Review article

Global research trends in the effects of exercise on depression: A bibliometric study over the past two decades

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ABSTRACT

Introduction: With depression's growing global prevalence and substantial impact, effective prevention and management strategies are imperative. Our study aims to perform a thorough bibliometric analysis of existing research on the impact of exercise on depression.
Methods: A comprehensive analysis of Web of Science Core Collection publications from 2000 to 2020 was performed, highlighting trends, themes, and influential authors. The study focused on subject categories, source journals, countries/regions, institutions, and prolific authors. Co-citation and keyword analyses revealed key themes, hotspots and the thematic evolution.
Results: The multidisciplinary nature of this research is evident across psychiatry, psychology, neuroscience, and sports science. Specific populations such as women, the elderly, and those with chronic illnesses were targeted. Mind-body exercises like yoga and tai chi gained prominence. Co-citation clusters showcased the evolution from early investigations on exercise's impact to recent dose-response and protocol studies.
Conclusions: This bibliometric analysis provides insights into the dynamic field of exercise interventions for depression. It underscores the importance of individual differences, calls for guidelines considering comorbidities, and points towards future directions such as exploring mind-body exercise mechanisms and well-designed clinical trials. This study contributes to a comprehensive understanding of the research landscape and informs future endeavors aimed at refining depression treatment through exercise interventions.

1. Introduction

Presently, there are more than 300 million individuals globally experiencing diverse degrees of depression, indicating an 18.4 % increase from 2005 to 2015 [1]. Depression has emerged as the primary cause of disability worldwide [2]. The depressive disorder typically endures for an extended duration, with the risk of recurrence, posing a significant threat to the individual's social function and health status, which may ultimately result in self-injury and/or suicide [3,4]. Of noteworthy concern is the association between

chronic somatic illnesses and comorbid conditions of depression [5]. This relationship has been identified in various conditions such as diabetes [6], fibromyalgia [7], chronic obstructive pulmonary disease(COPD) [8], myocardial infarction [9] and coronary heart disease [10]. Therefore, identifying effective approaches (e.g., mindfulness, cognitive behavioral therapy, and exercise) for preventing the onset of depression (by reducing depressive symptoms) and managing its symptoms in public health is of substantial clinical and practical significance. Among the strategies mentioned above, the potential of physical exercise to counter depression was initially investigated in 1905 [11]. Over nearly a century, exercise as a structured form of physical activity involving energy expenditure has been extensively documented as an effective means of reducing depression in multiple observational and intervention studies [12–14]. For instance, a recent meta-analysis of 120,000 participants demonstrated that those who engaged in regular exercise had lower depressive symptoms than their sedentary counterparts [15]. Another study involving 7968 individuals, using regression models, discovered that an additional 4 h of exercise per week reduced the risk of incident depression by 17 % [16]. Furthermore, the same robust correlation between physical activity levels and depression risk was identified even among individuals with the highest polygenic risk [16]. As of now, an abundance of randomized controlled trials has substantiated the effectiveness of exercise intervention in reducing depression [17–20].

Despite the extensive literature on this topic, there remains a gap in our understanding of the publication trends, influential works, and thematic evolution in this field. To address this gap, we aimed to conduct a comprehensive bibliometric analysis of the existing literature. Our specific objectives were to examine the subject category, source journals, countries/regions, institutions, prolific authors and keywords. We hypothesized that this analysis would reveal key themes, authors, hotspots, and research trends, providing a holistic view of the progress made and the areas where further exploration is warranted. Concurrently, we aimed to identify document co-citation, expecting to uncover the thematic evolution in this field and the interconnections between different research works and themes. Our research rationale is driven by the urgent need to comprehensively understand the landscape of research on exercise interventions for depression. This understanding is critical for shaping future research directions and informing evidence-based interventions and policies to combat depression and enhance mental well-being. While acknowledging the multifaceted nature of depression, this study specifically concentrates on the overarching impact of exercise on depression (including comorbid depression) as a condition, rather than isolating depressive symptoms, to provide a holistic analysis of the literature and the comprehensive understanding of the relationship between exercise and overall mental health.

2. Materials & methods

2.1. Data sources

The Web of Science core collection, comprising SCI-EXPANDED, SSCI, CPCI–S, CCR-EXPANDED, and IC editions, was searched from 2000 to June 28, 2020, using the search term "(TI = (exercise) OR AB = (exercise) OR AK = (exercise)) AND (TI = (depression) OR AB = (depression) OR AK = (depression)) NOT TS = (rat* OR mouse OR mice)". As this study primarily focuses on the effect of intervention on depression, all articles that mention "exercise" and "depression" in their titles, abstracts, and/or keyword lists will be included. Additionally, this study was limited to bibliographic records of the types of original research articles and reviews paper only (original research papers represent the field's current state of the art, and review papers are expert-selected representatives), to filter out less representative record types such as proceedings papers and notes [21,22]. In other words, any article that mentioned the impact of exercise on depression in its title, abstract, or keywords was retrieved and included in the analysis, regardless of whether depression was a primary or secondary outcome. A total of 4437 literature items were identified, including 3758 articles of original research and 679 reviews articles. This query strategy [21–23] is generic enough to be applicable to current study. After removing two duplicate articles, a total of 4435 valid articles were included.

2.2. Data analysis tool

As a visualization tool of progressive knowledge domain, CiteSpace5.7.R1 was used to analyze and visualize the trends and patterns in the scientific literature [24,25]. Furthermore, we employed UCINET, another software package, to calculate the network node degree centrality index derived from CiteSpace [26]. In this study, we also used Bibexcel [27] to count the frequency of authors and keywords in the collected literature. This allowed us to identify the most prolific authors and the most commonly used keywords in the field of exercise and depression research.

