

## Original Article

# Characteristics of the top 100 cited electroencephalography articles on aging: a bibliometric analysis

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**Abstract:** Electroencephalography (EEG) is a widely used tool in neuroscience. To explore the features of the top 100 cited articles related to EEG and aging over the past decade, we conducted a bibliometric analysis using Web of Science Core Collection (WoSCC) data as of January 21, 2024. The selected top 100 cited papers were analyzed using VOSviewer and Excel. We examined the distribution of publication years, authors, institutions, countries/regions, and journals. Hotspots were identified through keyword analysis. The analyzed articles were published between 2014 and 2021, with the majority being published before 2020 (n=91). Citation counts in WoSCC ranged from 24 to 250, with a median of 40 and a mean of 53. A total of 818 authors from 283 institutions/territories contributed to these top papers. The United States of America (USA) (n=37), Germany (n=14), and Canada (n=11) ranked in the top three in terms of total publications or citations. The predominant journals were in the fields of Neuroscience (n=58), Geriatrics & Gerontology (n=22), Clinical Neurology (n=13), and Anesthesiology (n=9), which published most of the high-quality articles. Key themes included EEG, aging, Alzheimer's disease, mild cognitive impairment, functional connectivity, and alpha oscillations. Emerging topics included sleep, machine learning, delirium, postoperative cognitive function, virtual reality, monitoring, resting state, coherence, and transcranial direct current stimulation. In conclusion, this study provides a comprehensive overview of the trends in scientific literature on EEG in aging over the past decade. Authors and institutions from North America, Europe, and East Asia led in contributions. Journals focusing on neuroscience, geriatrics, and anesthesiology published the majority of articles. Degenerative neurological diseases and cognitive impairment were prominent topics, suggesting future studies should explore EEG's diagnostic utility for these disorders.

**Keywords:** Bibliometric analysis, electroencephalography, the elderly, top papers, hot spots

## Introduction

Electroencephalography (EEG) is a valuable technique for clinical diagnosis and neuroscience research. It offers economic accessibility, non-invasiveness, functional sensitivity, temporal accuracy, and ongoing refinement [1, 2]. Despite advancements in neuroimaging technologies, EEG retains its importance for assessing brain activity and neural function. It is extensively used in diagnosing and monitoring neurological disorders, especially epilepsy [3, 4]. Non-epileptiform EEG findings in patients with altered consciousness aid in clinical decision-making. Moreover, EEG provides insights into acute and chronic neurological conditions

like dementia, metabolic encephalopathy, stupor, coma, and brain death determination [5, 6].

With the aging population, there's a growing focus on neurodegenerative diseases linked to nervous system degeneration. Conditions like Alzheimer's disease (AD), Parkinson's disease, Huntington's disease, amyotrophic lateral sclerosis, and dementia are closely tied to aging [7, 8]. These diseases primarily impact self-care abilities, escalating societal burden. According to the World Health Organization, AD and related dementias account for nearly 2 million deaths globally, ranking 7th among the top 10 causes of death in 2019 [9]. Mental health dis-

## Bibliometric analysis of the top-100 articles on EEG

orders also affect older adults significantly, with reports indicating a quarter to a third of European seniors suffering from such disorders, leading to diminished quality of life and functional capacity [10, 11]. Abnormal brain electrical activity is associated with both neurological and psychiatric disorders. Given its widespread use as a diagnostic tool, EEG research on the elderly has seen substantial growth, highlighting the importance of understanding current trends and focal points in this domain.

Bibliometric analysis provides insights into publication characteristics, including publication year, volume, and journal distribution [12]. Global trends can also be discerned by examining authors, institutions, and their nationalities [12, 13]. Bibliometric analysis has been extensively used to delineate current states and key areas in various scientific fields, such as obstetrics and gynecology [13], chronic heart failure [14], proteolysis targeting chimera [15], among others. However, there is a dearth of bibliometric research focused on EEG in the elderly, particularly regarding highly cited articles. Therefore, our study aims to delve into the features of the top 100 cited articles in this field over the past decade using bibliometric methods.

### Methods

Since this study is a bibliometric analysis based on previously published data, ethical approval is not required.

