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# Global trends and hotspots of exercise interventions for mild cognitive impairment

## A global bibliometric analysis

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**Abstract**

**Background:** Exercise interventions for mild cognitive impairment (MCI) have been extensively studied. However, there is no bibliometric study on exercise interventions for MCI. This study aimed to identify the collaborative networks, research hotspots, evolution trends, and future directions.

**Methods:** Relevant documents were retrieved from the Web of Science Core Collection database. VOSviewer was used to analyze the co-authorship of the author, countries and institutions, and the keywords co-occurrence. CiteSpace was used to detect burst keywords' research trends.

**Results:** A total of 569 articles were included and showed an overall increasing trend in annual publications. The most influential subject categories, authors, journals, country, and institutions were "geriatrics gerontology," "Doi, Takehiko and Shimada, Hiroyuki," "*Journal of Alzheimer's Disease*," USA, and "Veterans Health Administration," respectively. The research hotspots are "effectiveness," "neural mechanism" and "correlation" of exercise interventions, and the emerging trend is "intervention quality."

**Conclusion:** This area is in a rapid development phase, whereby research hotpots are focused and the research trend is clear. The highly productive authors and institutions have made outstanding contributions and the subject categories present an interdisciplinary trend. However, there is weak cooperation between countries and institutions, and a substantial research gap exists between developed and developing countries. Future research may highlight the intervention quality, emphasizing the combination with virtual reality technology.

**Abbreviations:** H = H-index, IF = impact factor, MCI = mild cognitive impairment, TC = total citations, WoSCC = Web of Science Core Collection.

**Keywords:** dementia, MCI, older adults, physical activity, visual analysis

## 1. Introduction

Dementia is recognized as a major cause of disability and death.[1] It was reported that there were over 55 million individuals with dementia in 2021, and the number is estimated to triple by 2050 worldwide.[2] Mild cognitive impairment (MCI) is a prodromal stage of dementia, which is a crucial phase to conduct an intervention to delay or even prevent the progression to dementia.[3] MCI patients exhibit memory loss or deficits in several cognition areas, but their ability to live independently remains intact.[4] The prevalence of MCI in the elderly population is 10% to 20%,[5] and the annual conversion rate from MCI to dementia is 5% to 10%.[6] Therefore, there is a necessity to identify effective interventions to reduce the rate of conversion of MCI to dementia.

Pharmacological and non-pharmacological interventions are the 2 primary treatment forms for cognitive impairment. Studies have reported that pharmacological interventions to enhance cognition are limited and have various side effects.[1,7] Conversely, non-pharmacological interventions have received great attention in slowing the progression of MCI to dementia without any side effects. Notable, exercise interventions have emerged as one of the crucial approaches. In 2007, a health promotion initiative called "exercise is medicine" was co-launched by the American Medical Association and the American College of Sports Medicine.[8] Since then, numerous empirical studies have proved the positive efficacy of various exercises on MCI patients, including aerobic exercise,[9,10] resistance exercise,[11] and multi-component exercise.[12,13] Scholars have conducted

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many meta-analyses and systematic reviews[14,15] relevant to exercise interventions for MCI. However, these studies have a small number of included documents due to their strict inclusion criteria. Therefore, these meta-analyses and systematic reviews were unable to offer an overview of this field.

Alternatively, bibliometrics is a quantitative method that combines retrieval and statistical analysis to examine dynamic information and indicators in a specific field.[16] Compared to meta-analysis and systematic reviews, bibliometrics could provide insights into hotspots and potential future research directions, helping researchers discover the research frontiers.[17] Based on the above advantages, the application of bibliometrics has grown substantially and has expanded to include a wide range of neurodegenerative diseases, such as Alzheimer's disease,[18,19] Parkinson's disease,[20,21] and MCI.[22–24] Among them, the bibliometrics on MCI have focused on virtual reality interventions,[22] computerized cognitive stimulation intervention,[23] and acupuncture and moxibustion treatment.[24] However, there are no relevant quantitative bibliometric analyses on exercise interventions for MCI.

This study aimed to conduct a comprehensive bibliometric analysis of exercise interventions for MCI patients. The literature, retrieved from the Web of Science Core Collection (WoSCC) between 2002 and 2023, was analyzed by VOSviewer and CiteSpace to identify the status of this area. Those analyses encompassed annual publications, subject categories, authors, journals, institutions, countries, keywords, and research trends, aimed at identifying emerging hotspots and global trends.

## 2. Materials and methods

### 2.1. Data acquisition and search strategy

The present study selected the WoSCC database as the source of documents. This database comprises over 20,000 peer-reviewed scholarly journals. The WoSCC database is extensively employed for bibliometric analysis and provides crucial information such as authors, institutions, and countries.[25] All data were obtained from publicly available databases and did not include human subjects, thus ethical approval was not needed.

By trying different keyword combination searches and referring to previous research,[26] the search strategy was finally settled on using the Boolean operator tools "OR" and "AND" combined with keywords related to "exercise" and "MCI" and limited to the title search. In addition, we also used an asterisk to ensure all related terms in the search were included. According to a Boolean algorithm, TI refers to the search title. The specific search strategies are as follows: TI =[("mild cognitive impairment*" OR "mild cognitive dysfunction" OR" MCI") AND ("exercise*" OR "sport*" OR "physical training" OR "physical fitness" OR "physical activity" OR "physical education" OR "training" OR "aerobic exercise*" OR "aerobic training" OR "aerobic activity" OR "aerobic fitness" OR "aerobic program*" OR "walking" OR "bicycle*" OR "bike ride*" OR "bicycle ride*" OR "strength training" OR "resistance exercise*" OR "resistance training" OR "anaerobic exercise*" OR "anaerobic training" OR "resistance program*" OR "weight bearing exercise" OR "high-intensity interval training" OR "HIIT" OR "balance exercise" OR "balance training" OR "motor learning" OR "movement" OR "functional training" OR "core training" OR "acute exercise*" OR "chronic exercise*" OR "isometric exercises" OR "flexibility training" OR "water exercise*" OR "hydrotherapy" OR "aquatic exercise" OR "dance*" OR "yoga" OR "mind-body exercise" OR "martial arts" OR " Chinese Traditional Sport*" OR "tai chi" OR "taiji" OR "tai chi chuan" OR "Ba Duan Jin" OR "Qigong")}.

The first literature retrieval date was May 31, 2023, and no start date was set. To avoid database update bias, the second search was conducted on October 3, 2023. We obtained 772 documents after retrieval. Additionally, referring to the selection criteria of document types in previous bibliometric studies,[27,28] we only selected "articles or reviews" as original documents, and the language was limited to "English," which can minimize deviation. The literature screening process is shown in Figure 1. After excluding 18 non-English documents and 185 other types of documents, we finally obtained 569 articles.

