



# Knowledge Mapping of Balance Rehabilitation in Multiple Sclerosis: A Bibliometric Analysis

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## Abstract

Multiple sclerosis (MS) is a complex neurological disorder that leads to multifactorial disability, with balance impairments being among the most prevalent and debilitating symptoms. These impairments may impede mobility and contribute to secondary complications such as increased fall risk. Using bibliometric methods, this study aimed to systematically assess the global research landscape on balance rehabilitation in MS patients. To conduct a comprehensive bibliometric analysis of global research trends, contributors, and thematic focuses related to balance rehabilitation in individuals with MS. A bibliometric analysis was conducted utilizing data retrieved from the Web of Science database on November 5, 2024. Using the search keyword “MS and balance rehabilitation,” we identified 1,400 initial records. After applying the inclusion criteria, 895 original research articles published between 1995 and 2024 were included in the final analysis. Bibliometric indicators examined included publication trends, geographic and institutional distributions, research categories, article types, leading authors, citation metrics, and keyword frequencies. Few publications were recorded before 2010, after which there was a sharp increase between 2020 and 2022, peaking at 95 publications in 2022. The observed decline in 2023-2024 may represent the lasting impact of the coronavirus disease 2019 pandemic. The United States led with 265 publications, followed by Italy (149) and Turkiye (77). The University of Illinois emerged as the top institution (40), followed by Hacettepe University (27) and Oregon Health & Science University (20). Elsevier was the leading publisher (262), ahead of Taylor & Francis (95) and Sage (83). Davide Cattaneo was the leading contributor with 48 publications and 2,060 citations. His 2002 study, “risks of falls in subjects with MS,” was the most cited, with 202 citations. Common keywords included “MS” (552), “balance” (186), and “walking” (109). This bibliometric study presents an in-depth assessment of the evolution and current state of balance rehabilitation research in MS. The findings highlight the significance of enhanced global collaboration and continued research efforts to foster innovation and advance evidence-based interventions in neurorehabilitation.

**Keywords:** Multiple sclerosis, bibliometrics, Web of Science, visualization of similarities, balance rehabilitation

## Introduction

Multiple sclerosis (MS) is a chronic inflammatory neurodegenerative disorder of the central nervous system (1). With disease progression, gait and balance impairments develop (2,3). Approximately 50-80% of MS patients experience balance dysfunction (4,5), which hinders mobility and increases the risk of falls (4,6).

Balance control is a complex motor skill that depends on the interaction of motor, sensory, and cognitive systems (7). Neural lesions and degeneration in MS impair axonal transmission and

integration, affecting peripheral nerves (8,9), the spinal cord, and the cerebral cortex (10). The degeneration of neural pathways disrupts the integration of sensory inputs and impedes the execution of rapid, adequate motor responses, leading to balance control deficits (11,12). Moreover, the cognitive aspects of sensory processing are also affected, influenced by factors such as limbic activity, fatigue, expectation, and divided attention.

Balance training refers to exercises aimed at controlling the center of mass relative to the support base during various challenging activities (13). The beneficial effects of balance

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training are attributed to neuroplasticity, which refers to “the central nervous system’s ability to adapt in response to environmental changes or lesions” (14). The effort to enhance performance quality during challenging motor tasks promotes neural network reorganization, thereby improving balance (15). A recent systematic review conducted by Wallin et al. (16) revealed improvements in balance scores and mobility because of MS balance rehabilitation training. Another meta-analysis performed in 2022 indicated that while all forms of exercise are beneficial for balance rehabilitation, yoga, virtual reality training, and aerobic training were particularly effective in improving balance function in MS patients (17).

Bibliometric analysis employs statistical methods that quantitatively evaluate publications, interpublication relationships, author impact, and citation rates, as well as monitor emerging academic trends within any field, region, or timeframe. The aim of a bibliometric approach is to generate measurable data and quantitative indicators for assessing research performance (18). This analysis is crucial for understanding advances in rehabilitation studies.

Few bibliometric studies have specifically focused on MS and balance rehabilitation (19,20). Scanning and categorizing a large volume of publications across multiple dimensions (including country, journal, authors, categories, institutions, and keywords) enables tracking of citation relationships and research trends in the field of MS and balance rehabilitation. This study conducted a bibliometric analysis of global research on MS and balance rehabilitation published between 1995 and 2024 using the Web of Science (WoS) database, aiming to evaluate the existing studies and summarize the characteristics of the obtained publications.

## Materials and Methods

All analyses were primarily based on citation metrics. We analyzed the distribution of publications across countries, institutions, authors, journals, articles, and keywords. To facilitate the readability of the analysis results, tables and figures were used. All tables and figures were generated using WoS and the visualization of similarities (VOSviewer) software version 1.6.20 (Leiden University, the Netherlands) and the WoS database. In the keyword analysis, only keywords with a minimum of two occurrences were included. Additionally, terms reflecting study design, such as “clinical research” or “retrospective study”, as well as noninformative descriptors like “case-control”, “human”, “male”, “female” and “adult” were excluded (18).

