NEUROSCIENCE RESEARCH NOTES

OPEN ACCESS | DATA NOTES ISSN: 2576-828X

Mapping the research landscape on chronic pain and electroencephalography (EEG): a bibliometric analysis

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Received: 2 October 2025; **Accepted:** 8 January 2025; **Published:** 20 April 2025
Edited by: Norshariza Nordin (Universiti Putra Malaysia, Malaysia)
Reviewed by: Kadir Uludag (Chinese Academy of Sciences, China);
Nurfaizatul Aisyah Ab Aziz (Universiti Sains Malaysia, Malaysia)
https://doi.org/10.31117/neuroscirn.v8i2.396

Abstract: Chronic pain is a complex and debilitating condition that affects an estimated 1.5 billion individuals worldwide. The impact of chronic pain extends beyond the individual, with significant socioeconomic consequences, including health care costs and decreased performance. Today, electroencephalography (EEG) has become a valuable non-invasive tool in the study of chronic pain, allowing researchers to measure and analyse the brain's electrical activity in response to pain stimuli. Thus, this bibliometric analysis evaluated the literature on chronic pain and EEG, identified main themes, authors, institutions, author keywords, and publications in the field and assessed the research impact and influence in this study area from 1972 to 2023. First, datasets were obtained from Web of Science (WoS) and Scopus, then analysed using ScientoPy and VOSviewer software. There has been a steady increase in the literature on chronic pain and EEG since 1972. In 2021, a significant number of publications (n = 69) were in WoS. Furthermore, "Neuroscience & Neurology" was the most popular subject matter, with 388 publications. Meanwhile, the top five author keywords associated with this subject were "chronic pain", "EEG", "fibromyalgia", "spinal cord injury", and "neurofeedback". The term "machine learning" has garnered significant attention in recent years, particularly in 2022 and 2023. In summary, the trend in chronic pain and EEG research has consistently shown a rise in scholarly interest. These study findings can guide future research efforts, policy-making, and practical measures in diagnosing and managing chronic pain, which can improve patients' well-being and quality of life.

Keywords: Chronic pain; EEG; Brainwaves; Bibliometric

1.0 INTRODUCTION

Pain is subjective, as it is a complex experience that involves both somatic mechanisms and psychological influences. It can be classified based on mechanism (nociceptive, inflammatory, or neuropathic) (King, 2013) or time (acute < 3 months or chronic > 3 months) (Bennett, 2010). Chronic pain research has contributed to new knowledge and treatment developments in the past decades. Despite that, chronic pain still recorded a high prevalence and disease and financial burden, thus remaining a global health concern (Breivik et al., 2005; Cohen et al., 2021; Vos et al., 2016).

Generally, healthcare practitioners opt for a multidisciplinary approach to managing chronic pain, which aligns with the biopsychosocial model (Cohen et al., 2021). This approach underscores the importance of non-pharmacological treatment options (Hylands-White et al., 2016), such as detecting brainwave activity via electroencephalography (EEG) neurofeedback.

The EEG is a non-invasive tool that offers reliable and relevant information about brainwave activity during sensory stimulation, cognitive tasks, and at rest (De Vries et al., 2013), thus valuable for objective pain analysis (Burle et al., 2015; Fallon et al., 2017; Kim et al., 2018; May et al., 2018; Meneses et al., 2016; Villafaina et al., 2019). Furthermore, this technique is suitable for the clinical setting because it is safe, economical, mobile, and easy to handle (Spronk et al., 2010).

Brainwaves comprise five frequencies which represent different states of brain activity: delta,ε (1-3 Hz), theta, θ (4-7 Hz), alpha, α (8-12 Hz), beta, β (13-30 Hz), and gamma, γ (>30 Hz) (Ali et al., 2024). Delta dominates in deep sleep and the unconscious mind, while theta is prevalent when an individual experiences dreamless sleep, is drowsy, inattentive, meditating, or in a trance. Meanwhile, the brain emits alpha brainwaves when relaxed, beta brainwaves when alert or focused, and gamma brainwaves during learning and concentrating. Numerous EEG studies have associated brain wave patterns with pain processing and discovered the synchronisation of EEG brainwaves produced by neurons in different brain regions when one is in pain.

Research on chronic pain and EEG has revealed different patterns in brainwave activity. For instance, patients who suffer from chronic pain experienced absolute power reductions in delta, theta, and alpha brainwaves in their frontal, middle, and temporal sites and increased relative beta power in the parietal region (Burroughs, 2011). These patients demonstrated increases in theta and alpha EEG power even at rest (Pinheiro et al., 2016).

Meanwhile, individuals with spinal cord injury and chronic pain produced higher theta and reduced alpha activities than those without pain (Jensen et al., 2013). Another study reported that the rise in alpha power among chronic low back pain patients suggests enhanced sensory information gating, highlighting a potential mechanism for pain perception (Bemani et al., 2023). According to Rajan et al., significant increases in the spectral density of delta, theta, and beta power were evident in patients with chronic neuropathic pain, indicating the differences in EEG patterns between the patients and healthy controls (Rajan et al., 2024). Furthermore, chronic pain patients exhibited increased theta and gamma brainwaves at the frontal brain regions and global network reorganisation in gamma brainwaves (Ta Dinh et al., 2019). Therefore, quantitative EEG may be beneficial in studying brain mechanisms involved in chronic pain to measure and evaluate therapeutic interventions (Pinheiro et al., 2016).

The current study utilised bibliometric methods to evaluate and analyse the existing literature on chronic pain and EEG. The analysis identified key themes, authors, and publications in the field and assessed the research impacts and influence in this study area from 1972 to 2023. This study also determined knowledge gaps in the existing literature on chronic pain and EEG, which require scholarly attention. **Table 1** presents the research questions derived from the research objectives of this study.

2.0 MATERIALS AND METHODS

The bibliometric analysis is a quantitative research method comprising the processes of identifying, organising, and analysing the main components in a specific field to determine the research quality and impact (Ruiz-Rosero et al., 2019). Furthermore, this method evaluates the contributions of influential authors, journals, countries, and institutions.