2.3. Data analysis

In order to create the visualization of the knowledge domain, we followed the main operational steps of CiteSpace, which include time slicing, thresholding, modeling, pruning, merging, and mapping [21,24]. Nodes within the different maps represented subject categories, countries, institutions, authors, keywords, or references.

In our study, we adopted Price's Law to identify highly productive authors in the field of exercise and depression research. Price's Law provides a mathematical approach to predict the productivity distribution among authors in a particular field [28]. This law allows us to objectively identify the most prolific authors based on their publication output. Based on Price's law, the threshold for prolific authors is determined by the formula "$m = 0.749 \times \sqrt{n_{max}}$". And in our study, we also adopted a more objective approach to identifying high-frequency keywords by using the high and low-frequency word definition formula ($T = \frac{1}{2}\left(-1 + \sqrt{1 + 8 \times I_1}\right)$, I_1 is

the number of words with frequency 1) proposed by Donohue in 1973 [29]. This formula is derived from Zipf's second law, which is a principle of word frequency distribution in natural languages.

The link strength was set to cosine, and the selection criteria was set to "Top N = 50". The "Pathfinder" algorithm of CiteSpace was used to form the different networks within the topic. The color of a link indicated the earliest appearance time of the link with reference to the chosen thresholds. In co-occurrence network, node degree centrality and betweenness centrality are two crucial evaluation indicators. Degree centrality is determined by counting the total number of edges (co-occurrences) that a node possesses, representing the node's degree in the network. Betweenness centrality quantifies its significance in facilitating connections between other nodes by determining how often it lies on the shortest paths between pairs of nodes. Nodes with higher betweenness centrality hold greater importance in the co-occurrence network and will be denoted with a distinctive purple outer circle.

The co-citation cluster analysis could group related scientific articles based on their co-citation patterns, revealing the intellectual structure and main themes in a research field, helping researchers identify themes, influential papers, and the overall structure of the area. In co-citation cluster analysis, the clusters were numbered from 0, with a smaller number indicating a larger cluster and more citations. The clustering results were visualized along a horizontal timeline, with the legend of the publication time of the literature displayed on top. Each cluster was displayed from left to right, while the cluster results were vertically arranged in descending order of their size. The color curve indicated the co-citation links added in the corresponding color years [21]. The large nodes in the figure represented highly cited literature, and the red nodes represented literature with burstiness. The cluster label was generated by the subject term through LLR algorithm, and the label of a cluster represented that the literature of the subject term refers to the cluster.

3. Results and analysis

3.1. Publication years

Fig. 1 presents the year-by-year distribution of the 4435 publications from 2000 to June 28, 2020. Publications grew rapidly in 2007, 2013, and 2018, indicating that more researchers paid attention to the exercise-depression research topic. Although the number of publications declined in 2001, 2005, and 2016, the number of papers published each year generally increased over time.

3.2. Analysis of subject category and source journals

The most prevalent subject categories were Psychiatry, Psychology, and Neurosciences & Neurology (as shown in Fig. 2). Other categories such as "General & Internal Medicine", "Cardiology & Cardiovascular Medicine", "Public, Environmental & Occupational Health", "Rehabilitation", and "Sport Sciences" also encompassed a significant body of research on this topic.

The analysis of node betweenness centrality indicated that the disciplines of applied psychology, neuroscience, multidisciplinary psychology, and oncology had a node betweenness centrality of 0.26, 0.24, 0.22, and 0.19, respectively. These findings suggest that there have been increased collaborations and a focus on clinical and applied research within and between these four disciplines.

All of the articles included in this study were sourced from a total of 1453 journals. Among the top 21 journals with the most publications, each had published at least 20 articles (refer to Table 1). *The Journal of Affective Disorders* had the largest number of
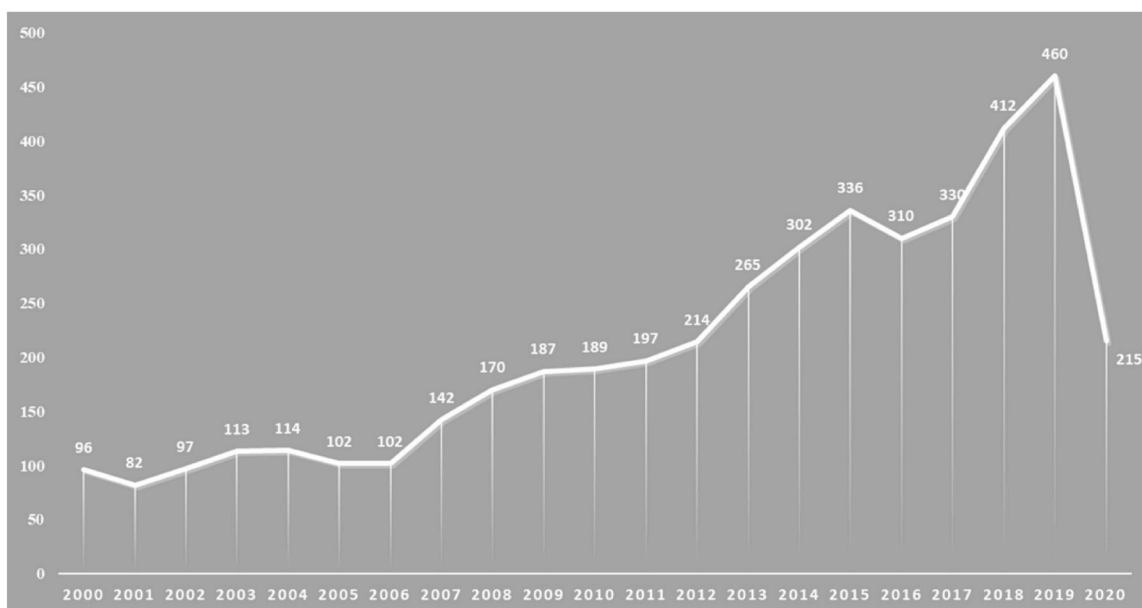

