SPORT I TURYSTYKA
Środkowoeuropejskie Czasopismo Naukov

UNIWERSYTET JANA DŁUGOSZA
W CZĘSTOCHOWIE

2024
t. 7, nr 4

received: 15.08.2023; accepted: 6.09.2024 http://dx.doi.org/10.16926/sit.2024.04.07

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BIBLIOMETRIC ANALYSIS OF THE APPLICATION OF DIGITAL TECHNOLOGY IN PHYSICAL REHABILITATION

How to cite [jak cytować]: Góra, T., Tsos, A., Indyka, S. (2024). Bibliometric Analysis of the Application of Digital Technology in Physical Rehabilitation. *Sport i Turystyka. Środkowoeuropejskie Czasopismo Naukowe*, *7*(4), 133–146.

Analiza bibliometryczna zastosowania technologii cyfrowych w rehabilitacji fizycznej

Streszczenie

Pandemia COVID-19 ujawniła znaczące ograniczenia globalnych systemów opieki zdrowotnej, szczególnie w obszarze rehabilitacji, gdzie rosnące zapotrzebowanie wynikające z chorób związanych z wiekiem przyspieszyło wykorzystanie nowych technologii. Celem niniejszego badania była analiza rozwoju dorobku naukowego dotyczącego technologii rehabilitacyjnych, z uwzględnieniem trendów publikacyjnych, rozkładu geograficznego oraz kategoryzacji obszarów tematycznych. Przeprowadzono mini-przegląd literatury z wykorzystaniem bazy danych Scopus, obejmujący odpowiednie artykuły opublikowane w latach 1995–2023. W celu oceny trendów publikacyjnych w czasie, obliczono skumulowaną roczną stopę wzrostu (CAGR), a publikacje skategoryzowano według rodzaju dokumentu, kraju, regionu oraz obszaru tematycznego, aby zidentyfikować kluczowych autorów i obszary badań. W wyniku przeszukiwania uzyskano 2771 dokumentów, a ogólny CAGR z lat 2000–2023 wyniósł 19,57%, choć w ostatnim okresie (2020–2023) tempo wzrostu obniżyło się do 9,30%. Europa wniosła największy udział w publikacjach (41%), następnie Ameryka Północna (24%) i Azja (19%). Podsumowując, choć dziedzina ta odnotowała silny wzrost, ostatnie obniżenie po pandemii wskazuje na zmniejszenie tempa rozwoju. Nierówność w wynikach badań między krajami rozwiniętymi i rozwijającymi się podkreśla znaczenie zwiększonego wsparcia globalnego. Rozwiązanie tych problemów wydaje się być istotne dla utrzymania dalszego wzrostu i wspierania innowacji.

Słowa kluczowe: fizjoterapia, technologie cyfrowe, urządzenia noszone, bibliometria, profilowanie badań, rzeczywistość wirtualna, telezdrowie.

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Abstract

The COVID-19 pandemic exposed significant limitations in global healthcare systems, particularly in rehabilitation, where growing demand from age-related conditions has accelerated the integration of technology. This study aimed to analyze the development of scientific output on rehabilitation technology, focusing on publication trends, geographic distribution, and subject area categorization. A mini-review was conducted using the Scopus database, covering relevant articles published from 1995 to 2023. The compound annual growth rate (CAGR) was calculated to assess publication trends over time, and publications were categorized by document type, country, region, and subject area to identify key contributors and thematic research areas. The search yielded 2,771 entries, with an overall CAGR of 19.57% from 2000 to 2023, though the growth slowed to 9.30% in the most recent period (2020–2023). Europe contributed the largest share of publications (41%), followed by North America (24%) and Asia (19%). In conclusion, while the field experienced strong overall growth, the recent post-pandemic decline indicates reduced momentum. The disparity in research output between developed and developing countries highlights the importance of increased global support. Addressing these challenges will be important for sustaining future growth and fostering innovation.

Keywords: physiotherapy, digital technologies, wearables, bibliometrics, research profiling, virtual reality, telehealth.

Introduction

The COVID-19 pandemic exposed the limitations of healthcare systems globally, highlighting the increasing burden they face, particularly in the realm of rehabilitation (Liu et al., 2020; Moorthy et al., 2021). This burden is becoming a critical issue in the context of aging societies. The World Health Organization (WHO) projects that by 2050, the global population of individuals aged 60 and older will reach 2.1 billion, doubling from current figures, while those aged 80 and above will increase threefold, rising to 426 million (World Health Organization, 2022). This demographic shift will significantly increase the demand for healthcare services, particularly rehabilitation, as age-related conditions such as musculoskeletal disorders, cardiovascular diseases, and neurological impairments become more prevalent (Jaul & Barron, 2017; Pippi et al., 2022; Çelikhisar & Demir, 2023).

