441 | Machine learning algorithms predict extended postoperative opioid use in primary total knee arthroplasty | Klemt C | 2022 | KNEE SURG SPORT TR A V |
| 19 | 46.6441 | Identifying modifiable and nonmodifiable cost drivers of ambulatory rotator cuff repair: a machine learning analysis | Lu Y | 2022 | J SHOULDER ELB SURG V |
| 20 | 41.9476 | DETERMINATION OF CONTRACTION-INDUCED CHANGES IN ELBOW FLEXOR CROSS-SECTIONAL AREA FOR EVALUATING MUSCLE SIZE-STRENGTH RELATIONSHIP DURING CONTRACTION | Akagi R | 2015 | J STRENGTH COND RES V |

Kunze KN, published in 2021, titled "Diagnostic Performance of Artificial Intelligence for Detection of Anterior Cruciate Ligament and Meniscus Tears: A Systematic Review" stands out with a ΔM value of 64.4294. This significant score indicates the paper's considerable influence in shaping current understanding and future directions of AI applications in Rehabilitation Science, especially in injury diagnosis and management. Furthermore, other papers authored by Kunze KN also exhibit high ΔM values, underscoring their pivotal role in advancing AI research in Rehabilitation Science. These works provide critical insights into the practical applications of machine learning algorithms for

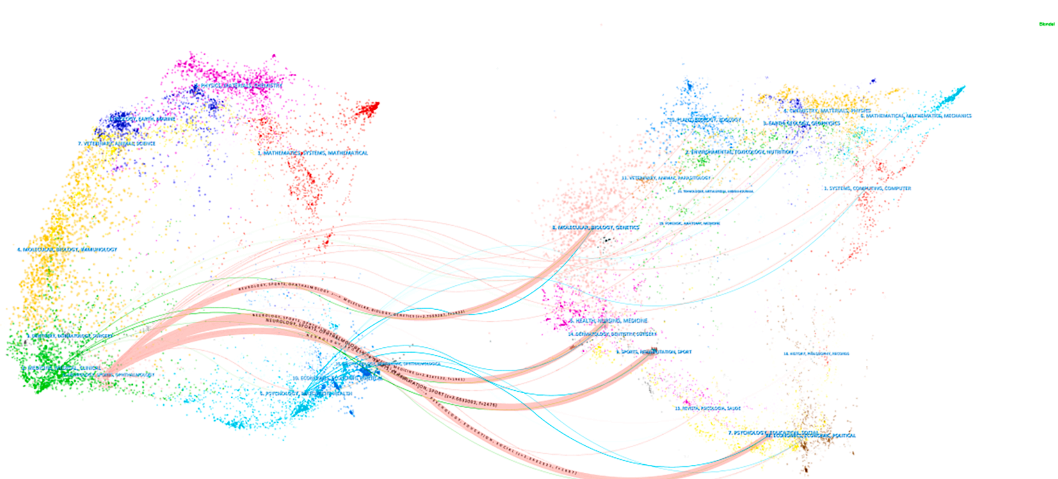

**Fig. 6.** Visualization of Knowledge Base Evolution in AI Applications within Rehabilitation Science (2002–2022).

predicting clinically meaningful outcomes, highlighting their potential to transform sports medicine and rehabilitation practices. The prominence of these papers underscores a shifting focus within the field, increasingly oriented towards leveraging AI for enhanced diagnostic accuracy and treatment efficacy in sports-related injuries.

### 3.5. Knowledge base evolution

The exploration of knowledge base evolution in research is pivotal for understanding the development and adaptation of a field over time. Within any research domain, subject areas act as foundational pillars, embodying core concepts, principles, and a wealth of scientific knowledge. Utilizing subject knowledge bases allows researchers to draw connections and unravel complex development patterns, linking diverse knowledge systems within a specific domain. In this context, the JCR-based classification map within CiteSpace software emerges as an instrumental tool for visualizing and examining the evolution of knowledge bases through various research phases.

This tool highlights two critical dimensions of knowledge evolution: the 'existing research domain' and the 'knowledge base domain.' The existing research domain, depicted on the left side of the map, signifies the current research trends and ongoing studies within a specific disciplinary area. Conversely, the knowledge base domain, situated on the right, represents the foundational knowledge and established principles cited in the research, providing the underpinnings for current scholarly pursuits.

Delving into the subject areas of cited references offers insights into the temporal evolution of the knowledge base. By tracking shifts within the knowledge base domain, researchers can pinpoint changes in fundamental principles and ideas shaping the direction of the field. This dynamic perspective reveals how novel discoveries and evolving paradigms become integrated into the established body of knowledge.