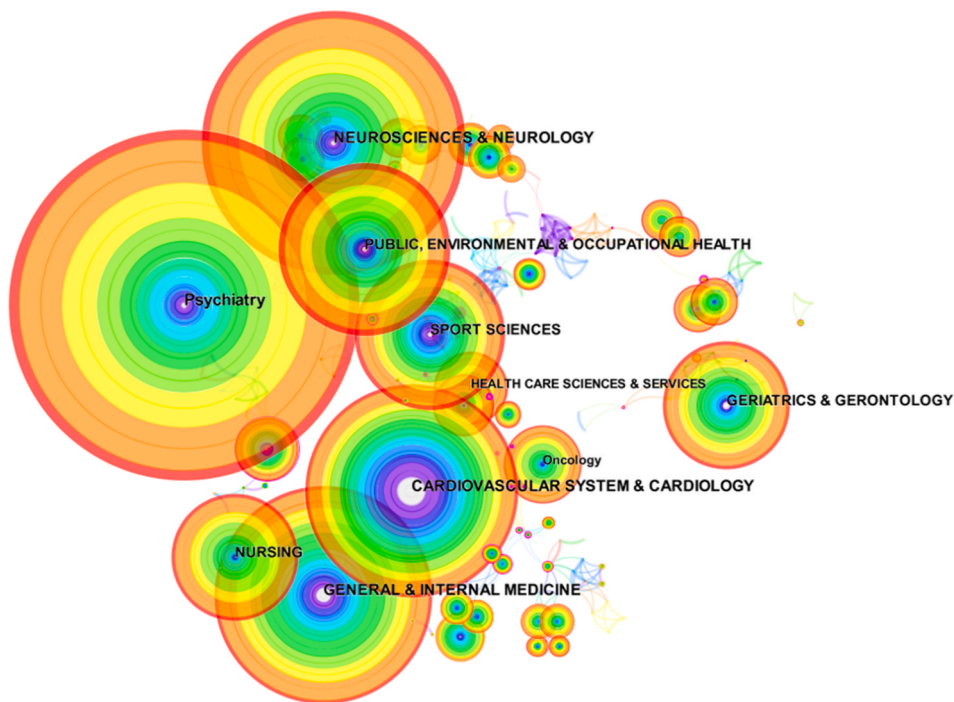**Fig. 1.** Annual trend of publications.

Fig. 2. Subject category network.

articles published and is an interdisciplinary journal that primarily publishes papers on affective disorders such as depression, mania, anxiety, and stress, and is ranked in the Q1 subdivision of the JCR. *Medicine & Science in Sports & Exercise* is the official journal of the American College of Sports Medicine, covering research in sports medicine topics for exercise physiologists, physiatrists, physical therapists, and athletic trainers. *Psychiatry Research* publishes research on the biochemical, physiological, neuroanatomical, genetic, neurocognitive, and psychosocial determinants of psychiatric disorders, as well as diagnostic assessment. As displayed in Table 1, almost half of the articles were published in Q1 journals. In summary, while many original findings were published in top-tier journals, most researchers chose to publish their findings in Q2 journals.

Table 1
Literature source statistics.

Source Journal	Counts	IF (5 years)	IF2021	JCR category quartile	JCI2021	JCI category quartile
Journal of Affective Disorders	54	6.569	6.533	Q1	1.37	Q1
PLOS ONE	44	3.752	3.752	Q2	0.88	Q1
Trials	40	2.754	2.728	Q4	0.55	Q3
American Journal of Cardiology	38	3.133	3.133	Q3	0.64	Q2
BMC Public Health	34	4.545	4.135	Q2	1.02	Q1
Journal of Cardiopulmonary Rehabilitation and Prevention	33	2.913	3.646	Q2	0.53	Q2
Medicine & Science in Sports & Exercise	31	6.131	6.289	Q1	1.83	Q1
Psychiatry Research	30	6.381	11.225	Q1	1.46	Q1
Clinical Rehabilitation	29	3.93	2.884	Q2	1.13	Q1
Mental Health and Physical Activity	27	4.365	5.957	Q1	0.97	Q2
Archives of Physical Medicine and Rehabilitation	26	4.336	4.06	Q1	1.43	Q1
Journal of Psychosomatic Research	26	4.57	4.62	Q2	0.85	Q2
BMJ Open	24	3.591	3.006	Q2	0.73	Q1
International Journal of Cardiology	24	3.998	4.039	Q2	0.92	Q1
Journal of the American Geriatrics Society	24	6.77	7.538	Q1	1.61	Q1
Journal of Physical Activity Health	22	3.029	3.0	Q2	0.82	Q1
Supportive Care in Cancer	22	3.677	3.359	Q1	1.01	Q2
Cochrane Database of Systematic Reviews	21	11.956	12.008	Q1	1.34	Q1
Aging Mental Health	20	4.115	3.514	Q2	0.88	Q2
Disability and Rehabilitation	20	2.871	2.439	Q2	1.08	Q1
Journal of Rehabilitation Medicine	20	3.585	3.959	Q1	1.03	Q2

Note: The above data were from Journal Citation Reports ™ 2021. If a Journal has more than one JCR category, the category quartile shall be the highest among the multiple categories. Impact Factor,IF; Journal Citation Reports,JCR; Journal Citation Indicator, JCI.

3.3. Country and institution analysis

The productivity of scientific research is a crucial indicator, and the number of published papers is the most straightforward metric to assess it. Table 2 provides detailed data on the top 10 countries and institutions in terms of publications on this topic.

