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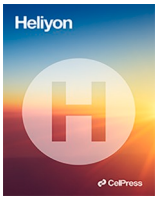

Research article

Twenty-five years of research on resting-state fMRI of major depressive disorder: A bibliometric analysis of hotspots, nodes, bursts, and trends

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ABSTRACT

Major depressive disorder (MDD) is a debilitating mental health condition that poses significant risks and burdens. Resting-state functional magnetic resonance imaging (fMRI) has emerged as a promising tool in investigating the neural mechanisms underlying MDD. However, a comprehensive bibliometric analysis of resting-state fMRI in MDD is currently lacking. Here, we aimed to thoroughly explore the trends and frontiers of resting-state fMRI in MDD research. The relevant publications were retrieved from the Web of Science database for the period between 1998 and 2022, and the CiteSpace software was employed to identify the influence of authors, institutions, countries/regions, and the latest research trends. A total of 1501 publications met the search criteria, revealing a gradual increase in the number of annual publications over the years. China contributed the largest publication output, accounting for the highest percentage among all countries. Particularly, the University of Electronic Science and Technology of China, Capital Medical University, and Harvard Medical School were identified as key institutions that have made substantial contributions to this growth. Neuroimage, Biological Psychiatry, Journal of Affective Disorders, and Proceedings of the National Academy of Sciences of the United States of America are among the influential journals in the field of resting-state fMRI research in MDD. Burst keywords analysis suggest the emerging research frontiers in this field are characterized by prominent keywords such as dynamic functional connectivity, cognitive control network, transcranial brain stimulation, and childhood trauma. Overall, our study provides a systematic

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overview into the historical development, current status, and future trends of resting-state fMRI in MDD, thus offering a useful guide for researchers to plan their future research.

1. Introduction

Major depressive disorder (MDD) is a prevalent mental health condition characterized by persistent feelings of sadness, loss of interest or delight, and a variety of physical and cognitive symptoms [1–3]. It affects millions of people worldwide and is a primary cause of disability, imposing a considerable burden on individuals and society. Existing research has demonstrated various patho-physiological aspects associated with MDD, such as genetics [4], environmental factors [5], inflammation [6], neuroendocrinology [7], and neuroplasticity [8]. However, the exact neural mechanisms underlying MDD remain poorly understood.

Resting-state functional magnetic resonance imaging (fMRI) is a promising approach for investigating the neural mechanisms implicated in MDD [9]. This non-invasive neuroimaging method allows researchers to explore the brain's functional properties without requiring participants to perform specific tasks [10]. Various methodologies are available for analyzing resting-state fMRI data, primarily encompassing the assessment of brain local activity, functional connectivity, and whole-brain functional network. The local activity analysis in resting-state fMRI studies focuses on assessing the spontaneous neural activity within specific brain regions, employing approaches such as regional homogeneity or amplitude of low-frequency fluctuations [11,12]. Functional connectivity analysis, on the other hand, explores the temporal correlations between different brain regions to identify synchronized activity patterns using methods such as seed-based approach or independent component analysis [13]. Conversely, whole-brain network analysis examines the complex network organization of the entire brain, applying graph theory metrics such as degree, betweenness, or small worldness to understand the brain's overall network architecture [14]. To date, existing studies have demonstrated abnormal neural activities [15,16], altered functional connectivity [17,18], and disrupted whole-brain functional networks [19,20] in patients with MDD. However, despite these advancements, the field of resting-state fMRI in MDD faces challenges such as fragmentation and overlapping research, along with a lack of consensus on main findings, which can impede the synthesis of a coherent understanding and delay the translation of research into practice. Without a systematic examination of the research landscape, individual studies may only contribute pieces to an incomplete picture.

Bibliometric analysis provides a quantitative method for comprehensively reviewing and synthesizing existing literature [21,22]. The application of bibliometric spans across diverse academic disciplines, including natural sciences [23], engineering [24], social