### 2.2. Data analysis and visualization

Microsoft Excel 2021 was employed for categorizing, implementing statistical programs, and creating all three-line tables. Descriptive data including the authors, journals, institutions, countries, and literature were obtained through online analysis and citation reports from the WoSCC. Additionally, Journal Citation Reports Science Edition 2022 was used to obtain the journal impact factor (IF), Journal Citation Reports. Datawrapper (https://www.datawrapper.de/tables, accessed on October 06, 2023) was used for the publication distribution world map.

VOSviewer is a Java-based bibliometric network analysis software, which is primarily used for analyzing literature data. Raw data were exported from the WoSCC database in text format (see Text Document, Supplemental Digital Content 1, http://links.lww.com/MD/N536, which illustrates the basic information of eligible literature), and then imported into VOSviewer (version 1.6.18) for analysis. VOSviewer was used to identify author, country, and institution collaborations, as well as the keywords co-occurrence to detect research hotspots. CiteSpace, known for robust visual analytics, effectively complements VOSviewer in identifying research trends. Thus, we chose CiteSpace (version 6.2.R4) to analyze the citation burst of keywords.

## 3. Result

### 3.1. The annual publications

The 569 English articles were published from 2002 to 2023, with 16,879 citations and each article was cited 29.66 times on average, and the H-index (H) was 6. As shown in Figure 2, in the first decade, the publications showed slow growth with a lower number of publications (n = 27), accounting for 4.745% of the total publications. In the second decade, the volume of publications had grown rapidly, with 416 articles accounting for 73.11% of the total documents. The number of publications and citations peaked in 2020 (n = 86) and 2022 (n = 3262), respectively. Notably, a slight decline was observed in 2020, but the publications were still at a high level. The fitting equation is $y = 3.9136\times - 7850.3$ (where × is the publication year, and y is the annual number of publications), R2 = 0.7798, suggesting that this area has received considerable attention and offers broad research prospects.

### 3.2. The subject categories

The 569 articles were from 60 WOS subject categories. The top 10 most popular categories were examined and revealed that geriatrics gerontology published the largest number of papers (n = 183), followed by neurosciences (n = 147), and clinical neurology (n = 90). It is worth noting that sport science also occupied an important position and ranked seventh in all subject categories (Fig. 3).

### 3.3. The prolific authors

Table 1 clearly shows 6 high-yield authors from Japan and the top 5 of them are all from the National Center for Geriatrics and Gerontology. Additionally, there are 2 prolific authors from China and Canada, and the USA has one prolific author. Notably, Doi, Takehiko, and Shimada, Hiroyuki both have the

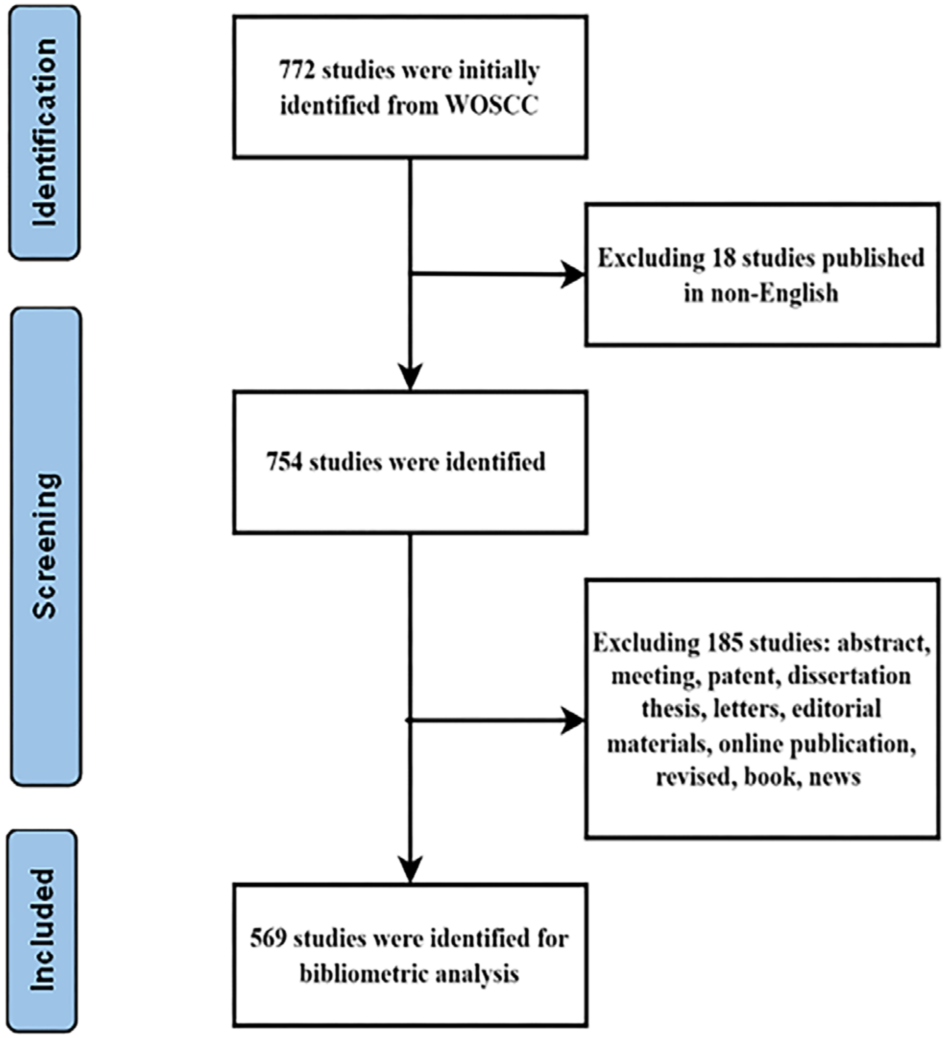


**Figure 1.** The screening process for included articles. The diagram illustrates the step-by-step selection procedure employed to identify relevant articles for inclusion in the study on exercise interventions for MCI. MCI = mild cognitive impairment.

