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REVIEW

Pain and Transcranial Direct Current Stimulation: A Bibliometric Analysis

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Context: Pain management is a constant struggle. Transcranial direct current stimulation (tDCS) is a neuromodulation technique with proved efficacy in chronic pain.

Objective: The aim of the study is to provide a bibliometric perspective regarding articles on pain and tDCS. Having a visualized and systematically overview of publication trends, new research ideas could arise for clinicians.

Methods: Articles on pain and tDCS were retrieved from Web of Science database. Using the R software version 4.1.2 and the "biblioshiny" R package, a quantitative and statistical analysis was performed. Time trend, number of publications, journals and authors, author country and institution, as well as citations and references were visualized.

Results: A total of 554 publication fulfilled the criteria and were analyzed. The scientific production has been increasing over time with an annual growth of 17.1%. Brain Stimulation Journal and Journal of Pain are the leading journals regarding articles and citations. Fregni F. (83 articles) is the most prolific researcher with important authorship in the field. USA is the country with most authors involved in the topic (558 authors), whereas the leading institution is represented by Universidade Federal Rio Grande Do Sul (84 articles). Lefaucheur JP. article from 2017 has the maximum citations, while keywords in trend in the last three years are osteoarthritis and low back pain.

Conclusion: This is the first bibliometric study that reflects the trends of tDCS in the field of pain. Journals as well as authors are limited and clustered. However the number of articles as well as number of citations are constantly increasing, supporting the idea that this is an emerging topic. The information obtained could be an important practical basis for future pain management research.

Keywords: chronic pain, noninvasive electric brain stimulation, neuromodulation, bibliometric analysis, Web of Science

Introduction

Pain, defined as "an unpleasant sensory and emotional experience", "is always a personal experience that is influenced to varying degrees by biological, psychological and social factors".[1] It is a broad symptom with multiple valences, subjective and individually experienced. To date, the pathophysiology of pain is not fully understood,[2] and new means of treatment are continually under research.

Transcranial direct current stimulation (tDCS) is a relatively new non-invasive stimulation procedure that provides beneficial effects in several psychiatric and neurologic conditions, as well as in chronic pain.[3–5]

tDCS works by using a low voltage source of electricity that delivers a fixed current of low intensity, below 3mA, between two electrodes placed on the scalp of the patient.[6] The most common electrode positioning is with the anode targeting the primary motor cortical area (M1).[7] The current delivered is not strong enough to trigger an action potential in a cell but has the ability to induce changes in cortical excitability by means of ion channels.[8] Early effects are seen during stimulation, with stimulation of the anode leading to depolarization, while stimulation of the cathode leads to hyperpolarization of the membrane. However, the method cannot induce activation of cells that are not spontaneously active, making it a safe method with minimal excitotoxic effects.[8]

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tDCS has the potential to modulate neural activity by means of synaptic plasticity.[9] This is based on two mechanisms: long-term potentiation-like (LTP) and long-term depression-like.[10] Late effects are directly related to N-methyl-D-aspartate (NMDA) receptors. Studies have shown that blocking the NMDA receptor, inhibits the occurrence of late effects, whereas the use of D-Cycloserine-a partial agonist at the glycine recognition site of the glutaminergic NMDA receptor, augments the effects.[11,12]

Based on these mechanisms, tDCS has been investigated and proved efficient in a wide range of pain conditions.[3,13,14] It has a level B of recommendation in neuropathic pain, fibromyalgia pain, migraine, and post-operative analgesia.[3]

Compared to other types of neuromodulatory techniques, this type of stimulation has multiple advantages, as it is non-invasive, painless, well-tolerated, and not expensive.

But why this new technique for pain has not been a significant breakthrough? Is it that data are insufficient and still too immature for conclusions to be objectively drawn? Is it that the method is so scientifically complicated that it can not be applied in real life? Or may it be just that companies are usually more interested in drug development and less in medical equipment?

Studies dedicated to this topic have been increasing in the last few years.[15] An objective regard on the topic is considered to bring clear and evidenced-based arguments for the uninitiated reader as well as for the junior researcher.

Bibliometric analysis, or research impact, is a quantitative tool that uses statistical methods for analyzing publications in regard to citation and scientific content and assess emerging trends in research.[16,17]

Bibliometrics appeared with the writings of Paul Otlet in 1934 and was defined as 'the measurement of all aspects related to the publication and reading of books and documents'.[18]

By use of bibliometric analysis, a large number of articles can be subjected to analytical processing providing as results: citation dynamics, publication landscape, and emerging trends in articles.[17] It can help researchers discover the roots of a particular field of study and identify the prominent authors as well as the collaboration networks.[17] Moreover, it has the potential to offer an objective view that may be used as a background for future studies.

Bibliometric studies have been used in various research fields, from economics to medical research. There are studies on pain[19–21] and non-invasive neuromodulation.[15,22–24] However, based on our research, bibliometric studies regarding tDCS and pain have not been published.

In this bibliometric analysis of articles related to tDCS and pain, we aimed to objectively overview the publications in the field and identify new research ideas.

Materials and Methods

Information Sources and Eligibility Criteria

Published papers were searched on Web of Science (WoS) database from Clarivate Analytics. We considered only WoS database because it contains sufficient information to reveal the current status of publications. Wos provides a comprehensive dataset with high level of confidence and brings together all relevant date we were interested in (as number of citations, abstracts, keywords, etc). Moreover it is the most commonly database used for bibliometric analysis.[25,26]

The flow chart of papers inclusion is shown in Figure 1. The main inclusion criteria for our study were original articles and reviews pertaining to transcranial current stimulation and pain. Exclusion criteria were - other document types classified in Web of Science as early access, book chapters, and proceeding papers. We excluded articles regarding only transcranial magnetic stimulation. Our main focus was on the role of tDCS and physical pain. Articles focused only on post-procedural pain as adverse effects of tDCS (slight tingling, a burning sensation) as well as articles on social pain, defined as a painful emotion, were also excluded.

An English language filter was applied, but we did not impose any restrictions on species. No time span was imposed. We searched all articles from database inception to time of research: 8th of December 2022.

Search Strategy

The exact search strategy employed was the following (TS= topic search): TS=("Transcranial direct current stimulation") OR TS=("Transcranial DC stimulation") OR TS=("Transcranial electric stimulation") OR TS=("Transcranial electrical

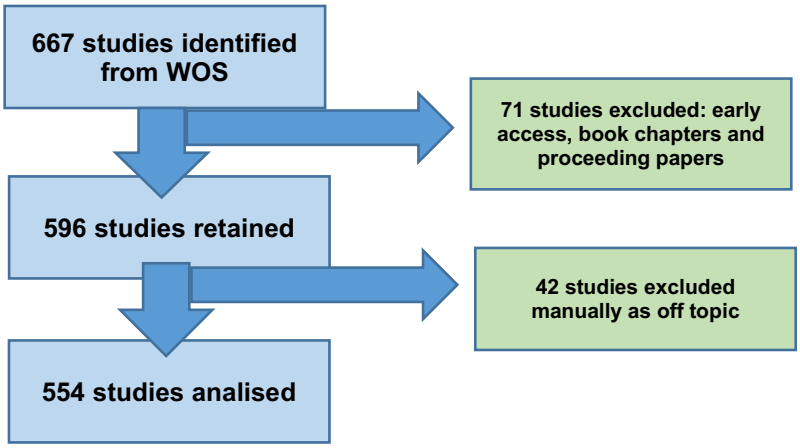

Figure 1 Flowchart of the search and selection process.

stimulation") OR TS=("Transcranial cathodal stimulation") OR TS=("Transcranial anodal stimulation") OR TS=("tDCS anodal") OR TS=("tDCS cathodal") OR TS=("Transcranial electrical current stimulation") OR TS=("Transcranial electric current stimulation") AND TS=(pain).

All literature searches and results downloads were executed on December 8, 2022.

Selection Process

Two authors screened the titles and abstracts of the search results, and only the papers that met the requirements for selection were retained for analysis. Any decision disputes were resolved through discussion.

Data Extraction and Analytical Methods

WoS provides a number of bibliometric data regarding the number of papers, citations, and Hirsch index.

We exported from WoS the full record and cited references in a plain text file. The R software version 4.1.2 and the "biblioshiny" R package was used to analyze the information from the WoS database.[27] Bibliometrix is a package that runs through R software and provides the instruments to conduct a bibliometric study. It is capable of performing a quantitative and statistical analysis on publications such as journal articles and their accompanying citation counts.