ScientoPy is the literature review script used to analyse the bibliographies in the present study. This open-source Python script is free and automatically identifies popular topics (based on author keywords), authors, countries, and documents on the subject matter. The automatic data synthesis eliminates bias, as in individual publications (Ruiz-Rosero et al., 2017). In addition, VOSviewer was utilised in the current study to map the co-occurrence of authors' keywords.

Table 1. Research questions (RQ).

	Research questions	Motivations
RQ1	What are the trends in the publication of chronic pain and EEG over the past decade?	To gain a better understanding of the current state of research on chronic pain and EEG
RQ2	What are the key scientific journals and research areas that have contributed to the field of chronic pain and EEG?	To provide insights into the progress of this subject and areas that require further research
RQ3	What are the top publications in the field of chronic pain and EEG?	To identify the most highly cited publications
RQ4	What are the most productive institutions, countries, and authors that have published research on chronic pain and EEG?	To identify the most productive institutions, countries and authors
RQ5	What are the major themes and research gaps requiring further investigation in chronic pain EEG?	To identify significant themes in the literature and provide recommendations for future research on chronic pain and EEG

2.1 Dataset

The study data were retrieved from Clarivate Web of Science (WoS) and Scopus databases. These databases are popular among researchers worldwide and are the world's largest abstract and citation databases of peer-reviewed research (Abdullah, 2021; Sweileh, 2020). The study period was set between January 1, 1972, and December 31, 2023.

The search was conducted using the string ("chronic pain" OR "persistent pain" OR "neuropathic pain") AND ("EEG" OR "electroencephalography" OR "brainwaves"), and the information was extracted on September 3, 2024. At the end of this process, 1768 documents were obtained from the databases. Subsequently, the dataset was analysed via ScientoPy and VOSviewer.

2.2 Pre-processing

ScientoPy was used at this stage to ensure that the dataset was unique and to generate a secondary bibliographic dataset for further analysis. The software normalised the dataset through several steps: (1) Replacing the author's name with a semicolon for the Scopus metadata, (2) removing dots, commas, and special characters from the metadata of both databases, and (3) eliminating duplicated samples (Abdullah & Sofyan, 2023; Rodriguez Pabon et al., 2020).

Figure 1 illustrates the pre-processing step, where documents were loaded from each database and duplicate records were removed. The ScientoPy pre-processing script prioritises Scopus documents over WoS documents. There were more documents sourced from Scopus than WoS after removing the duplicated items.

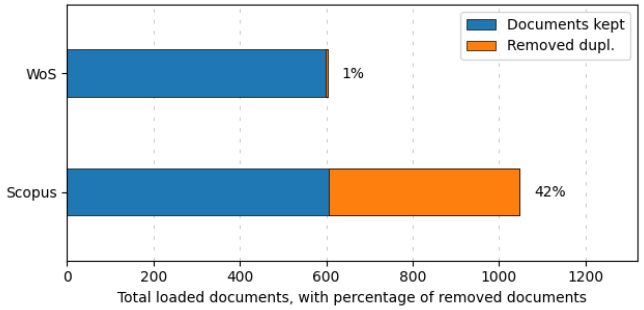

Figure 1. Pre-processing of data retrieved from WoS and Scopus databases.

Table 2 presents the initial results of the search, comprising 1768 raw data from WoS and Scopus. The first filtering process excluded 117 publications (6.60%), resulting in 1,651 publications for the deduplication step. A total of 448 duplicates were detected from both databases; thus, only 1203 publications were utilised in the current study [WoS: 598 (49.70%), Scopus: 605 (50.30%)].

3.0 RESULTS

3.1 Publication growth

Figure 2 shows the growing trend for publications in the field from 1972 to 2023, which can be divided into three distinct periods: early (1972–2001), growth (2002–2013), and surge (2014–2023). The early period (1972–2001) demonstrated limited research activity, with less than five documents published annually by Scopus and WoS. The research is still in its infancy, with sporadic contributions laying the groundwork for future growth.

During the growth period (2002–2013), there was a steady increase in research output, characterised by a rise in annual publications (from fewer than 10 to approximately 30 publications) by 2013. Advances in research methodology, the expansion of digital

databases, and increased global collaboration contributed to consistent growth during this period. Scopus consistently indexes more documents than WoS, reflecting its broader coverage.

The recent surge (2014–2023) saw an exponential increase in research activity, producing approximately 70 publications per year in Scopus (2022-2023). This surge could be attributed to increased funding, interdisciplinary research, and global interest in the topic. Despite the significant database improvements, Scopus outperformed WoS in document counts, possibly due to its broader indexing of interdisciplinary research. This trend reveals the evolving nature of the field from its early development to its current expansion, demonstrating the critical periods of growth and the role of databases such as Scopus and WoS in capturing scholarly outputs.

Table 2. Data integration and duplicate exclusion.

Data pre-processing output	Information	Number	%
Initial results	Raw data from WoS and Scopus	1768	-
	Automatic type-filter publication to remove non-related document(s)	117	6.60
	Total publications after selecting document types (Research articles, conference papers, review papers, proceedings papers, and articles in press)	1651	-
	Publications in WoS	603	36.50
	Publications in Scopus	1048	63.50
Duplicate removal	Duplicated publications in both databases	448	27.10
	Duplicated publications from WoS	5	0.80
	Duplicated publications from Scopus	1048	63.50
Final results	Total publications after duplicate removal	1203	-
	Publications in WoS	598	49.70
	Publications in Scopus	605	50.30

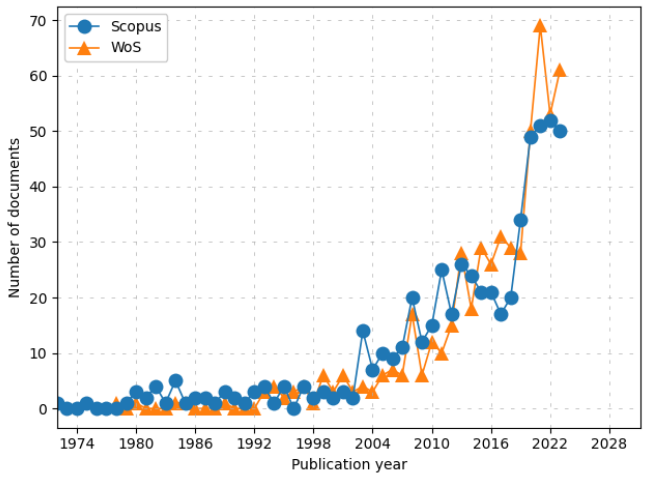

Figure 2. Publication growth trends in WoS and Scopus databases.

