

R E V I E W

Research trends in the application of artificial intelligence in physical therapy rehabilitation: A bibliometric study

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Abstract. *Background and aim:* Artificial intelligence (AI) assists physical therapy (PT) rehabilitation by assessing health improvement and tracking patients' progress toward individualized rehabilitation goals that are in line with their capabilities and needs. The aim of this study was to uncover research trends in the application of AI in PT rehabilitation through a bibliometric approach. *Methods:* An electronic search of the Web of Science (WoS) database was conducted on October 4, 2023 using specific keywords. The data was downloaded using the WoS database in a WoS plain text file and analyzed using various software, namely R Studio (biblioshiny), Visualization of Similarities Viewer and NetDraw. *Results:* Between 2014 and 2023, 1216 research documents on AI in PT rehabilitation were published by various authors worldwide. Most documents (15.21%; n=185) were published in 2022. The journal "Sensors" published 3.21% (n=39) of the research documents and showed 298 citations. Another journal, "Journal of Neuroengineering and Rehabilitation", published 2.22% (n=27) and showed 1406 citations. The document published by the author "Maciejasz P (2014)" in the "Journal of NeuroEngineering and Rehabilitation" had a high total citation score of 706. The United States has contributed significantly to AI-related documents in PT rehabilitation. *Conclusions:* The publication of AI in PT rehabilitation-related documents has shown an upward trend since 2015. These documents were actively published by various journals and authors around the world. Global researchers can further improve their affinity for AI in PT rehabilitation by providing more high-quality research papers in the future. (www.actabiomedica.it)

Key words: artificial intelligence, bibliometrics, physical therapy, rehabilitation, research

Introduction

Artificial intelligence (AI) technologies are widely used in healthcare to significantly improve various aspects of the healthcare system, such as diagnosing and

recommending treatments, engaging and caring for patients, and predicting health outcomes (1,2). Beyond diagnosis and treatment, there is great potential for AI to improve healthcare in areas such as patient recovery and rehabilitation. Therefore, it has become essential

for physicians and healthcare policymakers to stay abreast of the growing body of AI research in order to effectively use AI interventions to improve the well-being of patients and caregivers (3). The integration of AI into healthcare is promising as it will revolutionize the accuracy of diagnosis, treatment and rehabilitation (4). As in other areas of healthcare, the integration of AI technology into the practice of physical therapy (PT) is progressing slowly and steadily to automate clinical tasks. The field of AI-assisted physical rehabilitation is growing rapidly and has the potential to improve services through more personalized care, efficiency and accessibility (5). AI has been integrated into many PT practices, particularly through the automation of clinical tasks, and offers new applications in rehabilitation, including virtual (informatics) and physical (robotics) domains (6).

The utility of AI in PT rehabilitation serves multiple purposes. AI uses technologies such as motion analysis, wearable devices, and smart mobile devices to collect data to assist PT practices in patient care and provide users with information to assess health improvement and monitor progress toward personalized rehabilitation goals tailored to their individual needs and abilities (7,8). Using AI-guided moderate-resistance exercise programs, patients can experience improved functional outcomes and higher satisfaction, making life easier for both patients and therapists (9). Machine Learning (ML) is a subset of AI and is widely used in perioperative medicine, brain-computer interface, myoelectric control, symbiotic neuroprosthetics, patient data evaluation, clinical decision support, and diagnostic imaging in rehabilitation (10). Supervised ML technology has the potential to revolutionize PT practice by enabling diagnosis, decision-making, and measurement at superhuman levels (11). Notably, ML algorithms have been developed for stroke recovery that focuses on predicting the extent of recovery based on characteristics such as stroke duration and hospital stay, as well as patients' Bartels Index score (12).

ChatGPT, another AI tool, is having a significant impact on sports PT and rehabilitation. It provides training recommendations, tracks progress, assists in injury assessment and treatment, provides feedback to aid recovery from physical injuries, supports

perioperative care, and provides valuable support during patient care. (10,13,14). It also helps stroke or head injury patients practice speech and language skills through conversations accessible on digital devices (15). ChatGPT performs data mining and prediction to uncover correlations and trends in rehabilitation assessment data and predict difficulties and progress in patients' rehabilitation process (16).