Physical rehabilitation plays an important role in managing a wide range of health conditions, from acute injuries to chronic diseases (Cacciante et al., 2023; Horbacz et al., 2023). However, the field faces significant challenges, including limited accessibility, low patient engagement, and the need for personalized treatment plans. These challenges are intensified by the growing demand for rehabilitation services, which increasingly outpaces the available resources and professionals. Accessibility issues are often driven by geographic, economic, and systemic barriers, making it difficult for many individuals to receive adequate care (Bright et al., 2018). Additionally, patient engagement is a critical hurdle, as adherence to rehabilitation regimens can be hindered by a lack of motivation, proper guidance, or support systems (Bright et al., 2015).

In response to these challenges, technology is being increasingly integrated into healthcare, particularly in physical rehabilitation (Cieślik et al., 2023). For instance, tele-rehabilitation enables healthcare providers to deliver treatment remotely, effectively reaching patients in isolated areas or those with mobility challenges (Darkins & Cary, 2000). By offering real-time consultations and guided therapy sessions, it reduces barriers to care and ensures timely treatment for individuals who might otherwise face difficulties attending in-person sessions due to transportation issues or time constraints (Cacciante et al., 2021; Darkins & Cary, 2000).

Virtual reality (VR) is another innovative tool that offers digital, immersive environments, allowing users to engage in realistic simulations that can be tailored to various therapeutic and educational purposes (Birckhead et al., 2019). Virtual reality facilitates an easy implementation of augmented feedback, crucial for motor learning, and supports stroke survivors and others with neurological impairments in relearning motor skills through real-time visual and sensory feedback (Kiper et al., 2016; Massetti et al., 2018). Additionally, VR can transport patients into calming environments, offering psychological support and reducing anxiety, thus merging physical and psychological care for a holistic rehabilitation approach (Szczepańska-Gieracha et al., 2020). Exergaming, defined as a combination of exercise and gaming, could enhance patient engagement and motivation by making rehabilitation more interactive and enjoyable (Altorfer et al., 2021). Wearable devices offer further personalized care by enabling remote monitoring of health metrics like heart rate, sleep patterns, movement patterns, and others (Kang & Exworthy, 2022). This allows healthcare professionals to adjust treatment plans based on accurate, up-to-date data, reducing the need for frequent in-person appointments.

The integration of technology into physical rehabilitation holds great potential to enhance patient outcomes by providing more accessible, personalized, and effective solutions. However, this growing use of technology also underscores the need to ground interventions in evidence-based practice (Kamper et al., 2015). Thorough evaluation of current research and clinical data is essential to ensure the safety and effectiveness of innovations in rehabilitation technology, enabling healthcare professionals to make informed decisions that improve patient care (Zadro et al., 2019). Equally important is identifying disparities in research output, which fosters inclusive global collaboration and incorporates diverse perspectives into evidence-based practices, while also addressing potential risks such as impaired postural stability, accidental falls, increased spasticity, or dizziness (Cieślik et al., 2021; Prosperini et al., 2021). Therefore, the aim of this study was to analyze the development of scientific output related to the application of technology in physical rehabilitation, focusing on trends in publication growth, geographic distribution of research, and the categorization of

publications by document type and subject area. Additionally, the study sought to identify key contributors and thematic areas that have garnered significant academic interest within this rapidly developing field.

Material and methods

This study was designed as a mini-review aimed at analyzing scientific output related to the application of technology in physical rehabilitation. To achieve this, a comprehensive literature search was conducted using the Scopus database. The search included all relevant articles published from January 1, 1995, to December 31, 2023. This limitation was set due to the low number of studies published before 1995. The literature search was performed using a search query designed to capture relevant articles within the scope of this review. The query used was: (TITLE-ABS-KEY("physical rehabilitation" OR "physiotherapy") AND TITLE-ABS-KEY("health technologies" OR "digital health" OR "telehealth" OR "e-health" OR "wearable technology" OR "telemedicine" OR "virtual reality" OR "robotic devices" OR "smart devices" OR "mobile health" OR "mHealth" OR "exergaming" OR "augmented reality").