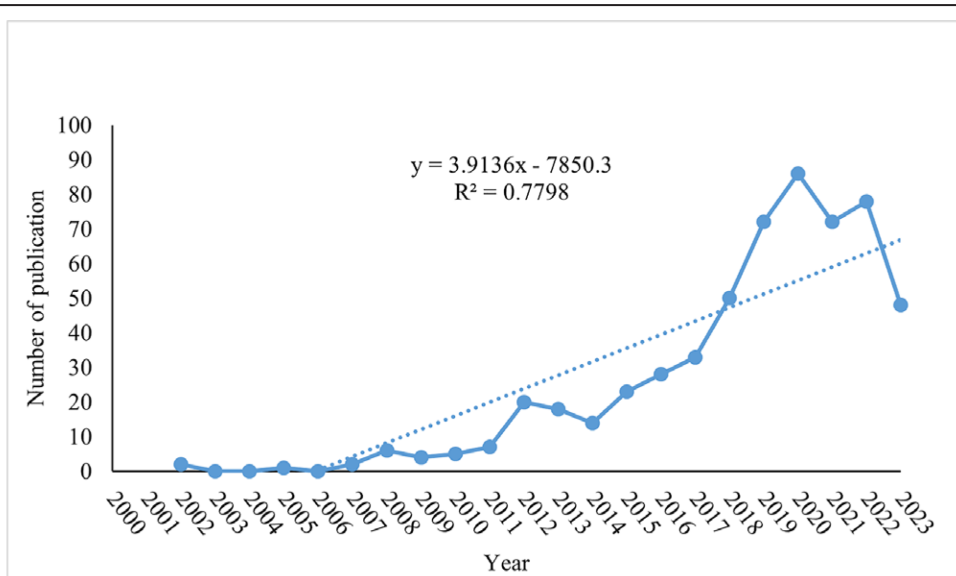


**Figure 2.** The number of publications and citations per year between 2002 to 2023. The graph depicts the yearly distribution of publications and corresponding citations sourced from the WoSCC. The data provides insights into the scholarly output and impact of research on exercise interventions for MCI over the specified period. MCI = mild cognitive impairment, WoSCC = Web of Science Core Collection.

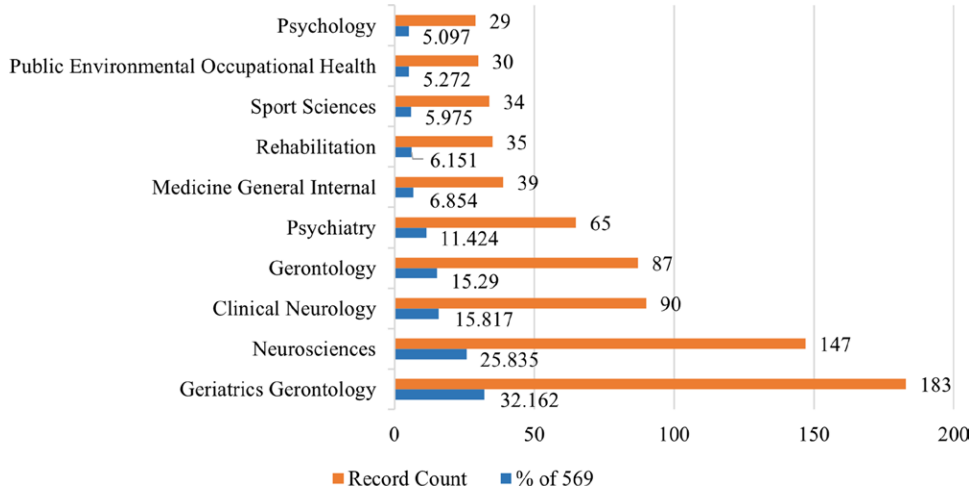


**Figure 3.** Top 10 most productive categories. This graph, based on WoSCC data, highlights the major disciplinary categories that have contributed to the MCI exercise intervention literature. Horizontal bars represent the productivity of each category, providing insight into the contributions of different disciplines to the field. WoSCC = Web of Science Core Collection.

**Table 1**

**Top 10 productive authors.**

| Author | Articles | TC | Country | Institution |
|---|---|---|---|---|
| Doi, Takehiko | 13 | 714 | Japan | National Center for Geriatrics and Gerontology |
| Shimada, Hiroyuki | 13 | 714 | Japan | National Center for Geriatrics and Gerontology |
| Suzuki, Takao | 12 | 772 | Japan | National Center for Geriatrics and Gerontology |
| Makizako, Hyuma | 12 | 713 | Japan | National Center for Geriatrics and Gerontology |
| Tsutsumimoto, Kota | 12 | 647 | Japan | National Center for Geriatrics and Gerontology |
| Liu-Ambrose, Teresa | 11 | 440 | Canada | University of British Columbia |
| Tao Jing | 10 | 318 | China | Zhengzhou University of Light Industry |
| Chen Lidian | 9 | 318 | China | Fujian University of Traditional Chinese Medicine |
| Hampstead, Benjamin M. | 9 | 356 | USA | University of Michigan |
| Park, Hyuntae | 9 | 538 | Japan | National Center for Geriatrics and Gerontology |

TC = total citations.

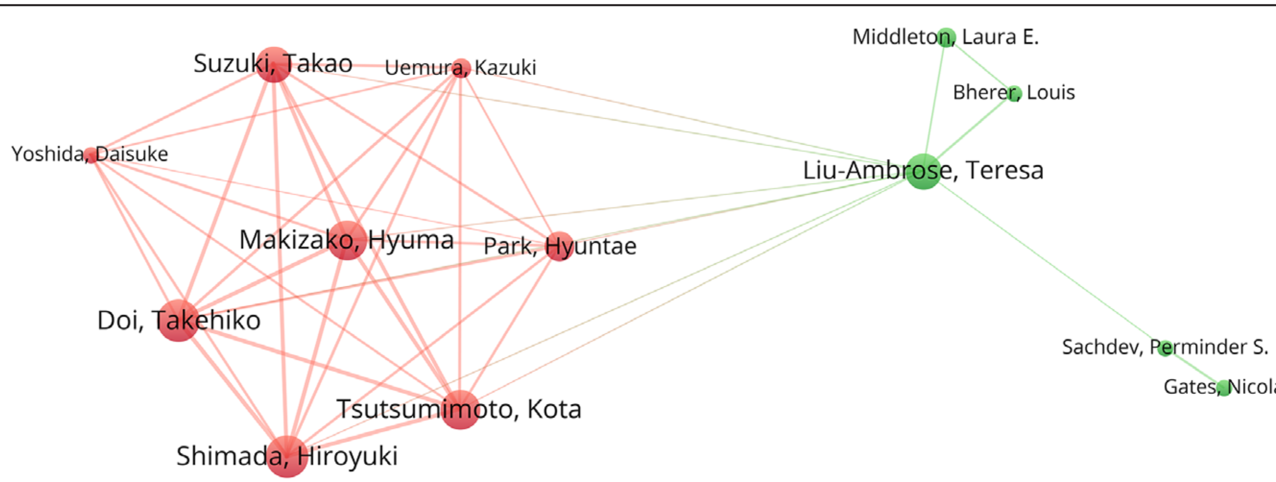


**Figure 4.** Authors Cooperation Map. The figure illustrates the collaborative network among prolific authors in the field of exercise interventions for MCI, generated using VOSviewer. Each node represents an author, and the connections signify collaboration. The map provides insights into the collaborative patterns and key contributors shaping research on this field. MCI = mild cognitive impairment.

highest publications with 13 articles and Suzuki, Takao has the highest total citations (TC) with 772 times.