On January 21, 2024, using the Web of Science Core Collection (WoSCC), we searched for articles related to EEG on the elderly published between 2014 and 2023 using the following retrieval formula: (TS = (electroencephalography) OR TS = (electroencephalogram) OR TS = (EEG)) NOT (TS = (stereoelectroencephalography) OR TS = (intracranial encephalography) OR TS = (scalp electroencephalography) OR TS = (oval foramen electrode)) AND (TS = (elderly patients) OR TS = (gerontal patients) OR TS = (geriatric patients) OR TS = (older adults)). We further limited the search to English language articles and excluded reviews, meta-analyses, case reports, case series, proceedings papers, commentaries, editorials, letters, and retractions.

The retrieved records were then ranked in descending order based on citation count. Two

independent researchers reviewed the abstracts and methods to select eligible articles. Subsequently, the top 100 cited articles were selected and exported to plain text and Excel files, respectively. The extracted information for each article included the title, journal name, publication year, citation count, authors, affiliations, nationalities, and WoS categories. Journal impact factor (IF) (version 2022) and Journal Citation Report (JCR) locations of the journals were manually obtained from WoS.

Descriptive statistics were used to analyze quantitative characteristics, such as the annual publication count. VOSviewer software was utilized to analyze relationships among authors, institutions, countries/regions, journals, and keywords. Due to the inherent limitations of VOSviewer, the science maps can only display the largest cluster of interconnected items.

### Results

The most frequently cited article had 250 citations in WoSCC, while the least cited one had 24 citations. The mean number of citations was 53, with a median of 40. **Table 1** presents the top 10 articles based on citations. These 100 articles were published between 2014 and 2021, with the majority appearing before 2020 (n=91) (**Table 2**). The number of classic publications steadily increased from 2014 (n=11) to 2017 (n=20), followed by a decline (**Table 2**). Among the publication years, 2015 had the highest mean citations (n=67), while 2017 had the lowest (n=46) (**Table 2**).

The top 100 most cited articles were authored by 818 researchers from 283 institutions across 35 countries/territories. The most prolific authors included Babiloni Claudio, Del Percio Claudio, Frisoni Giovanni B, Gesualdo Loreto, Lizio Roberta, and Soricelli Andre, while the most impactful authors were Avidan Michael S, Ben Abdallah Arbi, Fritz Bradley A, Maybrier Hannah R, and Lin Nan. Nobili Flavio had the highest average citations per article, followed by Triggiani Antonio Ivano, Carducci Filippo, Basar Erol, Lopez Susanna, and Mundi Ciro (**Figure 1**). Among institutions, Harvard Medical School emerged as the most productive, with IRCCS San Raffaele Pisana following closely behind. Harvard Medical School also ranked as the most influential institution, along with Washington University, University of

## Bibliometric analysis of the top-100 articles on EEG

**Table 1.** The top-10 cited article related to EEG on the elderly

Article Title	Citation	Journal	IF <sub>2022</sub>
Effect of Electroencephalography-Guided Anesthetic Administration on Postoperative Delirium Among Older Adults Undergoing Major Surgery The ENGAGES Randomized Clinical Trial	250	JAMA	120.7
Old Brains Come Uncoupled in Sleep: Slow Wave-Spindle Synchrony	247	Neuron	16.2
The Ageing Brain: Age-dependent changes in the electroencephalogram during propofol and sevoflurane general anaesthesia	223	British Journal of Anaesthesia	9.8
Intraoperative Electroencephalogram Suppression Predicts Postoperative Delirium	191	Anesthesia and Analgesia	5.9
Functional connectivity assessed by resting state EEG correlates with cognitive decline of Alzheimer's disease - An eLORETA study	137	Clinical Neurophysiology	4.7
Human Brain Networks in Cognitive Decline: A Graph Theoretical Analysis of Cortical Connectivity from EEG Data	126	Journal of Alzheimers Disease	4
Sleep as a Potential Biomarker of Tau and $\beta$ -Amyloid Burden in the Human Brain	123	Journal of Neuroscience	5.3
Older People's Experiences of Mobility and Mood in an Urban Environment: A Mixed Methods Approach Using Electroencephalography (EEG) and Interviews	88	International Journal of Environmental Research and Public Health	-
Sleep spindles and rapid eye movement sleep as predictors of next morning cognitive performance in healthy middle-aged and older participants	86	Journal of Sleep Research	4.4
Occipital sources of resting-state alpha rhythms are related to local gray matter density in subjects with amnesic mild cognitive impairment and Alzheimer's disease	85	Neurobiology of Aging	4.2