In terms of publication output, the top 10 countries contributed 3835 papers, which constituted 86.5 % of the total number of papers. The United States emerged as the leader in the research on this topic, with 1467 papers, accounting for 33 % of the total publications. The United States also had the largest node in the national co-occurrence network (Fig. 3A). It was followed by the United Kingdom, Australia, Canada, Germany, and China (refer to Table 2). As shown in Fig. 3A, the United States, the United Kingdom, Germany, Spain, and the Netherlands are marked with purple outer circles in the national co-occurrence network, which indicates that these countries are key nodes and have high centrality, indicating closer cooperation among them. China has a red outer circle in the network, indicating a dramatic increase in the number of articles in recent years. Moreover, Turkey had a high publication volume but lacked international cooperation.

In terms of institutions involved in publishing on this topic, 592 scientific institutions were identified. As presented in Table 2, nine of the top ten institutions were comprehensive universities, all located in the aforementioned top publishing countries. The node degree centrality of these universities was notably higher than the average of all nodes (0.002), and their betweenness centrality was also high. This indicates that the countries with the highest number of publications on this topic also comprise the top institutions in the field. Fig. 3B further illustrates the close cooperation among these research institutions. The only institution in the top 10 that is not a comprehensive university and not located in a top-publishing country is the Caroline School of Medicine. Many of these institutions began their research at an earlier stage, but the University of Melbourne achieved a significant number of publications within a short period since its establishment in 2011.

3.4. Authors analysis

The number of papers published by the most productive author in our dataset is 36. According to Price's law, the threshold for being considered a prolific author in this field is approximately 5. Based on this criterion, we identified a total of 164 prolific authors. Table 3 presents a subset of these authors, each with more than 14 publications, who collectively contributed a significant number of papers. The complete list of 164 productive authors is provided in the supplementary material. Notably, Davy Vancampfort and Michel Probst were affiliated with Leuven University, whereas Brendon Stubbs was affiliated with King's College London and Simon Rosenbaum hailed from the University of New South Wales. It is interesting to observe that they commenced publishing related articles almost simultaneously, yet they were almost all highly cited researcher and their H-indices were notably high. As depicted in Table 3 and Fig. 4, a majority of these prolific authors began their investigations within the past 10–15 years.

Their research primarily focused on exploring effective interventions and treatments for mental illnesses. A closer examination of these productive authors revealed that they frequently collaborated with each other, publishing numerous high-quality papers jointly. Their research topics included examining the impact of physical exercise [20,30–32] and elucidating influential factors [33], investigating intervention effects on elderly patients with depression and enhancing their quality of life [34] and cardiopulmonary function [35], exploring the neurobiological role of exercise in depression [36], and scrutinizing the effect of exercise on depression in patients with other illnesses [37]. Since most of these papers were published as reviews, the Matthew effect may have come into play in this field.

3.5. Keywords analysis

The frequency of the most frequent keyword in our dataset is 16,261. According to Donohue's formula, the threshold for being considered a high-frequency word in this field is approximately 128. Based on this criterion, all keywords were sorted out with the frequency of more than 128 by category as shown in Table 4. A total of 63 keywords were identified, with an emphasis on women and older adults, followed by adolescents. The experimental designs primarily consisted of randomized controlled trials (RCTs), meta-analyses, and double-blind experiments, in which computer-based programs and paper questionnaires were commonly employed.

Table 2
Top 10 countries and institutions in terms of publications.

| Country	Counts	DC	BC	Institution	Counts	DC	BC	Initial year	Institution's Country
1.The USA	1467	0.040	0.31	1.University of Toronto	70	0.009	0.07	2002	Canada
2.England	457	0.033	0.16	2.King's College London	61	0.007	0.06	2007	England
3.Australia	391	0.019	0.1	3.University of Washington	59	0.014	0.04	2003	The USA
4.Canada	338	0.018	0.05	4.University of Sydney	57	0.009	0.03	2001	Australia
5.Germany	264	0.028	0.12	5.Karolinska Institute	55	0.011	0.04	2006	Sweden
6.China	195	0.017	0.05	6.University of Illinois	52	0.008	0.03	2004	The USA
7.Brazil	189	0.017	0.07	7.University of Melbourne	50	0.006	0.05	2011	Australia
8.Turkey	185	0.001	0	8.University of British Columbia	46	0.008	0.03	2004	Canada
9.Spain	177	0.028	0.12	9.University of Queensland	41	0.006	0.01	2003	Australia
10.Netherlands	173	0.028	0.1	10.Harvard University	41	0.013	0.08	2002	The USA