We set the threshold at 5, resulting in 49 authors meeting the criteria out of a total of 2913 authors. As shown in Figure 4, only 13 authors among the 49 authors formed 2 collaboration networks. Each node represented the author's name, the link represented the co-authorship between different authors, and the node size represented the number of articles each author published. Figure 4 indicates that the red clusters represent the most prominent co-authorship network comprising 8 authors: Makizako, Hyuma; Doi, Takehiko; Suzuki, Takao; Shimada, Hiroyuki; Park, Hyuntae; Tsutsumimoto, Kota; Yoshida, Daisuke; Uemura, Kazuki. Notable, another large co-authorship network in green included 5 authors.

### 3.4. The prolific journals

The included articles were published in 228 diverse academic periodicals, and the top 10 journals are shown in Table 2, the *Journal of Alzheimer's Disease* published the highest amounts of articles (n = 40), followed by *Frontiers in Aging Neuroscience* (n = 30), and *International Journal of Environmental Research and Public Health* (n = 14). The average IF of the top productive 10 journals was 3.51. *Frontiers in Aging Neuroscience* had the highest IF (n = 4.8) with the second highest publications (n = 30). These journals mainly belong to the neurosciences, geriatrics and gerontology. Notably, the journals ranked second and third are open access journals, and the journal ranked first is a hybrid journal.

### 3.5. The prolific institutions

A total of 1110 institutions are involved in this area. As listed in Table 3, the Veterans Health Administration was the most productive institution (n = 20), followed by the University of California System (n = 18) and Harvard University (n = 16). Notably, the USA has an overwhelming majority with 6 institutions in the top ten. Among the top 5 institutions, the top 4 were affiliated with the USA, and only one Canadian institution ranked fifth. Moreover, Japan, Australia, and China each have one institution in the top ten. Overall, universities play a leading role in this field.

The institutional cooperation map reveals that out of 1085 organizations, 32 met the minimum document threshold of 7 documents per organization. Figure 5 illustrates that 25 out of these 32 institutions formed 4 collaborative networks. The most extensive cooperations were red clusters involving 11 countries. The third and fourth-ranked cooperation networks encompass 7 and 5 institutions, which are represented by green and blue, respectively.

### 3.6. The prolific countries

A total of 54 countries have conducted relevant studies in this area. As shown in Table 4, the publications of the USA (n = 153) and China (n = 126) occupied a dominant position, followed by Australia (48). Regarding influence, the most influential country was also the USA (H = 40), followed by China (H = 25), and Australia (H = 23). The top 3 countries with the highest TC are the USA (TC = 7066), Germany (TC = 3280), and England (TC = 2306). Notable, China is the only developing country among the top 10 countries. A total of 20 countries met the minimum publication threshold of 7 documents. Figure 6 shows that the 20 countries have formed 6 cooperation clusters. Specifically, the largest cluster represented by red includes England, Germany, Italy, Greece, Switzerland, and France. The second largest cluster represented by blue includes the USA, Japan, South Korea, and

**Table 2**

**The top 10 productive journals.**

| Rank | Journal | Record count (%) | IF (2022) | JCR category |
|---|---|---|---|---|
| 1 | Journal of Alzheimer's Disease | 40 (7.030) | 4.0 | Neurosciences (Q2) |
| 2 | Frontiers in Aging Neuroscience | 30 (5.272) | 4.8 | Geriatrics and Gerontology (Q2); Neurosciences (Q1) |
| 3 | International Journal of Environmental Research and Public Health | 14 (2.460) | 4.6 (2021) | Environmental Sciences (Q2); Public, Environmental and Occupational Health (Q2) |
| 4 | BMJ Open | 12 (2.109) | 2.9 | Medicine, General and Internal (Q2) |
| 5 | Journal of Aging and Physical Activity | 12 (2.109) | 1.5 | Geriatrics and Gerontology (Q4); Gerontology (Q3); Sport Sciences (Q3) |
| 6 | Aging Clinical and Experimental Research | 11 (1.933) | 4.0 | Geriatrics and Gerontology (Q2) |
| 7 | Aging Mental Health | 11 (1.933) | 3.4 | Geriatrics and Gerontology (Q3); Gerontology (Q2); Psychiatry (Q3); Psychiatry (Q2) |
| 8 | BMC Geriatrics | 11 (1.933) | 4.1 | Geriatrics and Gerontology (Q3); Gerontology (Q2) |
| 9 | Trials | 10 (1.757) | 2.5 | Medicine, Research and Experimental (Q4) |
| 10 | Brain Sciences | 8 (1.406) | 3.3 | Neurosciences (Q3) |

IF = impact factor, JCR = Journal Citation Reports.

**Table 3**

**The top 10 institutions.**

| Rank | Institutions | Country | Article | TC | CPD | H |
|---|---|---|---|---|---|---|
| 1 | Veterans Health Administration | USA | 20 | 3298 | 164.9 | 13 |
| 2 | University of California System | USA | 18 | 2532 | 140.67 | 10 |
| 3 | Harvard University | USA | 16 | 816 | 51 | 10 |
| 4 | Universite De Montreal | Canada | 16 | 777 | 48.56 | 10 |
| 5 | Mayo Clinic | USA | 15 | 2198 | 146.53 | 10 |
| 6 | National Center for Geriatrics and Gerontology | Japan | 15 | 773 | 51.53 | 12 |
| 7 | State University System of Florida | USA | 14 | 255 | 18.21 | 9 |
| 8 | University of New South Wales Sydney | Australia | 14 | 1256 | 89.71 | 12 |
| 9 | University of Texas System | USA | 13 | 249 | 19.15 | 8 |
| 10 | Chinese University of Hong Kong | China | 12 | 433 | 36.08 | 9 |

CPD = citations per document, H = H-index, TC = total citations.