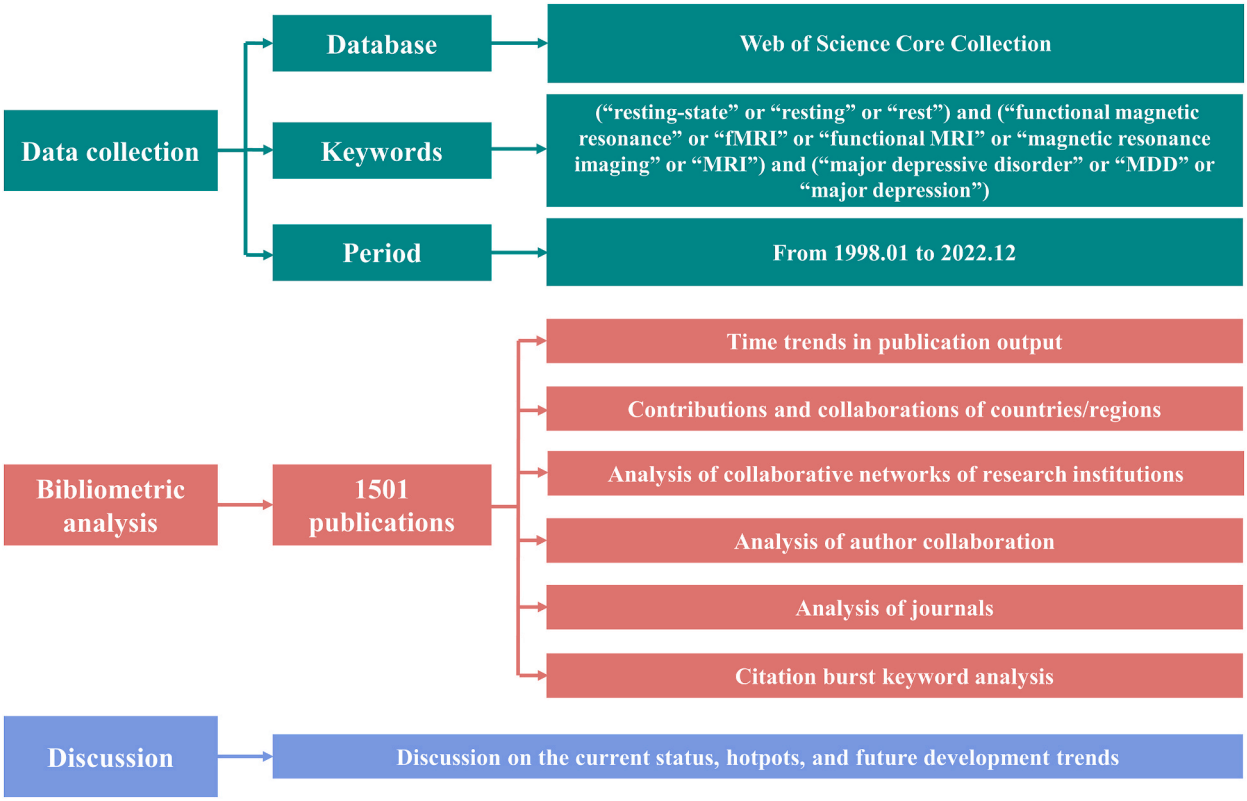

Fig. 1. Flowchart for bibliometric analysis in resting-state fMRI studies of MDD.

sciences [25], and medicine [21]. It involves a systematic analysis of publication patterns, citation networks, author collaborations, and other bibliographic information to uncover trends and impact of scientific research. In addition, this methodology enables an assessment of the current status and evolution of scientific knowledge in a particular domain. By conducting a bibliometric study of publications on resting-state fMRI in MDD, we can map the evolution of the field, identify key studies, discern prevailing trends, and reveal gaps in the current research [26,27]. Such an analysis not only enhances our understanding of how resting-state fMRI has contributed to unraveling the complexities of MDD but also guides future research directions by highlighting areas in need of further exploration.

In light of these considerations, this study aims to perform a bibliometric analysis of resting-state fMRI research in MDD. Specifically, we collected scientific publications related to resting-state fMRI in MDD from the Web of Science database, spanning from 1998 to 2022. Utilizing CiteSpace software, we conducted a quantitative analysis to ascertain various aspects of resting-state fMRI research in MDD, including the trend in the number of publications, collaborative networks between countries/regions, productive authors and institutions, influential journals, disciplinary research, and keywords with citation bursts. By performing this analysis, we aim to identify research trends and current status, pinpoint areas of rapid development, and provide useful guidance for future investigations into resting-state fMRI in MDD. A flowchart of this study is shown in Fig. 1.

2. Materials and methods

2.1. Data source and search strategy

To conduct this bibliometric analysis, a systematic search of relevant publications was performed. Web of Science database was used to retrieve articles, which is widely recognized for its extensive coverage of high-quality scholarly publications across various disciplines [28]. The search query employed was TS = (“resting-state” OR “resting” OR “rest”) AND TS = (“functional magnetic resonance” OR “fMRI” OR “functional MRI” OR “magnetic resonance imaging” OR “MRI”) AND TS = (“major depressive disorder” OR “MDD” OR “major depression”). The search was focused on English articles and reviews, excluding document types like letters, meeting abstracts, corrections, editorial, and book chapters, with publication years ranging from 1998 to 2022. The extracted information from the retrieved literature covered details such as publication year, journal name, article title, author names, keywords, institutions, countries/regions, and citation information.