Furthermore, examining the subject area of the target dataset illuminates the diffusion of knowledge within the field, showcasing how research in a particular domain influences and is influenced by related disciplines. This interplay fosters interdisciplinary collaboration and innovation, underscoring the symbiotic nature of knowledge exchange across disciplinary boundaries.

In our study focusing on the application of artificial intelligence in Rehabilitation Science from 2002 to 2022 (Fig. 6), we identify a core knowledge base centered around the theme "Neurology, Sports, Ophthalmology." This central theme encapsulates the foundational concepts and principles driving research in this area. Surrounding this core are complementary domains like "Medicine, Medicine, Medical, Clinical," offering additional insights and perspectives.

The core knowledge base further diversifies into subcategories such as "Molecular Biology, Genetics," "Health, Nursing, Medicine," "Sports, Rehabilitation, Sport," and "Psychology, Education, Social." These subcategories collectively forge the groundwork for AI research in Rehabilitation Science. They highlight the field's multidisciplinary character and the importance of cross-disciplinary collaboration in advancing AI applications in Rehabilitation Science. This intricate network of interconnected knowledge not only facilitates the assimilation of novel ideas but also cultivates a comprehensive understanding of the field, driving its ongoing evolution.

## 4. Conclusion

This comprehensive scientometric study, focused on the intersection of artificial intelligence (AI) and Rehabilitation Science from 2002 to 2022, marks a significant stride in understanding the evolution and impact of AI in this dynamic field. Employing the Web of Science Core Collection and the advanced capabilities of CiteSpace visualization software, this research offers a nuanced, temporal, and spatial analysis of AI's integration into Rehabilitation Science.

A key innovation of this study lies in its temporal trend analysis, revealing an exponential increase in AI-related Rehabilitation Science research, particularly since 2017. This uptick, as illustrated in Fig. 1, signals a burgeoning interest and recognition of AI's critical role in Rehabilitation Science. The research also sheds light on the global landscape of AI contributions in Rehabilitation Science, highlighting the United States' dominance in publication volume. The wide geographical spread of these contributions, as shown in Fig. 2, underscores the global reach and collaborative nature of this field. Furthermore, the study delves into institutional contributions, identifying leading academic institutions that are at the forefront of AI research in Rehabilitation Science, as presented in Fig. 3.

The study's main findings reveal a robust growth of AI applications within Rehabilitation Science, indicating a significant shift towards more data-driven and technologically advanced research and practices. CiteSpace analysis uncovers various emerging research themes, emphasizing AI's multifaceted roles in enhancing athletic performance, injury prevention, and rehabilitation strategies. Additionally, the identification of keywords with notable burst strength points to the evolving frontiers and future trajectories of AI in Rehabilitation Science, suggesting a growing focus on areas like deep learning and computer vision. Our research highlights several important applications of artificial intelligence technology in Rehabilitation Science, including motion analysis, predictive modeling, activity recognition and monitoring, assistive technologies, and neurorehabilitation. These applications provide more precise and personalized assessment, treatment, and care plans for Rehabilitation Science, with the potential to significantly improve rehabilitation outcomes and patient quality of life.

However, the study is not without its limitations. The reliance on the Web of Science Core Collection may exclude some relevant research not indexed in this database. The analysis's dependence on specific keywords and search queries might not fully capture all aspects of AI's application in Rehabilitation Science. Additionally, it is important to acknowledge that interpretations of the CiteSpace visualizations are not absolute and can vary among researchers. This subjective element in data interpretation highlights the need for careful consideration and cross-referencing with other studies.Furthermore, it is essential to recognize the potential biases inherent in AI algorithms and their impact on research findings. Biases in data collection, preprocessing, and algorithm design can inadvertently skew results, leading to erroneous conclusions or reinforcing existing stereotypes. For instance, if AI algorithms are trained on biased datasets, they may perpetuate societal inequalities or exhibit discriminatory behavior, particularly in sensitive areas like healthcare. Moreover, the lack of diversity in the development teams or the data used to train AI models can further exacerbate these biases.Addressing these biases requires a concerted effort to enhance algorithm transparency, accountability, and fairness. Researchers must critically evaluate the datasets and algorithms used in their studies, actively identify and mitigate biases, and transparently report any limitations or potential sources of bias in their research. Additionally, interdisciplinary collaborations involving experts in ethics, sociology, and other relevant fields can provide valuable insights into the ethical implications of AI technologies in Rehabilitation Science. Moving forward, future research in this area should prioritize addressing these biases and ensuring the ethical use of AI in Rehabilitation Science. Engaging with and building upon existing studies that explore the ethical dimensions of AI, such as those by Mishra & Singh [29], Cheng et al. [30], Maiden et al. [31], Livingston et al. [32], and Turdaliyev et al. [33], can offer valuable guidance and frameworks for navigating these complex ethical challenges. By doing so, researchers can work towards developing more equitable, transparent, and ethically responsible AI systems that advance the goals of Rehabilitation Science while minimizing potential harms to vulnerable populations.

