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Review Article

Quantifying and visualizing the transcranial direct current stimulation research indicators

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ABSTRACT

The field of transcranial direct current stimulation (tDCS) has experienced significant growth in the past 15 years which is mainly devoted to determining the basic and clinical potential of tDCS in humans. The aim of this study is to quantitatively analyze the current worldwide progress on tDCS research as well as to highlight researchers, journals, institutions and countries which are contributing significantly in the past 18 years. We conducted a quantitative analysis of research articles regarding tDCS published from 1998 to 2016 and indexed in the web of science core collection database. Data was downloaded in October, 2016. In the past 18 years, there were 2457 studies on tDCS indexed by web of science database, including all documents type such as article, review, meeting abstract, proceedings paper, letters, and etc. This study is focusing on the main articles and reviews; therefore, the research production was reduced to 2000 publications. The analysis showed that most of the studies in the field were published by North American and European institutions with a reasonable proportion of the publications were also by Japanese institutions from Asia. From the perspective of research progress, we found that the number of published papers on tDCS has increased significantly in the past 10 years, between them a remarkable positive correlation exists.

Keywords: Bibliometric analysis, Bibliometric indicators, Rehabilitation, Reviews, TDCS, Treatment, Web of science

INTRODUCTION

Noninvasive stimulation of the brain has become extensively applicator in the past two decades in research and it had shown its valuable potential therapeutic effect in cognitive neuroscience, neurophysiology, psychiatry, and neurology. There are two applications neuromodulation of this modality which are transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS). TMS works on neuro-stimulation and neuro-modulation, while tDCS is a purely neuromodulator.[1]

tDCS is a safe non-invasive brain stimulation that consists of a current generator and two electrodes, an active electrode is placed on the target area of stimulation of the scalp and a reference electrode over the contralateral area which can deliver weak direct currents in brain.[2] The low cost and simplicity in technique has guided interest in potential basic and clinical applications which showed promising results in cognitive enhancement and physical performance.[3] One of the major areas of interest is the enhancement of memory function in healthy individuals.

tDCS delivers either cathodal or anodal current to the brain cortex directly. Cathodal stimulation type is negatively-charged current which is proven in animal studies to decrease the stimulation and cause hyperpolarization, while anodal stimulation increase resting membrane to become more positive.[4] In human, these two different types of stimulation showed distinct effect. Anodal stimulation can increase blood-oxygen level-dependent (BOLD) signal in the fMRI where cathodal stimulation decreases it.[5-7] These proprieties of the tDCS can help us to understand the brain physiology and treating various conditions of brain's diseases. The influence of the excitability can be altered depending on the level of intensity, the site of the stimulation, the performed task during stimulation and also there is a variability from session to session within the same individual.[2,8-10]

tDCS has provided a promising results in neurologic and psychiatric disorders.[11,12] tDCS can be used for craving reduction for substance-related and addictive disorders, alcohol.[13-16] Also, tDCS has a lot of clinical applications, for example, in tinnitus, major depression disorder, pain management.[17-20] In smokers, tDCS showed to reduce the daily cigarette consumption.[21,22] Finally, tDCS has many applications when it used with post-stroke patients, for example, it has analgesic effect for central post-stroke pain and it has a great role in motor recovery in rehabilitation.[23,24]

Bibliometrics is a research field that studies the bibliographic material in a quantitative way and assesses the impact of scientific contributions.[25,26] It is very useful in analyzing research area and identifies its leading trends. Bibliometric can be developed in a wide range of contexts including the analysis of a research topic, journals, institutions and countries.[27-31] These bibliometric research studies enable researchers and specialists to analyses a specific research field by highlighting influential articles, journals, authors, institutions and countries. This countenances researchers to have an understanding of the research field and think beyond existing contributions.