Throughout the study, several bibliometric elements were used:

- The journal impact factor (IF) is a journal characteristic that has been designed to calculate the ratio between citations received in a certain year over the number of publications from the two preceding years.[28] As the impact factor is specific to a time period, a 5-year IF is also in use. Other parameters to be considered are the H-index which measures the quality and quantity of papers a journal publishes (it is calculated as the number of published articles, each being cited h times in other papers) as well as the not so well known m-index. The m-index is a ratio dependent on H-Index and the number of years since the first published paper of the journal.
- One law of distribution in bibliometrics is the Law of Bradford. It describes the scattering of articles on a certain subject, considering that few sources have the majority of relevant information on the topic, with the rest of the sources having just a few.[27,29]
- Another bibliometric law is Lotka's law which describes the frequency of publication by authors. It is an inverse square law, where the number of authors publishing a number of articles is a fixed ratio to the number of authors publishing a single article. Lotka's law affirms, "As the number of articles published increases, authors producing that many publications become less frequent". Lotka's law explains scientific productivity and the relationship between authors and the number of papers published.[30]

Results

A total of 667 studies were identified using the search strategy in WoS database. During the manual screening of the results, after the exclusion of early access, book chapters, and proceeding papers, we obtained 596 studies. Furthermore, 42 studies were excluded since they were not pertinent to our study aim. We ended up with a number of 554 papers that were available for the bibliometric analysis. The search and selection process is described in Figure 1.

Publication Trend

The publication date of the published articles spanned between 2001 and 2022. The scientific production over time as well as the trend of annual production, can be seen in Figure 2. The trend is positive, with an annual growth measured at 17.1%. Average article citations per year can be seen in Figure 3.

Journals

The 554 articles were published in 227 journals. The top 10 journals, ordered by the number of articles published, can be seen in Table 1. The average impact factor (IF 2021) was 4.906 (median 4.249, range 2.832–9.184). Most studies were published in Brain Stimulation Journal, from Elsevier, an open access journal with a 5-year IF 9.611 (27 publications and 1076 citations), followed by Journal of Pain with 5Y IF 7.04 (22 publications and 1018 citations), and Pain Medicine from Oxford Academic with 5Y IF 3.721 (17 publications with 196 citations). A top 10 of journals, based on the h-index, having published articles on the topic, is represented in Table S1.

The best-represented publisher is Elsevier, followed by Springer Nature and Frontiers Media. Moreover, regarding Web of Science (WOS) categories, almost 65% of articles were published in journals included in the category of neuroscience or clinical neurology (Figure S1).

The first five journals have each at least 15 articles published with a parallel dynamic over time (Figure 4). This cumulates 17.3% of all studies in the field. Considering the first ten journals, they have gathered approximately 28% of publications. Of the rest of 217 sources, 201 have less than five articles published in this domain, and 152 journals have published just one article on this topic.

Moreover, Figure 5 shows the Journal Clustering through Bradford's Law. In our study - The core section is composed of 13 journals that published 187 articles. The first section has 47 journals that published 185 articles, and the minor zone has the rest 167 journals that published 182 articles.

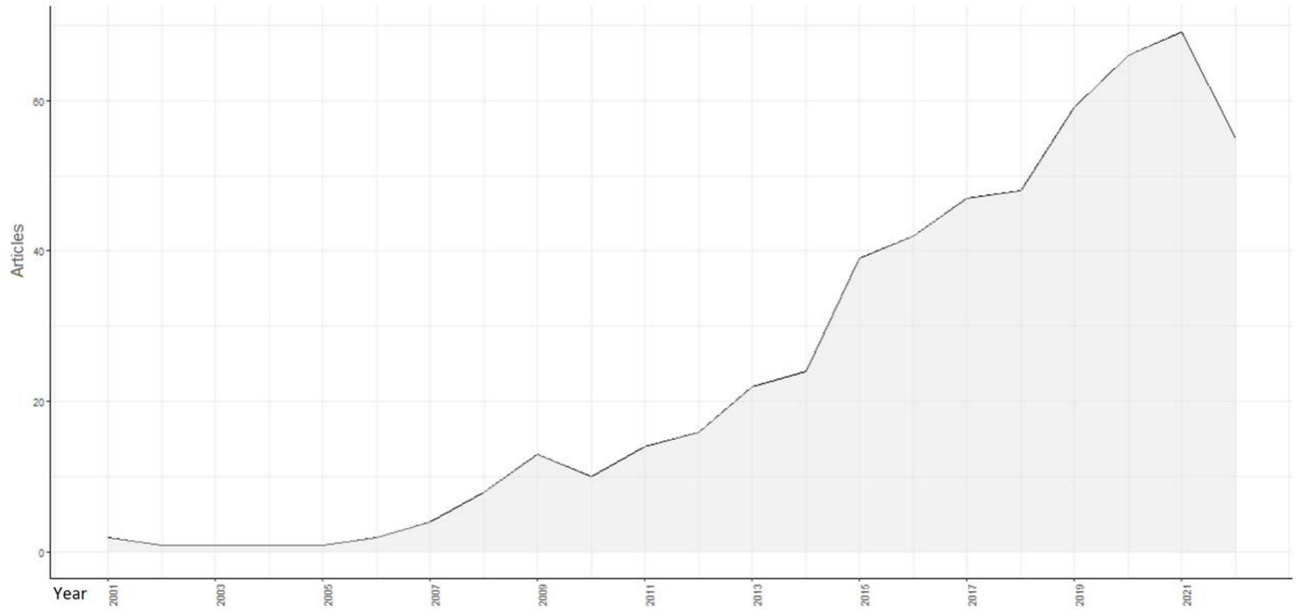

Figure 2 Annual scientific production.

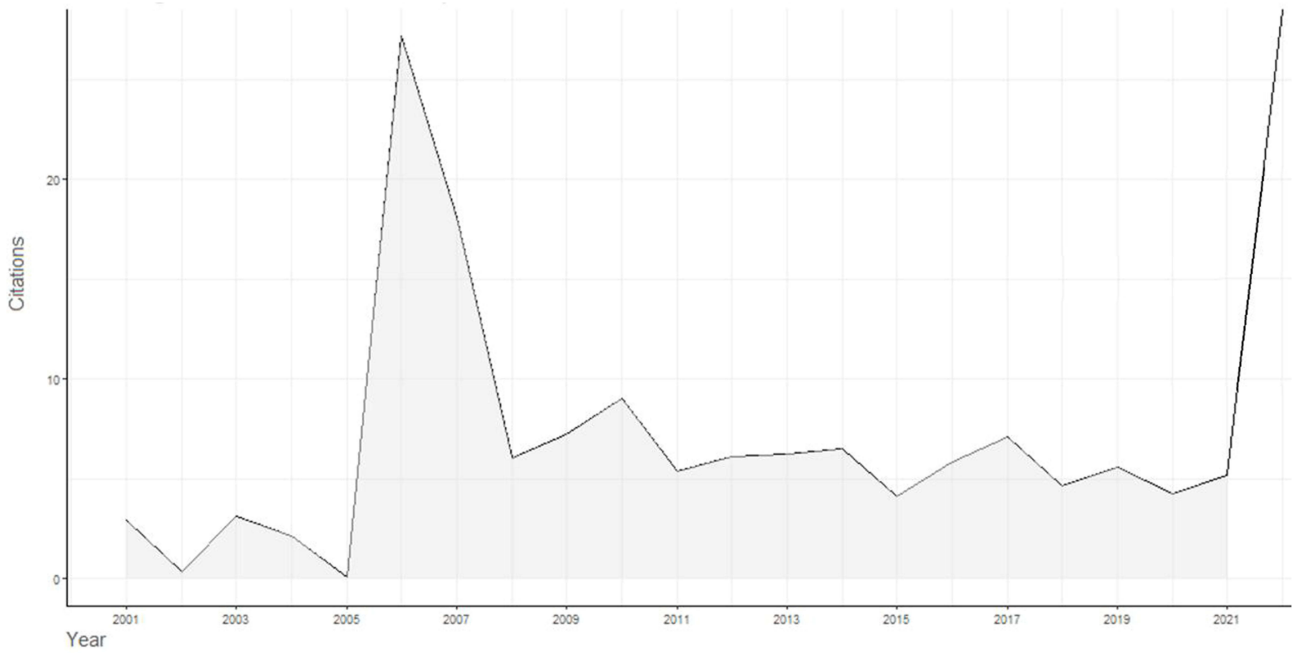

Figure 3 Average article citations per year.

Regarding citations, articles published in Clinical Neurophysiology have the maximum number of citations (1360), with Brain Stimulation and Pain Journal coming in second and third place.

The 554 articles bibliographies included 18.739 references and 3301 cited sources. A cited source is a source (journal) cited by one or more documents, included in at least one reference list of the document set. The most cited journals are presented in Table 2. Pain Journal is the most cited journal, followed by Brain Stimulation and Clinical Neurophysiology, each having more than 1000 articles cited. All three sources gather 5092 articles, approximately 27% of all references. If we look at the top 10 cited sources, they include more than half of all references.

Authors

The articles analyzed had 2253 authors, with mean co-authors per doc of 6.22 (Co-author = author appearance/documents). A 37.73% of international co-authorship (multiple countries publication/total publication *100) has been identified.

Table 1 Top 10 Journals Ordered by the Number of Articles Published

Element	NP	h-Index	m-Index	TC	PY_start	IF 2021
Brain Stimulation	27	15	0.938	1076	2008	9.184
Journal of Pain	22	14	0.875	1018	2008	5.383
Pain Medicine	17	9		196		3.637
Frontiers in Human Neuroscience	15	9	0.818	447	2013	3.473
Pain	15	12	0.667	1055	2006	7.926
Neuroscience Letters	14	8	0.667	265	2012	3.197
Clinical Journal of Pain	13	10	0.625	452	2008	3.423
Clinical Neurophysiology	12	10	0.625	1360	2008	4.861
Journal of Pain Research	11	7	0.636	135	2013	2.832
Frontiers in Neuroscience	11	6	0.750	225	2016	5.152

Abbreviations: NP, number of publications; h-index, the largest number h such that at least h articles in that journal were cited at least h times each; m-index, h-index divided by the number of years since the first publication; TC, total citations; PY start, publication year of start; IF, impact factor, number of citations divided to the number of published articles in a period of time.