Several studies have been conducted on the effectiveness of AI in PT rehabilitation, particularly in exercise training (17,18); biomechanical gait analysis (19,20,21); robot-assisted therapy (22,23); Virtual Reality (VR) Rehabilitation (24,25); and remote patient monitoring and telemedicine (7,26). A recent study examined the effectiveness of AI-powered devices in the rehabilitation of patients with stroke and post-stroke psychological impact and concluded that an AI-supported neurorehabilitation program was more effective in reducing psychological stress in stroke patients (27). Another study concluded that exercise with robot-mediated VR gaming successfully controlled spasticity and enhanced upper limb motor function among chronic stroke patients (28). Park et al. (29) observed that a wearable device-based rehabilitation program with routine PT efficiently enhanced upper limb function, performance of activities of daily living, and rehabilitation involvement among acute stroke patients.

Although there are studies addressing the integration of PT rehabilitation, research using a bibliometric approach to the impact of AI on PT rehabilitation is sparse. This leads this study to examine the outcomes of AI in PT rehabilitation and highlight the affinity of researchers in this area. Therefore, the aim of the research is to analyze bibliometric data to identify research trends in the application of AI in PT rehabilitation, so that researchers can learn more about the field and conduct further research. Specifically, the study is conducted to reveal (i) the publication trend of researchers focusing on AI in PT rehabilitation; (ii) the top ten authors, keywords commonly used by these authors, and top ten journals that published these research articles; (iii) the ten most cited research articles on AI and the top ten countries that published the most articles on AI in the field of PT rehabilitation in the last decade.

Methodology

Study design

A descriptive study design was used to reveal the research trends in the application of AI in PT rehabilitation through a bibliometric approach. An electronic search was conducted through the Web of Science (WoS) database for documents published between 2014 and 2023 by researchers around the world on the topic of AI.

Procedure

The search terms used in the WoS database were TS=(((“physical therapy”) OR (“physiotherapy”) OR (“physical rehabilitation”) OR (“manual therapy”)) AND (“artificial intelligence” OR “robotics” OR “robot” OR “robotic” OR AI OR (“machine learning”) OR (“deep learning”) OR (“deep neural networks”) OR chatbot OR (“Chat Generative Pretrained Transformer”) OR ChatGPT OR (“natural language processing”) OR (“Big Data”) OR (“human-computer interaction”) OR (“data visualization”) OR transformer OR (“AI-powered metaverse”))). In addition, a number of inclusion criteria were adopted in this study to screen documents to be included in the bibliographic analysis: i) documents published on AI, ii) documents published in the WoS database between 2014 and 2023 and iii) no restrictions on document type or language were highlighted. Furthermore, since this is a bibliometric study, the researchers set a specific period of time to collect the necessary data to conduct the bibliometric analysis, following the criteria proposed by Weng et al. (30). Consequently, 1216 documents were retrieved on October 04, 2023. There was no exclusion of documents. The collected data (N=1216) were further exposed to bibliometric analysis. This study is exempt from Institutional Review Board approval because it is bibliometric in nature.

Data analysis

The data was downloaded as a plain WoS text file using the WoS database. R Studio (biblioshiny) software (version 2023.09.0 build 463) was used to

analyze the information on publication frequency, keywords, authors, most cited documents and countries to which the corresponding author belongs. Biblioshiny software is also used to visualize the frequency of keywords over time. The Visualization of Similarities (VOS) viewer software (version 1.6.19) was used to examine and visualize the author data. Additionally, the countries of the corresponding author were visualized using NetDraw software (version 2.176).

Results

Publication frequency

Using the WoS database, 1216 research documents published by various authors around the world on the topic of AI in PT rehabilitation were retrieved and described in Table 1. The results showed that a high percentage of documents (15.21%; n=185) were published in 2022 and only 5.18% (n=63) were in 2015. Notably, the authors showed greater affinity for conducting research on AI in PT rehabilitation starting in 2017, with an abrupt decline in 2023. The total number of citations (2718), the total number of citations per document (39.97), and the total number of citations per year (4.00) were found to be high in 2014, although 68 documents were published (Table 1 and Figure 1).