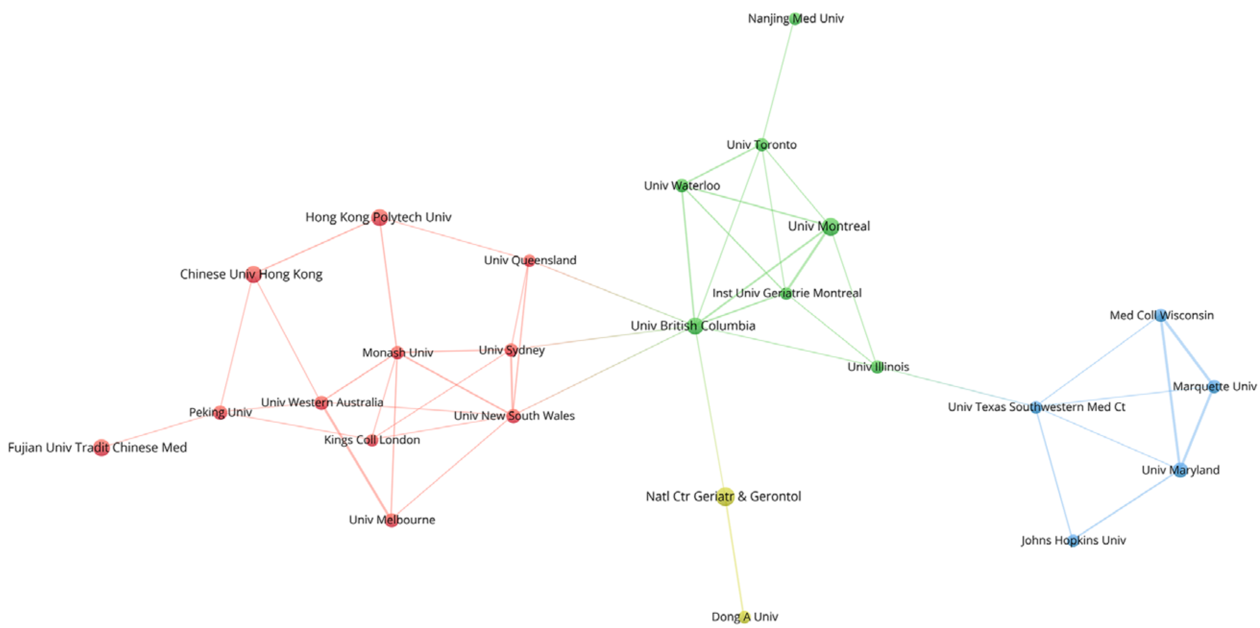


**Figure 5.** Institutions cooperation map. This figure, generated using VOSviewer, depicts the collaborative network among prolific institutions in the field of exercise interventions for MCI. Each node represents an institution, and the connections reflect collaborative relationships. The map provides insights into the collaborative patterns and key institutional contributors shaping research on this field. MCI = mild cognitive impairment.

**Table 4**

**The top 10 countries.**

| Rank | Country | Articles | TC | CPD | H |
|---|---|---|---|---|---|
| 1 | USA | 153 | 7066 | 46.18 | 40 |
| 2 | China | 126 | 2250 | 17.86 | 25 |
| 3 | Canada | 48 | 1553 | 32.35 | 19 |
| 4 | South Korea | 48 | 608 | 12.67 | 14 |
| 5 | Australia | 46 | 2166 | 47.09 | 23 |
| 6 | Germany | 43 | 3280 | 76.28 | 15 |
| 7 | Japan | 35 | 1227 | 35.06 | 19 |
| 8 | England | 33 | 2306 | 69.88 | 15 |
| 9 | Italy | 28 | 772 | 27.57 | 15 |
| 10 | Spain | 24 | 2207 | 91.96 | 11 |

CPD = citations per document, H = H-index, TC = total citations.

Taiwan, China, and the smallest cooperation network consists of only 2 countries, Australia and Thailand.

Subsequently, we analyzed the distribution of publications in different countries to understand the current status of global publications. The data of the publications used in the drawing were from all 54 countries included in this study. Figure 7 depicts that the most active continents in terms of publication are America, Asia, Europe, and Oceania.

### *3.7. The global research hotpots and trend*

***3.7.1. The research hotpots.*** The keyword co-occurrence map could well present the research hotspots in an area. We created the map using co-occurrence analysis and a full counting strategy, setting the minimum number of keyword occurrences at 20. As shown in Figures 8, 57 of the 1932 keywords met the threshold. According to the classification generated by the VOSviewer algorithm represented by the 4 different colors, we could identify the research hotspot.

Figure 8 shows that the research hotspots mainly focused on: the effectiveness of different exercises for MCI ("exercise," "aerobic exercise," "physical exercise," "performance," "cognitive function," "mobility," "balance," "gait") represented in the red cluster; neural mechanisms of exercise interventions for MCI ("intervention," "efficacy," "plasticity," "rehabilitation," "memory," "working-memory") represented in the blue cluster; and association between exercise and MCI ("association," "prevalence," "MCI," "depression," "Alzheimer's-disease," "dementia") represented in green cluster. Notable, the yellow cluster includes only 4 keywords, "physical activity," "Alzheimer's disease," "aging", and" meta-analysis," and since the difference of writing actually "physical activity" and "Alzheimer's disease" have been included in the red cluster (physical-activity and Alzheimer-disease). Therefore, the yellow cluster cannot be recognized as a research hotspot due to include limited keywords.

***3.7.2. Research trend.*** The CiteSpace was used to examine the citation burst of keywords. The values in brackets reflect the burst's strength and the red nodes represent the aggregation of time. Occurrence burst, which indicates the steep increment of a keyword in appearance over a period, can reflect the evolution of a topic.[29,30] As shown in Figure 9, the top 5 keywords with the highest citation burst in exercise interventions for MCI were physical activity (5.23), "Alzheimer's disease" (4.94), "decline" (4.67), "cognitive dysfunction" (4.53), and "executive function"