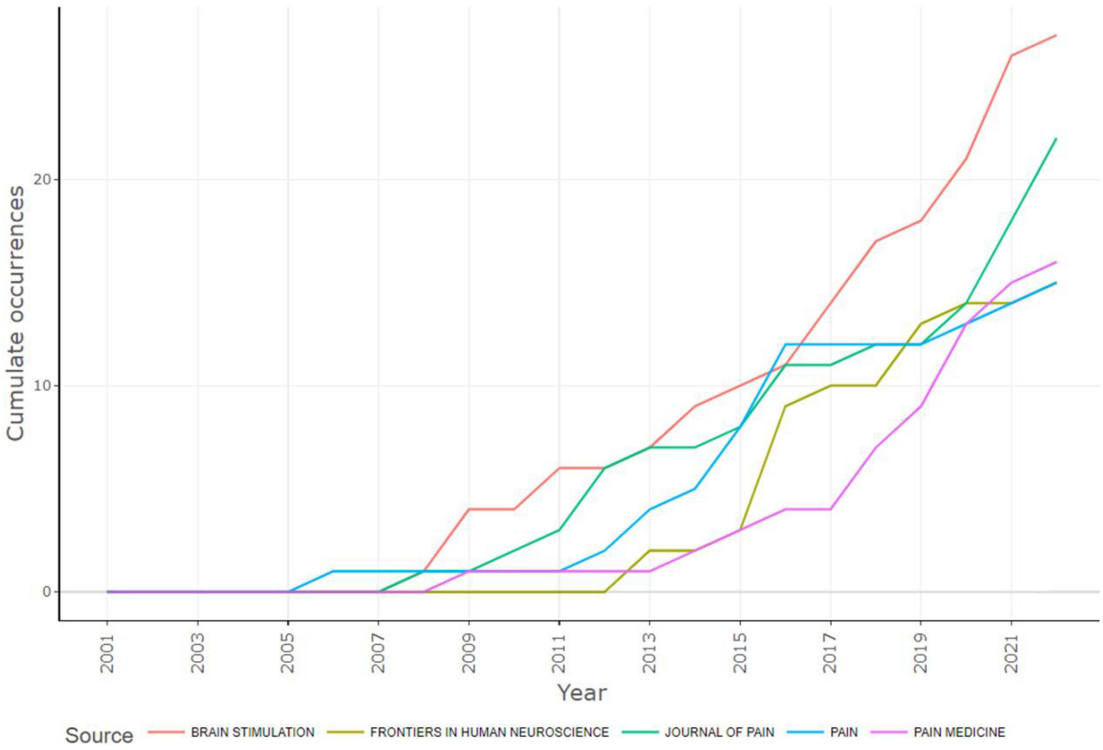

Figure 4 Cumulative occurrence of articles by source.

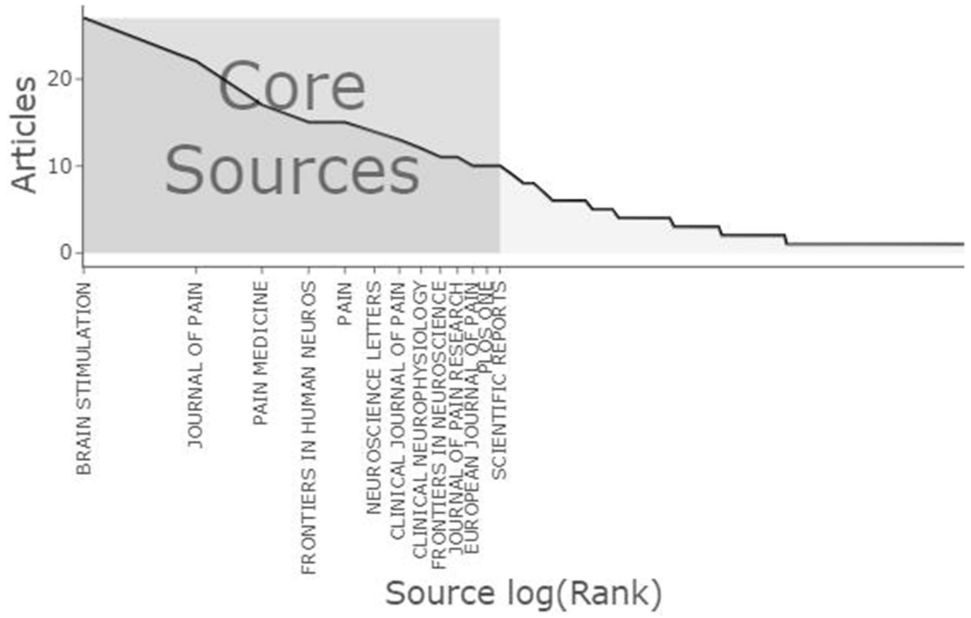

Figure 5 Source clustering.

The top 10 authors and articles fractionalized are seen in Table 3. (FF= number of authored documents/number of co-authors). Fregni is the most prolific author, with 83 articles published, representing 15% of all articles. He is also the most locally cited author with 1723 citations and Nitsche with 665 citations (Table S2). Local citations are the citations of an author retrieved from the articles included in the present bibliometric analyzed collection.

Table 2 Top 10 Cited Sources

Sources	Articles
Pain	2268
Brain Stimulation	1510
Clinical Neurophysiology	1314
Journal of Pain	913
Neurology	681
Journal of Neuroscience	651
Journal of Physiology	645
Neuroimage	628
Brain	603
European Journal of Pain	509

Table 3 Top 13 Most Productive Authors

Authors	Articles	Total Citations on WOS	Articles Fractionalized	H-Index	Total Publication WOS
Fregni F	83	5155	12.71	93	639
Caumo W	36	694	3.97	34	190
Torres ILS	23	416	2.58	33	183
Bikson M	21	1686	2.58	68	332
Lefaucheur JP	15	1664	5.90	65	433
Ahn H	14	150	2.70	15	48
Medeiros LF	14	256	1.53	16	46
Paulus W	14	1981	2.47	116	659
Baptista AF	13	387	1.52	24	93
DaSilva AF	12	870	1.86	19	53
Nitsche MA	12	2235	1.72	98	513
Antal A	11	1536	2.02	63	241
Pascual-Leone A	11	2152	2.23	148	1006

Abbreviations: WoS, Web of Science; h-index, the largest number h such that at least h articles of an author were cited at least h times each; Fractionalized frequency, number of authored documents/number of co-authors - a parameter that quantifies an author's contribution to a published set of papers.

Looking at the total citations retrieved from WOS, Fregni's articles on pain and tDCS sums up 5155 citations, whereas in the second place is Nitsche with 2235 and Pascual-Leone with 2152 citations (Table 3).

The authors' production over time and citation impact can be seen in Figure 6. The size of the circle is linked to the number of articles published, but its intensity depends on the number of citations.

In our bibliometric study, 1764 authors have published 1 article and are considered "occasional authors". Core authors, as considered by Lotka's law, are considered 17 of them as they have published more than ten papers on the topic (Figure 7).

The relation between the top authors, fields of research, and references is presented in a three-field plot (Figure S2). An authors' collaboration network relevant to the publications of tDCs and pain is depicted in Figure 8.

The 2253 authors were affiliated with 54 countries. The top 10 country production based on authors' affiliation is depicted in Table 4 and Figure 9. Authors' institution affiliations, organized by the number of articles published, can be seen in Table 5, and the top 5 institution's production over time in Figure 10.

Top relevant institutions start with Brazil Universidade Federal do Rio Grande do Sul being at the top with 84 publications, followed by Harvard University and Harvard Medical School with 75 and 69 studies. The top European institution with publications in this area is the University of Gottingen, with 17 papers. With 6 institutions in top 10, USA is the foremost most productive and influential country in the field of tDCS and pain, followed by Brazil.