2.2. Bibliometric analysis

In this bibliometric analysis, several measures were utilized to investigate different aspects of the research landscape [29,30]. First, the collaboration patterns among different geographic locations were explored in the network of countries/regions, shedding light on research efforts between researchers from diverse regions. Second, the relationships and interactions between research institutions were revealed in the network of institutions, offering insights into institutional research networks. Third, collaboration networks among researchers were examined in the network of co-authors, identifying co-authorship patterns and influential researchers. Fourth, journal co-citation network analysis was conducted to identify core and important journals in a research field. Fifth, the dual-map overlay analysis of journals was performed to provide information about the distribution of journals, citation relationships, and main citation pathways, thereby facilitating the comprehension of knowledge flow within the academic domain. Finally, the keywords with the strongest citation bursts were also identified, revealing emerging trends and topics of interest. These measures collectively provide a comprehensive overview of research collaboration, publication patterns, and emerging trends within this research area.

2.3. Data visualization

CiteSpace, an application built on Java, serves as a useful tool for researchers engaged in bibliometric analysis and visualization in their studies [31]. By utilizing CiteSpace, researchers can uncover the structure of academic domains, trends in knowledge flow [24], and the academic collaboration networks. This software also provides an intuitive and comprehensive perspective, enabling researchers to discover novel research directions, recognize emerging fields, and evaluate academic influence with ease. In the visualization of bibliometric analysis, each node represents an observation—such as a country, institution, author, co-cited journals, or keywords—with the node’s size indicating its frequency of occurrence and the links between nodes depicting collaborative relationships, while the different colors of the nodes denote various years. Betweenness centrality measures the number of times a node lies on the shortest paths between any two other nodes in the network, and a higher betweenness centrality value suggests that the node takes on more bridging roles in the network, playing a more critical part in information transfer and network connectivity. In CiteSpace, nodes with high betweenness centrality are displayed as purple rings, with the thickness of the rings indicating the centrality value [32,33].

3. Result

3.1. Time trends in publication output

A total of 1501 publications met the search criteria for inclusion in this analysis. The publication output trend in the field of resting-state fMRI in MDD research, as shown in Fig. 2 and Table S1, demonstrates a gradual increase over the years. Initially, the number of

publications were low, starting with only 3 articles in 1998, and gradually increased to 13 by 2009. A significant rise occurred in 2011, with the count jumping to 36 publications. From 2013 to 2015, there was a steady increase in output, with 49, 68, and 98 articles published, respectively. Between 2020 and 2021, publication numbers remained high, at 177 articles, and this trend continued into 2022, reaching a peak of 231 publications.

3.2. Contributions and collaborations of countries/regions

As presented in Fig. 3 and Table S2, the collaboration network for research on resting-state fMRI in MDD illustrates the leading countries/regions and their respective contributions. China leads with 722 publications, indicating its prominence in research output. However, with a centrality score of 0.19, there is potential for increased international collaboration. The United States of America follows closely in the second position with 558 publications and a higher centrality score of 0.61, emphasizing its strong presence and influence within the network. Germany ranks third with 154 publications and a centrality score of 0.28, pointing a substantial research contribution and active engagement in collaboration. In the fourth position, England reports 122 publications and a centrality score of 0.22, representing considerable research output and a moderate level of collaboration. Canada occupies the fifth position with 98 publications and a centrality score of 0.09, demonstrating remarkable research contributions and some degree of collaboration. Furthermore, countries such as the Netherlands, Australia, Japan, Italy, and South Korea also contribute to the research on resting-state fMRI in MDD, though to a lesser extent, as evidenced by their lower publication counts and centrality scores.

3.3. Analysis of collaborative networks of research institutions

Fig. 4 and Table S3 present the institutions actively involved in the domain of resting-state fMRI research on MDD. Among them, the University of Electronic Science and Technology of China stands out, leading with a total of 78 publications. Following this, Capital Medical University, with 73 publications, demonstrates its robust research productivity. Furthermore, with an impressive centrality score of 0.16, Capital Medical University also exhibits significant collaborative influence within the research network. Additionally, both the Chinese Academy of Sciences and Harvard Medical School, each with a centrality score of 0.1, are prominent in this research area.

3.4. Analysis of author collaboration

As shown in Fig. 5 and Table S4, in the field of resting-state fMRI research on MDD, Wenbin Guo ranks first in terms of publication quantity, with a total of 43 papers published. Following behind are Feng Liu and Fei Wang, with 37 and 35 papers, respectively. Qiyong Gong exhibits the highest centrality value of 0.06, indicating the closest collaborative relationships with other authors in the entire collaboration network and plays a crucial role as a hub in the network. Jingping Zhao and Yonggui Yuan also demonstrate relatively high centrality values, at 0.05 and 0.04.