Motivated by this, the aim of this research study is to depict bibliometric view of the scientific research indicators on the tDCS between 1998 and 2016, which has indicated that tDCS research is attaining substantial attention recently from researchers, academicians and professionals. Furthermore; the main advantage of this study is that one can comprehend who is leading and contributing significantly in the tDCS research and what are the main trends emerging in recent years which have influenced even more? Bibliometric research study in this regard; analyses published articles, citations and their sources of information. Moreover, this study also utilizes the VOS viewer software to visualize relations between authors and organizations, such as co-authorship in the tDCS research through bibliographic couplings and co-citation analysis. There have been many studies published recently concerning bibliometrics and networks mapping analyses, however, with the best of our knowledge no such study is found for the tDCS research area in the scientific research literature.[32-35]

The rest of the paper is structured as follows. Section 2 briefly reviews the bibliometric methods used in the analysis. Section 3 presents the publication and citation structure of the all tDCS results in the WOS. Section 4 develops a mapping and research networks analysis of the all tDCS articles in the WOS by using the VOS viewer software. Section 5 summarizes the main findings and conclusions of the paper.

REVIEW OF LITERARURE

Authors collected data from the web of science database on tDCS to provide an understanding of international research trends over the past 18 years using bibliometric indicators. Recent research indicators would be reflected in its publication outputs.[25] It has also been pointed out that citation rate is not only a direct measure of the impact or importance of a particular scholarly work, but also provides a marker of its recognition within the scientific community.[36] A common research tool for this analysis is the bibliometric method, which has already been widely applied in many disciplines of management, science and engineering areas.[37] Using bibliometric analysis such as citation rates of top-cited articles reveal useful and interesting information about scientific progress in a research field. Several recent studies have identified and analyzed citation classics and top-cited articles in various fields of science and engineering.

Although there are a wide range of methodologies that can be implemented when developing a bibliometric review, however; this study focuses on a general overview that presents different research indicators so each reader can get its own understanding of the bibliometric analysis. The main reason for this is that there exists no single method that everyone agrees upon as the unique method to be applied to evaluate research. The key problem is that some people may prefer to focus on some bibliometric indicators while the others may prefer some other influential indicators. However; specifically, it is clear that the comparison between productivity and influence is measured with the number of publications and citations. Some authors may give more importance to productivity and vice versa. Therefore, each method may evaluate the data in a different way. An alternative to get a unified method could be through the use of a consensual process where everybody agrees on the importance of each variable. However, this would be a subjective method because it is mainly based on the opinion of some experts in the field. To provide a detailed overview of the data, this study analyzes the total number of publications and citations, the citations per paper, the H-index The H-index is a measure that aims to represent the importance of a set of papers. It combines papers with citations.[38] For example,

if a set of papers have an H-index of 20; this means 20 of the papers included in the set have received at least 20 citations each. Note that since its introduction, the H-index has been extended and generalized by many authors.[39]

As mentioned earlier; this research study analyzes the Web of Science (WOS) data which is currently owned by Clarivate analytics. there are many databases containing these informative data. This work considers only web of science core collection, which considers several sub databases, containing the conference proceedings citation index. Web of science core collection includes research mostly from all well-known fields, which currently includes databases of more than 15,000 journals and 60,000,000 papers. WOS provides categorization of the contents according to 251 subject categories and in 151 research areas. As mentioned earlier this research is depending only on the web of science, although there are other databases such as Scopus and Google Scholar which are not considered here in this study.

Defining an appropriate search scheme is an important step in any such study. In this research; "Transcrainal Magnetic Stimulation" has been used as keywords to develop the search process with option "Topic" in the search section. This search has collected all the articles belonging to "Transcrainal Magnetic Stimulation" field. However, this kind of search process will bring some articles which have used this keyword but it does not belong to the scope of this research study. After carefully reviewing, such articles have been omitted. Note that WOS only includes the journal since 1987.

DISCUSSION

Publication and citation evolution of tDCS

tDCS methods started publishing papers in 1998. In the last few years it increased publication dramatically. According to WOS records; Figure 1 shows the evolution of the number of papers (Y-axis) published annually. As we can see, the number of papers starts increasing from 2008 onward with an exponential increase from 2011. One may visualize that this growth is due to the increased number of researchers worldwide as well as due to inclusion of the new journals in the WOS, the average citations received in each year is increasing throughout the selected time period of this research study.