### Article Selection

The article search was performed on November 5, 2024. Studies on balance rehabilitation in the context of MS, indexed in Science Citation Index Expanded (SCIE) within the WoS, were included in the analysis. The search employed the keywords

“MS and balance rehabilitation”, without applying any time constraints. The research included studies published between 1995 and 2024. As the study used publicly available data and posed no ethical concerns, ethical approval was not required.

### Inclusion and Exclusion Criteria

This study included research articles published between 1995 and 2024 in journals indexed in the SCIE that focused on balance rehabilitation methods and clinical treatment for MS. Only original research articles were considered for analysis, while other publication types-such as abstracts, notes, letters, discussions, and book chapters-were excluded. This selection prioritized peer-reviewed, full-text studies offering comprehensive data and methodological details.

### Data Analysis

The search conducted on November 5, 2024, using the keyword “MS and balance rehabilitation” across all fields retrieved 1,400 results. After applying the inclusion criteria, 895 studies were retained for analysis. This study utilized content indexed in the WoS database as its data source.

The articles included in the study were examined using WoS and the VOSviewer software version 1.6.20. VOSviewer, a tool for visualizing similarities between objects, was used to analyze co-occurrence patterns of author keywords in the imported article data (18).

To reveal publication trends in MS balance rehabilitation research, analyses were performed on the distribution of countries, institutions, and the twenty most cited articles over the last 29 years. Additionally, data mining, mapping, and clustering were conducted on the included articles using VOSviewer software. The VOSviewer analysis generated outputs in distinct colors and shapes. The size of the labels and circles for each item was determined by its assigned weight in the analysis. Items with greater weight were represented by proportionally larger labels and circles.

## Results

According to WoS data, a total of 895 publications related to MS and balance rehabilitation were published worldwide between 1995 and 2024. Publication trends over the years were analyzed and are shown in Figure 1. The first publication on MS and balance rehabilitation indexed in WoS dates back to 1995. From 1995 to 2010, studies on MS and balance rehabilitation were quite limited. However, a considerable increase in the number of publications was observed after 2010. Notably, the publication rates peaked between 2020 and 2022. In 2022, the highest annual output of publications was recorded, with 95 publications (Figure 1). In the last two years (2023-2024), the number of publications has shown a declining trend.

### Country Distribution Analysis

Over the past 29 years, 34 countries have published articles on MS balance rehabilitation. The analysis results for the top 25 contributing countries are presented in Figure 2. Research on MS balance rehabilitation demonstrated that the United States of America (USA) ranks first in terms of the number of published articles (265), followed by Italy (149) and Türkiye (77) (Figure 2). An analysis of yearly publication trends reveals that the USA led in 2016, Italy in 2017, and Türkiye in 2018 (Figure 3).

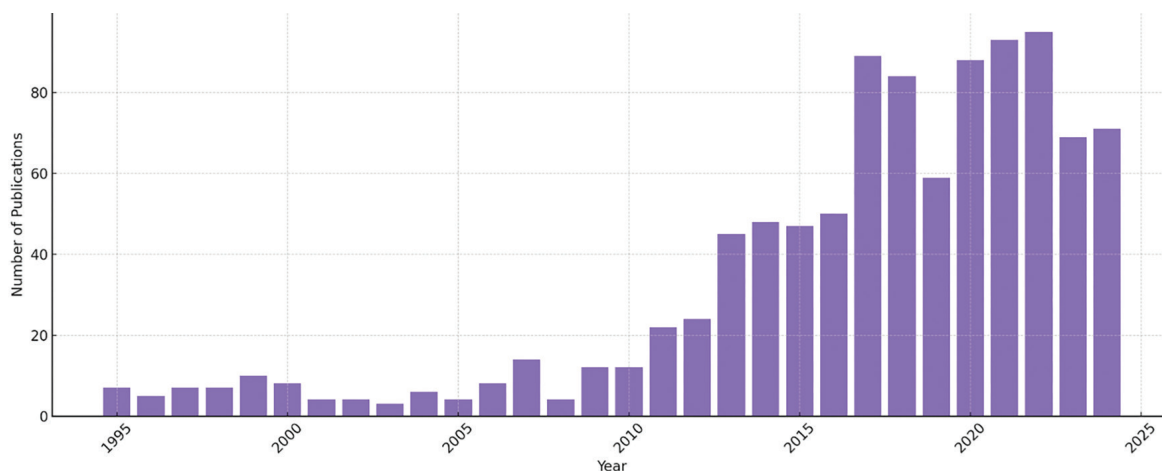
Notably, due to the official change of the country name from "Turkey" to "Türkiye" in 2021, the visual representations in Figures 2-4 display them as separate circles. The VOSviewer software could not merge these entries, although they refer to the same country.