DC：Degree centrality; BC: Between centrality.
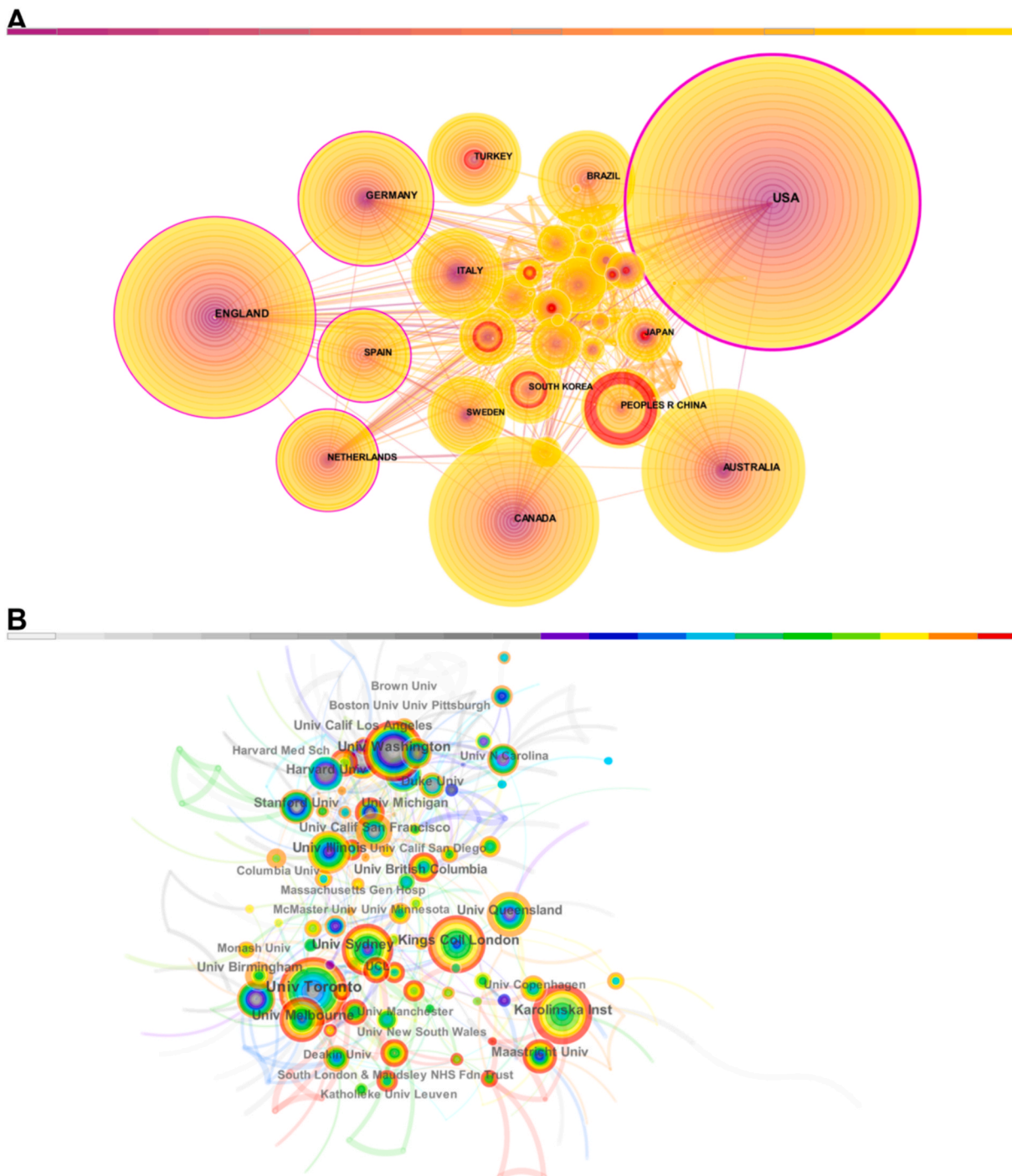
Fig. 3. Country and Institute Co-occurrence. In the country co-occurrence network (A) and institute co-occurrence network (B), the larger the nodes, the greater total number of publications on the topic of "exercise and depression". Country nodes with red inner or outer circle represent the number of publications was increased dramaticallyin the corresponding year.

The diseases that were primarily involved in this topic were cardiopulmonary diseases (including coronary artery disease and coronary heart disease, myocardial infarction, and chronic obstructive pulmonary disease), breast cancer, mood disorders, pain, and dementia. The primary indicators included anxiety, stress, fatigue, mood, and depression.

Table 3
Information of authors whose publications are 14 or more.

Author	Counts	Initial year	Affiliated Institution	Nationality	H-index
Davy Vancampfort	36	2013	KU Leuven	Belgium	79
Brendon Stubbs	33	2015	King's College London	England	96
Simon Rosenbaum	28	2015	University of New South Wales	Australia	55
Robert W Motl	28	2010	University of Alabama Birmingham	USA	75
Markus Gerber	16	2014	University of Basel	Switzerland	45
Mats Hallgren	16	2017	Karolinska Institutet	Sweden	36
Hale Karapolat	16	2009	Ege University	Turkey	21
Dilek Durmus	15	2009	Ondokuz Mayis University	Turkey	18
Felipe B Schuch	14	2016	Universidade Federal de Santa Maria	Brazil	49
Michel Probst	14	2013	KU Leuven	Belgium	45
James J Annesi	14	2004	California State University	USA	45
Kerry S Courneya	14	2011	University of Alberta	Canada	94
Edward McAuley	14	2011	University of Illinois	USA	54
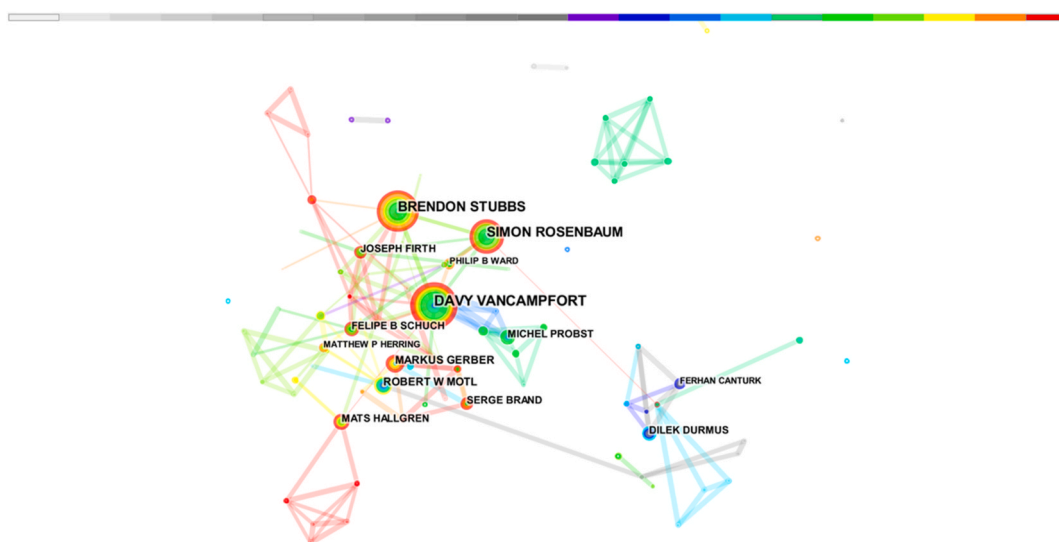
Fig. 4. Author Co-occurrence.