To analyze publication growth rates over time, the Compound Annual Growth Rate (CAGR) of publications was calculated using the formula:

$$CAGR = \left(\frac{Final\ value}{Initial\ value}\right)^{\frac{1}{n}} - 1$$

The CAGR was calculated for the entire period from 2000 to 2023 to determine the average annual growth rate in the number of publications. Additionally, it was calculated for several sub-periods to analyze trends within smaller time frames. The sub-periods were 2000–2005, 2005–2010, 2010–2015, 2015–2020, and 2020–2023. These sub-period analyses helped to identify variations in growth rates at different times, providing insights into changes in research activity and interest in the field.

Moreover, publications were categorized by country and region and were also classified across several broad subject areas, including Life Sciences, Applied Sciences, Physical Sciences, Social Sciences, and Multidisciplinary fields. This classification was based on the Scopus journal classification system, where a single journal could be assigned to multiple categories.

Results

The search results based on the specified algorithm yielded 2,771 entries in Scopus. A total of 1,602 entries were categorized as articles, making up 54.8%

of the total. Reviews accounted for 510 entries, representing 17.5%. Conference papers had 427 entries, i.e. 14.6%. Both book chapters and editorials were listed 48 times each, comprising 1.6% each of the total. Letters were documented in 47 entries (1.6%), and notes were categorized in 44 entries (1.5%). Other document types included conference reviews with 20 entries (0.7%), short surveys with 17 entries (0.6%), errata with 3 entries (0.1%), retracted publications with 3 entries (0.1%), and books with 2 entries (0.1%).

Figure 1 illustrates the number of scientific articles conforming to the search algorithm over consecutive years. Periods of rapid growth were observed in several years, including 1997 (200%), 2000 (75%), 2007 (62.5%), and 2009 (43.75%), indicating a significant increase in research activity. Moderate growth occurred in years such as 2003 (18.18%), 2006 (7.69%), 2022 (7.03%), and 2023, reflecting a steady increase in publications. In contrast, years like 1998, 2011, and 2015 showed stagnation, with minimal changes in publication numbers, indicating periods of relative stability in research output. Significant declines in publication numbers were noted in several years, particularly in 1999 (−85.71%), 2004 (−50%), 2008 (−65.22%), 2010 (−42.86%), 2012 (−29.49%), and 2019 (−44.95%).

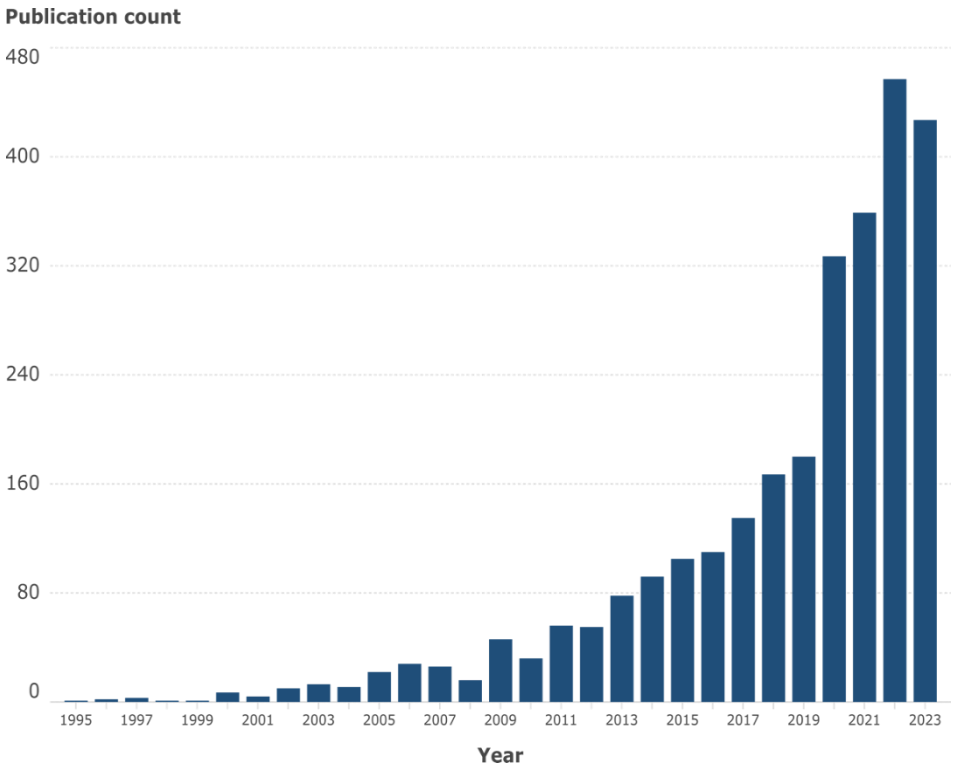

Figure 1
Number of scientific articles conforming to the search algorithm in consecutive years