3.2 Key scientific journals and research areas

Based on **Figure 3**, "Pain" was the most prolific journal, with over 40 published documents. Of these, 11% were published between 2022 and 2023, indicating a relatively stable publication rate in recent years. Meanwhile, the "Frontiers in Neuroscience" journal demonstrated significant growth, increasing by 44% from 2022 to 2023, highlighting a notable rise in activity over the last two years. Other prominent journals showing moderate growth between 2022 and 2023 include "Clinical Neurophysiology" and "Journal of Pain", which published 19% and 29% of the documents, respectively. Likewise, "Brain Science" and "PLOS One" illustrated similar trends, publishing 31% and 24% of documents in the last two years.

Journals such as "Neuromodulation" and "Pain Medicine" have also experienced a moderate increase in recent publications, with 20% of articles published between 2022 and 2023. Nevertheless, journals such as "The European Journal of Pain" and "NeuroImage" have seen only 10% of their publications recently, suggesting stable but non-significant growth. Overall, there has been an increasing trend in publications in several journals in the past two years, notably "Frontiers in Neuroscience" and "Brain Sciences," which is attributed to higher research activity. Other journals maintain a generally consistent publication rate (**Figure 3**). **Figure 4** shows that "Neurosciences & Neurology" is the top research area that studied chronic pain and EEG (388 publications), indicating a strong interest from experts in this field. Other fields with high publication rates on the subject in the last two years (2022–2023) are "Behavioural Sciences" at 40% and "Engineering" at 32% (**Figure 4**).

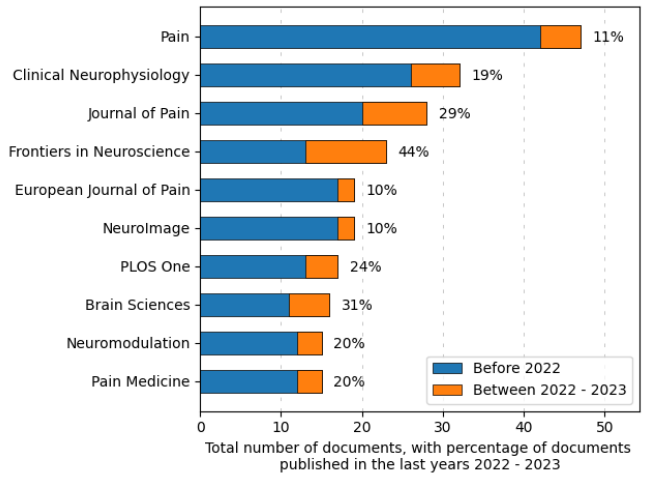

Figure 3. Top 10 scientific journals on chronic pain and EEG.

3.3 The most cited articles

Table 3 details the top 10 highly cited articles on chronic pain and EEG. The leading article on this subject, authored by Apkarian et al. (2005) on "Human brain mechanisms of pain perception and regulation in health and disease," was published in the European Journal of Pain and has been cited 2,490 times. The next popular article is 'Non-invasive electrical and magnetic stimulation of the brain, spinal cord, roots and peripheral nerves: Basic principles and procedures for routine clinical and research application: An updated report from an IFCN Committee' by Rossini et al. (2015) with 1883 citations, followed by 'How do sleep disturbance and chronic pain inter-relate? Insights from the longitudinal and cognitive-behavioural clinical trials literature' by Smith and Haythornthwaite (2004) with 712 citations. Among the top 10 articles, two were published in the Journal of Neurophysiology.

3.4 Most productive institutions

Authors listed in an article are often affiliated with an institution for publication purposes. Based on this data, ScientoPy synthesised information about institutions and countries. **Figure 5** and **Table 4** illustrate the top 10 most productive institutions in the field of chronic pain and EEG. The University of Glasgow in the United Kingdom is ranked first, with 23 publications and 1,072 citations, followed by Aalborg University, Denmark (20 publications), and the University of Washington, United States of America (USA) (19 publications). Harvard Medical School, USA and the Technical University of Munich, Germany, each recorded 14 publications, placing them in the top five most productive institutions.

3.5 Most productive countries

The USA is currently the leading country in terms of publications on chronic pain and EEG, with 365 publications in 2023, representing a significant increase since 2010 (**Figure 6**). This country also recorded the highest average number of publications per year in 2022 and 2023, indicating sustained leadership in research results. In addition, the USA leads in chronic pain and EEG research, with the highest average documents per year (ADY) at 31.5 and an h-Index of 62, reflecting the quantity and impact of research in the field. Nonetheless, the country charted a negative (-5) average growth rate (AGR), which can be attributed to the country's robust research results over time. Moreover, the USA demonstrated a consistent output rate, with 17.3% of its publications appearing in the last year (PDLY), indicating its active participation in the research field (**Table 5**).

The United Kingdom (UK), Germany, and China also experienced a steady increase in publications over time, with a cumulative publication count approaching or exceeding 100 documents. The UK demonstrated a substantial increase in productivity between 2022 and 2023 by producing a higher percentage of publications. Nevertheless, the UK has a strong h-Index of 42, reflecting ITS substantial contribution to the field. Meanwhile, Canada, Japan, Italy, Spain, France and Denmark exhibited similar trajectories with moderate but consistent publication growth. These countries reported between five and 15 documents per year from 2022 to 2023, with recent publications ranging between 10% and 30%. Each of these countries maintains a respectable h-Index, indicating the quality of their publications. This trend highlights the leading role of the USA, with European and Asian countries not far behind in the race.