Table 4
High-frequency keywords.

Category	Keywords (Counts)
Population	Women (332), older adult (332), adult (296), people (206), adolescents (137)
Intervention type	exercise (1466), intervention (363), aerobic exercise (282), physical exercise (165)
Emotion	depression (1782), anxiety (659), fatigue (265), stress (261), major depression (223), hospital anxiety (153), mood (153)
Research topic	quality of life (1143), health (465), symptoms (433), prevalence (377), risk (290), rehabilitation (306), mental health (305), risk factor (237), mortality (225), therapy (214), validation (214), association (187), impact (180), validity (179), reliability (171), outcomes (164), efficacy (157), prevention (140), fitness (131)
Methods and tools	randomized controlled trial (437), meta-analysis (411), program (211), scale (193), questionnaire (140), double blind (127)
Diseases	disorder (247), depressive symptom (213), disease (204), disability (186), coronary artery disease (177), pain (174), obesity (152), COPD (136), myocardial infarction (132), coronary heart disease (127)

3.6. Burst detection analysis

Burst detection analysis of keywords enables the identification of keywords with sudden changes in frequency. As illustrated in Fig. 5A, the burst duration of keywords exceeding 9 years revealed that depression symptoms caused by cardiovascular diseases became a sudden hotspot from 2000 to 2012. Exercise intervention for elderly people with depression was the second focus during this period. The effects of exercise intervention on depression were studied using a case-control design and double-blind design since 2000. In Fig. 5B, keywords with a burst duration from 2018 to 2020 indicated recent research hotspots. Remarkably, diverse forms of exercise intervention, including resistance exercise, yoga, and tai chi, emerged. Additionally, more systematic reviews and meta-analytic
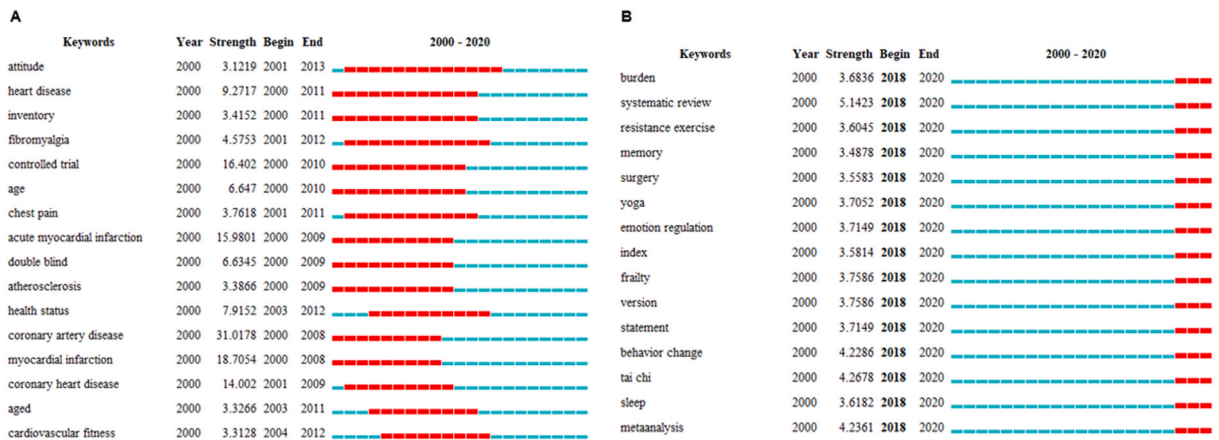
Fig. 5. Keyword Burst detection analysis. The keywords with burstiness duration over 9 years is shown in the left (A). The right (B) shows the keywords that have been burst for more than 2 years since 2018.

studies have been published in recent years, and more studies have utilized exercise as a tool to regulate negative emotions.

Recent systematic reviews and meta-analyses have demonstrated that resistance exercise, Tai Chi, and yoga are effective interventions for alleviating depression [38–41]. Specifically, Tai Chi and yoga have been found to be more effective than other types of exercise, such as dance, running, and ball games [38–41]. Tai Chi and yoga are considered to be mind-body exercises, emphasizing the integration of the body, mind, and external environment. Through slow body movements, deep breathing, and meditation, these exercises improve overall well-being [40]. Moreover, these exercises have been found to significantly decrease negative affects, reduce cortisol levels and neuro-inflammatory sensitization, regulate the autonomic nervous system, facilitate hippocampal neurogenesis, and elevate the anterior activation in the left hemisphere when combined with typical abdominal breathing techniques and mindfulness meditation [39,42]. Additionally, it is suggested that mind-body movements allow the practitioner to focus on internal orientation of breathing and proprioception, and therefore regulate and manage depression through interoceptive states [41].