3.5. Analysis of journals

According to Fig. 6 and Table S5, Neuroimage has the highest count of co-citations, followed by Biological Psychiatry, Journal of Affective Disorders, and Proceedings of the National Academy of Sciences of the United States of America, indicating their influence in

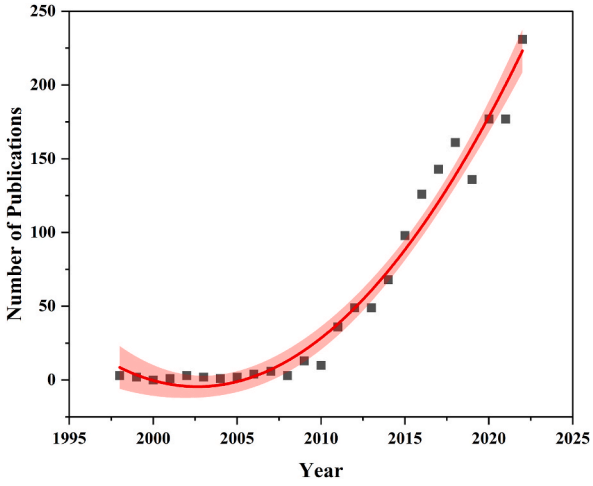

Fig. 2. Publication output trends in resting-state fMRI studies of MDD from 1998 to 2022. Dark red areas represent 95% confidence intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

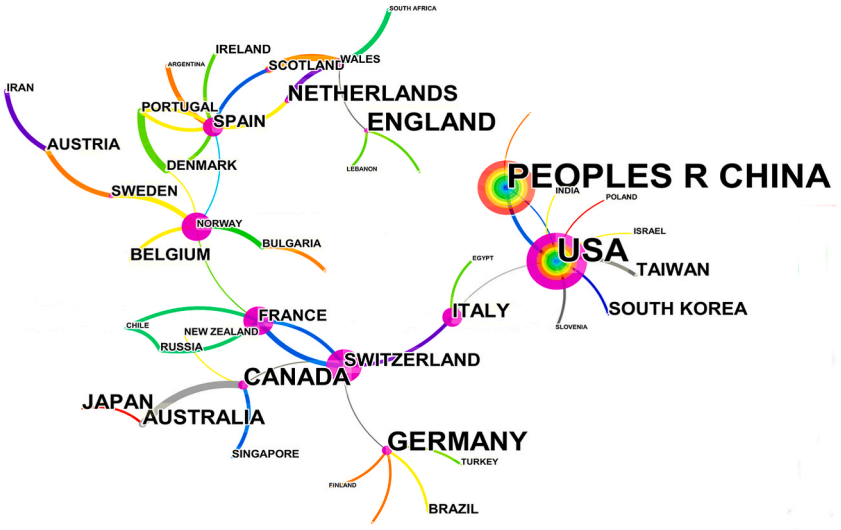

Fig. 3. Network of countries/regions in resting-state fMRI studies of MDD.

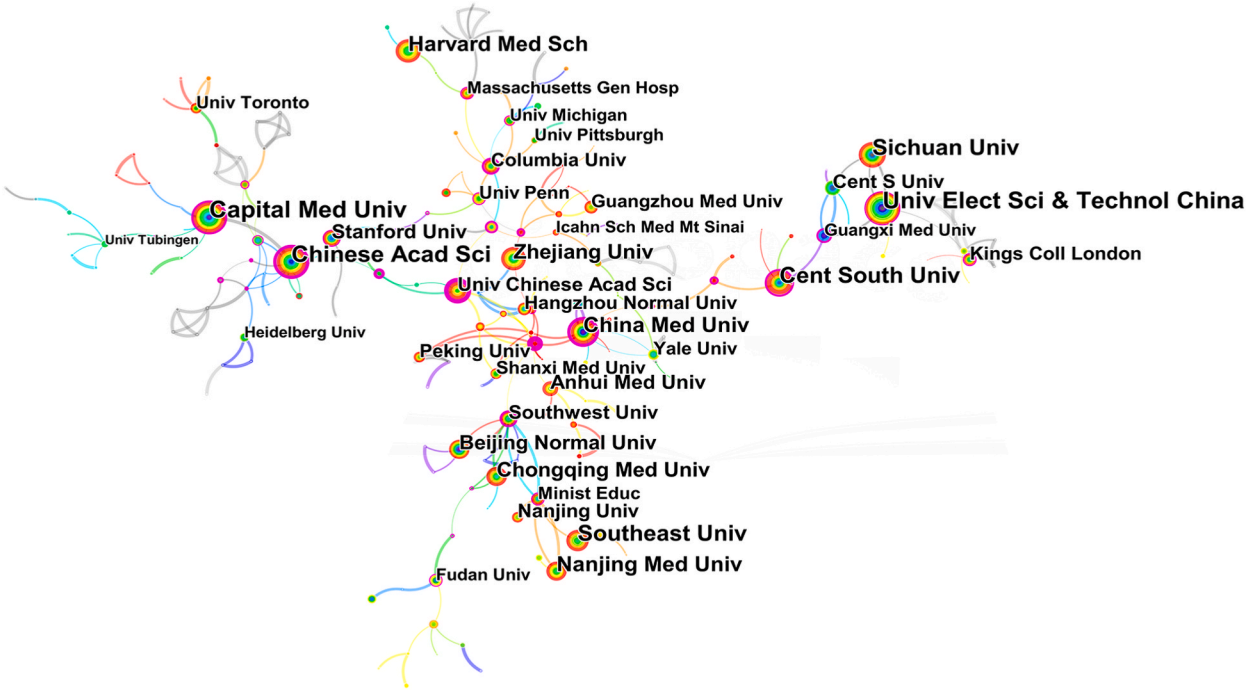

Fig. 4. Network of institutions in resting-state fMRI studies of MDD.