The coauthorship relationship network among countries was analyzed and visualized using the VOSviewer software. Countries with at least three citations and three publications were included

in this study, resulting in 34 countries meeting the threshold. As illustrated in Figure 4, the USA serves as the central hub for research on MS balance rehabilitation and has strong collaborative links with countries such as Australia, Canada, and Italy. Significant research collaborations are also observed between countries like Belgium, Italy, the United Kingdom, and the USA (Figure 4).

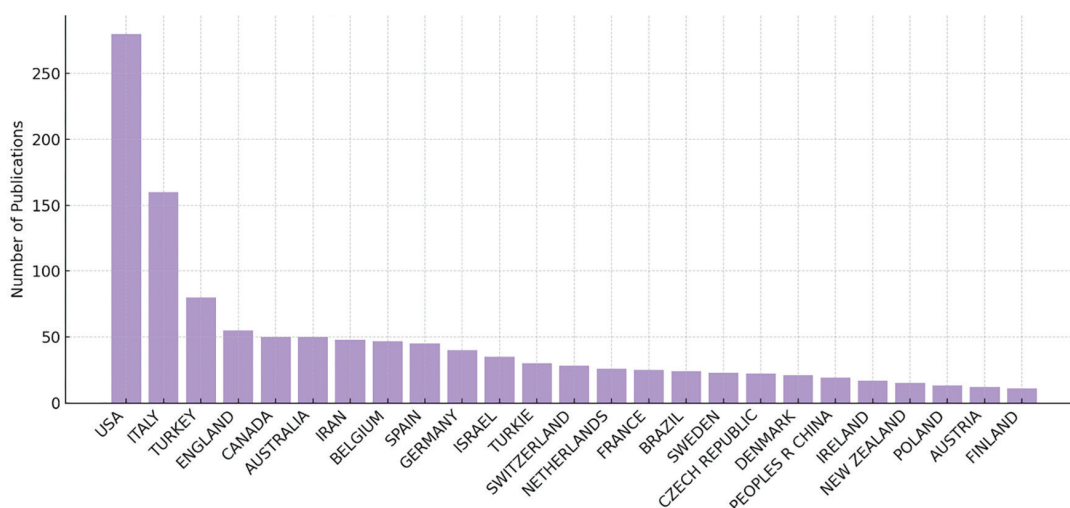
### Analysis of Publications by Institution

A bibliometric network analysis of publications by institution was performed, with the results presented in Figure 5. Between 1995 and 2024, a total of 74 institutions or organizations published articles related to MS and balance rehabilitation, with USA institutions leading in publication activity. The University of Illinois was the leading contributor with 40 publications, while Hacettepe University and Oregon Health & Science University followed with 27 and 20 publications, respectively. In this analysis, the thickness of the lines between countries represents the frequency of coauthorship collaborations between institutions or organizations (Figure 5).



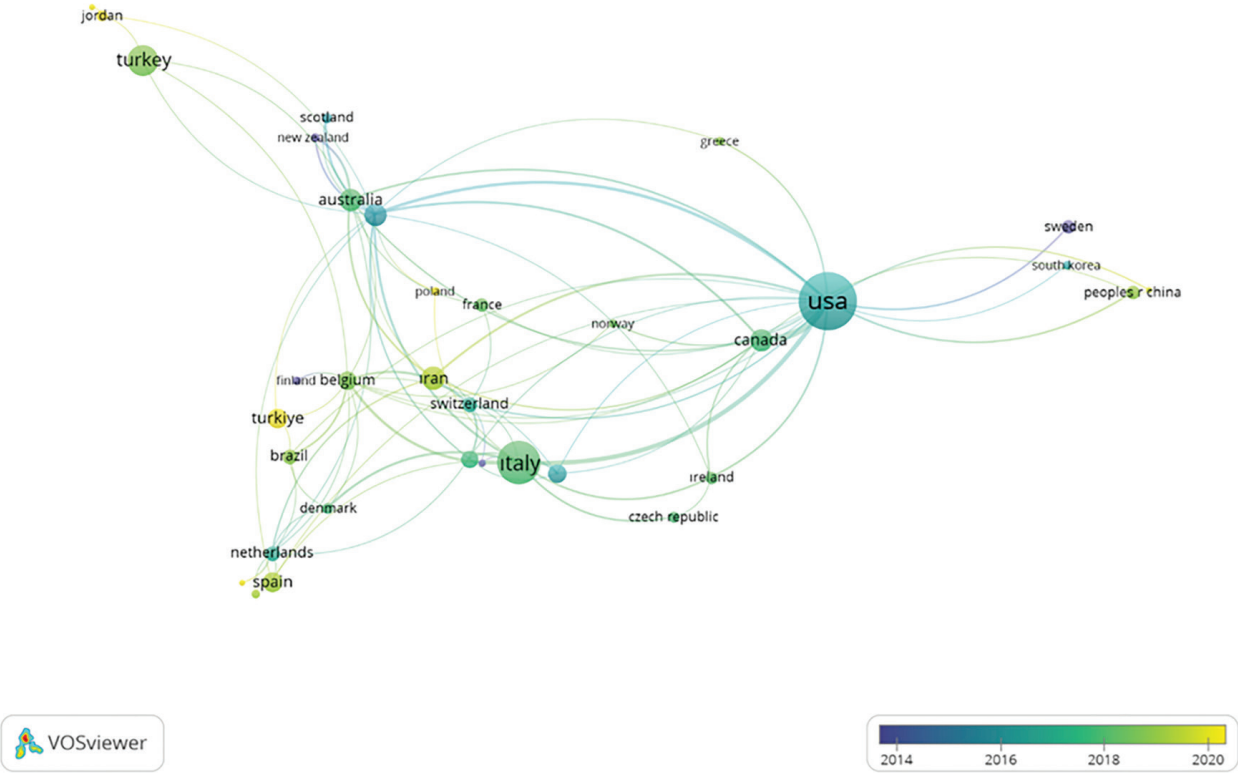
**Figure 1.** Yearly analysis of publications on MS and balance rehabilitation (1995-2024)