Analyzing the CAGR from 2000 to 2023, the number of publications in the field of technology application in physical rehabilitation experienced varying growth rates. The CAGR for the entire period was 19.57%. For the sub-period from 2000 to 2005, the CAGR was 25.74%. Between 2005 and 2010, the CAGR slowed to 7.78%. The CAGR then increased to 26.83% from 2010 to 2015 and remained high at 25.51% from 2015 to 2020. In the most recent period, from 2020 to 2023, the CAGR was 9.30%.

Figure 2 presents the distribution of publications by country, grouped by regions. In North America, 657 publications were reported, accounting for approximately 24% of the total. Europe contributed the highest number with 1,149 publications, representing around 41%. Asia followed with 527 publications, i.e. about 19% of the total. Oceania accounted for 292 publications (10%), South America had 218 publications (8%), and Africa contributed 89 publications (3%).

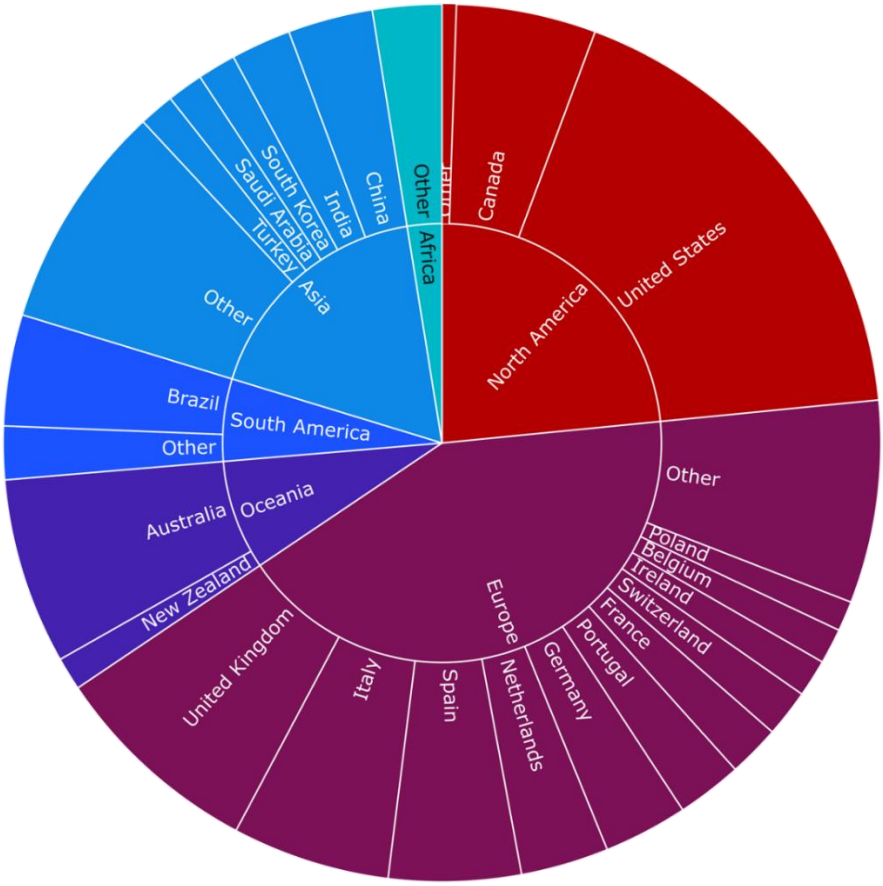

Figure 2
Sunburst chart showing the distribution of scientific publications by country and region. Note: The size of each segment corresponds to the number of publications, with larger segments indicating higher publication counts.

Focusing on countries with publication counts greater than 40, the United States leads in North America with 642 publications. In Europe, the United Kingdom recorded 282 publications, Italy 210, Spain 176, the Netherlands 117, Germany 112, Portugal 87, France 69, Switzerland 63, Ireland 50, Belgium 47, and Poland 40. In Asia, China had 113 publications, India 80, South Korea 51, Saudi Arabia 48, Turkey 47, Israel 38, and Taiwan 35. Oceania's contributions were led by Australia with 248 publications and New Zealand with 44. In South America, Brazil had 148 publications, while in Africa, the country with the highest number of publications was Egypt with 24.