3.7. Co-citation analysis

The co-citation clustering network was constructed using the top 100 cited articles each year from 2000 to 2020. This network consisted of a total of 2443 citations, which were organized into 26 co-citation clusters with 14 networks, as illustrated in Fig. 6. The modularity of the network was 0.8673, indicating that the field of "exercise and depression" was clearly delineated in the co-citation
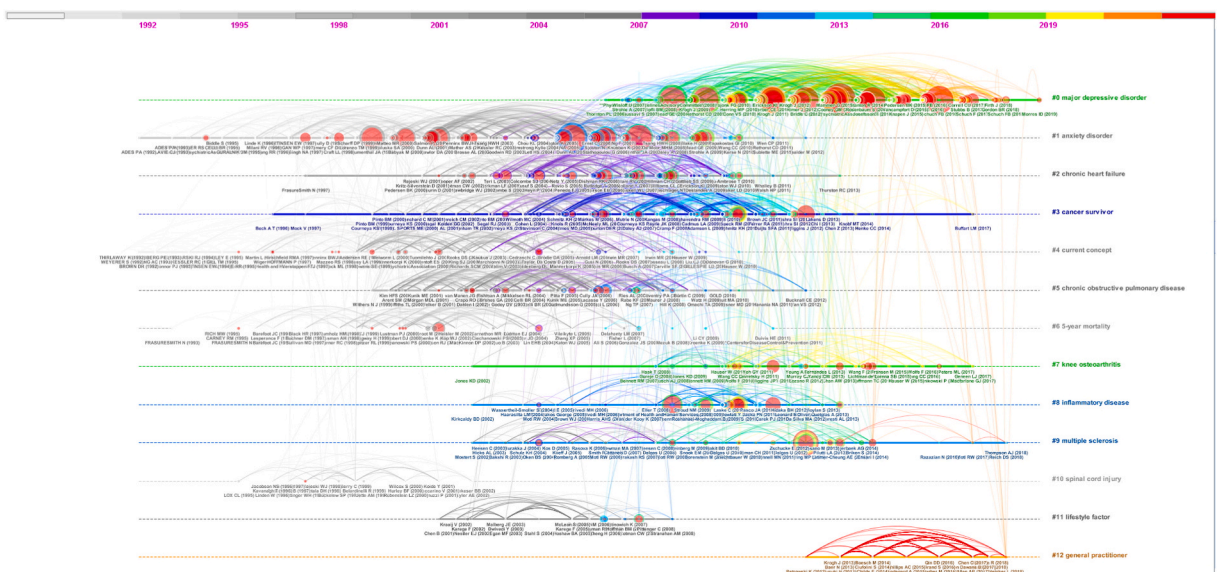

Fig. 6. Timeline view of document co-citation. The smaller the cluster number, the more citations it has. Purple represents the earliest year and yellow represents the latest year. The large nodes in the figure represented highly cited literature, and the red nodes represented literature with burstiness.

clustering. The clustering results were deemed reliable and credible. Generally, larger clusters contain more high-cited and high-burst literature. The two largest clusters are detailed below.

Cluster #0 constituted the most largest cluster in the entire network, featuring 270 papers published within the timeframe of 13 years, from 2006 to 2019. This cluster encompassed a significant volume of highly cited reviews on exercise intervention as a remedy for depression. The Silhouette value of this cluster was 0.867, which bears witness to its highly consistent and credible clustering outcome.

In 2007, the World Health Organization conducted a survey indicating that depression exerted a more substantial health impact than angina, arthritis, asthma, and diabetes, thereby advocating the pressing need to consider depression as a full-fledged public health priority [5]. In the same year, it was discovered that physical exercise proved to be an effective adjunctive therapy for patients with major depressive disorder (MDD) [43]. The years spanning from 2008 to 2016 saw a proliferation of numerous articles exploring exercise interventions for depression, during which a multitude of highly cited reviews also emerged. These findings suggested that exercise could significantly alleviate the symptoms of depression in MDD patients [17,44,45]. In 2016, a meta-analysis featuring rigorous bias correction disclosed that the previous meta-analyses might have underestimated the advantages of exercise. Both moderate-intensity and vigorous aerobic exercise were found to have substantial antidepressant effects on MDD patients [20]. Moreover, the American Psychiatric Association released *The Diagnostic and Statistical Manual of Mental Disorders* (DSM-V) in 2013, which constitutes a robust guide for exercise interventions in depression [46]. Following 2016, the relevant reviews began to wane, and more studies started to focus on investigating the effects of diverse types of exercise on depression. In cluster 0, after the WHO's survey, a considerable number of systematic reviews and meta-analyses delving into this subject matter were published. In the aftermath of 2016, various studies commenced probing the dose-response of exercise interventions for depression.

Cluster #1 was the second largest cluster in the network, comprising 202 papers published between 1992 and 2012. Citations in this cluster pertained to the early investigations of exercise interventions for depression. The Silhouette value for this cluster was 0.856, indicating the clustering results were equally persuasive. Between 1992 and 1997, there were a few highly cited and highly bursty literature items. With the release of *the Diagnostic and Statistical Manual of Mental Disorders (*4th *edition)* (DSM-IV) in 1994, highly bursty citations began to emerge during this period. Subsequently, from 1997, numerous original studies have explored the impact of exercise interventions on depression. For instance, a study focused on the elderly population found that progressive resistance training had antidepressant effects in depressed older adults [47]. Exercise training was equally effective as medication after 16-week treatment in elderly patients with MDD [48]. The antidepressant effect of exercise was sustained for at least 10 months, and the depression relapse rate was lower than that of medication treatment [49]. Furthermore, quasi-experimental studies revealed that almost all exercise intensities, ranging from mild to high, could alleviate depressive symptoms. However, studies with rigorous experimental designs seldomly focused on dose-response relationships, randomized controlled trials [50], methodologically rigorous studies, high-quality clinical studies, and adequate follow-up are still lacking [51,52]. In 2005, a randomized controlled trial concluded that high-intensity progressive resistance training was more effective than low-intensity progressive resistance training or home care in treating elderly patients with depression [53]. Another study discovered that exercise with the recommended dose (a specific amount of energy expenditure and frequency) was more effective than low exercise for patients with mild to moderate depression [54]. These studies have significantly enhanced our understanding of the dose-response relationship of exercise in the treatment of depression. Furthermore, a review found that exercise interventions were more effective than control conditions in treating MDD, which prompted clinicians to consider exercise interventions in clinical practice [55]. However, some researchers have criticized the treatment of exercise for depression due to the lack of long-term observation of exercise interventions and the potential overestimation of treatment effects [56]. Additionally, there is still no consensus on the optimal type, intensity, frequency, and duration of exercise [57]. The analysis of Cluster #1 indicates that since the publication of DSM-IV in 1994, there has been a growing number of studies on exercise therapy for depression with more robust results. This extensive exploration in Cluster #1 has also laid the foundation for high-quality reviews in Cluster #0.