Top 10 keywords

During the study period, 2757 keywords were used by various authors in their AI in PT rehabilitation documents. When looking at the top 10 keywords, “rehabilitation” was used in the most documents (n=196; 7.11%), followed by “recovery” (n=124; 4.50%) and “stroke” (n =120; 4.35%) (Table 2). The frequency of keywords that authors use in their documents is shown in Figure 2.

Top 10 journals

676 peer-reviewed journals published a total of 1216 documents on AI in PT rehabilitation. Among those journals, the top 10 journals that published

Table 1. Publication trend of AI in PT rehabilitation documents published by different authors between 2014 and 2023.

Year	Frequency of Documents	Sum of Total citations	Total citations per document	Total citations per year	Citable Years
2014	68	2718	39.97	4.00	10
2015	63	1021	16.21	1.80	9
2016	98	1808	18.45	2.31	8
2017	102	1773	17.38	2.48	7
2018	111	1850	16.67	2.78	6
2019	145	1474	10.17	2.03	5
2020	151	1661	11	2.75	4
2021	165	1250	7.58	2.53	3
2022	185	460	2.49	1.25	2
2023	128	87	0.68	0.68	1
Total	1216	14102			

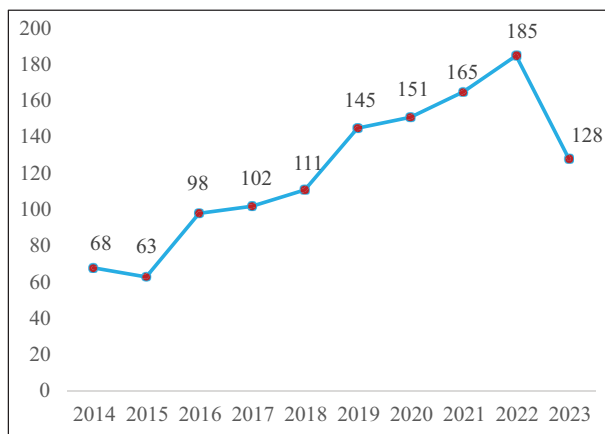


Figure 1. The growth trend showing publications by different authors on AI in PT rehabilitation between 2014 and 2023.

AI in PT rehabilitation documents by authors were listed based on publication frequency. In the last decade, these journals had published 14.06% (n=171) of the total articles (N=1216). The “Sensors” published the most documents (3.21%; n=39) and showed 298 citations. The “Journal of Neuroengineering and Rehabilitation” took second place with 2.22% (n=27) and had 1406 citations. Subsequently, the “IEEE Transactions on Neural Systems and Rehabilitation Engineering” published 1.64% (n=20) and had 427 citations (Table 3). Besides, the journals that published AI-in-PT rehabilitation papers from various authors from around the world were presented using VOS viewer software (Figure 3).

Table 2. Frequency of keywords used over time, observed by VOSviewer.

Year	Rehabilitation	Recovery	Stroke	Therapy	Reliability	Walking	System	Design	Gait	Performance
2014	15	6	9	8	4	6	3	1	3	4
2015	28	12	13	14	10	13	5	5	6	8
2016	41	23	21	18	14	18	11	11	10	16
2017	61	34	36	30	20	32	20	21	17	22
2018	79	50	49	39	29	37	30	32	20	26
2019	99	60	61	49	36	47	37	39	21	28
2020	123	75	71	57	48	52	42	44	31	34
2021	151	95	89	72	62	66	56	56	38	43
2022	180	111	109	91	71	79	65	60	52	52
2023	196	124	120	108	86	86	71	66	63	58