the field of resting-state fMRI research on MDD. Furthermore, several other influential journals, including Human Brain Mapping, American Journal of Psychiatry, PLOS ONE, Journal of Neuroscience, Neuropsychopharmacology, and Cerebral Cortex also make a substantial contribution to the development of knowledge in this research area. Particularly, among the top 10 most co-cited journals, 7 journals have an impact factor (IF) greater than 5, with 3 journals having an IF greater than 10, emphasizing the high academic quality and significance of these journals in this field. Researchers can rely on these journals as reliable sources to access the latest advancements and contribute to the progress of resting-state fMRI research in understanding MDD.

Fig. 7 provides a dual-map overlay of the journals of resting-state fMRI research in MDD. Each dot represents a journal, categorized into different clusters. The clusters are labeled with common terms found in the citing (left side) and cited (right side) journals. The colored lines represent the citation relationships between disciplines, reflecting knowledge flow and cross-disciplinary connections. Line thickness represents the frequency of citations, determined by scaled z-scores. Five main citation paths were identified and ranked

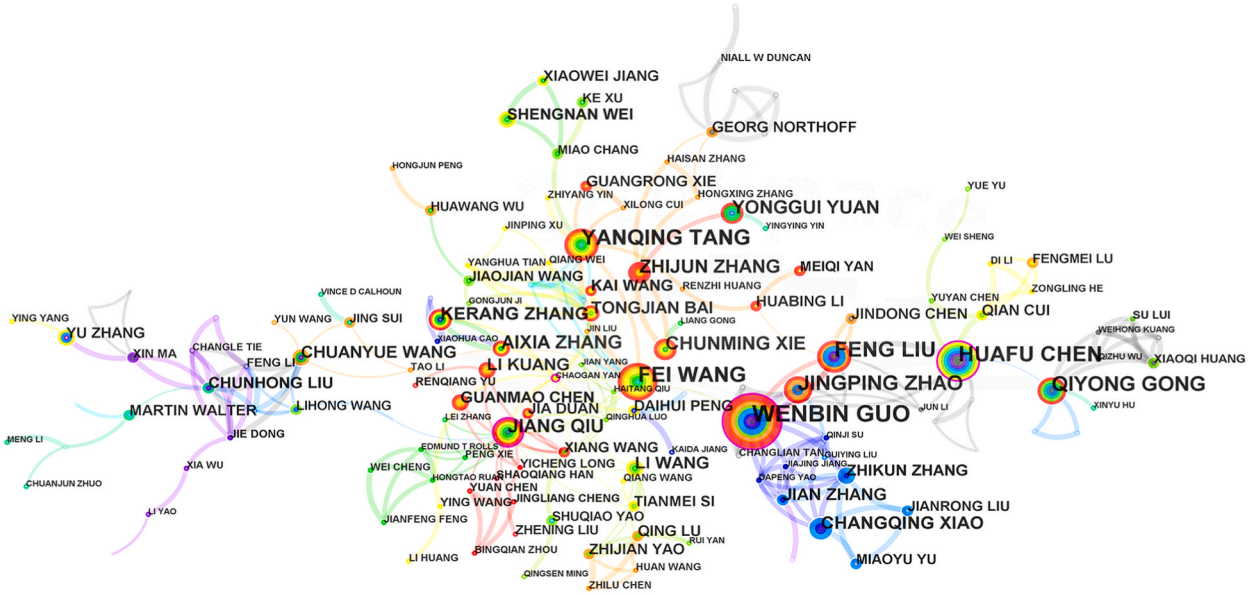

Fig. 5. Network of co-authors in resting-state fMRI studies of MDD.