Table 1: General citation structure in tDCS research.

Number of Citations (NOC)	Number of papers	% of category in total
NOC < 50	1690	86.62
50 ≤ NOC < 100	160	8.2
100 ≤ NOC < 500	96	4.92
500 ≤ NOC	5	0.26
Total	1951	100

There are a number of abbreviations which are used by the WOS. Without having knowledge of them, it is difficult to follow-up the results and analysis of this research study. Table 1 presents all the abbreviations used in this research study.

Table 2 illustrates a broader picture of the citation status in the field of tDCS research. It depicts a general citation structure of all the papers, which categorizes the articles according to the times of citations they have received, with the percentage of every category.

Note that a bit more than 0.26% of the articles have received more than 500 citations, about 4.92% receive at least more than 100 citations and 8.2% of the articles received more than 50 citations; whereas more than 86% of all results have been cited less than 50 times.

Most influential and productive journals

tDCS research articles are being published in various and high number of journals listed in the WOS. Table 3 provides information regarding the influential journals. Top 30 influential journals are sorted in Table 3 by the number of research articles published in the field of tDCS. Brain Stimulation Journal is the top most productive and influential journal based on total number of publications (155), total number of citation (4658) as well as H-index criterion.[34] Journal of Physiology London although ranked 14 with H-index; however, it has obtained the 2nd highest number of citations (3117) among the top 30 selected journals.[15] To present the most interested journals in tDCS; Table 3 also contains a column (%TP) showing the percentage of tDCS papers published in a journal with respect to total number of papers in the same journal. According to TP% indicator, Brain Stimulation journal again ranked top (17%) followed by Frontiers in Human Neuroscience (1.96%) and Neuro-rehabilitation and Neural Repair (1.75%) respectively.

Further; we consider the most productive and influential journals keeping in view BIs criterion of TP, H-index, TC, % TP and the number of articles with more than 50 citations throughout the selected time period. A list of the most productive and influential journals and their ranking with respect to each selected BIs is presented in Table 4. Ranking is based on tDCS research only.

Table 4 illustrates that Brain Stimulation (BS) Journal is the only journal which maintains its highest rank among all selected BIs except %TP; Journal of Neuroscience which is ranked the top most influential journal with the number of articles having more than 50 citations throughout the selected period. In addition; among the list of most influential journals (Table 4), six journals (BS, FHN, PO, NL, CN and JN (based on citations >50) are considered as top most productive journals in this field of tDCS research study.

Table 2: Most influential journals.