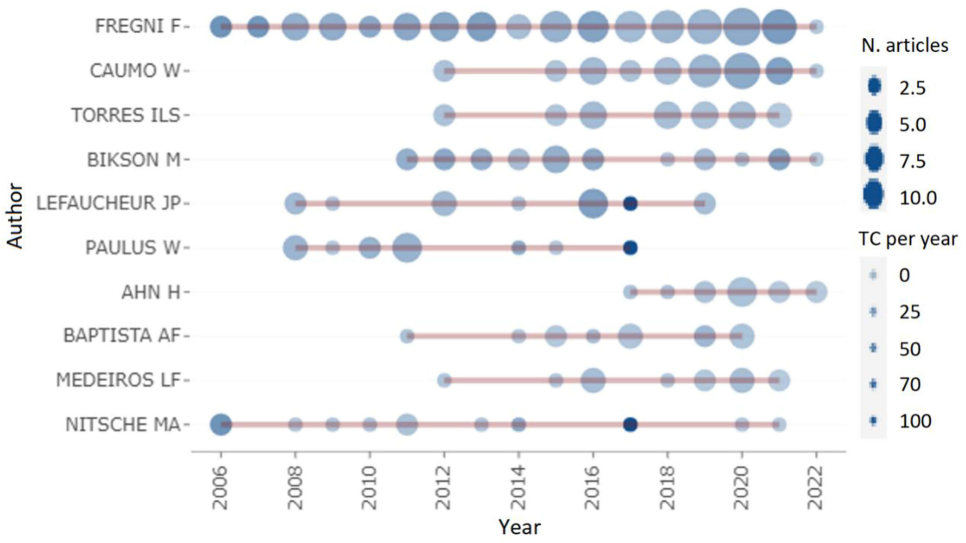

Figure 6 Author's scientific production over time.
Abbreviations: N, number; TC, total citations.

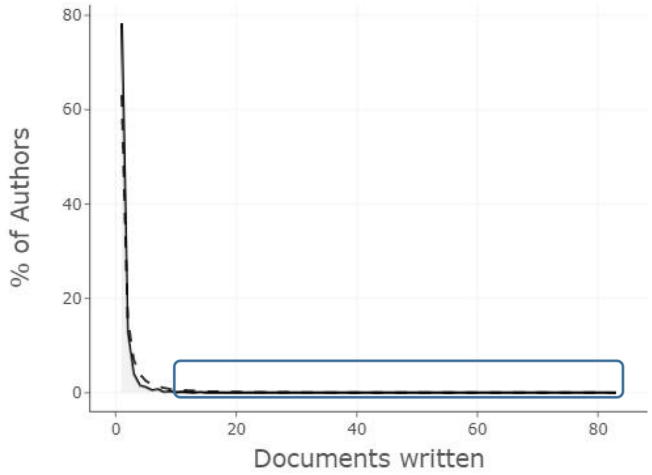

Figure 7 Lotka's law [In square brackets are the occasional authors that published only 1 article].

The world map of collaboration based on all author's nationalities is depicted in Figure 11. The distribution of single-country production and multiple-country production (as a measurement of international collaboration of a country) is presented in Figure 12. Reflecting authors' country, we observe that USA is leading but with almost half of articles being in collaboration with at least one author from another country. "Closed" countries with just local/national studies are China, Japan, Korea, or Turkey.

Documents

Citations can be defined as global citations that are imported from Web of Science. The top 5 papers are presented in Table 6.

Local citations are the citations of an article based only on the reference list of articles included in the present bibliometric analyzed collection. The top 5 papers are presented in Table 7.

The 554 article's bibliographies included 18.739 references. Regarding the references, the most cited are depicted in Table 8. Fregni's article from 2006 is the document with the most local citations and is the most cited reference. Six

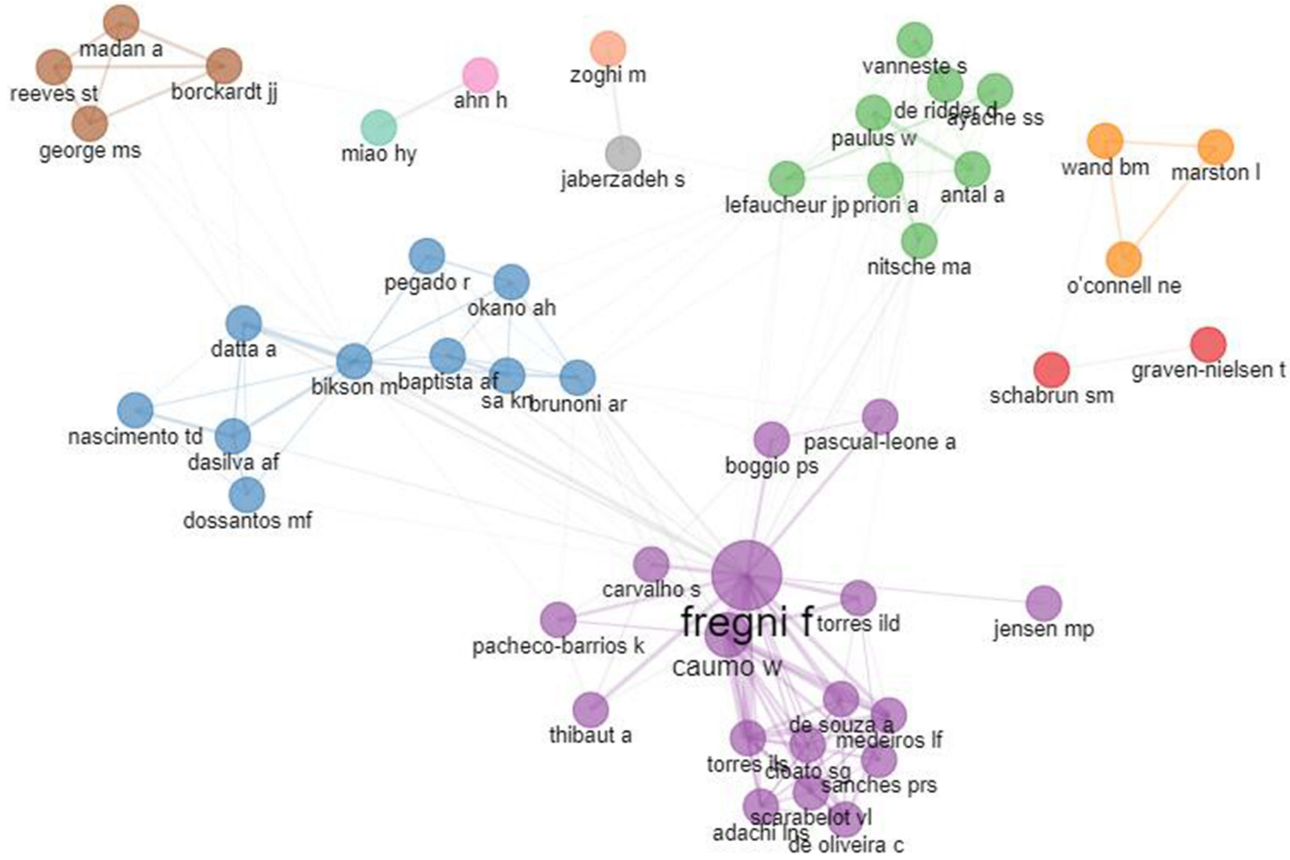

Figure 8 Authors' collaboration network.

articles from the top ten references are articles analyzed in our dataset, whereas the other 4 of them are retrieved just as references.

For the intellectual structure, a historiograph with 20 nodes was created, showing only one historical path of the research topic with its core authors/documents (Figure 13).

The documents analyzed contained 1020 keywords. The top 10 are depicted in Table 9. Looking at pain conditions found as keywords top 10 are as follows: Table 10. We extracted keywords from articles published in the last ten years. The trend of using certain keywords is seen in Figure 14. The terms being in trend (which have at least 50% of occurrence in the last three years) are osteoarthritis, low back pain, conditioned pain modulation, knee osteoarthritis, non-invasive brain stimulation, rehabilitation, multiple sclerosis, and stroke.

Table 4 Country Production

Country	Author Freq
USA	588
Brazil	441
Italy	161
China	123
Canada	111
Germany	103
France	96
Australia	93
Spain	83
UK	82

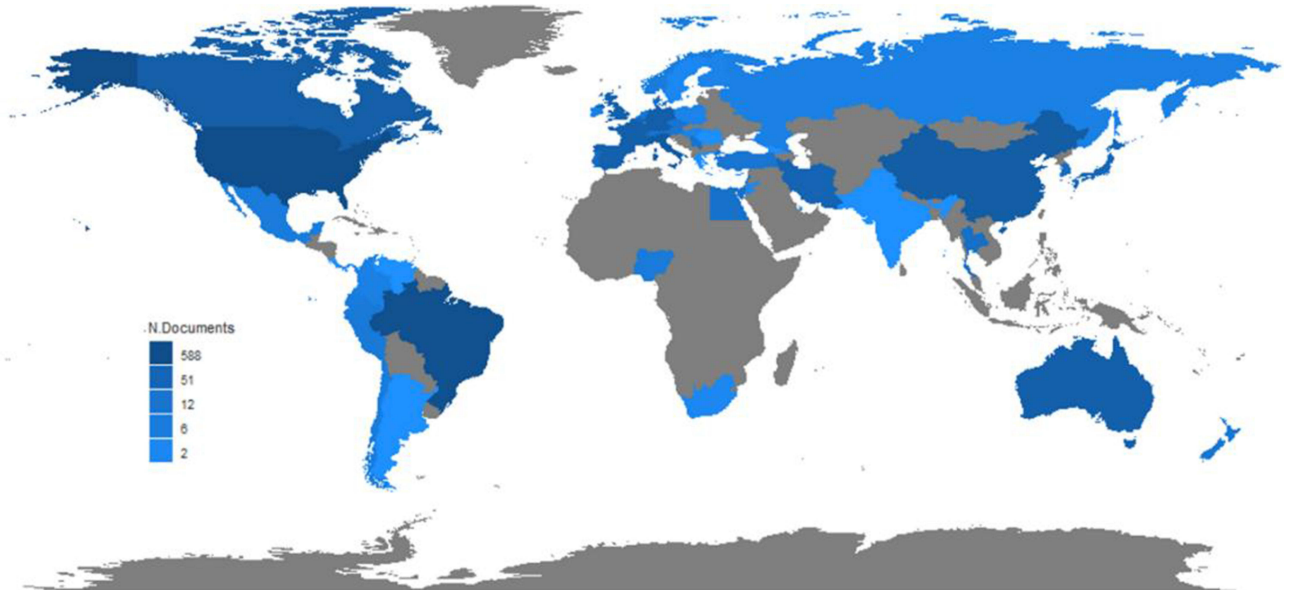

Figure 9 Map of country production.