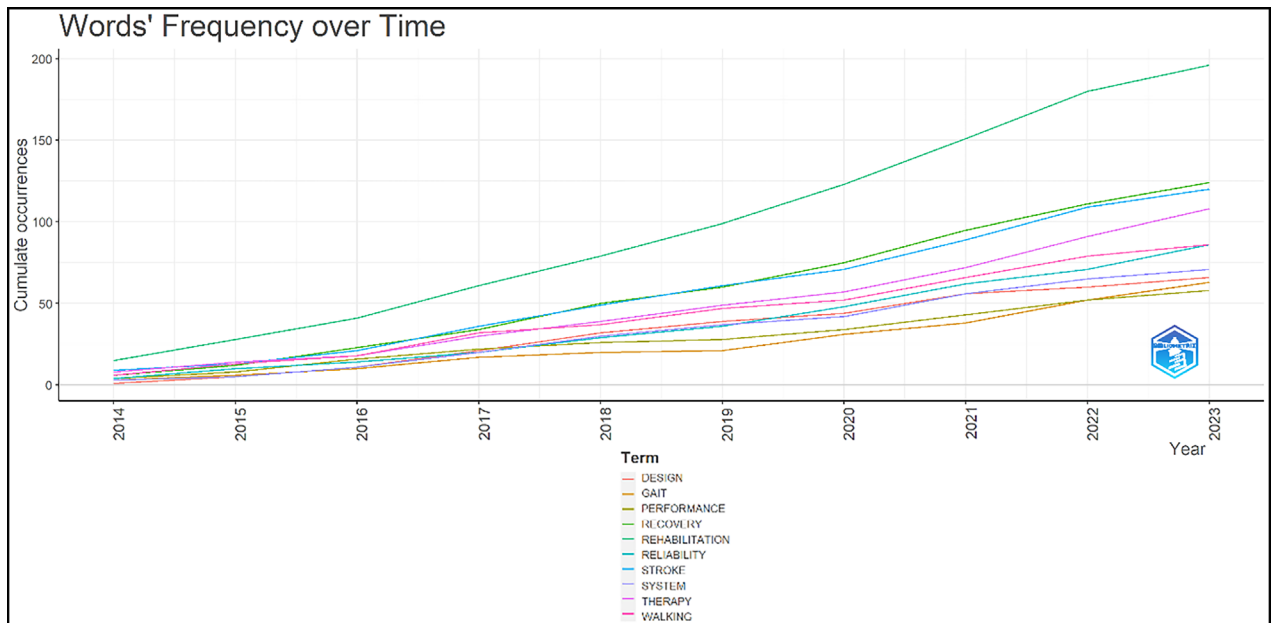


Figure 2. Keywords used by various authors in their Publications on AI in PT rehabilitation.

Table 3. The top 10 journals published AI in PT rehabilitation publications by various authors between 2014 and 2023.

S.No	Journal Name	Rank	Frequency	Citations
1	Sensors	1	39	298
2	Journal of NeuroEngineering and rehabilitation	2	27	1406
3	IEEE transactions on neural systems and rehabilitation engineering	3	20	427
4	Frontiers in neurology	4	14	309
5	Neurorehabilitation	4	14	194
6	IEEE access	5	13	109
7	International journal of environmental research and public health	5	13	76
8	Applied sciences-basel	6	11	93
9	European journal of physical and rehabilitation medicine	7	10	173
10	Medicine	7	10	46

Top 10 authors

The top 10 authors were identified among 5032 based on their publication frequency towards AI in PT rehabilitation documents. These authors accounted for 9.21% (n=112) of all documents (N=1216). In particular, Calabro RS published 21 documents (1.73%) with a total of 453 citations from 2015. Followed by Hussain S who had 16 documents (1.32%) and a total of 548 citations since 2014. Another author, Naro A,

reported 15 documents (1.23%) with a total of 278 citations from 2015 (Table 4).

The top 10 most cited AI in PT rehabilitation documents

Table 5 describes the ten most frequently cited documents from various authors on the topic of AI in PT rehabilitation. A paper published by the author “Maciejasz P (2014)” in the “Journal of NeuroEngineering and Rehabilitation” had a high total citation