Figure 7 illustrates the network visualisation of countries, displaying global collaborative relationships in chronic pain and EEG research. Each node symbolises a country, and its size reflects the number of publications contributed by the nation. The lines between nodes (links) represent the strength of collaboration between countries, as measured by co-authorship in research papers, with thicker lines indicating greater collaboration.

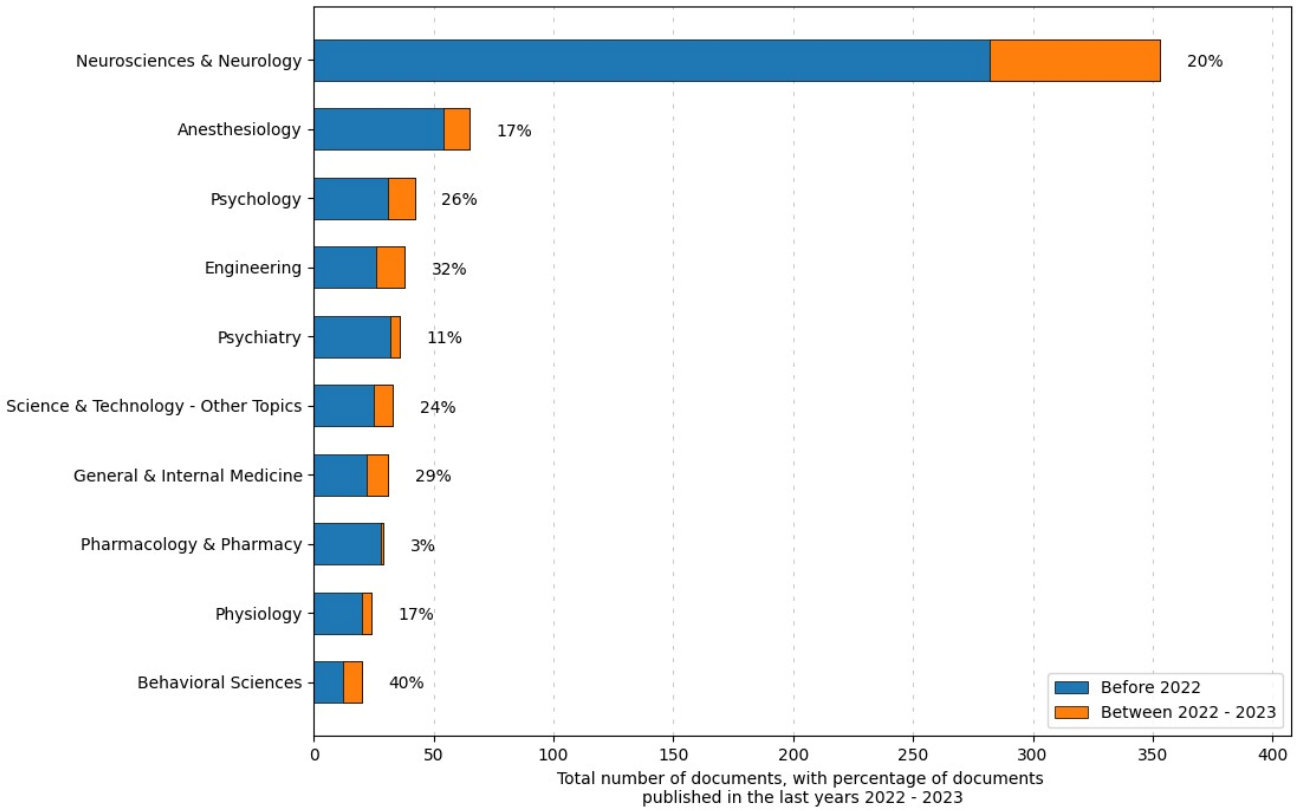

Figure 4. Top 10 research areas on chronic pain and EEG.

Table 3. Top 10 highly cited articles on chronic pain and EEG.

Rank	Authors	Title	Year	Source Title	Cited by	Document Type	Source
1	Apkarian AV, Bushnell MC, Treede RD, and Zubieta JK	Human brain mechanisms of pain perception and regulation in health and disease	2005	European Journal of Pain	2490	Review	WoS
2	Rossini PM, Burke D, Chen R, Cohen LG, et al.	Non-invasive electrical and magnetic stimulation of the brain, spinal cord, roots and peripheral nerves: Basic principles and procedures for routine clinical and research application: An updated report from an IFCN Committee	2015	Clinical Neurophysiology	1883	Review	Scopus
3	Smith MT and Haythornthwaite JA	How do sleep disturbance and chronic pain interrelate? Insights from the longitudinal and cognitive-behavioural clinical trials literature	2004	Sleep Medicine Reviews	712	Review	WoS
4	Miljanich GP	Ziconotide: Neuronal calcium channel blocker for treating severe chronic pain	2004	Current Medicinal Chemistry	518	Review	Scopus
5	Crowley K	Sleep and sleep disorders in older adults	2011	Neuro psychology Review	443	Review	Scopus

6	Sarnthein J, Stern J, Aufenberg C, Rousson V, and Jeanmonod D	Increased EEG power and slowed dominant frequency in patients with neurogenic pain	2006	Brain	357	Article	WoS
7	Herrington TM, Cheng JJ, Eskandar EN	Mechanisms of deep brain stimulation	2016	Journal of Neuro physiology	334	Review	Scopus
8	Claassen J, Doyle K, Matory A, Couch C, et al.	Detection of brain activation in unresponsive patients with acute brain injury	2019	New England Journal of Medicine	303	Article	Scopus
9	Jeanmonod D, Werner B, Morel A, Michels L, et al.	Transcranial magnetic resonance imaging-guided focused ultrasound: non-invasive central lateral thalamotomy for chronic neuropathic pain	2012	Neuro surgical Focus	297	Article	WoS
10	Mouraux A and Iannetti GD	Nociceptive Laser-Evoked Brain Potentials Do Not Reflect Nociceptive-Specific Neural Activity	2009	Journal of Neuro physiology	296	Review	WoS

This network visualisation highlights the global distribution of research in chronic pain and EEG, emphasising the vital role that specific countries play in fostering international collaboration. Encouraging collaboration with underserved nations can improve research outcomes in countries where chronic pain and EEG research are underrepresented.