Discussion

The start of the century has brought into attention through the publications of Nitsche and Paulus the impact and potential usefulness of weak transcranial direct current stimulation (tDCS).[5] The next year, the first two articles integrating transcranial electric stimulation and pain were published.[42,43] From there on, the trend has been positive. There were two articles published in 2006 and 69 in 2021.

The number of articles on tDCS and pain published over the years has increased in a consistent manner. The annual growth rate is calculated at 17.1% and shows the growing development and interest in the domain. This ascending trend reflects the worthiness of the topic and its potential future impact on pain research.

Journals

Journals are the main approach for distributing scientific information. They are essential to science development. The bibliographic analysis of the most relevant sources, the source impact and source dynamics are essential for authors and researchers to identify the most appropriate journal in their field. Even if not designed for this purpose, over time, the impact factor (IF) has become a major tool for journal success.

Table 5 Most Relevant Affiliations

Affiliation	Articles
Univ Fed Rio Grande Do Sul	84
Harvard Univ	75
Harvard Med School	69
Univ Sao Paulo	44
Univ Michigan	38
Hosp Clin Porto Alegre	27
Univ Fed Rio Grande Do Norte	27
Univ Texas Hlth Sci Ctr Houston	26
Univ Sherbrooke	22
CUNY City Coll	18
Univ Florida	18
Univ Gottingen	17

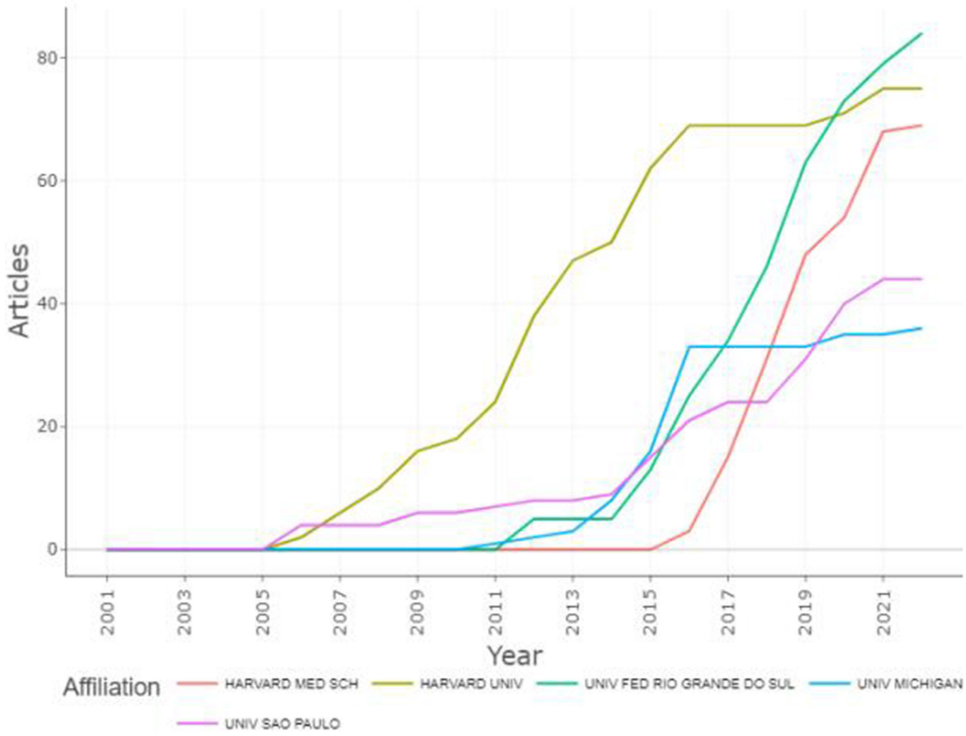

Figure 10 Affiliation's production over time.

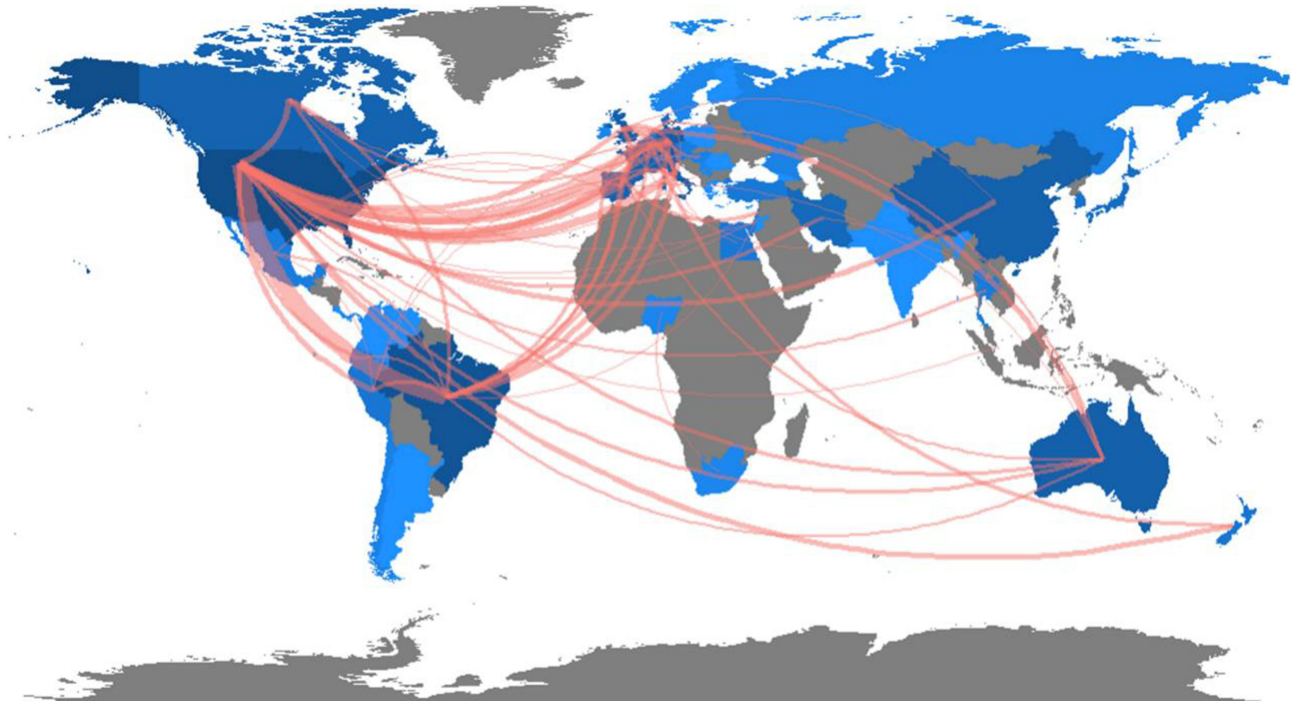

Figure 11 Collaboration world map. [The color intensity is proportional to the number of publications].

Among the first ten journals, based on the number of articles published, four of them have an impact factor of more than 5. Source impact can also be measured based on the journal H-index. The first ten journals based on article production are somewhat similar to the top 10 journals ordered by H-index, with 2 journals: European