Moving forward, several strategic directions emerge as particularly beneficial or necessary. Firstly, there is a need to further explore the ethical implications of AI integration in Rehabilitation Science. This includes addressing biases in AI algorithms, ensuring fairness and transparency in AI applications, and promoting equity in healthcare access. Such investigations need future studies to integrate qualitative or interdisciplinary methods [34,35]. Additionally, research efforts should focus on enhancing the interpretability and explainability of AI models to foster trust among clinicians and patients. Secondly, future studies should prioritize the development of AI-driven personalized rehabilitation interventions. This involves leveraging AI technologies to tailor treatment plans to individual patient needs, optimize therapy outcomes, and improve patient engagement and adherence. Moreover, there is a growing opportunity to integrate AI with wearable sensors and Internet of Things (IoT) devices to enable continuous monitoring of patients' progress and facilitate remote rehabilitation services. By pursuing these strategic directions, researchers and practitioners can harness the full potential of AI to advance the field of Rehabilitation Science, ultimately improving patient outcomes and quality of life.

## CRediT authorship contribution statement

**Ren Yang:** Writing – original draft, Resources, Formal analysis, Data curation, Conceptualization. **Qiong Yuan:** Methodology, Formal analysis, Conceptualization. **Wuwu Zhang:** Funding acquisition, Supervision, Writing – review & editing. **Helen Cai:** Project administration. **Yue Wu:** Software, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