Cluster #2, comprising 140 articles published from 1997 to 2013, primarily focused on the elderly population. Cluster #3, consisting of 139 citations from 1996 to 2017, emphasized the treatment of depression among cancer patients and survivors. Other significant clusters focused on somatic diseases with depressive symptoms, including fibromyalgia [58], coronary heart disease [59], COPD [60,61], diabetes [6], multiple sclerosis [62] and other chronic illness [63]. Furthermore, it has been suggested that exercise intervention may have the most potent antidepressant effect on patients with mild to moderate depression [63].

4. Implications for future directions

The available evidence consistently demonstrates the effectiveness of appropriately dosed exercise for treating or preventing depression, providing valuable research insights for precise depression treatment. The healthcare providers should consider integrating exercise regimens into treatment plans. Based on the aforementioned keyword and co-citation analysis, several directions merit exploration in future studies.

4.1. Demographic-specific studies and individualized exercise interventions

While a significant number of studies have explored the effects of exercise on depression across various populations, including women, the elderly, adolescents, and patients with different diseases, there has been a limited examination of individual differences in the effectiveness of exercise for depression (not detected in this study). Key demographic variables, such as sex and age, still need to be further examined in the context of exercise and depression. For instance, it remains unclear whether sex differences exist in depression

treatment efficacy when men and women follow the same exercise protocol, or whether older adults experience the same benefits from exercise as younger adults. While the existing literature may touch upon these aspects, there is a potential gap in fully exploring the influence of sex and age on the effectiveness of exercise as a treatment for depression. Further research in these areas is therefore needed to gain a more nuanced understanding. Only then can tailored exercise programs be developed to optimize treatment outcomes for men and women separately, as well as for different age demographics.

4.2. Standardized guidelines for exercise therapy

Secondly, despite demonstrated effectiveness of exercise, the substantial heterogeneity in in treatment outcomes highlights the challenge of establishing standardized guidelines. Furthermore, although some current international guidelines for the treatment of depression recommend integrating exercise into health care and intervention [64,65], clinical interventions must account for the heterogeneous and complex results associated with patients with depressive symptoms who often have comorbidities.

4.3. Exploring mind-body exercise

The emerging trend of mind-body exercise, as indicated by the burst detection analysis, deserves greater attention from researchers. Though recent intervention studies suggest that mind-body exercises are more effective than other forms of exercise for treating depression [38–41], the mechanisms underlying this effectiveness remain poorly understood. Additionally, dose effects related to mind-body exercise warrant further investigation. This could lead to more effective, evidence-based recommendations for practices like Tai Chi and yoga in depression management.

4.4. Investigating brain mechanisms

Current behavioral studies rely predominantly on randomized controlled trials and double-blind experiments. To understand the underlying neural mechanisms of exercise therapy, future studies should prioritize replicating these methodologies in brain imaging studies. Utilizing RCTs or at least single-blind designs in brain research will eliminate confounding factors and enhance the interpretation and validity of findings.

5. Limitations

First, the study relies on data retrieved solely from the Web of Science Core Collection (WOSCC) database. While WOSCC is a comprehensive citation database that is broader coverage and includes citation information crucial for co-citation analysis, it may not cover all relevant publications in the field. Other databases and sources may still have additional relevant studies that were not included in the analysis. Second, the study covers publications from 2000 to 2020, which means that any relevant research conducted before 2000 or after 2020 is not considered, potentially missing important contributions to the field. This temporal window was chosen to focus on the most current and relevant research trends, reflecting the significant advancements and evolving methodologies in the field of exercise and depression over the last two decades. Third, the study focuses on mapping and visualizing research outputs, but it does not assess the quality or rigor of the included publications. This limitation might affect the overall reliability of the findings. Forth, the keywords used for analysis might be subjective and could potentially overlook important terms or concepts related to the topic. Fifth, while the study aims to determine research frontiers, the provided results may not comprehensively cover all emerging or cutting-edge areas in the field of exercise interventions for depression. Sixth, this analysis does not assess the effectiveness of exercise interventions for different severities of mental diseases. Future research could investigate this important aspect by employing meta-analysis or systematic reviews specifically focusing on the stratified analysis by the severity of the disorders. Overall, while the study provides valuable insights into the research landscape on exercise interventions and depression, researchers should be cautious about drawing definitive conclusions solely based on its findings due to the mentioned limitations.

6. Conclusion

In summary, our analysis reveals a multidisciplinary approach to studying the effects of exercise on depression, involving fields such as psychiatry, psychology, neuroscience and neurology, and sports science. The majority of intervention studies have focused on specific populations such as women, the elderly, patients with depression, cardiopulmonary diseases, and cancer. Recent studies have also explored the potential benefits of mind-body exercise interventions such as yoga and tai chi. Moving forward, it is crucial to take into account individual differences, dose-response effects, and the development of standardized exercise protocols in future research.

Ethics declarations

Review and/or approval by an ethics committee and informed consent were not required for this study because this study is a bibliometric analysis of publicly available data and did not involve any human subjects or animals, or collect any personal or sensitive data.

Data availability

No data was used for the research described in the article.

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CRediT authorship contribution statement

Li-Kun Ge: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation, Conceptualization. **Zheng Huang:** Writing – review & editing. **Gao-Xia Wei:** Writing – review & editing, Resources, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32315.

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