**Table 2.** Distribution of publication year and the citation count

Publication Year	Documents	Citations	Average Citations
2021	2	101	51
2020	7	342	49
2019	19	944	50
2018	14	760	54
2017	20	914	46
2016	15	873	58
2015	12	801	67
2014	11	536	49

California Berkeley, University of Manitoba, and Washington University, all of which had higher mean citation rates (**Figure 2**). Regarding country contributions, the United States of America (USA) significantly outpaced others in both publications and total citations, trailed by Germany, Canada, and Italy (**Figure 3**). However, articles from Chile, New Zealand, and Belgium were relatively recent in publication (**Figure 3**).

The 100 articles were published across 73 journals, spanning over 20 disciplines within WoS. Neurosciences (n=58) had the highest representation, followed by Geriatrics & Gerontology (n=22), Clinical Neurology (n=13), and Anesthesiology (n=9). Journal impact factors (IF) ranged from 0 to 120.7, with an aver-

age of 6.066 and a median of 4.2. Regarding Journal Citation Report (JCR) quartiles, 28 articles were in Q1, 57 in Q2, 12 in Q3, and 2 in Q4. Only one journal was not classified in the system.

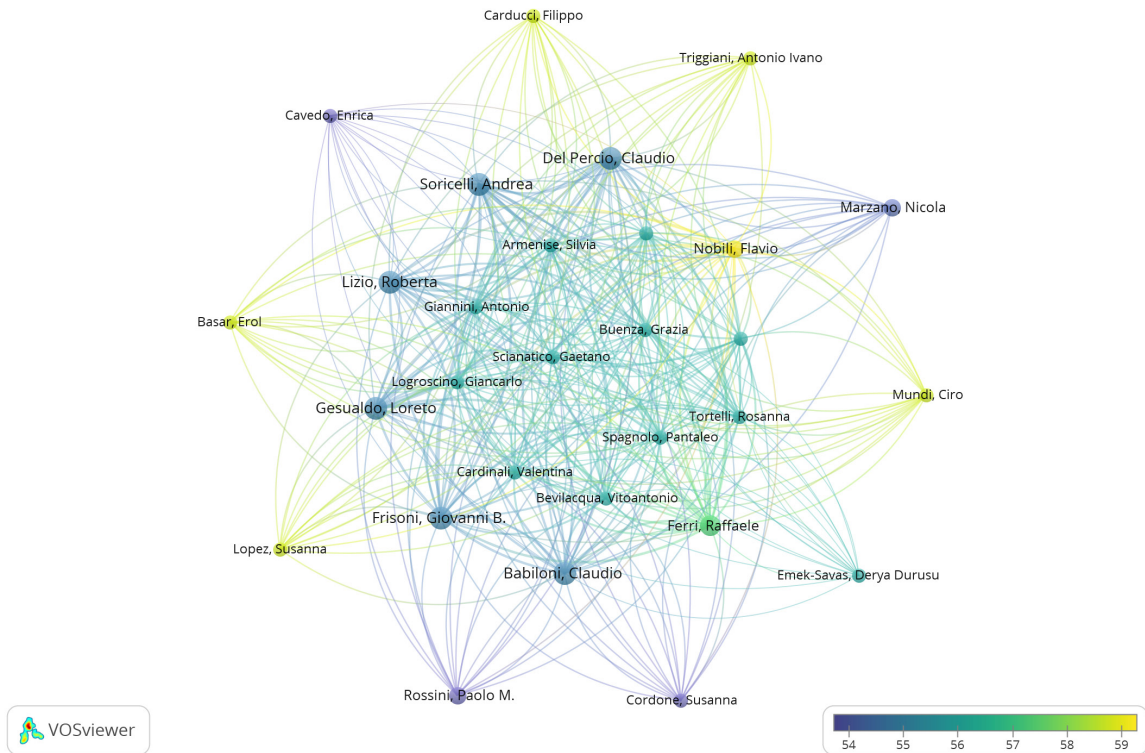
We conducted an analysis of Author Keywords provided by the authors. As shown in **Figure 4**, key topics included EEG, aging, Alzheimer's disease, mild cognitive impairment, functional connectivi-

ty, and alpha oscillations, while emerging themes comprised sleep, machine learning, delirium, postoperative cognitive function, virtual reality, monitoring, resting state, coherence, and transcranial direct current stimulation. Major diseases addressed in the literature were Alzheimer's disease, dementia, depression, and epilepsy. EEG features discussed included alpha and delta rhythms, power, P300, and functional connectivity.