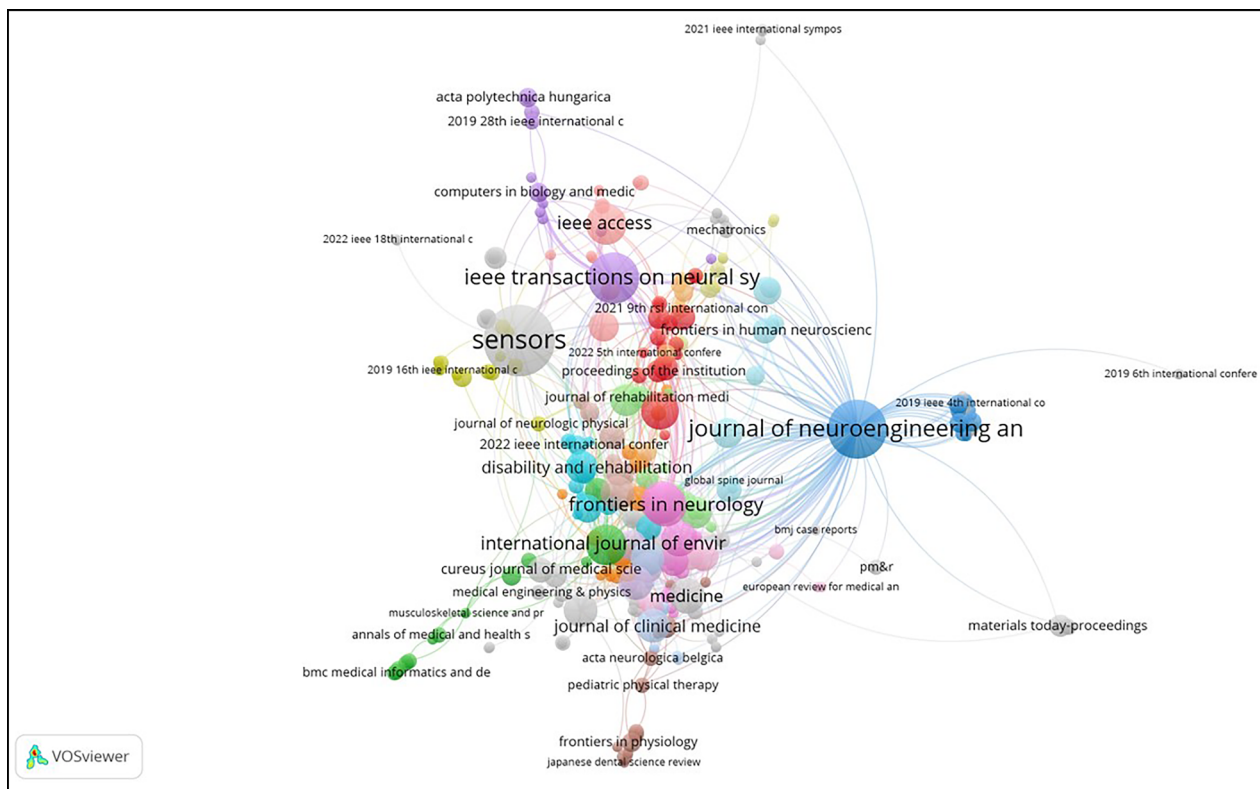


Figure 3. Journals that published AI in PT rehabilitation documents by various authors.

Table 4. Top 10 authors who have published documents focused on AI in PT rehabilitation and the number of citations received since 2014.

S. No	Author name	Frequency	Total citations	Start of the publication year
1	Calabro RS	21	453	2015
2	Hussain S	16	548	2014
3	Naro A	15	278	2015
4	Jamwal PK	12	474	2014
5	Bramanti P	9	375	2015
6	Jayaraman A	8	140	2016
7	Posteraro F	8	197	2014
8	Balletta T	8	92	2015
9	Manuli A	8	190	2016
10	Ghayesh MH	7	236	2016

score of 706 and 70.6 citations per year. Subsequently, “Veerbeek JM (2014)” received a total of 655 citations and 65.5 citations per year in “PLOS ONE”. “Abruzzese G. (2016)” in “Parkinsonism & Related Disorders” had 217 total citations and 27.13 citations per year.

Top 10 countries

Table 6 shows the top 10 countries that have published AI in PT rehabilitation documents by various authors based on publication frequency. The United

Table 5. The top 10 most cited AI in PT rehabilitation documents.