Figure 3
Word cloud representing the distribution of scientific publications by country, grouped by regions. Note: The size of each country's name reflects the number of publications, with larger names indicating higher publication counts.

Figure 4 shows the categorization of journals across several broad subject areas. Life Sciences is the largest category, encompassing 43.4% of the total entries. Within this category, Medicine has the highest representation with 1,916 entries (35.1%), followed by Health Professions with 548 entries (10%). Applied Sciences account for 19% of the total entries, with the leading fields being Computer Science, with 561 entries (10.3%), and Engineering, with 475 entries (8.7%). Physical Sciences represent 13.3% of the total entries, with Physics and

Astronomy having 91 entries (1.7%) and Chemistry having 50 entries (0.9%). Social Sciences make up 4.8% of the total entries, with Social Sciences having 123 entries (2.3%) and Psychology having 79 entries (1.4%).

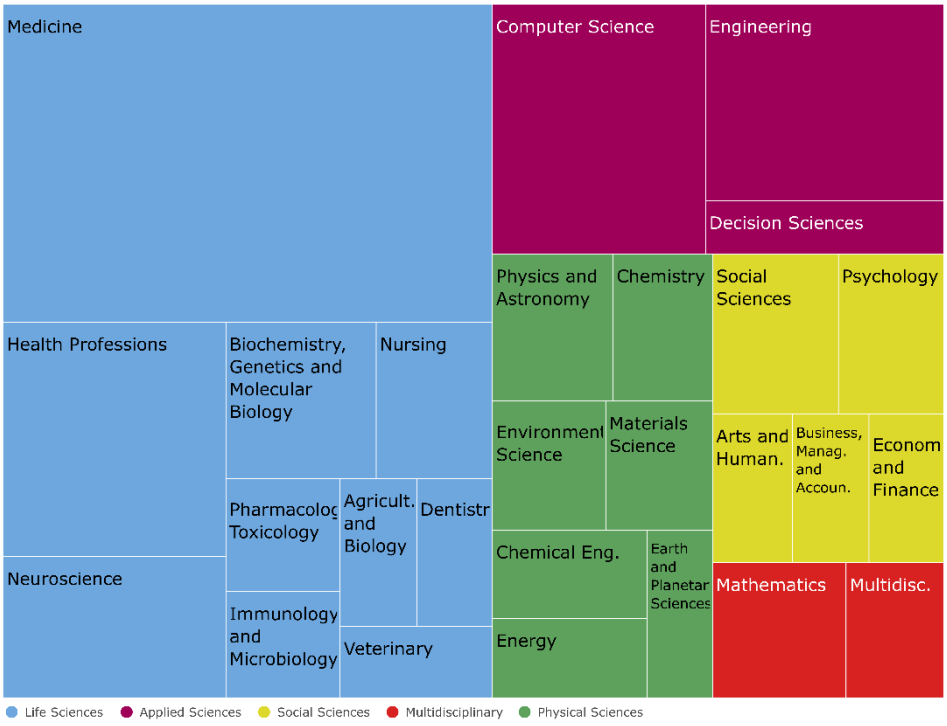

Figure 4
Tree map displaying the distribution of journals across various subject areas, categorized into broader fields. Note: The size of each rectangle represents the number of journals categorized under each subject area.

Discussion

The aim of this research was to analyze the development of scientific output related to the application of technology in physical rehabilitation. Analyzing the compound annual growth rate (CAGR) from 2000 to 2023, it reveals a generally steady increase in the number of publications, with an overall CAGR of 19.57%. However, there were fluctuations in growth rates. The field experienced strong growth from 2000 to 2005, with a CAGR of 25.74%, which then slowed to 7.78% between 2005 and 2010. The growth accelerated again from 2010 to 2015, reaching a CAGR of 26.83%, and remained high from 2015 to 2020, with a CAGR of 25.51%. A similar trend was observed by Zhang et al. (2023), who analyzed

emerging trends in research on rehabilitation robots from 2001 to 2020 (Zhang et al., 2023). Our results indicate a notable spike in 2020, likely due to the COVID-19 pandemic, as digital health became a focal point for addressing healthcare challenges (Budd et al., 2020). However, from 2020 to 2023, the CAGR dropped to 9.30%, nearly half the overall average, indicating a slowdown. This decline is concerning as it suggests reduced momentum in the post-pandemic field, potentially due to shifts in funding priorities or a return to traditional research focuses (Olsen, 2024). Continued investment in this area is crucial to maintain the progress made during the pandemic.