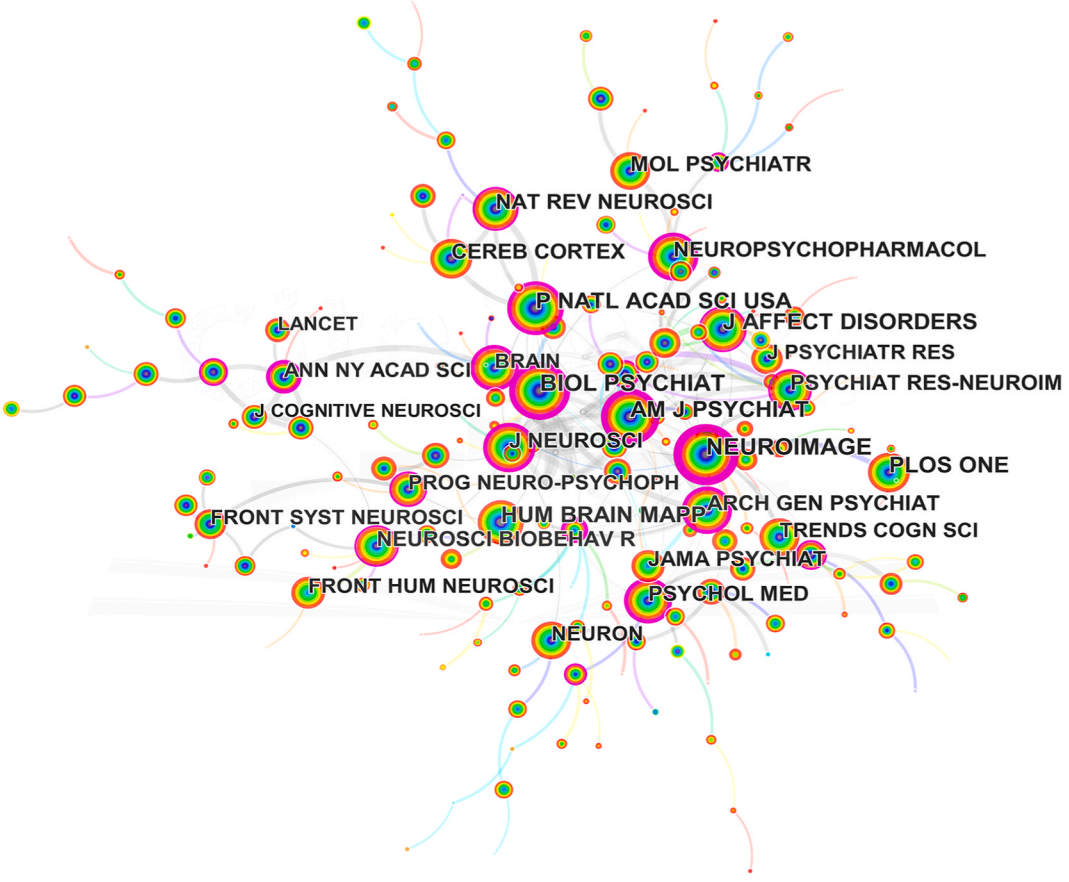

Fig. 6. Network of journals in resting-state fMRI studies of MDD.

by z-scores, as shown in Table S6. Research domains covered diverse fields, including Psychology/Education/Health, Molecular/Biology/Immunology, and Neurology/Sport/Ophthalmology. These areas are influenced by Psychology/Education/Social, Molecular/Biology/Genetics, and Psychology/Education/Social.

3.6. Citation burst keyword analysis

Fig. 8 provides an overview of the 28 keywords with citation bursts, shedding light on research hotspots and emerging trends in the field of resting-state fMRI research for MDD. The most recent burst keywords, including dynamic functional connectivity, machine learning, connectome, cognitive control network, electroconvulsive therapy, transcranial magnetic stimulation, suicide attempt, and childhood trauma, illustrate the current focus areas and emerging topics within the research community.

4. Discussion

To the best of our knowledge, this study represents the first attempt to conduct bibliometric analysis, exploring the research trends and frontiers of resting-state fMRI in MDD research. By analyzing publication output, country collaborations, research institutions, author collaborations, and influential journals, we have highlighted developments in this field and pinpointed potential directions for future research.

4.1. Growing interest and global collaboration in resting-state fMRI research on MDD

Over the past 25 years, there has been a prominent and consistent growth in the number of publications utilizing resting-state fMRI in MDD research (Fig. 1). This rise can be attributed to several factors, including the growing popularity of resting-state fMRI as a technique and the increasing attention being paid to MDD as a global health issue [34,35]. Resting-state fMRI has proven to be a valuable tool in unraveling the pathophysiology of depression, allowing researchers to identify abnormal local activity [36], functional connectivity [37], and whole-brain functional network [38] associated with MDD [9,39]. From the perspective of national contributions, China has demonstrated the highest publication output in the field of resting-state fMRI studies on MDD. However, there is still potential for enhancing international collaboration. On the other hand, the United States of America exhibits the highest centrality, suggesting its global influence in this domain. Germany and England have also made contributions to the field, further enriching the global research landscape. To promote knowledge innovation and technological progress in this domain, it is essential to enhance collaboration among different countries. International cooperation not only strengthens data sharing and resource integration but also accelerates the translation and application of research findings, leading to improvements in depression treatment and management.