S. No	Author name, Publication year, and Document title	Digital Object Identifier (DOI)	Total Citations	Citations per year
	Maciejasz P, 2014, Journal of NeuroEngineering and Rehabilitation	10.1186/1743-0003-11-3	706	70.6
1	Veerbeek JM, 2014, PLOS ONE	10.1371/journal.pone.0087987	655	65.5
2	Abbruzzese G, 2016, Parkinsonism & Related Disorders	10.1016/j.parkreldis.2015.09.005	217	27.13
3	Mehrholz J, 2017, The Cochrane Database of Systematic Reviews	10.1002/14651858.CD006185.pub4	167	23.86
4	Kayani B, 2018, The Bone & Joint Journal	10.1302/0301-620X.100B7.BJJ-2017-1449.R1	160	26.67
5	Jamwal PK, 2014, IEEE/ASME Transactions on Mechnronics	10.1109/TMECH.2012.2219065	151	15.1
6	Nam KY, 2017, Journal of NeuroEngineering and Rehabilitation	10.1186/s12984-017-0232-3	129	18.43
7	Rahman MH, 2015, Robotica	10.1017/S0263574714000034	125	13.89
8	Jarrasse N, 2014, Frontiers in Human Neuroscience	10.3389/fnhum.2014.00947	116	11.6
9	Veale AJ, 2016, Medical Engineering & Physics	10.1016/j.medengphy.2016.01.010	114	14.25

Table 6. Top 10 countries that contributed to AI in PT rehabilitation research.

S. No	Country	Documents	Citations	Average citations (citations/article)
1	USA	248	2711	10.93
2	Italy	129	2264	17.55
3	Peoples R China	103	862	8.37
4	Germany	69	2008	29.10
5	Spain	68	771	11.34
6	Australia	63	935	14.84
7	Canada	58	584	10.07
8	England	58	790	13.62
9	South Korea	56	703	12.55
10	India	48	291	6.06

States contributed a high percentage (20.39%; n=248) of the total documents (N=1216). 2711 citations were recorded, with an average citation rate of 10.93 per document. Subsequently, Italy (10.61%; n=129) received 2264 citations with an average citation of

17.55, followed by Peoples R China (8.47%; n=103) with 862 citations with an average citation of 8.37. Figure 4 shows the country-wise scientific output on AI in PT rehabilitation by various authors using Net-Draw software.

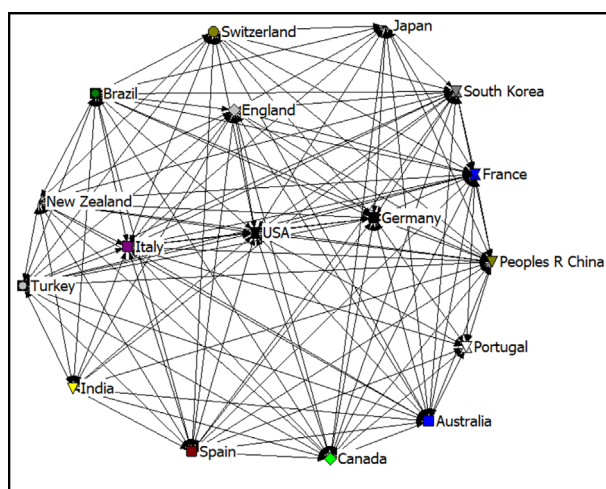


Figure 4. Country-wise scientific output on AI in PT rehabilitation by various authors.

Discussion

Through the analysis of bibliometric data, this study digs into the exciting idea of research on AI in PT rehabilitation. By examining the growth rate of publications, total citations, and citations per research document published in the last decade, this study attempted to provide valuable insights into the progress made in this field. In addition, this study identified the top ten journals and authors who made significant contributions to AI-related publications in the field of PT rehabilitation between 2014 and 2023.