Research collaborations are critical in most scientific fields; thus, this study also analysed co-authorships to observe how multiple authors worked together in chronic pain and EEG studies. Co-authorship can be defined as collaboration among multiple authors within the scientific community to achieve specific research objectives. Researchers are often eager to collaborate with other experts in their field, as this promotes the discovery of new knowledge and the development of better solutions to research challenges. Currently, there is no known limit for co-authorship analysis by country. Therefore, this study set the minimum number of publications of a country as 20 and the minimum number of citations as nil in the VOSviewer software. At the end of the analysis, 34 items, grouped into six clusters, met the threshold of 63 countries within the dataset. **Figure 7** presents the co-authorship between countries in the field of chronic pain and EEG research.

The USA, being the largest node, is a major contributor to chronic pain and EEG research, and it has strong collaborations with China, the United Kingdom, Germany, and Canada. China, Germany, and the United Kingdom are also major players in this field, forming extensive international cooperation in Europe and Asia. The green cluster includes countries such as France, Netherlands, Sweden, and Israel, reflecting a strong partnership in Europe. The blue cluster includes Spain, Brazil and Mexico, indicating collaboration within the Spanish and Latin American regions.

Meanwhile, the red cluster encompasses countries from the Asia Pacific region, including Australia, Japan, New Zealand, Taiwan, and India. Some countries, such as Thailand, are relatively isolated with fewer collaborations, which implies regional or independent research within the country.

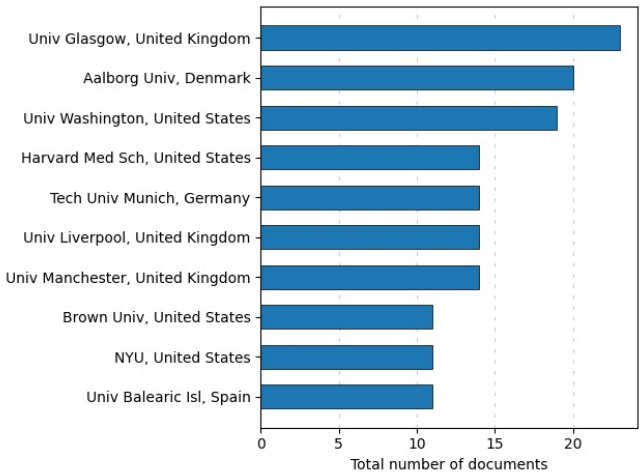

Figure 5. Top 10 productive institutions that contributed to chronic pain and EEG studies.

Table 4. Top 10 organisations/ institutions that contributed to chronic pain and EEG studies.

Affiliation	Total publications	No of citations	%
University of Glasgow, United Kingdom	23	1072	20.0
Aalborg University, Denmark	20	422	7.9
University of Washington, United States	19	839	15.7
Harvard Medical School, United States	14	189	3.5
Technical University of Munich, Germany	14	1214	22.7
University of Liverpool, United Kingdom	14	204	3.8
University of Manchester, United Kingdom	14	469	8.7
Brown University, United States	11	292	5.5
New York University (NYU), United States	11	252	4.7
University of the Balearic Islands, Spain	11	403	7.5
TOTAL of citations (summation of the top 10 affiliations)	-	**5356**	**100.0**

3.6 The most productive authors

Productive authors are researchers who produce a substantial number of publications, owing to their organised, disciplined, and high motivation in meeting deadlines and achieving writing goals. These authors may work on multiple projects at once or focus on one project until it is completed. Furthermore, they have strong research, organisational, and time management skills and may have the ability to work in various genres. **Table 6** lists the 10 highly productive authors who have published papers on chronic pain and EEG, with a minimum of 11 publications. The affiliated institutions and countries of these authors were identified from their latest work.

The analysis revealed that Jensen MP from the University of Washington is the most productive author, recording 17 publications with 705 citations. Likewise, Montoya P has produced the same number of publications as the leading author. Meanwhile, Vuckovic A has published 15 publications, and Fregni F and Jones AKP have written 14 documents each. Not far behind are Ploner M and Wang J with 13 publications each, and De Ridder D with 12 publications. Finally, Brown CA and Fraser M have published 11 publications.

3.7 Major themes and research gaps

This study derived important themes from 16 common keywords used by authors in their articles. **Figure 8** shows the author's keywords, frequency, and percentage of documents published in the last two years, from 2022 to 2023, that used the keywords. The top five author keywords are "chronic pain", "EEG", "fibromyalgia", "spinal cord injury", and "neurofeedback". "Chronic pain" is the most common keyword, reflecting the central theme of pain research. There was a 22% increase in publications between 2022 and 2023, highlighting the consistent global interest in exploring new aspects of chronic pain, including its physiological mechanisms and innovative therapeutic approaches.

Keyword co-occurrence is when two or more keywords are used by authors in the same article or dataset. This analysis helps researchers understand what the research article is about and how the keywords reflect the article's content. This study set the minimum co-occurrence threshold at 10 out of 1679 total keywords for analysis, and the results revealed that 36 keywords met the criteria. The findings can be presented using network, overlay or density visualisation. The authors opted for the overlay visualisation generated by VOSviewer to illustrate the co-occurrence of popular authors' keywords and understand their relevance to the publications (**Figure 9**).

The four colours indicate the development of the author's keywords: Red rectangles contain keywords found in publications from 2022 to 2023 and are being studied, while keywords in yellow, green, and blue rectangles represent keywords that were introduced before 2020. The rectangle size implies the frequency of occurrences; a larger rectangle indicates more appearances in previous studies. Meanwhile, the connection between the rectangle sizes is related to the strength of the link or nexus, where the thickness is shown in close proximity.

The co-occurrence network demonstrates the interdisciplinary nature of chronic pain and EEG research, covering advanced data analysis, neuroimaging, and therapeutic interventions. "Electroencephalography (EEG)", "neurofeedback", "fMRI", and "transcranial magnetic stimulation" were popular keywords among researchers prior to 2020.