Rank	Journal name	tDCS Research							Impact factor	All publications		
		H	TP	TC	%TP	>500	>100	>50		TP	TC	H
1	BS	34	155	4658	17	1	7	14	4.79	912	10881	43
2	FHN	16	78	775	1.96	0	0	1	3.63	3988	28924	51
3	PO	17	66	866	0.04	0	1	2	3.06	164623	1256490	190
4	NL	18	62	1032	0.19	0	1	5	2.11	32348	746568	199
5	NI	25	54	1907	0.37	0	1	14	5.46	14692	626975	268
6	CN	21	54	2361	0.92	1	3	9	3.43	5880	139941	134
7	NP	17	52	1215	0.62	0	4	5	2.99	8324	330602	198
8	JN	24	47	2624	0.14	0	9	15	5.92	34103	2511583	433
9	EJN	18	46	1548	0.26	0	4	6	2.98	17840	412825	181
10	EBR	18	45	1629	0.31	0	4	6	2.06	14680	501882	215
11	RNN	17	44	1075	3.62	0	3	3	2.66	1214	18992	58
12	JNP	17	27	952	0.14	0	1	3	2.65	19581	1044229	313
13	JCN	10	27	1187	0.34	0	4	4	3.56	7850	178302	181
14	NR	12	26	1001	0.22	0	3	2	1.34	11802	322218	170
15	BBR	7	24	328	0.22	0	0	2	3	10902	265864	159
16	JPL	15	20	3117	0.03	1	5	2	4.73	62649	1889456	391
17	NNR	13	20	595	1.75	0	2	2	4.04	1146	25268	68
18	CC	11	19	762	0.43	0	2	5	8.29	4432	245373	202
19	NS	7	19	178	0.09	0	0	1	3.23	22258	874971	267
20	IJN	10	18	668	0.19	0	3	0	4.33	9474	38056	76
21	C	9	18	204	0.47	0	0	0	4.31	3805	86200	103
22	JAD	9	16	362	0.18	0	0	2	3.57	9000	210199	144
23	FN	3	15	19	0.72	0	0	0	3.4	2071	11370	36
24	NH	5	14	81	0.87	0	0	0	1.45	1602	13067	43
25	JPT	4	14	54	0.51	0	0	0	0.39	2721	5246	13
26	T	3	14	14	0.47	0	0	0	1.86	2973	17519	41
27	JE	7	13	133	0.74	0	0	0	1.83	1764	11694	42
28	NM	6	13	138	0.85	0	0	0	2.41	1526	837	36
29	FP	4	13	111	0.18	0	0	0	2.46	7360	27212	47
30	FCN	3	13	45	0.79	0	0	0	4.61	1642	10724	36

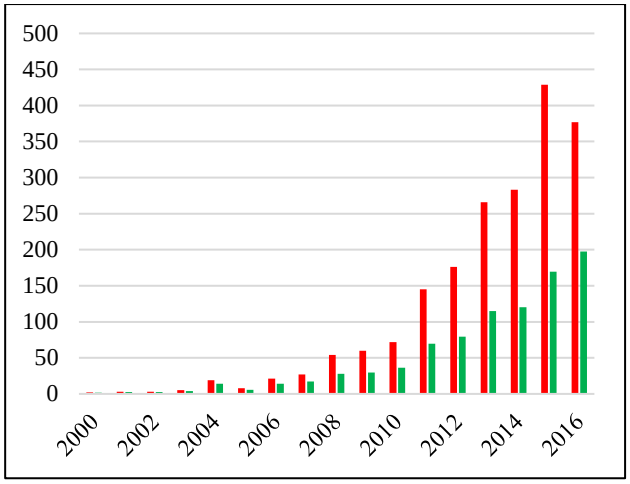
Table 3: Selecting the most productive and influential journals.

Rank	TP	H-index	TC	%TP	>50
1	BS	BS	BS	BS	JN
2	FHN	NI	JPL	RNN	BS
3	PO	JN	JN	FHN	NI
4	NL	CN	CN	NNR	CN
5	CN	EBR	NI	CN	EJN
6	NI	EJN	EBR	NH	EBR
7	NP	NL	EJN	NM	NL
8	JN	NP	NP	FCN	NP
9	EJN	RNN	JCN	JE	CC
10	EBR	JNP	RNN	FN	JCN

Another important and common BI measure to assess the quality of a journal is the impact factor. Impact factor (IF) basically is an indicator of the journal value, which is calculated by dividing the number of citations received in the last two years (i.e. n-1 and n-2 which is "TC_2" in Table 4, Figure 1) from year n divided by the total number of papers published in the last two years (n-1 and n-2 which is "TP_2"in Table 4).

Table 4: Impact factor in tDCS research.

Year	TP	TC	TC_2	TP_2	IF
2006	21	3051	208	27	7.704
2007	27	3126	206	29	7.103
2008	54	4969	365	48	7.604
2009	60	3953	480	81	5.926
2010	72	3938	711	114	6.237
2011	145	6223	999	132	7.568
2012	176	5151	1216	217	5.604
2013	266	4863	2269	321	7.069
2014	283	3354	2395	442	5.419
2015	429	1902	3152	549	5.741



The red bars indicate the total number of TDCS papers published each year in the WoS and the green bars indicate the ratio (N-TDCS-P/TNP) × 1,000,000 where N-TDCS-P is the number of TDCS papers in year X and TNP is the total number of papers published in the WoS in year X.