The 1,216 documents retrieved were exclusively journal articles. The number of articles published between 2014 and 2016 was low, but there was an increase in the later years up to 2022. Furthermore, articles written after 2019 account for 64% of total publications. This trend shows that researchers are showing a greater affinity for AI-related scientific investigations and more research in PT rehabilitation would be conducted in the formative years to understand how AI technology could be used in PT rehabilitation. Several reasons could contribute to this increase in the research concerning AI in PT rehabilitation, namely: (i) healthcare workers, including PTs are motivated to explore AI technologies to improve their understanding of patient conditions and improve rehabilitation outcomes (31,32); (ii) The availability of digital

health data, wearable devices, and other technology-enabled patient information has created opportunities for researchers to conduct AI-based research studies (33,34); (iii) researchers may be interested in studying how AI can streamline administrative tasks, data analysis, and other processes, leading to more efficient and effective healthcare delivery (1,35); (iv) The interdisciplinary nature of AI research allows researchers to benefit from the expertise of professionals in other fields, thereby promoting innovation and new approaches to rehabilitation (36) and (v) the researchers believe AI can help them improve patient outcomes by enabling more accurate assessments, early intervention strategies and overall better treatment of musculoskeletal disorders, leading to more research in this area (36). Notably, the rate of publications on AI in PT rehabilitation showed a decline in 2023; however, this data only reflects findings till October 4, 2023, and further research may have been published in the final quarter of the year.

Research on the use of AI in PT rehabilitation has drawn researchers from around the globe, but developed countries dominate the field in which the USA contributed about 20.39% of the studies with 2711 citations. This observation could be due to the fact that the USA spends heavily on AI studies, which have resulted in leading revolutionary life-enhancing innovations, rising technology industry, motivating workers, and empowering security interests (37,38). Further, in commensurate with the number of publications, USA tops in the total number of citations followed by Italy and Germany. When looking at the number of publications and citations of research documents, the USA and Italy are at the top in both categories. In contrast, although Germany only provided 69 documents, each document was cited an average of 69 times. However, citation-based indicators cannot be considered a robust measure of quality when used in isolation, and the quality of scientific impact must be viewed as a multi-dimensional concept that encompasses originality and novelty and arises from the fundamental requirement that research should produce new knowledge (39,40).

The study identified 10 prominent publication sources, of which *Sensors* was the only one to produce 39 articles on the application of AI in PT rehabilitation-related research. Other prominent

journals that produced AI in PT rehabilitation-related articles included IEEE Transactions on Neural Systems and Rehabilitation and the Journal of NeuroEngineering and Rehabilitation. The majority of these journals' scope revolve around the scientific and technological aspects of sensor applications and neurological rehabilitation. In addition, *Frontiers in Neurology*, and *Neurorehabilitation* publishes 14 articles on the application of AI technology in neurological rehabilitation, demonstrating the publisher's dominance in this field. Similar to our observations, a previous study found that the most cited neurorehabilitation research papers between 2005 and 2016 were published in journals such as *Stroke*, *Movement Disorders*, and *Neurology*; however, these studies are limited to generic neurorehabilitation research that did not focus exclusively on AI (41).

When visualizing the results on author productivity in the field of AI in PT rehabilitation research, it is evident that the ten most productive authors published documents between 2014 and 2016. The top four (57%) are Calabro RS, Hussain S, Naro A and Jamwal PK. Calabro has the most publications and Hussain has the most citations (n=548), meaning they are extremely influential in their field of AI-related PT rehabilitation research. Additionally, articles published in the *Journal of NeuroEngineering and Rehabilitation*, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, and *Frontiers in Neurology* received a total of 1406, 427, and 309 citations, respectively. This result implies that the researchers can continue to publish their potential articles on AI in PT rehabilitation in high quality international journals, which could result in high citation counts for these articles.

Bibliometric analysis accurately measures the impact of an article by quantifying its citations and effectively highlighting its significant contributions to the development of a topic (42). It can be challenging to determine the importance of an individual article in its field, but the total number of citations it has received can serve as a measure of its impact (43). In this study, it is observed that Maciejasz (2014) and Veerbeek (2014) received a total of 706 and 655 citations, respectively, for research papers on AI in PT rehabilitation published in the *Journal of NeuroEngineering and Rehabilitation* and *PLOS ONE*.

Keyword analysis is crucial for bibliometric research. It identifies trends, maps the research landscape, measures impact, finds collaboration opportunities, tracks knowledge evolution, improves retrieval, aids decision-making, and facilitates meta-analysis of research findings (44). Further, it is effective in analysing the knowledge structure of an academic field from a bibliometric perspective, which can help identify potential research hotspots (45). Therefore, the most commonly used keywords by various authors who have conducted AI in PT rehabilitation-related research and published their results in the journals indexed in WoS are "rehabilitation", "recovery", "stroke", "therapy", "reliability", "walking", "system", "design", "gait" and "performance".