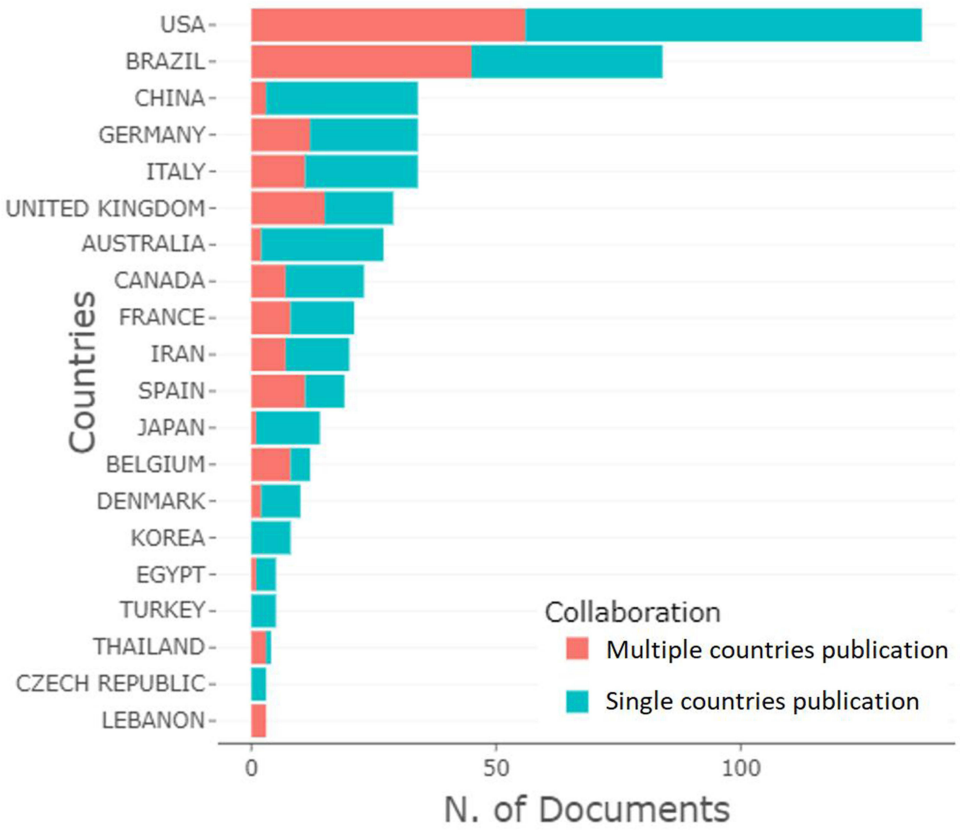

Figure 12 Corresponding author's country and international collaboration measure the international collaboration intensity of a country.

Journal of Pain and PLoS One, having better H-index but fewer published articles. Regarding Bradford law, in our study - The core section is composed of 13 sources. However, the first five journals gather more than half of the core section.

Table 6 Top 5 Articles on Global Citation

Paper	DOI	Total Citations	TC per Year
Lefaucheur JP, 2017, Clinical Neurophysiology[31]	10.1016/j.clinph.2016.10.087	769	109,86
Fregni F, 2007, Nature Clinical Practice Neurology[32]	10.1038/ncpneuro0530	560	32,94
Fregni F, 2006, Pain[33]	10.1016/j.pain.2006.02.023	505	28,06
Olesen J, 2009, Lancet Neurology[34]	10.1016/S1474-4422(09)70.090–0	370	24,67
Fregni F, 2006, Arthritis Rheum[35]	10.1002/art.22195	363	20,17

Abbreviations: DOI, digital object identifier; TC, total citations.

Table 7 Top 5 Articles on Local Citation

Document	DOI	Year	Local Citations	Global Citations	LC/GC Ratio (%)
Fregni F, 2006, Pain[33]	10.1016/j.pain.2006.02.023	2006	205	505	40,59
Fregni F, 2006, Arthritis Rheumatology[35]	10.1002/art.22195	2006	177	363	48,76
Antal A, 2010, Journal Pain Symptom Management[36]	10.1016/j.jpainsymman.2009.09.023	2010	118	221	53,39
Lefaucheur JP, 2017, Clinical Neurophysiology[31]	10.1016/j.clinph.2016.10.087	2017	118	769	15,34
Boggio PS, 2008, European Journal Neurology[37]	10.1111/j.1468–1331.2008.02270.x	2008	102	190	53,68

Abbreviations: DOI, digital object identifier; LC/GC, local citation/global citation.

Table 8 Top 10 Cited References

Cited References	Citations
Fregni F, 2006, Pain, V122, P197, DOI 10.1016/J.PAIN.2006.02.023[33]	205
Nitsche MA, 2000, Journal of Physiology, V527, P633, DOI 10.1111/J.1469–7793.2000.T01-1-00633.X[5]	187
Fregni F, 2006, Arthritis Rheumatology, V54, P3988, DOI 10.1002/ART.22195[35]	177
Nitsche MA, 2008, Brain Stimulation, DOI 10.1016/J.BRS.2008.06.004[38]	123
Antal A, 2010, Journal of Pain and Symptom Management, V39, P890, DOI 10.1016/J.JPAINSYMMAN.2009.09.023[36]	118
Lefaucheur JP, 2017, Clin Neurophysiology, V128, P56, DOI 10.1016/J.CLINPH.2016.10.087[31]	118
Nitsche MA, 2001, Neurology, V57, P1899, DOI 10.1212/WNL.57.10.1899[39]	113
Gandiga PC, 2006, Clinical Neurophysiology, V117, P845, DOI 10.1016/J.CLINPH.2005.12.003[40]	111
Boggio PS, 2008, European Journal of Neurology, V15, P1124, DOI 10.1111/J.1468–1331.2008.02270.X[37]	102
Mori F, 2010, J Pain, V11, P436, doi 10.1016/j.jpain.2009.08.011[41]	92

Abbreviations: V, volume; P, first page; DOI, digital object identifier.

Another way of understanding the expansion of research is by looking at cited journals. These are the journals where we can find the cited references of our analyzed articles. In our bibliometric study, there is a similarity between journals that published the articles and cited journals.

The information provided by source/journal analysis confirms that the topic has great relevance for the ongoing research. High-impact factor journals are the main publishers in the field, proving the seriousness of the subject. Furthermore, the nucleus of journals devoted to the subject is well-defined and not very broad. It implies that the topic is niche-like, having a limited area of journal publication that comes with a dedicated target audience. This brings along relief for the young researchers. They will have a narrow domain of search, with specific journals and quality pre-provided. On the other hand, the publication pressure is augmented.

Authors

Authors with many publications in a field can be considered influential and are a proof of high-quality articles. Moreover, they can be identified as experts in the domain and become potential research collaborators.

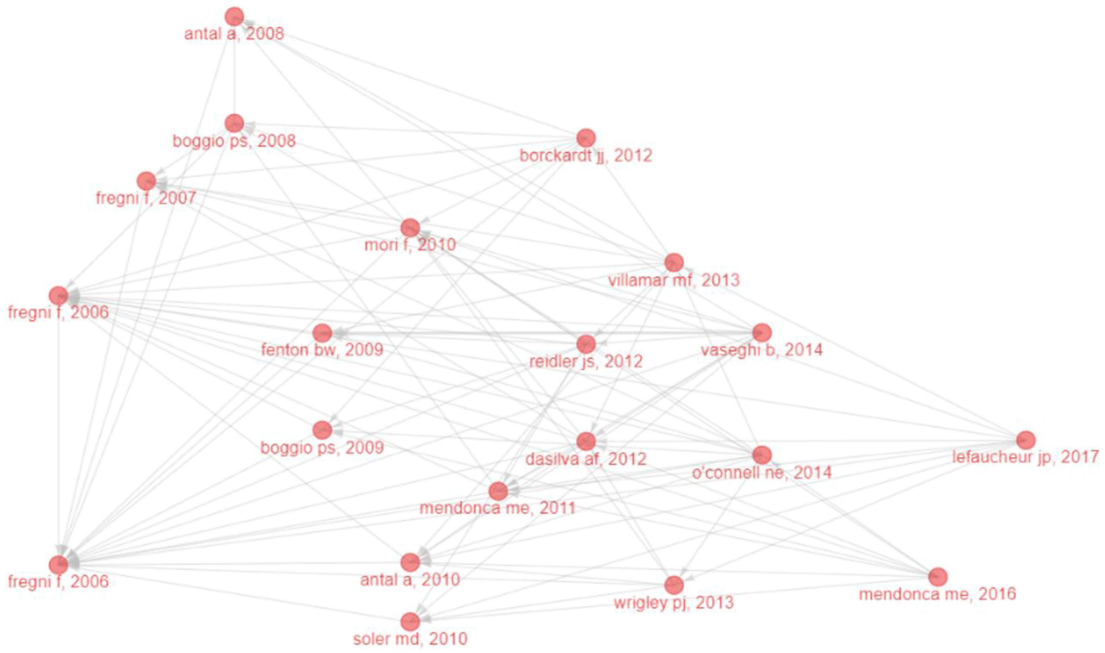

Figure 13 Historiograph. [Nodes – articles identified by the first author and year of publication, edge – a citation. The horizontal axis is the year of publication].