Among the research institutions, the University of Electronic Science and Technology of China, Capital Medical University, and Harvard Medical School have emerged as major contributors to the advancement of resting-state fMRI research for MDD. In the collaborative network of institutions, Chinese organizations hold the largest proportion, indicating the China's considerable research activity and influence in this field. However, it is crucial to enhance communication and collaboration among research institutions from diverse countries and regions, enabling collective efforts to address challenges and advance scientific progress for the betterment of society. Through bibliometric analysis, we have also identified a group of outstanding authors in the field of resting-state fMRI research on MDD. Among them, Wenbin Guo stands out as the author with the highest number of published papers, while Qiyong Gong has demonstrated the highest centrality value in this research area. These authors have made contributions to the progress of our

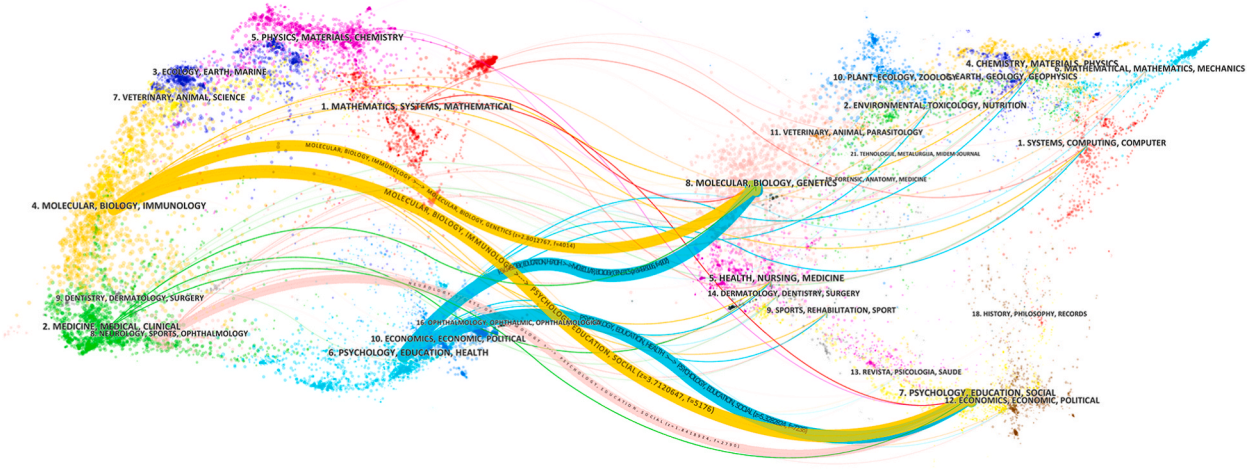

Fig. 7. Dual-graph overlays of journals in resting-state fMRI studies of MDD.

Keyword	Year	Strength	Begin	End	1998-2022
prefrontal cortex	1998	5.12	**1998**	2011	
cingulate	1998	3.92	**1999**	2015	
mood	1998	4.14	**2001**	2012	
amygdala	1998	2.41	**2002**	2009	
hippocampal volume	1998	3.06	**2003**	2013	
motor cortex	1998	2.79	**2004**	2012	
neural response	1998	5.58	**2006**	2017	
functional neuroanatomy	1998	2.05	**2006**	2008	
default mode	1998	5.48	**2007**	2015	
abnormal neural activity	1998	2.78	**2009**	2016	
antidepressant treatment	1998	3.04	**2010**	2011	
regional homogeneity	1998	5.54	**2011**	2014	
independent component analysis	1998	2.61	**2012**	2014	
autobiographical memory	1998	2.33	**2013**	2014	
deep brain stimulation	1998	2.29	**2014**	2014	
gray matter volume	1998	2.93	**2015**	2017	
functional connectivity density	1998	3.6	**2016**	2017	
insular cortex	1998	4.89	**2017**	2018	
reliability	1998	3.52	**2018**	2022	
machine learning	1998	4.93	**2019**	2022	
dynamic functional connectivity	1998	4.79	**2019**	2022	
connectome	1998	4.09	**2019**	2022	
cognitive control network	1998	2.63	**2019**	2022	
electroconvulsive therapy	1998	2.44	**2019**	2022	
biomarker	1998	5.42	**2020**	2020	
transcranial magnetic stimulation	1998	4.68	**2020**	2022	
suicide attempt	1998	2.97	**2021**	2022	
childhood trauma	1998	2.43	**2021**	2022	

Fig. 8. Top keywords with strongest citation bursts in resting-state fMRI studies of MDD.

understanding of the neural mechanisms underlying MDD.

In terms of journal distribution, Neuroimage emerges as the leading publication with the highest number of co-citations, closely followed by Biological Psychiatry, Journal of Affective Disorders, and Proceedings of the National Academy of Sciences of the United States of America. These highly-cited journals serve as reliable and indispensable sources of information for researchers investigating MDD using resting-state fMRI, offering access to the latest progress and research contributions in the field. Researchers can rely on the outcomes published in these reputable journals as crucial references and support for their own studies, aiding in the thorough understanding and effective treatment of depression. Moreover, the interdisciplinary nature of resting-state fMRI research on MDD is

highlighted by the frequent cross-referencing among journals specializing in various fields such as health, psychology, molecular biology, and genetics, illustrating its extensive scope. Collaborations across these diverse disciplines are crucial for advancing our understanding and developing innovative diagnostic and treatment strategies.