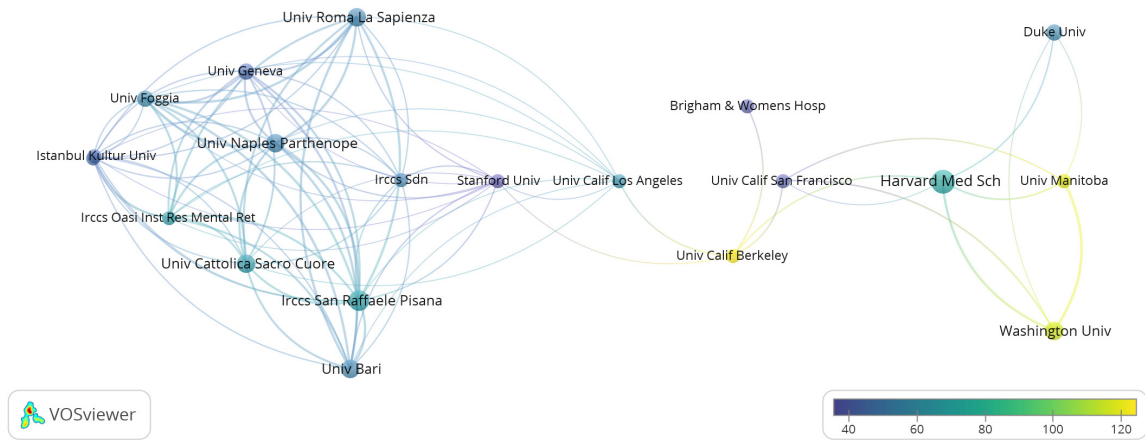
### Discussion

The present study is a bibliometric analysis aimed at examining the top 100 cited articles on EEG in WoSCC. We analyzed various aspects, including publication trends, citations, authors,

## Bibliometric analysis of the top-100 articles on EEG



**Figure 1.** Co-citation analysis of the authors.



**Figure 2.** Co-citation analysis of the institutions.

institutions, countries/regions, journals, and keywords of these articles.

Citation count is considered an objective measure of quality and is easily calculable using modern citation databases [16]. Analyzing the citation trends of articles can offer valuable insights into their significance within a specific field. However, this metric may not accurately reflect the impact of newer publications, as

their citation counts are typically lower due to limited time [17]. Our analysis of publication year distribution revealed that most articles have been in circulation for a considerable period, with newer ones needing time to accrue citations, aligning with this observation.

Additionally, we assessed usage count, which indicates the practical utility of publications based on the number of times their full text is