Table 9 Top 10 Author Keywords

Words	Occurrences
Transcranial direct current stimulation	363
Pain	173
Neuromodulation	57
Neuropathic pain	52
Transcranial magnetic stimulation	50
Brain stimulation	36
Non-invasive brain stimulation	30
Fibromyalgia	29
Motor cortex	29
Spinal cord injury	27

Table 10 Top 10 Diseases Indicated as Keywords

Words	Occurrences
Fibromyalgia	29
Spinal cord injury	27
Stroke	22
Osteoarthritis	19
Multiple sclerosis	18
Migraine	13
Chronic low back pain	10
Phantom limb pain	6
Trigeminal neuralgia	5
Abdominal pain	4

In our article selection, there is a high number of authors (2253) identified, but only 79 of them published more than five articles, with a vast majority of authors having a small contribution to the topic. From the perspective of publications, Fregni F. from Harvard Medical School (WOS H-index of 93) is the most prolific author, with 83 articles

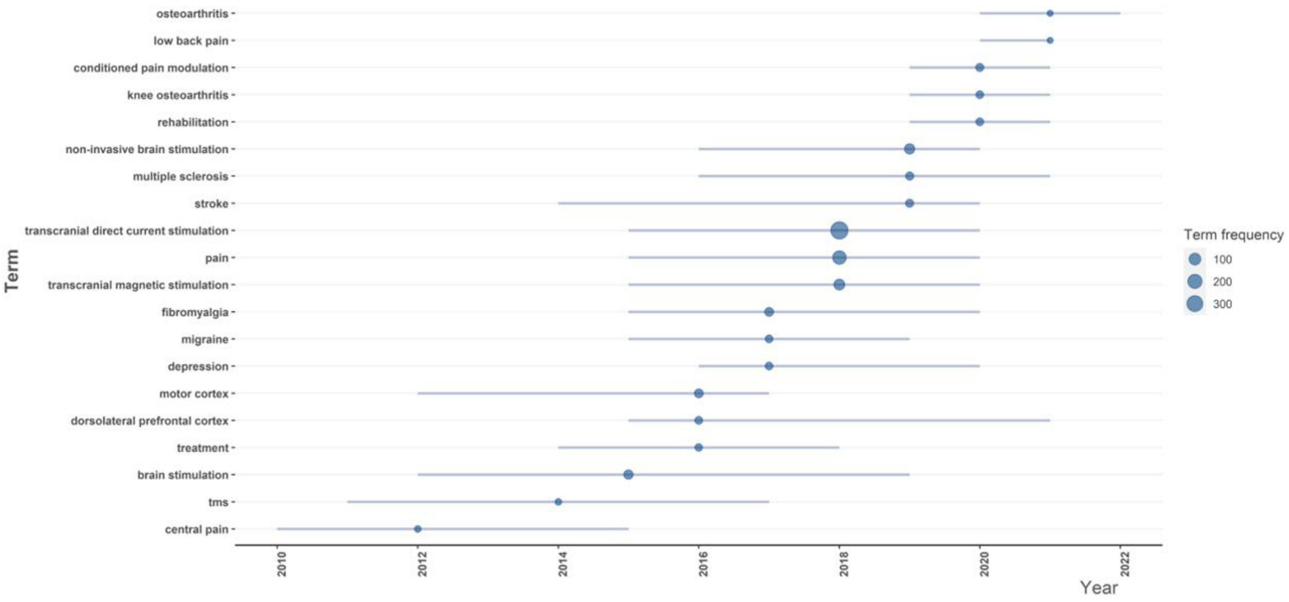

Figure 14 Trend topics [The size of the circle = term frequency. The gray bar = the first and third quartiles of the occurrence distribution].

published, representing 15% of all articles. He is also leading in local citations with 1723 citations and in global citations with 5155 citations. We mention from our top ten list Paulus W from University of Gottingen, with an H-index of 116, considered on WOS a Highly Cited Researcher in the field of Neuroscience and Behaviour from 2018 to 2022.

Analyzing authors' production over time, with citation per year as a supplemental variable, we can see that the first two authors to publish were Fregni and Nitsche in 2006, and they have been stable in article production over time as well as citations per year (Figure 6). For example Fregni and Nitsche had two articles published in 2006 that were cited 48.22 times per year.[33,35] Paulus, Nitsche, and Lefaucheur had one common article in 2017 that was cited 109.86 times per year.[31]

Few authors have the capacity to write a significant number of articles, and they become specialists in the field. They are the ones leading the way in science. But they are not alone in their scientific production. We can nicely observe their aggregation and cluster formation. A vast majority of publications are the outcome of international collaboration. Strong international teamwork can be seen in USA, Brazil, Germany, and Spain. The networking and cluster connections are increasing productivity but mostly the quality of research. This is also the idea of the Painless project.[44] This international initiative brings together multidisciplinary teams from different European countries in a common effort to test the effectiveness of transcranial electrical stimulation in cancer pain. Regarding this project, it is worthy of mentioning the implication of one of the top ten authors, Andreea Antal, from the top European institution University of Gottingen. She is the author of eleven publications in our bibliometric study, but has more than 200 articles indexed on Web of Science. The majority of her work relates to transcranial electrical stimulation.

Documents

Relevant documents are important to be known as they impact future research. The quality of a document can be measured by the number of citations it receives.

Lefaucheur's guideline on tDCS has the maximum global citations (769), as is to be expected from a guideline.[31] Second on the list is another fundamental document published by Fregni and Pascual-Leone with 560 global citations.[32]

Looking at local citations, Fregni's publications from 2006 are on top. They are two randomised controlled trials that provided evidence of pain relief using tDCS in fibromialgia[35] and in central pain caused by traumatic spinal cord injury.[33] Being cited in 37% (205/554) and 32% (177/554) of articles from this database, they can be considered the historical grounds of future studies. This can be graphically observed also in the historiograph where the two articles from 2006 have multiple connections.

References are relevant as cardinal articles that provide information about the research domain. We can notice that Fregni's article from 2006 is the most cited reference as well as the most locally cited. In a close subject, it is to be expected that articles on the topic are mostly cited in other articles discussing the same subject. This is the case with the top 5 locally cited articles that are included in the top 10 cited references. However, there are articles (for example Nitsche 2000 and Nitsche 2008) that are intensively cited as references but are not included in our article selection.[5,38] These are crucially important in the field, as they are part of the scientific base of tDCS.

Keywords are significant, as authors choose them as a reflection of the article content. Of course that the top 10 keywords are led by the search terms we imposed. Focusing on diseases as keywords, we might notice an increased interest in research in fibromyalgia, spinal cord injury, and other neurologic pain conditions. Trending keywords in the last three years include pathologies such as stroke, osteoarthritis, and back pain. This might signify that researchers have found the applicability of tDCS and have focused on therapy. As the authors of the present manuscript have a professional interest in oncology, we must emphasize that from the 1020 keywords, only five were cancer-related (head and neck cancer, breast cancer, hepatocellular carcinoma, and cancer pain). We identified through this study a major gap in research on tDCS and cancer pain. Pain affects more than half of patients in active treatment, and the numbers are even higher in metastatic cancer.[45] Having in mind this terrible disease burden and the challenges existing in pain management, research in the field of transcranial electrical stimulation is appealing.

The main advantage of this study is the objective overview of publications related to tDCS and pain and the perspective that it gives in this new area of research. It provides information for medical professionals, industry, and policy makers in a field where there is still much to be found.

This bibliometric analysis also has its limitations as it focuses more on quantitative analysis and not on qualitative one. Moreover, it was conducted only on Web of Science, and did not include other databases.

Conclusion

Our study focuses on a numerically and visually analysis of publications regarding tDCS and pain. Using the bibliometric method we could identify that the field is somewhat closed, with core authors and journals that can be contained in small clusters. The best represented journals were those focusing on pain and neuroscience as: Journal of Pain or Pain Medicine.

Fregni F, Lefaucheur JP. or Nitsche MA. are examples of prolific authors, whereas their studies are in the top cited articles and references. Moreover their affiliation and country of origin have a parallel representation. Strong international collaboration can be identified between USA, Brazil and Germany. Pain pathologies among which: stroke and osteoarthritis, have been identified as trending keywords, thus providing a pragmatical scope to this new brain stimulation technique.

With an increasing in both articles and citations over time, the topic demonstrates its growing interest. Hopefully the results of this study can help researchers to identify emerging trends on the topic. The main goal is to provide insights for the benefit of patients with chronic pain conditions.

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The authors report no conflicts of interest in this work.