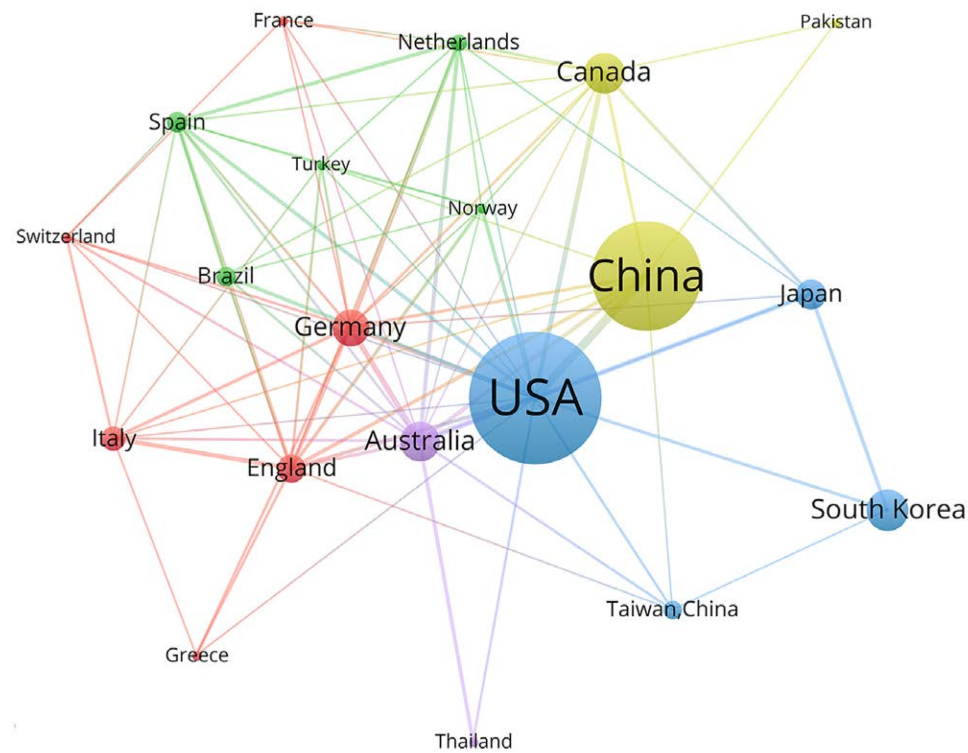


Figure 6. Countries cooperation map. This visualization, created using VOSviewer, illustrates the collaborative network among countries in the field of exercise interventions for MCI. Each node represents a country, and the connections depict collaborative relationships. The map provides insights into the global distribution of collaborative efforts. MCI = mild cognitive impairment.

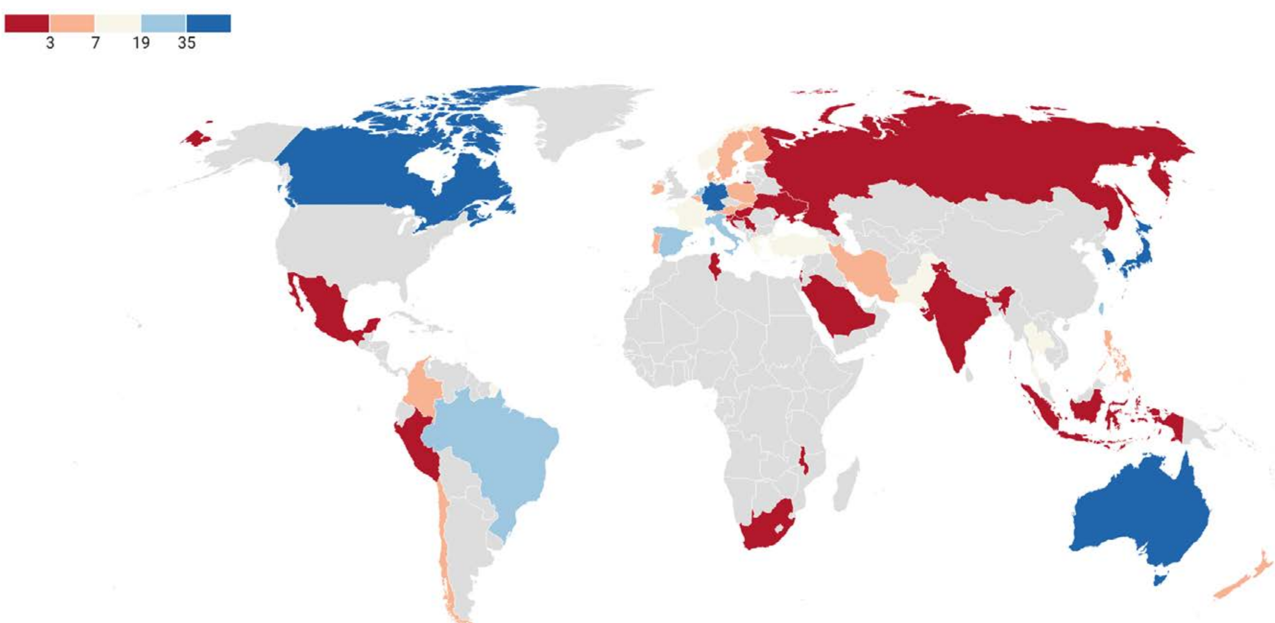


Figure 7. Geographical distribution of publications. The map depicts the global distribution of scholarly publications related to exercise interventions for MCI. Each region is color-coded based on the volume of contributions, offering a visual representation of the geographical spread of research output in this field. MCI = mild cognitive impairment.

(4.24). In addition, the lowest burst strength item was "risk" (2.27), and "Alzheimer's disease" achieved the longest burst duration of 8 years. Notable, "quality," "reliability," "therapy," and "virtual reality," are the latest co-occurrence terms (2020-2023). Combining co-occurring terms and text analysis, we identified research trends as the "quality of exercise interventions" with an emphasis on integration with virtual reality technology.

## 4. Discussion

### *4.1. Basic information*

Starting in 2018, publications saw a notable uptick, attributed to the popularity of "exercise is medicine" and the Alzheimer's Association's Mild Cognitive Impairment Guidelines, endorsing exercise as an intervention for MCI patients.[31] This led to a