MS: Multiple sclerosis

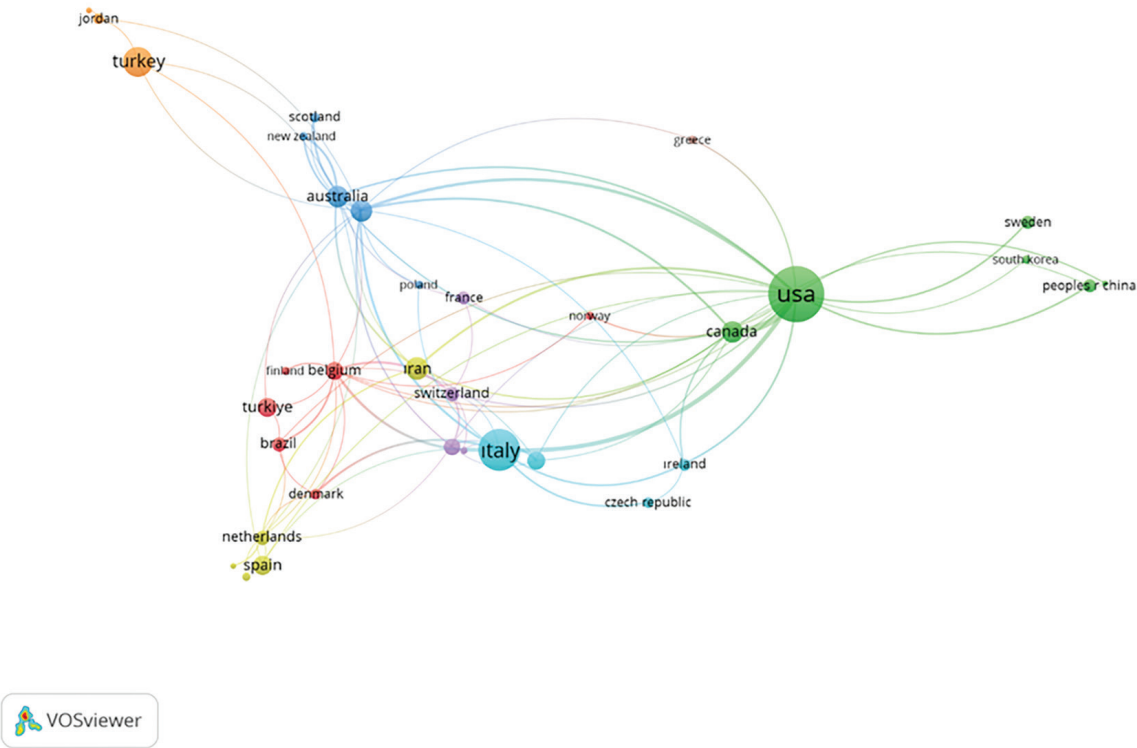


**Figure 2.** Distribution of publications by the top 25 contributing countries

USA: United States of America



**Figure 3.** Bibliometric analysis of publications across countries  
USA: United States of America



**Figure 4.** Country-level bibliometric network analysis of publications  
USA: United States of America

Research Categories and Article Types

In total, 74 journal categories were identified for articles on MS and balance rehabilitation, with the most represented being rehabilitation (351), clinical neurology (287), and neuroscience (209). The distribution of publications across journal categories is displayed in Figure 6. Elsevier published the most articles in the field of MS balance rehabilitation (262), with Taylor & Francis (95) and Sage (83) following (Figure 7).