## Bibliometric analysis of the top-100 articles on EEG

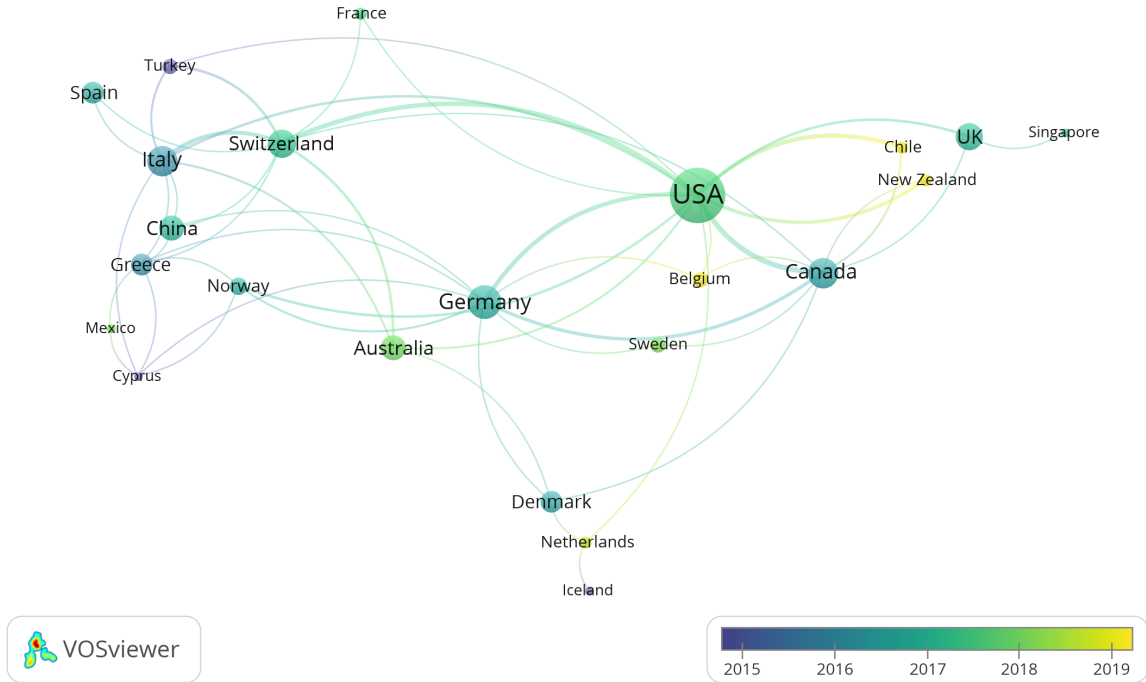


Figure 3. Co-citation analysis of the countries or regions.

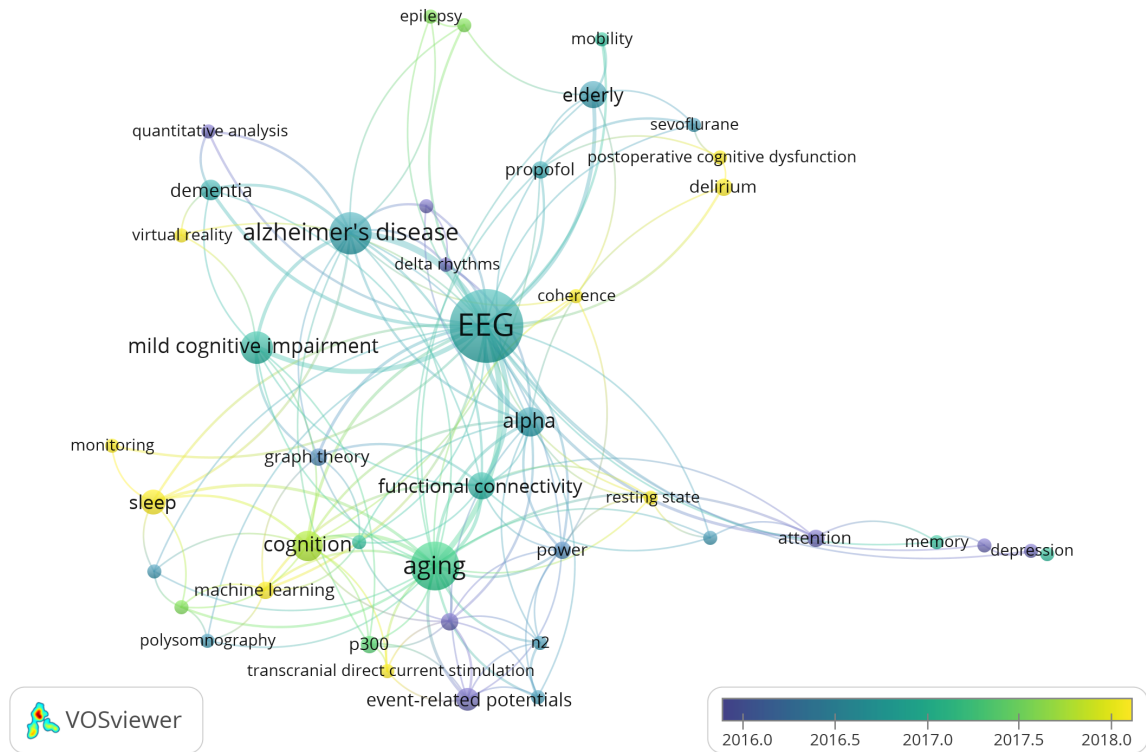


Figure 4. Co-occurrence analysis of the keywords.

accessed via URLs. In our study, we identified the most frequently cited article as of the

retrieval date. This top-ranked article, published in JAMA-Journal of the American Medical

## Bibliometric analysis of the top-100 articles on EEG

Association (IF=120.7) in 2019, is titled “Effect of Electroencephalography-Guided Anesthetic Administration on Postoperative Delirium Among Older Adults Undergoing Major Surgery: the ENGAGES Randomized Clinical Trial” [18]. Although this study did not yield positive outcomes, its findings can guide future research, stimulate discussion on study methodologies, and foster advancements in the field [19, 20].