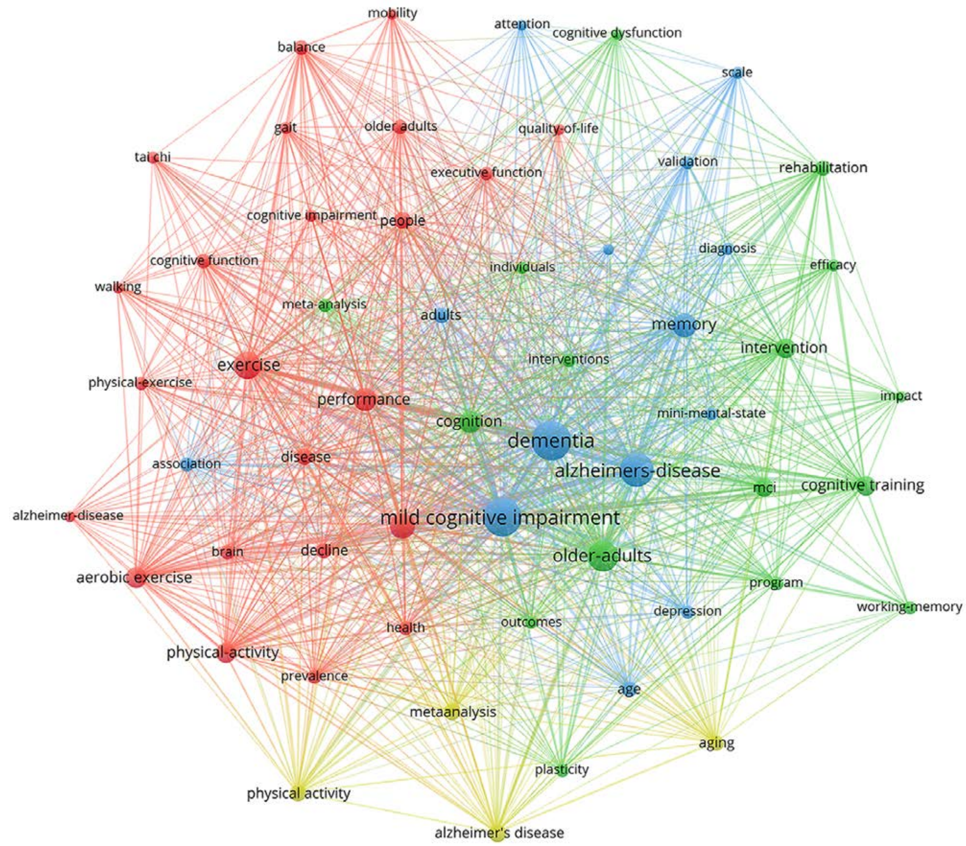


**Figure 8.** Keywords co-occurrence map. This visualization, generated using VOSviewer, illustrates the collaborative network among countries in the field of exercise interventions for MCI based on keyword co-occurrence. Each node represents a keyword, and the connections depict co-occurrence relationships. Clusters of keywords can be used to identify research hotspots. MCI = mild cognitive impairment.

heightened focus on exercise intervention protocols, resulting in a rapid publication increase. In addition, the fitting equation ($R = 0.7798$) also suggests that this field has broad prospects. However, from 2020 to 2022, a decline occurred, possibly influenced by the global impact of COVID-19, hindering relevant studies due to worldwide home quarantine. Disciplinary classifications by WOS revealed associations with geriatrics, neurosciences, psychiatry, psychology, internal medicine, and sport science, showcasing the interdisciplinary nature of MCI research. This aligns with the prevalent notion that "exercise is medicine"[8] and the effectiveness of exercise as a nonpharmacological intervention for MCI.[32]

The top 5 prolific researchers, all from Japan, particularly the National Center for Geriatrics and Gerontology, form a stable collaboration network. Their research covers multicomponent exercise interventions,[33,34] dual-task training,[35,36] neural mechanisms of exercise for individuals with MCI,[36,37] and safety of driving skills training in patients with MCI.[38] Another significant collaboration network is led by Teresa Liu-Ambrose, indicating that the top 10 authors have made outstanding contributions to the field.

Seven of the top 10 journals boast a high impact factor (IF > 3), with an average IF of 3.51, emphasizing quality in the MCI research field. The top 3 prolific journals, *Frontiers in Aging Neuroscience*, *International Journal of Environmental Research and Public Health*, and *Journal of Alzheimer's Disease*, are open access or hybrid journals, aligning with the current emphasis on open-access publication for broader accessibility.[39] Prolific institutions are largely dominated by the USA, with the Veterans Health Administration leading in productivity. However, the institution cooperation map reveals limited collaboration among the top 6 institutions, indicating little contact or cooperation. Among the top 10 productive countries, all except China are developed countries, emphasizing a significant gap between developing and developed countries in MCI research. The USA leads in published papers and H-index, with notable discrepancies in cooperation among highly productive countries, possibly due to diverse research focuses and spatial barriers.

### 4.2. Global research hotspots

#### 4.2.1. Effectiveness of different exercise interventions.

Figure 8 shows that the red cluster represents the effects of exercise ("physical exercise" and "exercise") on cognitive ("cognitive function") and physical function ("mobility" and "gait"). Regarding the efficacy of different exercise interventions on cognition, one meta-analysis reported that aerobic exercise was the optimal format.[14] In contrast, another meta-analysis indicated that resistance exercise would be more beneficial.[40] Some studies also reported that multicomponent exercise[41] and mind-body exercise[15] could also improve cognitive function in MCI patients. Moreover, some studies have focused on the effects of exercise interventions on gait and mobility functions in patients with MCI.[42,43] Furthermore, emerging studies have begun to focus on new exercise intervention forms, such as exergaming that combine virtual reality technology and exercise, which is described in the next section.

To comprehensively assess the impact of exercise interventions, it is crucial to consider various targeted symptoms like sleep quality, depression, and quality of life. Another key challenge lies in accurately evaluating the effects, with the most rigorous approach currently involving a blend of subjective