References

1. Raja SN, Carr DB, Cohen M, et al. The revised international association for the study of pain definition of pain: concepts, challenges, and compromises. *Pain*. 2020;161(9):1976–1982. doi:10.1097/j.pain.0000000000001939
2. Woolf CJ. What is this thing called pain? *J Clin Invest*. 2010;120(11):3742–3744. doi:10.1172/JCI45178
3. Fregni F, El-Hagrassy MM, Pacheco-Barrios K, et al.; Neuromodulation Center Working Group. Evidence-based guidelines and secondary meta-analysis for the use of transcranial direct current stimulation in neurological and psychiatric disorders. *Int J Neuropsychopharmacol*. 2021;24(4):256–313. doi:10.1093/ijnp/pyaa051
4. Knotkova H, Nitsche MA, Bikson M, Woods AJ. *Practical Guide to Transcranial Direct Current Stimulation: Principles, Procedures and Applications*. 1st ed. Springer; 2019.
5. Nitsche MA, Paulus W. Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *J Physiol*. 2000;527(Pt 3):633–639. doi:10.1111/j.1469-7793.2000.t01-1-00633.x
6. DaSilva AF, Volz MS, Bikson M, Fregni F. Electrode positioning and montage in transcranial direct current stimulation. *J Vis Exp*. 2011;(51):2744. doi:10.3791/2744
7. DosSantos MF, Ferreira N, Toback RL, Carvalho AC, DaSilva AF. Potential mechanisms supporting the value of motor cortex stimulation to treat chronic pain syndromes. *Front Neurosci*. 2016;10:18. doi:10.3389/fnins.2016.00018
8. Antal A, Paulus W, Nitsche MA. Principle and mechanisms of transcranial Direct Current. Stimulation (tDCS). *J Pain Manag*. 2009;2:3.
9. Kronberg G, Bridi M, Abel T, Bikson M, Parra LC. direct current stimulation modulates LTP and LTD: activity dependence and dendritic effects. *Brain Stimul*. 2017;10(1):51–58. doi:10.1016/j.brs.2016.10.001
10. Monte-Silva K, Kuo MF, Hessenthaler S, et al. Induction of late LTP-like plasticity in the human motor cortex by repeated non-invasive brain stimulation. *Brain Stimul*. 2013;6(3):424–432. doi:10.1016/j.brs.2012.04.011
11. Liebetanz D, Nitsche MA, Tergau F, Paulus W. Pharmacological approach to the mechanisms of transcranial DC-stimulation-induced after-effects of human motor cortex excitability. *Brain*. 2002;125:2238–2247. doi:10.1093/brain/awf238
12. Nitsche MA, Jaussi W, Liebetanz D, Lang N, Tergau F, Paulus W. Consolidation of human motor cortical neuroplasticity by D-cycloserine. *Neuropsychopharmacology*. 2004;29:1573–1578. doi:10.1038/sj.npp.1300517
13. Baptista AF, Fernandes AMBL, Sá KN, et al. Latin American and Caribbean consensus on noninvasive central nervous system neuromodulation for chronic pain management (LAC2-NIN-CP). *Pain Rep*. 2019;4(1):e692. doi:10.1097/PR9.0000000000000692
14. Xiong HY, Zheng JJ, Wang XQ. Non-invasive brain stimulation for chronic pain: state of the art and future directions. *Front Mol Neurosci*. 2022;15:888716. doi:10.3389/fnmol.2022.888716
15. Sun W, Song J, Dong X, et al. Bibliometric and visual analysis of transcranial direct current stimulation in the web of science database from 2000 to 2022 via CiteSpace. *Front Hum Neurosci*. 2022;16:1049572. doi:10.3389/fnhum.2022.1049572
16. Cooper ID. Bibliometrics basics. *J Med Libr Assoc*. 2015;103(4):217–218. doi:10.3163/1536-5050.103.4.013
17. Donthu N, Mukherjee D, Kumar S, et al. How to conduct a bibliometric analysis: an overview and guidelines. *J Bus Res*. 2021;133:285–296. doi:10.1016/j.jbusres.2021.04.070
18. Rousseau R. Library science: forgotten founder of bibliometrics. *Nature*. 2014;510(7504):218. PMID: 24919911. doi:10.1038/510218e
19. Wang XQ, Peng MS, Weng LM, et al. Bibliometric study of the comorbidity of pain and depression research. *Neural Plast*. 2019;2019:1657498. doi:10.1155/2019/1657498

20. Zheng K, Wang X. Publications on the association between cognitive function and pain from 2000 to 2018: a bibliometric analysis using citeSpace. *Med Sci Monit*. 2019;25:8940–8951. doi:10.12659/MSM.917742
21. Yang S, Tan W, Ma X, Qi L, Wang X. Worldwide productivity and research trend of publications concerning cancer-related neuropathic pain: a bibliometric study. *J Pain Res*. 2022;15:2747–2759. doi:10.2147/JPR.S378119
22. Lucena MFG, Teixeira PEP, Bonin Pinto C, Fregni F. Top 100 cited noninvasive neuromodulation clinical trials. *Expert Rev Med Devices*. 2019;16 (6):451–466. doi:10.1080/17434440.2019.1615440
23. Bareeqa SB, Ahmed SI, Samar SS, Anwar A, Husain MM. A bibliometric analysis of top 50-most cited articles on repetitive trans-cranial magnetic stimulation (rTMS) for treatment of depression. *Heliyon*. 2021;7(1):e06021. doi:10.1016/j.heliyon.2021.e06021
24. Zheng KY, Dai GY, Lan Y, Wang XQ. Trends of repetitive transcranial magnetic stimulation from 2009 to 2018: a bibliometric analysis. *Front Neurosci*. 2020;14:106. doi:10.3389/fnins.2020.00106
25. Ke L, Lu C, Shen R, Lu T, Ma B, Hua Y. Knowledge mapping of drug-induced liver injury: a scientometric Investigation (2010–2019). *Front Pharmacol*. 2020;11:842. doi:10.3389/fphar.2020.00842
26. Wu H, Tong L, Wang Y, Yan H, Sun Z. Bibliometric analysis of global research trends on ultrasound microbubble: a quickly developing field. *Front Pharmacol*. 2021;12:646626. doi:10.3389/fphar.2021.646626
27. Aria M, Cuccurullo C. bibliometrix: an R-tool for comprehensive science mapping analysis. *J Informetr*. 2017;11(4):959–975. doi:10.1016/j.joi.2017.08.007
28. Garfield E. "The history and meaning of the journal impact factor". *JAMA*. 2006;295(1):90–93. doi:10.1001/jama.295.1.90
29. Vickery BC. "Bradford's law of scattering". *J Doc*. 1948;4(3):198–203. doi:10.1108/eb026133
30. Lotka AJ. The frequency distribution of scientific productivity. *J Wash Acad Sci*. 1926;16:317–323. As cited in Kawamura M, Thomas CD, Tsurumoto A, Sasahara H, Kawaguchi Y. Lotka's law and productivity index of authors in a scientific journal. *J Oral Sci*. 2000 Jun;42(2):75–8. doi:10.2334/josnusd.42.75.
31. Lefaucheur JP, Antal A, Ayache SS, et al. Evidence-based guidelines on the therapeutic use of transcranial direct current stimulation (tDCS). *Clin Neurophysiol*. 2017;128(1):56–92. doi:10.1016/j.clinph.2016.10.087
32. Fregni F, Pascual-Leone A. Technology insight: noninvasive brain stimulation in neurology-perspectives on the therapeutic potential of rTMS and tDCS. *Nat Clin Pract Neurol*. 2007;3(7):383–393. doi:10.1038/ncpneuro0530
33. Fregni F, Boggio PS, Lima MC, et al. A sham-controlled, Phase II trial of transcranial direct current stimulation for the treatment of central pain in traumatic spinal cord injury. *Pain*. 2006;122(1–2):197–209. doi:10.1016/j.pain.2006.02.023
34. Olesen J, Burstein R, Ashina M, Tfelt-Hansen P. Origin of pain in migraine: evidence for peripheral sensitisation. *Lancet Neurol*. 2009;8 (7):679–690. doi:10.1016/S1474-4422(09)70090-0
35. Fregni F, Gimenes R, Valle AC, et al. A randomized, sham-controlled, proof of principle study of transcranial direct current stimulation for the treatment of pain in fibromyalgia. *Arthritis Rheum*. 2006;54(12):3988–3998. doi:10.1002/art.22195
36. Antal A, Terney D, Kühnl S, Paulus W. Anodal transcranial direct current stimulation of the motor cortex ameliorates chronic pain and reduces short intracortical inhibition. *J Pain Symptom Manage*. 2010;39(5):890–903. doi:10.1016/j.jpainsymman.2009.09.023
37. Boggio PS, Zaghi S, Lopes M, Fregni F. Modulatory effects of anodal transcranial direct current stimulation on perception and pain thresholds in healthy volunteers. *Eur J Neurol*. 2008;15(10):1124–1130. doi:10.1111/j.1468-1331.2008.02270.x
38. Nitsche MA, Cohen LG, Wassermann EM, et al. Transcranial direct current stimulation: state of the art 2008. *Brain Stimul*. 2008;1(3):206–223. doi:10.1016/j.brs.2008.06.004
39. Nitsche MA, Paulus W. Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology*. 2001;57 (10):1899–1901. doi:10.1212/wnl.57.10.1899
40. Gandiga PC, Hummel FC, Cohen LG. Transcranial DC stimulation (tDCS): a tool for double-blind sham-controlled clinical studies in brain stimulation. *Clin Neurophysiol*. 2006;117(4):845–850. doi:10.1016/j.clinph.2005.12.003
41. Mori F, Codecà C, Kusayanagi H, et al. Effects of anodal transcranial direct current stimulation on chronic neuropathic pain in patients with multiple sclerosis. *J Pain*. 2010;11(5):436–442. doi:10.1016/j.jpain.2009.08.011
42. Johnson M. Transcutaneous Electrical Nerve Stimulation (TENS) and TENS-like devices: do they provide pain relief? *Pain Rev*. 2001;8(3–4):121–158. doi:10.1191/0968130201pr182ra
43. Tamburin S, Manganotti P, Zanette G, Fiaschi A. Cutaneomotor integration in human hand motor areas: somatotopic effect and interaction of afferents. *Exp Brain Res*. 2001;141(2):232–241. doi:10.1007/s002210100859
44. Painless project. Horizon-HLTH-2021-DISEASE-04 (2022–2027) Project ID: 101057367. Available from: https//palliativeprojects.ru/painless/. Accessed April 18, 2023.
45. van den Beuken-van Everdingen MH, Hochstenbach LM, Joosten EA, Tjan-Heijnen VC, Janssen DJ. Update on prevalence of pain in patients with cancer: systematic review and meta-analysis. *J Pain Symptom Manage*. 2016;51(6):1070–1090.e9. doi:10.1016/j.jpainsymman.2015.12.340