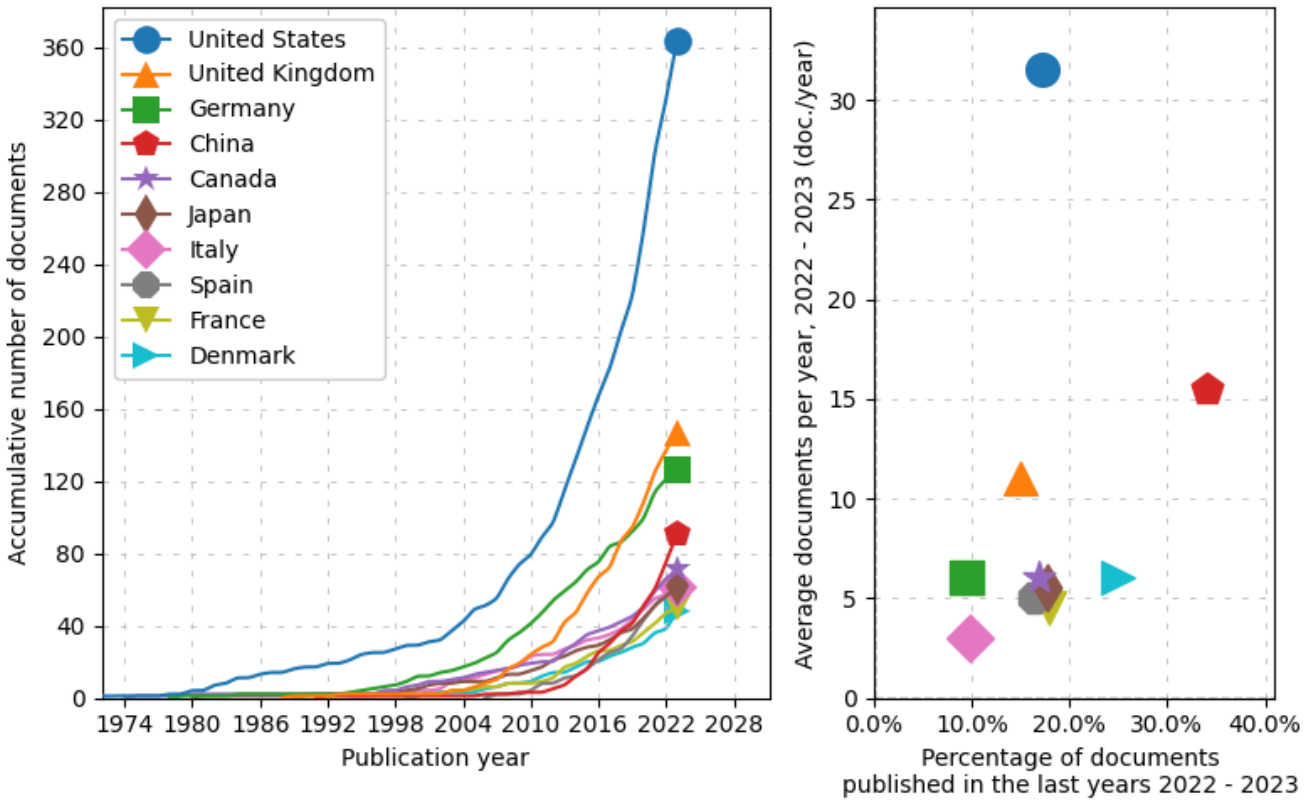

Figure 6. The most productive countries that contributed to chronic pain and EEG studies.

Table 5. The top ten productive countries on chronic pain and EEG.

Rank	Country	Total	AGR	ADY	PDLY	h-Index
1	United States	365	-5	31.5	17.3	62
2	United Kingdom	147	-3.5	11	15	42
3	Germany	126	-5	6	9.5	41
4	China	91	3.5	15.5	34.1	24
5	Canada	71	-2	6	16.9	32
6	Japan	62	-0.5	5.5	17.7	20
7	Italy	61	-1	3	9.8	28
8	Spain	61	-2.5	5	16.4	22
9	France	50	-1	4.5	18	20
10	Denmark	48	2	6	25	21

AGR = Average growth rate; ADY = Average documents per year; PDLY = Percentage of documents in the last year.

In contrast, keywords that appeared in most publications in 2022 and 2023 included "machine learning", which is more closely related to "biomarker" and "functional connectivity". As "machine learning" appears in proximity to "biomarker" in 2023, researchers can gain an accurate understanding of the direction for future studies and emerging trends, including the integration of neurofeedback in chronic pain management and machine learning applications.

4.0 DISCUSSION

Recent literature has iterated the benefits of EEG as a tool in addressing chronic pain. The EEG application is most commonly used in epilepsy but has also served as a non-invasive clinical tool to help clinicians understand the complexity of brain networks and identify areas of dysfunction (Zis et al., 2022). This bibliometric analysis of research on chronic pain and EEG shows several significant trends in the field.