Top 3 Active Authors and Most Cited Articles

The most productive authors in the fields of MS and balance rehabilitation were identified through the WoS database, and a network analysis of their publications was performed. Figure

8 illustrates the analysis results. The analysis identified Davide Cattaneo (Italy) as the leading contributor to the literature, with 48 publications and 2,060 citations. He is followed by Motl et al. (10) (USA), who has contributed 28 publications with 997 citations, and Peter Feys (Belgium), with 24 publications and 670 citations. Together, they are central to MS and balance rehabilitation research, with frequent collaborations and significant scholarly influence. An analysis of the citation counts revealed that Cattaneo’s 2002 study as the most cited publication, with 202 citations to date (Figure 9). This highlights the enduring impact of foundational work in the field and highlights the significance of early contributions to the scientific discourse on MS rehabilitation.

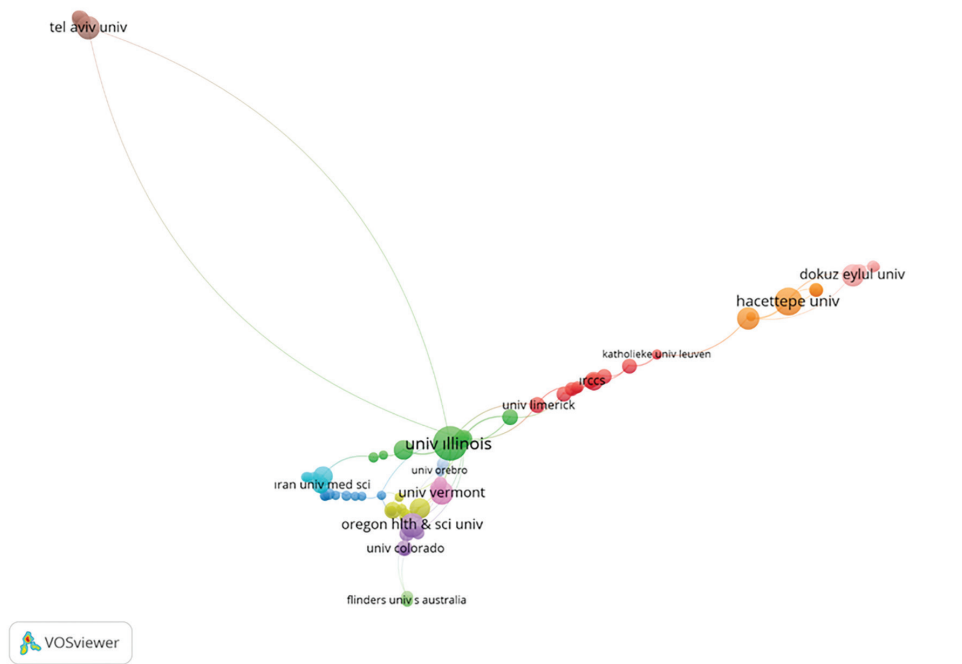


Figure 5. Bibliometric network visualization of publications by institution

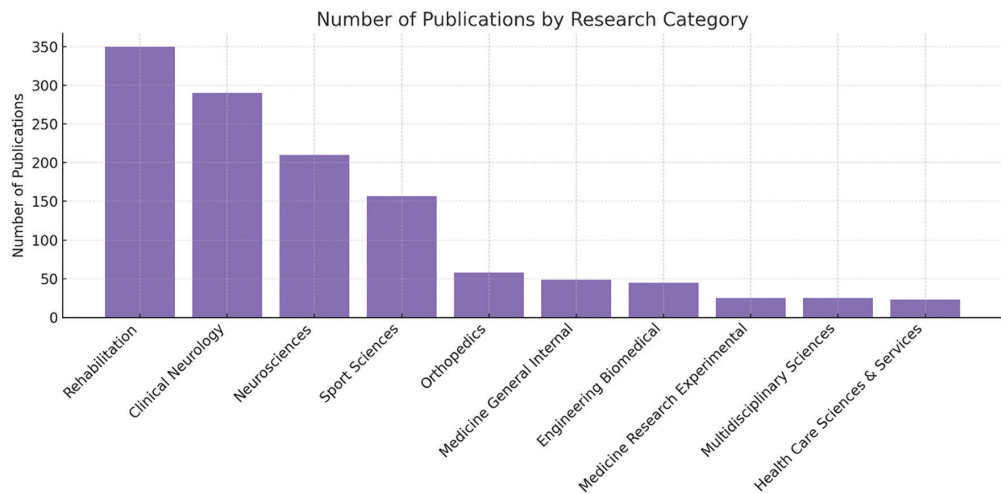
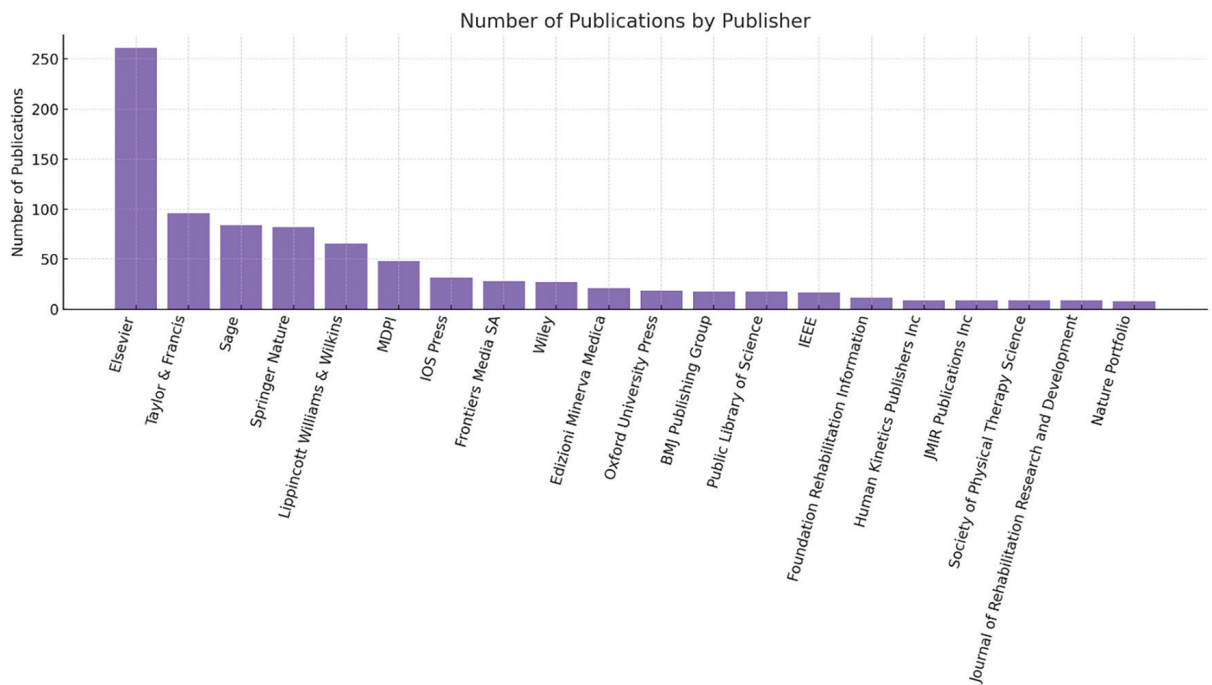
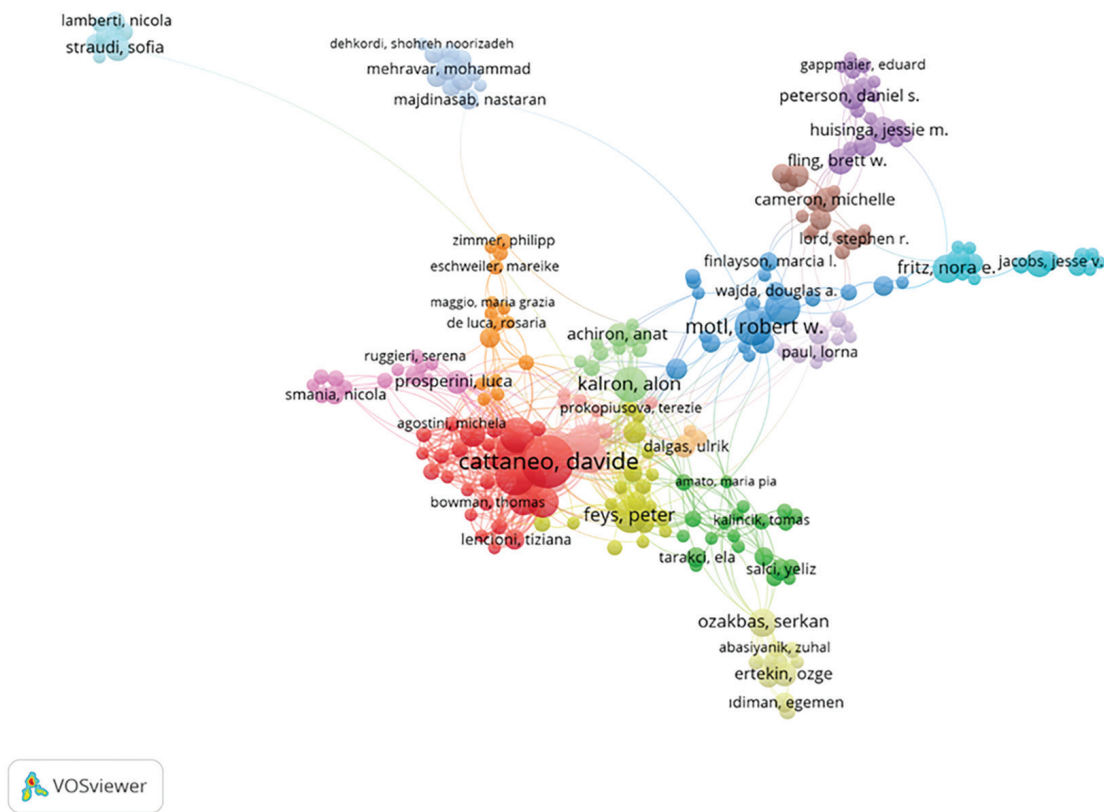