Furthermore, we noted the most frequently accessed article in the past 180 days, published in 2020, titled “The Effect of a Virtual Reality-Based Intervention Program on Cognition in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial” [21]. This article also focuses on cognitive function in older adults, highlighting its significance as a current hot topic. Our keyword analysis corroborated the prominence of cognitive function in recent years, consistent with our earlier observations.

Sixty-four journals published the 100 articles. The highest number of papers (n=10) were published in *Neurobiology of Aging* (IF=4.2, Q2), followed by *Frontiers in Aging Neuroscience* (n=7, IF=4.8, Q2), *Frontiers in Neuroscience* (n=5, IF=4.3, Q2), and *Journal of Alzheimer’s Disease* (n=5, IF=4, Q2). This distribution of journals does not precisely align with Bradford’s law, which posits that a small number of core journals should account for a significant portion (1/3) of articles in a field, with a larger number of journals accounting for the next one-third, and a larger number still for the remaining one-third [22]. This deviation may be attributed to the comprehensive nature of EEG research on the elderly, which encompasses gerontology, neurology, psychiatry, imaging, anesthesiology, and more. Therefore, it’s challenging for a single journal to dominate in highly cited articles. Nevertheless, as 85% of the articles were published in journals ranked Q1 and Q2, it indicates that the highly cited articles are of high quality.

A total of 818 authors from 283 institutions across 35 countries/territories contributed to these top papers. The United States is the leading country in this field, with significant contributions also coming from countries in Europe and East Asia with developed economies. This trend may be attributed to factors such as increased funding, higher research quality, citation biases, and easier access to local journals for American authors [23].

Neuroscience plays a central role and is consistently featured prominently in citation classics because EEG is primarily used to detect neuronal electrical activities. However, one specialty that deserves more attention is anesthesiology. Our study results provide several reasons for this. Firstly, the article with the highest citations and IF is closely tied to anesthesiology [18]. This study investigated whether EEG-guided anesthesia could reduce postoperative delirium incidence in the elderly, a condition characterized by acute cognitive dysfunction [24]. With over 19 million elderly patients undergoing surgery under general anesthesia annually [25] and the global aging trend increasing, there will likely be an uptick in geriatric surgical cases [26]. Secondly, there are nine journals dedicated to anesthesiology, ranking fourth in terms of publication frequency. Lastly, postoperative cognitive function emerges as one of the latest hot keywords based on our keyword analysis.

Other hot topics in this field include aging, Alzheimer’s disease, mild cognitive impairment, and functional connectivity. Although EEG is commonly used to diagnose epilepsy [3, 27], its value and standards in diagnosing neurodegenerative diseases require further scrutiny [28, 29]. Additionally, emerging areas such as sleep, machine learning, delirium, postoperative cognitive function, virtual reality, and transcranial direct current stimulation indicate growing attention toward these topics.

There are a few methodological limitations to consider in this study. We only included articles published within the last 10 years, which means we may have overlooked earlier publications. However, given the rapid advancements in EEG research, older publications may offer less relevant guidance. While many studies use a citation count threshold of 100, this is not scientifically grounded. Citation counts vary both quantitatively and qualitatively across different databases. Our search was conducted in the WoSCC database, which primarily includes citations from journal articles. In contrast, Scopus may retrieve more citations from non-English sources but fewer citations from articles [30]. Consequently, the list and ranking of the top 100 articles may differ in other databases.

In conclusion, this study provides a comprehensive analysis of the top 100 cited articles on

EEG in the elderly, offering insights into trends in scientific literature in this field over the last decade. Authors and institutions in North America, Europe, and East Asia demonstrate strong scientific research capabilities and high-quality output. Journals focusing on neuroscience, geriatrics, and anesthesiology publish the majority of articles. Degenerative neurological diseases and cognitive impairment remain hot topics, suggesting future studies should continue to explore how EEG can aid in diagnosing these disorders.

#### Disclosure of conflict of interest

None.

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## Bibliometric analysis of the top-100 articles on EEG

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