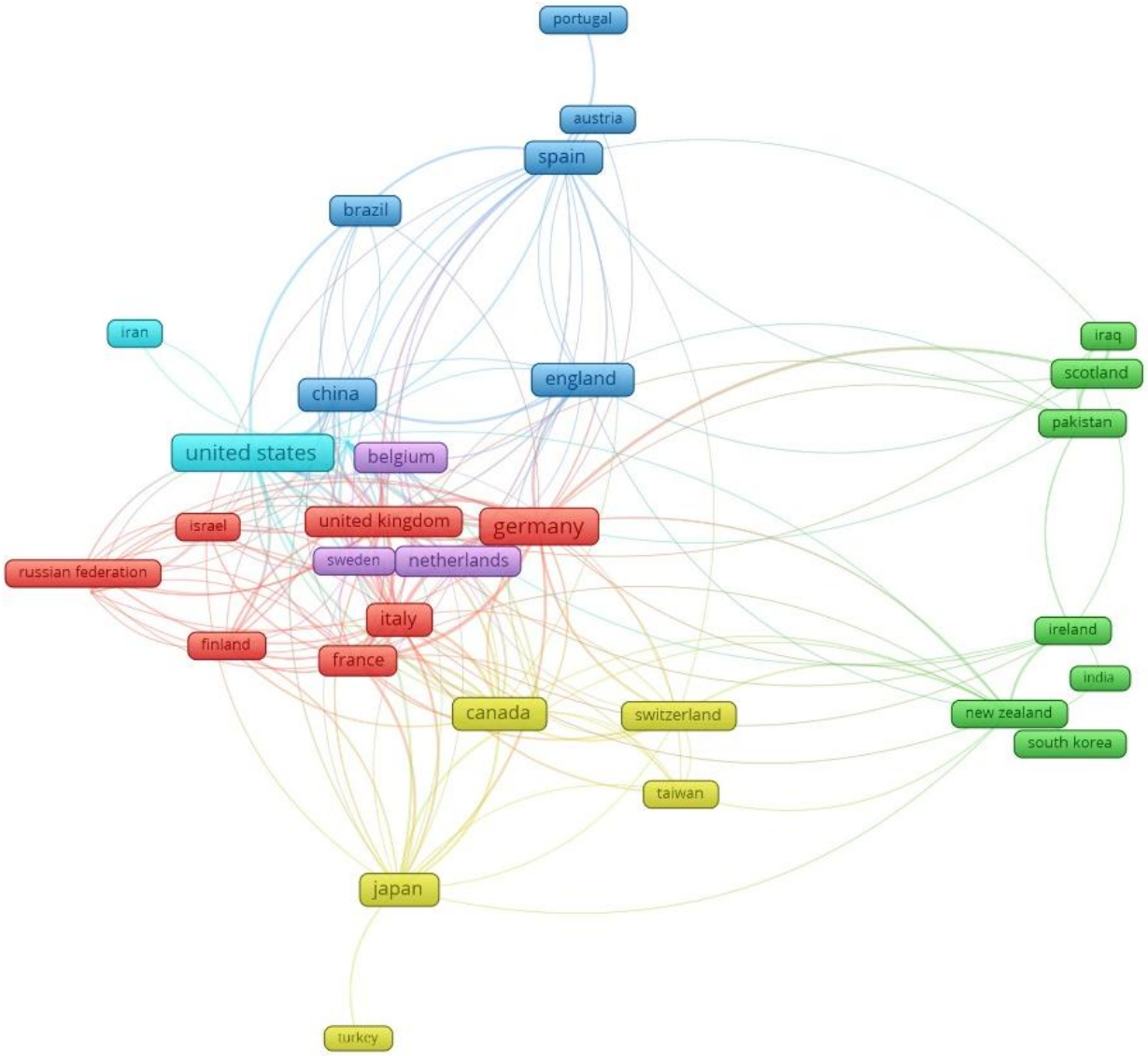

Figure 7. Network visualisation of co-authorship by country, chronic pain, and EEG research.

Publication growth from 1972 to 2023 is characterised by three phases: an early period (1972–2001), a growth period (2002–2013), and a surge period (2014–2023). The exponential increase in the number of publications during the surge period can be attributed to advances in EEG technology and its application in non-invasive pain analysis. This finding is in line with the increasing global prevalence of chronic pain and the need for multidisciplinary, non-pharmacological interventions consistent with the biopsychosocial model of pain management (Cohen et al., 2021; Hylands-White et al., 2016).

Key journals, such as "Pain" and "Frontiers in Neuroscience," are among the most productive, with "Frontiers in Neuroscience" showing a remarkable 44% increase in contributions between 2022 and 2023. This trend reflects a growing interest in neural oscillations and brain wave patterns associated with pain perception. Specifically, the studies published highlighted EEG's ability to record real-time neural activity, providing insights into the brain wave patterns of chronic pain patients that may differ from those of healthy controls (Burroughs, 2011; Pinheiro et al., 2016).

The leading research field in the studies of EEG and chronic pain is "Neuroscience & Neurology," reflecting the research focus on brain mechanisms of pain perception. This idea is supported by previous study finFdings, where altered theta and alpha brain wave activity in patients with conditions such as chronic back pain and fibromyalgia were significantly different from their healthy counterparts (Fallon et al., 2017; Villafaina et al., 2019).

Table 6. Top 10 productive authors in chronic pain and EEG research.

Author	Affiliation	Country	Total Publication	No of Citation	h-index
Jensen, MP	University of Washington	United States	17	705	15
Montoya, P	University of Balearic Islands	Spain	17	421	8
Vuckovic, A	University of Glasgow	United Kingdom	15	291	7
Fregni, F	Harvard Medical School	United States	14	344	8
Jones, AKP	University of Manchester	United Kingdom	14	518	10
Ploner, M	Technical University of Munich	Germany	13	1050	11
Wang, J	Capital Medical University	China	13	225	7
De Ridder, D	University of Otago	New Zealand	12	497	8
Brown, CA	Hope Hospital, Salford	United Kingdom	11	362	8
Fraser, M	Southern General Hospital	United Kingdom	11	277	7

In addition, there is a growing interest in using computational models on EEG data to improve diagnostic accuracy and predict pain-related outcomes, with the emergence of machine learning as a prominent theme (Zis et al., 2022).

Geographical analysis revealed the United States as the leading country in EEG and chronic pain studies, with the highest number of publications and citations, followed by the United Kingdom, Germany, China, and Canada. The network of co-authors demonstrates extensive collaboration among the main hubs, particularly between the USA and European countries (Germany and the UK), as well as China. The global partnership demonstrates a collaborative effort to advance the understanding of chronic pain through EEG (Cohen et al., 2021).

The University of Glasgow, Aalborg University, and the University of Washington are the most productive institutions in chronic pain and EEG research. These institutions are major contributors to the progress of the study field through high-impact publications and a broad collaboration network. Similarly, top productive authors, such as Jensen MP from the University of Washington and Montoya P from the University of the Balearic Islands, have made substantial contributions through their research on chronic pain and EEG (Jensen et al., 2013).