4.2. Emerging research trends and hot topics

The identified prominent keywords in the citation burst keyword analysis, such as dynamic functional connectivity and machine learning, highlight the diverse and relevant areas of investigation. By comparing our research focus with existing publications and the perspectives of other scholars, we have found substantial agreement with previous research findings, which further validates the results of our analysis. For instance, Yao et al. conducted research that employed time-varying connectivity analysis to identify functional connectivity abnormalities in patients with MDD, indicating that dynamic functional connectivity analysis might aid in the clinical diagnosis of depression [40]. Similarly, Luo et al. discovered dynamic functional connectivity aberrations related to childhood trauma, supporting the idea that childhood trauma may have an impact on the development of MDD [41]. Furthermore, Harris and colleagues utilized machine learning techniques, functional connectivity metrics, and dimensionality reduction algorithms to develop a model that predicts the response of MDD patients to SSRI-class medications using resting-state fMRI data [42]. Likewise, a recent study demonstrated that employing the multi-feature concatenation and multi-classifier stacking method, enhanced the ability to discriminate MDD using resting-state fMRI data, achieving an accuracy rate of 96.9% [43]. Therefore, the findings from our citation burst keyword analysis shed light on the current research patterns in the field of resting-state fMRI studies on MDD.

4.3. Impact and future trajectory of resting-state fMRI in MDD research

The exponential increase in publications from 1998 to 2022 has significantly enhanced our understanding of the neurobiological foundations of MDD. Key advancements include detailed insights into the roles of resting-state brain networks, particularly the default mode network and the salience network [44–46]. These networks are now understood to be central to the pathophysiology of MDD, influencing both its development and therapeutic approaches [47]. The growth in scientific research, coupled with advancements in neuroimaging technologies and analytical methods, has substantially deepened and enriched the quality of research in this field.

Emerging from resting-state fMRI studies, biomarkers of functional connectivity have been proposed as tools for personalizing treatment strategies in MDD. Specific connectivity patterns have been identified that predict individual responses to certain antidepressants or psychotherapies, offering a foundation for personalized treatment protocols [48–50]. This capability is promising for enhancing treatment efficacy and improving patient outcomes by customizing therapeutic strategies to individual neurobiological profiles. The use of these biomarkers in clinical settings illustrates the practical application of our enhanced understanding, directly contributing to optimized patient care in affective disorders.

In the future, resting-state fMRI is expected to maintain a crucial role in the investigation of MDD, propelled by technological advancements such as deep learning [51] and large language model applications [52]. These cutting-edge techniques are anticipated to enhance our ability to elucidate more detailed aspects of the neural basis of MDD. Such developments hold the potential to identify novel therapeutic targets and refine clinical interventions, thereby continuing to drive both academic interest and practical applications in the field.

4.4. Limitations

Several limitations of this study should be acknowledged. First, there may be a bias introduced by relying solely on the Web of Science database, which may not cover all relevant publications in this field. Second, the analysis is limited to English-language literature, potentially overlooking significant contributions published in other languages. Finally, by exclusively focusing on resting-state fMRI studies in MDD, the analysis disregards other neuroimaging modalities that could provide a deeper understanding of the neural mechanisms of MDD.

5. Conclusion

This bibliometric analysis provides a comprehensive overview of the scope of resting-state fMRI research in MDD from 1998 to 2022. By examining the evolution of publication trends, collaborative networks, and emerging hotspots, we have identified significant advances and current challenges in the field. By conducting a thorough analysis of publication patterns, author contributions, and citation networks, we have revealed the core contributing countries and institutions that shape the research landscape. Future research should advance these insights, pursuing novel methods and technologies to improve our understanding and management of MDD, ensuring that scientific advancements are effectively translated into practical improvements in the real world.

Data availability statement

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

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CRediT authorship contribution statement

Linhan Fu: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Mengjing Cai:** Writing – review & editing, Writing – original draft, Formal analysis. **Yao Zhao:** Writing – review & editing, Writing – original draft, Formal analysis. **Zhihui Zhang:** Software, Resources, Investigation, Data curation. **Qian Qian:** Software, Resources, Investigation, Data curation. **Hui Xue:** Resources, Investigation, Data curation. **Yayuan Chen:** Resources, Investigation, Data curation. **Zuhao Sun:** Investigation, Data curation. **Qiyu Zhao:** Investigation, Data curation. **Shaoying Wang:** Investigation, Data curation. **Chunyang Wang:** Writing – review & editing, Funding acquisition. **Wenqin Wang:** Writing – review & editing. **Yifan Jiang:** Writing – review & editing. **Yuxuan Tian:** Writing – review & editing. **Juanwei Ma:** Writing – review & editing, Conceptualization. **Wenbin Guo:** Writing – review & editing. **Feng Liu:** Writing – review & editing, 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.e33833.

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