The analysis of publication counts highlights a significant disparity between developed and developing countries in terms of research output in the application of technology in physical rehabilitation. While developed countries such as the United States, United Kingdom, Germany, and Australia lead with the highest number of publications, developing countries have considerably lower outputs. For instance, in Africa, Egypt, the country with the highest number of publications, contributed only 24 entries, which is markedly lower compared to developed countries. Similarly, in South America, Brazil, although having a higher output with 148 publications, still lags behind most developed nations. In Asia, while countries like China and India are emerging as significant contributors, the publication counts from other developing countries in the region remain relatively low. As indicated by Neill et al. (2023), this disparity underscores the challenges faced by developing countries in contributing to global research, which may be due to limited access to funding, technological resources, and research infrastructure (Neill et al., 2023). Additionally, it may demonstrate that policymakers and governments have devoted little attention to expanding rehabilitation services and have not been able to encourage a greater focus on this issue (Neill et al., 2023). Recently, the International Society of Physiotherapy Journal Editors, along with its member journals, expressed support for research from Low- and Middle-Income Countries (LMICs). Addressing these inequalities is crucial for fostering inclusive global research collaboration and enhancing the health and well-being of the 85% of the world's population inhabiting LMICs (Sharma et al., 2024).

Additionally, the categorization of journals across various subject areas reflected the interdisciplinary nature of the field and showed a strong focus on Life Sciences and Applied Sciences, with Medicine and Computer Science being particularly prominent. This interdisciplinary approach offers significant opportunities, such as fostering innovation through the integration of diverse methodologies and perspectives, enabling comprehensive solutions to complex problems in physical rehabilitation (Smye & Frangi, 2021). However, it also presents challenges, including difficulties in communication and collaboration across different disciplines, the need for researchers to acquire broad skill sets beyond their

traditional expertise, and potential difficulties in publishing interdisciplinary research due to the varying standards and expectations of different academic fields.

This study has several limitations that should be considered when interpreting the results. First, the literature search was conducted exclusively using the Scopus database, which, although comprehensive, may not include all relevant publications from other databases such as PubMed, Web of Science, or IEEE Xplore. Unfortunately, among bibliometric databases, there is lack of unification of the possibilities regarding criteria collection and indexing (Góra et al. 2021). This could result in the omission of pertinent studies and a biased representation of the research landscape. Additionally, the categorization of journals into multiple subject areas could lead to an overestimation of research activity in certain fields, as a single journal might be indexed under multiple categories. While this interdisciplinary overlap reflects the multifaceted nature of the field, it may also obscure a clear delineation of research trends within specific disciplines. Finally, the analysis focused on publication counts and trends without a qualitative assessment of the research quality or impact. As a result, the findings may not fully capture the depth and breadth of advancements in the application of technology in physical rehabilitation.

Future research should prioritize overcoming regional disparities in research output by supporting initiatives that enhance research capacity in developing countries, enabling a more equitable global contribution to the field. Additionally, enhancing interdisciplinary collaboration is crucial, as this field inherently spans multiple disciplines, from medicine to engineering and computer science. Strengthening cross-disciplinary partnerships can foster innovation and address complex rehabilitation challenges more effectively. Moreover, addressing emerging challenges, such as integrating new technologies into existing healthcare systems, ensuring their accessibility and affordability, should be a focus of future studies to maximize the impact of technological advancements in physical rehabilitation.

Conclusions

In conclusion, the study highlights several important findings regarding the application of technology in physical rehabilitation. While the overall CAGR from 2000 to 2023 was 19.57%, the recent decline to 9.30% from 2020 to 2023 is notable, suggesting reduced momentum in the post-pandemic field, possibly due to shifts in funding priorities or a return to traditional research focuses. Additionally, there is a significant disparity in research output between developed and developing countries, indicating a need for increased support and resources to ensure more equitable global contributions. The field is also characterized by

significant interdisciplinarity, which serves as both a strength, enabling diverse approaches to complex challenges, and a challenge, due to the difficulties in collaboration and varying standards across disciplines. Addressing these issues will be crucial for sustaining growth and innovation in the application of technology in physical rehabilitation.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interests with respect to the research, authorship, and/or publication of the article *Bibliometric Analysis of the Application of Digital Technology in Physical Rehabilitation.*

FUNDING

The authors received no financial support for the research, authorship, and/or publication of the article *Bibliometric Analysis of the Application of Digital Technology in Physical Rehabilitation.*

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