Figure 6. Distribution of publications across journal categories





**Figure 7.** Distribution of publications across to the top 20 journals in MS balance rehabilitation research  
MDPI: Multidisciplinary Digital Publishing Institute, IEEE: Institute of Electrical and Electronics Engineers, MS: Multiple sclerosis



**Figure 8.** Researcher-based network analysis of publications

## Keyword Analysis

Keywords associated with MS and balance rehabilitation in the literature were analyzed using VOSviewer software. For all the 1,526 keywords, the total strength of their connections with other keywords was calculated. The findings revealed that “MS,” “balance,” and “gait” were the most frequently utilized keywords. The keyword “MS” appeared in 552 articles, “balance” in 186 articles, and “gait” in 109 articles. In total, 199 frequently used keywords were identified across the 29-year period (Figure 10).

## Conclusion

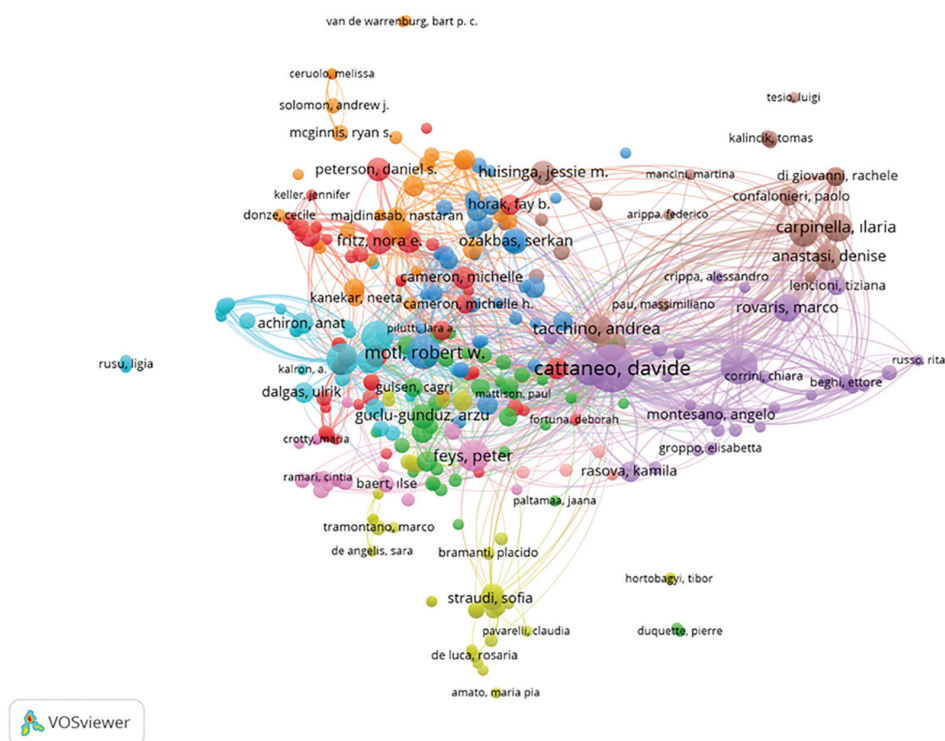
This bibliometric study charts the evolution and current research trends in balance rehabilitation in MS patients over the last 29 years. Using WoS and VOSviewer, 895 studies published between 1995 and 2024 were analyzed. The findings indicate a limited number of studies until 2010, followed by substantial growth-particularly between 2020 and 2022, when publication activity reached its peak. This upward trend can be attributed to increasing awareness of balance impairments in MS patients, advances in rehabilitation strategies, and greater international collaborations (16,17).

However, a marginal decline in publication numbers was observed during 2023-2024, which may be attributed to the residual impact of the coronavirus disease 2019 pandemic, disruptions in research funding, and delays in data collection and dissemination (12,20).