This study only used one search engine, WoS, for bibliometric analysis and could not identify studies not included in WoS, so articles and research published elsewhere could not be recognized. Future research can focus on analyzing the research output of the researchers in other databases to determine their research productivity. The authors also believe that the inability to incorporate other objective tools, such as the H-index and i-10 index, limits this study's external and internal validity. Besides, this study revealed the scientific output of researchers around the world on AI in PT rehabilitation; however, further research can be conducted to uncover the scientific output of PT researchers on a similar topic. In particular, future studies can analyze factors that influence the research productivity of PT researchers and develop strategies to improve scientific production.

Although AI is revolutionizing the field of PT rehabilitation, there are pros and cons when dealing with patients in clinical practice, research scenarios, and healthcare education. Specifically in clinical practice, AI chatbots deliver valuable information to help clinicians understand patients' conditions, advise on treatment methods, assist in planning the treatment process, and enable remote monitoring (46). Nevertheless, AI chatbots are likely to result in inaccuracy and uselessness among physicians, including PTs, with inappropriate and outdated information, distracting practice from the superlative accessible evidence, as these devices have no direct clinical exposure and no deep understanding of medical complications,

nuances, and each patient's problems. As a result, it often offers general responses without considering the personal features, favorites, and patients' preceding experiences (46). Therefore, overreliance on AI tools may diminish clinicians' skills and judgment, leading to the loss of the human touch in patient care (47). Besides, there are several barriers to implementing AI-guided physical rehabilitation, including user fatigue, reliability, and knowledge of the technology of health-care workers (48). Lastly, performance or operational barriers hindering AI implementation in rehabilitation include regulatory and ethical difficulties, resource restrictions, data privacy & storage, security needs, scalability and generalization problems, cost restraints, and education and training challenges (49,50). Close teamwork between policymakers, official regulators, healthcare providers, and AI developers is required to overcome those barriers to AI implementation in healthcare (49).

Conclusion

AI is used for various purposes, is evolving, and is particularly prevalent in healthcare as investment in this technology has increased. This study examined the research trends on AI in PT rehabilitation using WoS database. It demonstrated an upward trend since 2015, whereas 1216 articles were published in the WoS database from 2014 to 2023. It also brings out the top 10 journals that published documents related to AI in PT rehabilitation, where 'Sensors', 'Journal of NeuroEngineering and Rehabilitation', and 'IEEE Transactions on Neural Systems and Rehabilitation Engineering' secured the top three positions, considering the number of publications made and the total citations received for their result outputs. It also identified the top 10 authors significantly contributing to the research on AI in PT rehabilitation. Further, those publications made by Maciejasz (2014) in the Journal of NeuroEngineering and Rehabilitation and Veerbeek (2014) in PLOS ONE are the top two research articles concerning the total number of citations received during the study period. Further, the USA is the top country that contributed to AI-related documents in the field of PT rehabilitation.

Ethic Committee: The ethical approval is not applicable since it is a bibliometric study.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Authors Contribution: AVS has designed the study. MI and PRM have conducted the data collection and analysis. MS, SAS, and AP have performed the literature search. MBA, ARP, and VKP were responsible for the literature screening. AVS, SP, and AK have prepared the original draft. AVS, MI, SP, and AK have critically revised the manuscript. AVS has approved the final version of the manuscript to be published. AVS-Arun Vijay Subbarayalu, MI-Mohamed Idhris, PRM-Palanivel Rubavathi Marimuthu, MS-Muhil Sakthivel, SAS-Surgeon Anandraj Samuel, AP-Anand Pandiyarajan, MBA-Mohammed Barkath Ali, ARP-Abdurahiman Pattukuthu, VKP-Vinosh Kumar Purushothaman, SP-Sivasankar Prabaharan, AK-Ajayan Kamalasanan.

Data Availability Statements: The data presented in this study are available on request from the corresponding author.

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