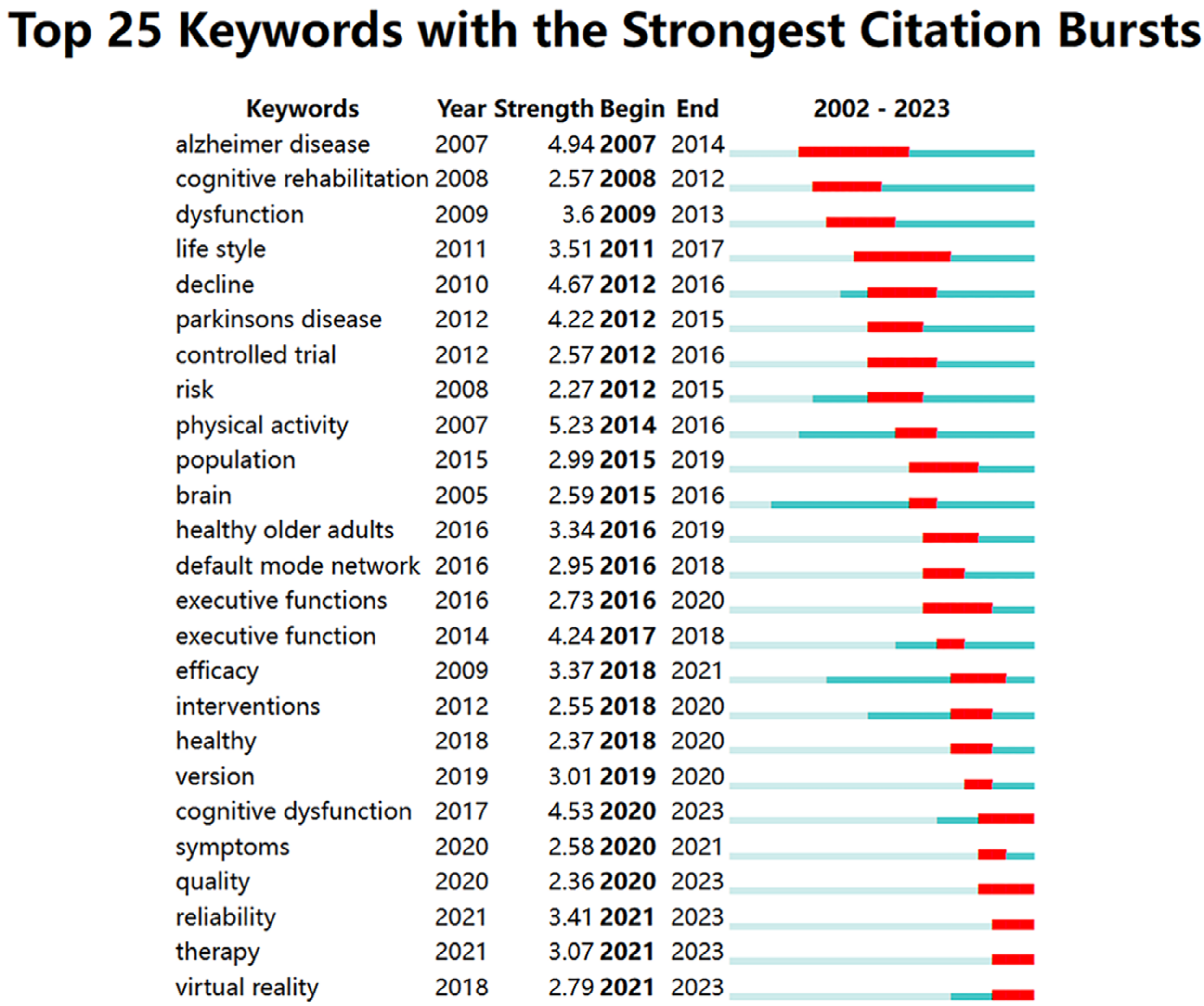


**Figure 9.** Top 30 keywords with the strongest citation burst. The diagram, generated using CiteSpace, highlights the keywords with the most significant citation bursts in the literature on exercise interventions for MCI. The value of "Strength" in the figure represents the burst strength, and begin and end represent the emergent start and end time points. The visualization provides insights into the dynamic trends and influential themes within the field over time. MCI = mild cognitive impairment.

measures (such as scales) and objective assessments (including magnetic resonance imaging, electroencephalography, and biological markers).[44] Notably, existing research has paid less focus on the long-term effects of exercise interventions. More multi-armed and long-term randomized controlled trials with follow-up are needed to compare various exercise interventions.

*4.2.2. Neural mechanisms of exercise interventions for MCI.* Exercise interventions that could improve cognitive function may be related to neuroplasticity and brain plasticity and the theory indicates that cognitive function can be improved and to some extent reversed by exercise interventions. The specific mechanisms of cognitive improvement by exercise are to increase cortical thickness, improve white matter integrity, alter the activity of functional brain areas, enhance connectivity between brain areas, and promote the secretion of biological factors.[45–47] Additionally, studies have proposed the selective improvement hypothesis,[48] the cardiovascular fitness hypothesis,[49] and a model of the effectiveness of physical activity on mediators of cognition.[50] For instance, Aerobic exercise is essential for enhancing cardiovascular fitness,[51] which boosts cerebral blood flow, increases oxygen and glucose supply to brain tissue, and improves neurotransmitter availability and cognitive efficiency.[52] Moreover, aerobic exercise also could stimulate the synthesis of neurotrophic factors.[53] Notably, to comprehensively explore this mechanism, researchers have combined multiple neuroimaging methods, such as fMRI and electroencephalography , to assess changes in brain structure and function.[54]

*4.2.3. Associations between exercise and MCI.* Many cross-sectional studies have used correlation analysis to identify a positive association between participation in exercise and reduced prevalence of MCI.[55,56] Specifically, one study using a representative sample from Spain showed a higher prevalence of MCI at low compared to moderate levels of physical activity.[55] Additionally, some cross-sectional studies have utilized logistic regression analysis to examine their relationship, revealing that exercise serves as a protective factor against MCI.[57] Some cohort studies have also reported a positive association with exercise to alleviate MCI.[58] Moreover, some randomized controlled trials have explored this association and demonstrated that regular exercise intervention can effectively improve the cognition of MCI patients.[40,59] Notably, "depression" is presented in the green cluster in Figure 8. The possible explanation is that depression is the most common psychiatric symptom in MCI patients,[60] and the severity of depressive symptoms is also an important mediating variable for exercise to improve MCI.[61,62]

For instance, Wang et al verified that depressive symptoms were an important mediator variable for structured exercise improving the general cognitive function.[61]

### 4.3. Research trend

Keywords with citation bursts are recognized as signs of research frontier. Based on a comprehensive analysis, "the quality of exercise interventions" was identified as the frontier topic. The quality of exercise intervention for MCI is affected by factors such as intervention type, intensity, frequency, length, duration, setting, delivery (individual/group), supervision, and other factors. However, there is currently no consensus on the optimal dose of exercise interventions for MCI. A meta-analysis has reported that vigorous intensity can achieve better intervention effects than moderate intensity. Additionally, this study indicated that the effect of training 3 times/week is superior to that of 1 to 2 times/week.[63] It was also reported that the prevalence of older adults with cognitive impairment who exercised more than 4 times/week was significantly lower than those who exercised less than 3 times/week.[64] In addition, studies have shown that group and supervised interventions are more effective.

Recently, virtual reality interventions for MCI have gained substantial attention. Exergaming, which combines physical exercise with virtual reality technology, is an emerging and promising intervention that is reported to have positive effects on MCI patients.[65,66] Importantly, the study has demonstrated that participating in exergaming interventions is more entertaining and closer to daily life settings, which may enhance compliance with the intervention.[67] Nintendo's exergaming device is a popular choice due to its rich and adaptable content. However, due to the limitations of the required equipment for the intervention, relevant research is still scarce. Notably, some studies suggest that combined interventions, such as combined exercise and cognitive[68] or nutritional intervention,[69] may have additive effects on MCI. Future more studies with robust designs should be conducted to confirm the additive effects.

## 5. Limitations

The present study has 3 limitations. Firstly, it was limited to the WoSCC, excluding non-English published articles. Second, we have attempted to cover more systematic search terms, but there may be missing literature. Third, citation analysis is inherently biased as older publications tend to accumulate more citations over time than newer ones, which may impact the reliability of the findings.

## 6. Conclusion

This study provides a bibliometric analysis of exercise interventions for MCI publications from 2002 to 2023. The current status indicates that this area has a promising development trend, the principal authors and institutions have made prominent contributions, the subject classification was interdisciplinarity, the research hotpots were concentrated, and the research trend was distinctive. However, there is poor collaboration between countries and institutions, and there is a large gap between developed and developing countries. Future research should emphasize improving the quality of interventions. The present study provides a valuable scientific perspective and practical insights for scholars.

## Author contributions

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