The analysis of keywords co-occurrence revealed "chronic pain," "EEG", and "fibromyalgia" as dominant themes in the literature. Emerging topics such as machine learning and biomarkers suggest that future research will increasingly focus on harnessing artificial intelligence to analyse EEG data. As a result, researchers will be able to identify more precise pain biomarkers and better integrate EEG into clinical pain management strategies (Rajan et al., 2024).

In summary, this bibliometric analysis helps paint a clearer picture of the research landscape on chronic pain and EEG. The findings emphasise the growing prominence of EEG as a non-invasive tool for understanding the role of the brain in pain perception and highlight the importance of interdisciplinary collaboration and emerging technologies in advancing this field.

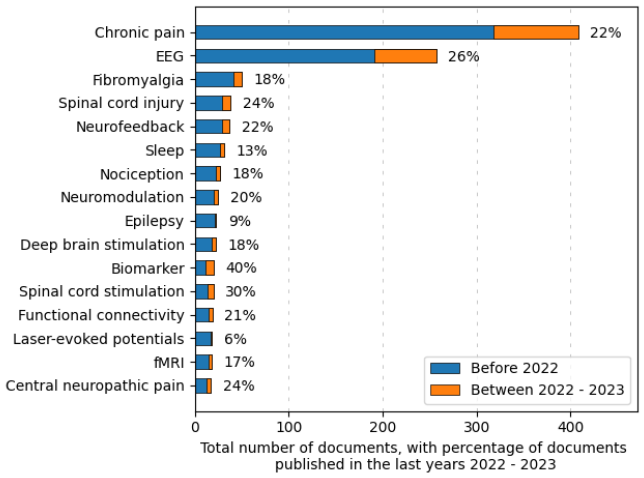

Figure 8. Top 16 authors' keywords in chronic pain and EEG publications

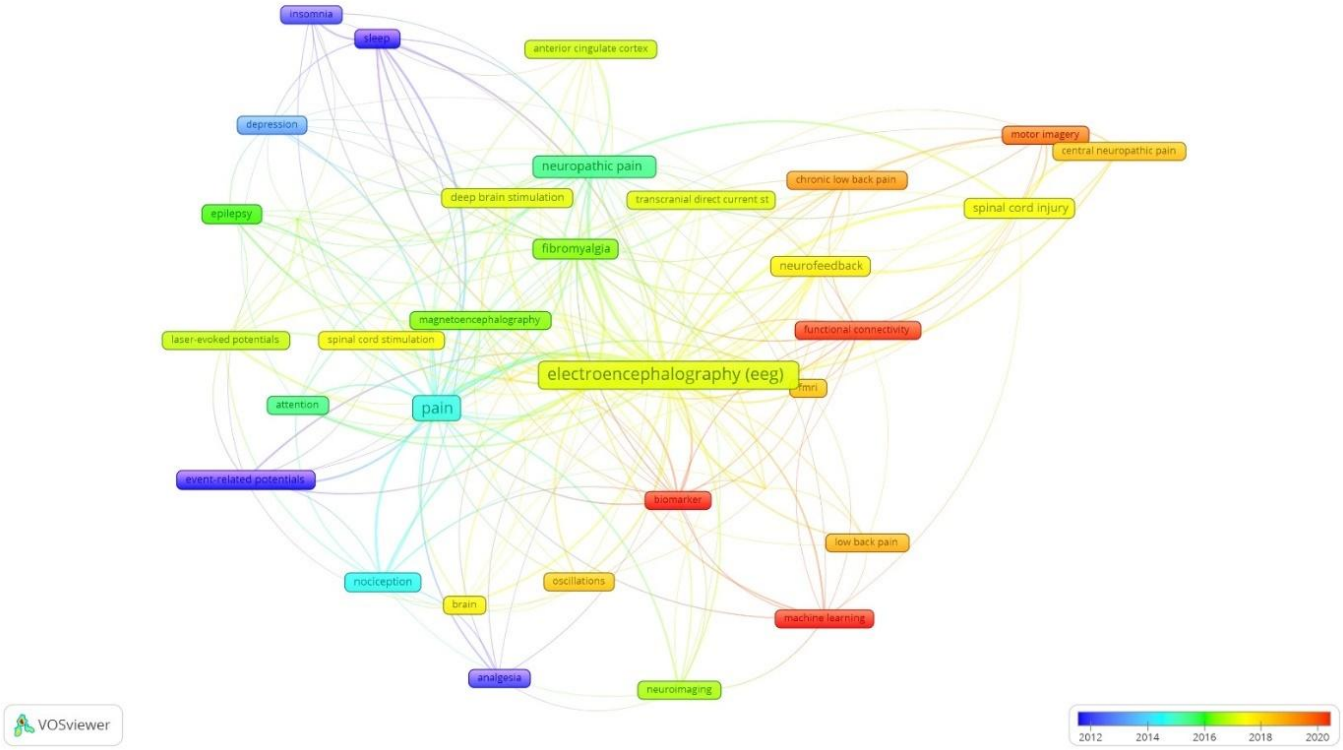

Figure 9. Overlay visualisation of authors' keywords in chronic pain and EEG publications

5.0 CONCLUSIONS

The findings of this bibliometric analysis implied the gradual growth in scholarly interest in chronic pain and EEG. The recent increase in publications on this subject in the WoS and Scopus databases indicates a rising interest among researchers in this field. The publication rate should not be the sole indicator for determining research quality and impact in a particular field. Thus, the authors recommend that researchers assess and analyse publication content and its impact on different research areas. Furthermore, this analysis identified critical scientific journals, research areas, highly cited publications, authors, countries, author keywords, and institutions that have made significant contributions to advancing knowledge and practice in chronic pain and EEG. These findings can inform future research directions, policy-making, and practical interventions aimed at enhancing patient management and diagnosis of chronic pain, while also protecting their health and well-being.

Acknowledgements:
This study was funded by the UniSZA Internal Grant (DPU1'2022) (UniSZA/2022/DPU1.0/26).

Author Contributions:
This study was conceptualised and designed by MMG. The bibliometric data was analysed by MMG and the manuscript was written, reviewed and edited by MMG, MRAMZ, KI and SI.

Conflicts of Interest:
The authors declared no conflict of interest.

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