[1] Van Eetvelde H, Mendonça LD, Ley C, Seil R, Tischer T. Machine learning methods in sport injury prediction and prevention: a systematic review. J Experim Orthopaedics 2021;8:1–15.
[2] Ma R, Cai L. Visual analysis of forest sports and health tourism based on artificial intelligence. J Electron Imaging 2022;31(6):062008. 062008.
[3] Russell, S.J., & Norvig, P. (2016). Artificial Intelligence: a Modern Approach.
[4] Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep Learning.
[5] Zadeh A, Taylor D, Bertsos M, Tillman T, Nosoudi N, Bruce S. Predicting sports injuries with wearable technology and data analysis. Inf Syst Front. 2021;23: 1023–37.
[6] Biró A, Cuesta-Vargas AI, Szilágyi L. AI-assisted fatigue and stamina control for performance sports on IMU-Generated multivariate times series datasets. Sensors 2023;24(1):132.
[7] Araújo D, Couceiro M, Seifert L, Sarmento H, Davids K. Artificial intelligence in sport performance analysis. Routledge 2021.
[8] Pashaie S, Dickson G, Abdavi F, Badri Azarin Y, Golmohammadi H, Zheng J, Habibpour R. Football and the video assistant referee: a grounded theory approach. In: Proceedings of the Institution of Mechanical Engineers. Part P: Journal of Sports Engineering and Technology; 2023, 17543371231213739.
[9] Scanlon C, Griggs G, McGillick C. 'It's not football anymore': perceptions of the video assistant referee by english premier league football fans, 23. Soccer & Society; 2022. p. 1084–96.
[10] Benítez AJ, Stepanian E, López ÁM. Video technology for refereeing in other sports: tennis and Rugby The use of video technologies in refereeing football and other sports 2019:138–63.
[11] Ghosh I, Ramasamy Ramamurthy S, Chakma A, Roy N. Sports analytics review: artificial intelligence applications, emerging technologies, and algorithmic perspective. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery 2023:e1496.
[12] Naik BT, Hashmi MF, Bokde ND. A comprehensive review of computer vision in sports: open issues, future trends and research directions. Appl Sci 2022;12(9): 4429.
[13] ... & Tuyls K, Omidshafiei S, Muller P, Wang Z, Connor J, Hennes D, Hassabis D. Game Plan: what AI can do for Football, and What Football can do for AI. J Artificial Intelligence Res 2021;71:41–88.
[14] Liu A, Mahapatra RP, Mayuri AVR. Hybrid design for sports data visualization using AI and big data analytics. Complex Intellig Syst 2023;9(3):2969–80.
[15] Shen Z, Wu Y. Understanding accessibility of health and fitness with big data techniques: facility visualization in shanghai with multi-source data. J Eng Res 2022.
[16] Liu YY, Zhang Y, Wu Y, Feng M. Healthcare and fitness services: a comprehensive assessment of blockchain, IoT, and edge computing in smart cities. J Grid Comput 2023;21(4):82.
[17] Kamruzzaman MM, Yan B, Sarker MNI, Alruwaili O, Wu M, Alrashdi I. Blockchain and fog computing in IoT-driven healthcare services for smart cities. J Healthc Eng 2022:2022.
[18] Chmait N, Westerbeek H. Artificial intelligence and machine learning in sport research: an introduction for non-data scientists. Front Sports and Active Living 2021;3:363.
[19] Claudino JG, Capanema DDO, de Souza TV, Serrão JC, Machado Pereira AC, Nassis GP. Current approaches to the use of artificial intelligence for injury risk assessment and performance prediction in team sports: a systematic review. Sports Med-Open 2019;5:1–12.
[20] Rigamonti L, Estel K, Gehlen T, Wolfarth B, Lawrence JB, Back DA. Use of artificial intelligence in sports medicine: a report of 5 fictional cases. BMC Sports Sci Med Rehabil 2021;13:1–7.
[21] Feely Ciara, et al. A case-based reasoning approach to predicting and explaining running related injuries. In: Case-Based Reasoning Research and Development: 29th International Conference, ICCBR 2021. 29. Salamanca, Spain: Springer International Publishing; 2021. September 13–162021Proceedings.
[22] Patel D, Shah D, Shah M. The intertwine of brain and body: a quantitative analysis on how big data influences the system of sports. Annals of Data Sci 2020;7:1–16.
[23] Liu J, Wang L, Zhou H. The application of human–computer interaction technology fused with artificial intelligence in sports moving target detection education for college athlete. Front Psychol 2021;12:677590.
[24] Kunze KN, Polce EM, Chahla J. Response to "Regarding 'Editorial Commentary: artificial intelligence in sports medicine diagnosis needs to improve. Arthroscopy 2021;37(5):1367–8.
[25] Chaudhary S, Sharma S, Mongia S, Tripathi K. Artificial Intelligence (AI) in Healthcare: issues, Applications, and Future. Concepts of artificial intelligence and its application in modern healthcare systems. CRC Press; 2024. p. 1–17.
[26] Dai J, Selvaraj J, Hasanuzzaman M, Cai HH. Scientometric analysis of research hotspots in electrochemical energy storage technology. J Energy Storage 2024;93: 112300.
[27] An S, Xing M. The application of CiteSpace software in document visual analysis and writing. In: Third International Conference on Artificial Intelligence, Virtual Reality, and Visualization (AIVRV2023). 12923. Chongqing, China: SPIE; 2023. p. 584–91. https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12923/129232B/The-application-of-CiteSpace-software-in-document-visual-analysis-and/10.1117/12.3011365.short#_=_.
[28] Chen C. The citespace manual. College of Comput Inform 2014;1(1):1–84.
[29] Mishra P, Singh G. Internet of medical things healthcare for sustainable smart cities: current status and future prospects. Applied Sciences 2023;13(15):8869.
[30] Cheng K, Guo Q, He Y, Lu Y, Xie R, Li C, Wu H. Artificial intelligence in sports medicine: could GPT-4 make human doctors obsolete? Ann Biomed Eng 2023:1–5.
[31] Maiden N, Lockerbie J, Zachos K, Wolf A, Brown A. Designing new digital tools to augment human creative thinking at work: an application in elite sports coaching. Expert Systems 2023;40(3):e13194.
[32] Livingston LA, Cunningham I, Forbes SL. Using technological innovation to manage and develop sport officials. Managing Sport and Leisure 2023:1–3.
[33] Turdaliyev R, Botagariyev T, Ryskaliyev S, Doshybekov A, Kissebaev Z. Virtual reality technology as a factor to improve university sports. Retos: Nuevas Tendencias en Educación Física, Deporte Y Recreación 2024;51:872–80.
[34] Li C, Lou S. What drives interlocal cooperation in economic development? A qualitative comparative analysis of interlocal industrial parks in China's Yangtze River Delta. Public Perf Mgmt Rev 2024;47(2):387–418.
[35] Zhang W, Yuan Q, Cai H. Unravelling regional development through the production-living-ecological perspective: Assessing heterogeneity and expert insights. Urban Clim 2024;55:101937.