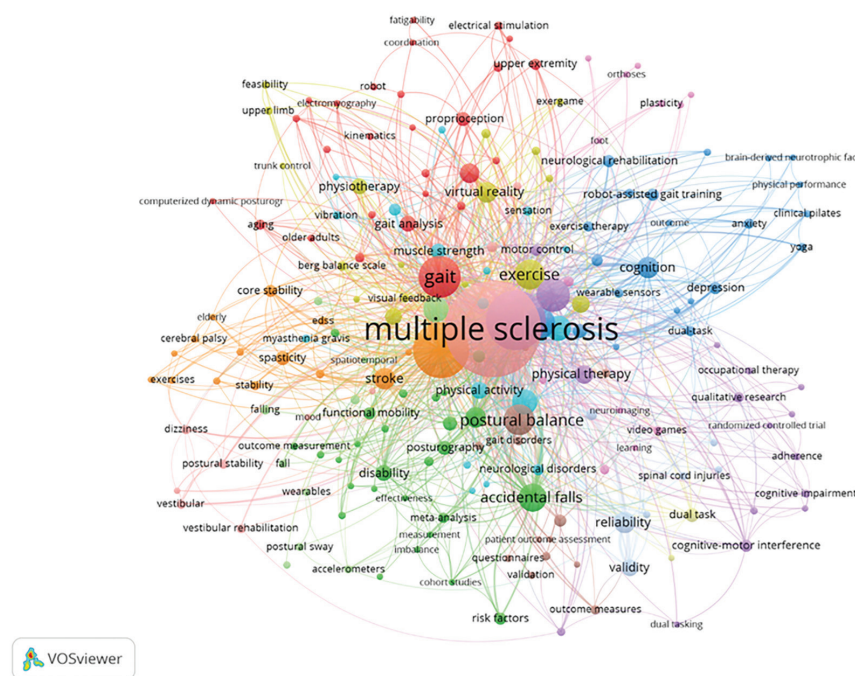
In terms of country-based contribution, the USA, Italy, and Türkiye emerged as the top three. The dominance of USA-based institutions and their frequent collaborations with European partners such as Italy and Ireland were evident in co-authorship network visualizations. Despite Türkiye’s high publication volume, the analysis revealed relatively limited international research collaboration. This could be attributed to language barriers, rising costs of international research due to currency fluctuations, and limited funding opportunities-factors that may impede participation in multicenter trials or cross-border projects (18).

From an author-level perspective, Davide Cattaneo (Italy), Robert W. Motl (USA), and Peter Feys (Belgium) emerged as the most influential contributors to this field. Cattaneo, with 48 publications and 2,060 citations, has played a pivotal role in shaping the field of MS balance rehabilitation. Motl and Feys followed with 997 and 670 citations, respectively. Cattaneo et al.’s (21) 2002 publication, “risks of falls in subjects with MS,” emerged as the most cited work in the dataset, garnering 202 citations.

The most frequent keywords “MS,” “balance,” and “gait” suggest an ongoing focus on core motor impairments in MS. Yet, terms related to cognitive rehabilitation, psychological factors, or virtual reality-based interventions remain underrepresented, suggesting potential areas for future exploration (19).



**Figure 9.** Network analysis of publications by citation counts



**Figure 10.** Network analysis of publications by keywords

## Clinical Recommendations

The findings of this study offer valuable clinical insights for advancing rehabilitation strategies in MS patients. Given the multifactorial nature of balance impairment in MS, future interventions should extend beyond purely motor-based strategies to also incorporate sensory and cognitive components (10). Clinicians are encouraged to adopt technology-assisted rehabilitation approaches such as virtual reality, wearable sensors, and exergaming which have shown promise in enhancing engagement and personalization of treatment (11). Additionally, advancing the development of low-cost, scalable, and home-based rehabilitation programs is crucial, especially in low- and middle-income settings where access to specialized care may be limited. Rehabilitation outcomes should address physical improvements as well as psychosocial dimensions such as fall-related self-efficacy, quality of life, and participation in daily activities. Finally, there is an urgent need for strong international and interdisciplinary collaboration to establish clinical guidelines and funding strategies that ensure equitable access to high-quality MS rehabilitation across diverse socioeconomic contexts (7).

In conclusion, this bibliometric analysis provides detailed analysis of trends in MS and balance rehabilitation research, highlights key contributors and collaborative patterns, and identifies critical gaps and emerging opportunities to guide future studies. It offers valuable guidance to emerging researchers and emphasizes the importance of sustained support and innovation to meet the complex rehabilitation needs of MS patients.

A key limitation of this study is its reliance on a single database (WoS), which may not capture all relevant publications indexed in other databases such as Scopus, PubMed, or Embase. Additionally, only original research articles were included, while reviews, editorials, and conference proceedings were excluded. This may have resulted in the omission of valuable insights from the literature. The data were also analyzed using VOSviewer, which, although effective for network visualization, may have limitations in addressing inconsistencies in author or institution naming conventions.

## Footnotes

## Authorship Contributions

Surgical and Medical Practices: N.C., Concept: N.C., I.C., Design: N.C., Data Collection or Processing: N.C., S.K., Analysis or Interpretation: N.C., E.C.M., I.C., Literature Search: N.C., E.C.M., B.K., Writing: N.C.

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