Figure 1: Number of annual publications in TDCS research (articles + reviews) since 1988.

The IF measure is also presented for the analysis of BIs in the tDCS research study. WOS provides the IF information under the Journal Citation Reports (JCR) section and results are presented in Table 5.

The IF analysis for a period of ten years is conducted and results are consolidated and illustrated in Table 5. The impact factor (IF) for all of the tDCS published papers in each year is calculated with respect to the total number of publications. For instance; in 2006 and 2007, the impact factor was more than seven, whereas in the following years, it is slightly drifting down but maintaining with an average of 6.6 impact factor. Overall; it can be considered that there is a stable trend in the tDCS research in the last 10 years. Regarding yearly trend, as seen in Table 5, there is a progressive growth throughout in the number of publications and in the number of citations.

Furthermore; to determine whether the tDCS research is currently active and is progressing with the passage of time; a statistical analysis (t test) is conducted for the data retrieved from the WOS in regards to the total number of publications and the total number of citations on yearly basis. Analysis results indicate that there is a significant increase in the number of publications (P-value = 0.040) as well as in the number of citations (P-value = 0.001).

Figure 2 and Figure 3 represents tDCS research trend analysis for the selected period of ten years (2006 -2015). Results indicate that there is a strong interest by researchers and professionals in the research area and both total number of publications and the total number of citations received by the published articles are growing not only significantly but also upward trend is exponentially increasing. Publications and citations exponential growth models with $R^2 = 0.9902$ and $R^2 = 0.9848$ in Figure 2 and 3 are illustrated in the following equations respectively.

$$Y \text{ (publications)} = 17.295e^{0.3563x} \quad (1)$$

$$Y(\text{citations}) = 133.12e^{0.3267x} \quad (2)$$

Most influential articles

To focus on important and influential articles published in the tDCS research field, all the articles have been sorted according to the number of citations received. The more the citations received by an article the more important and influential it is in the respective field. The articles with new and innovative ideas always receive higher number of citations. Table 6 shows the 50 most cited articles of all time in tDCS research. Nitsche et al has the most cited paper (1430 citations) which was published in 2000 and analysed tDCS excitability changes induced in the human motor cortex by weak transcranial direct current stimulation (40). Second top cited (841 citations) article (which is one of the safety paper about tDCS) followed by the 3rd top cited article (782 citations) belongs to Nitche et al as well. Fourth (549 citations) and fifth (536 citations) most cited papers are by authors Gandiga et al and by Hummel et al respectively.[41,42]

Figure 4 showed analysing the citations on yearly basis (C/Y); it is worth noting that Nitsche et al, has received the highest number of citations (98) in 2008 followed by Nitsche et al article; which has received 89 citations in 2000; whereas articles and by Stagg.; et al in 2011 and by Brunoni et al in 2012 have received 66 citations respectively.[46,42,56,66]

Most productive and influential authors

As mentioned earlier, tDCS research is very active in recent years and a number of authors and researchers are contributing significantly. In order to determine which authors have the highest influence and presence; Table 7 shows the 40 most active authors contributing to the field with having more than 15 research articles. The ranking (R) in Table 7 is done according to the number of total citations (TC) received by each article in the tDCS research, however; the criterion for the selection of influential authors is that only those authors which have published more than 15 articles are included in the list.

Nitsche MA is the most influential (14538 citations) author followed by Paulus W and Fregni F which have received the 2nd and 3rd positions by having number of citations 13376 and 8529 respectively. However, it is worth noting that Fregni F is the most productive author among the selected list based on number of publications (TP = 169) published in the tDCS field.

Table 5: 50 most cited papers in TDCS research of all time.

R	J	TC	Author/s	Year	C/Y
1	JPL	1,430	Nitsche et al	2000	89
2	N	841	Nitsche et al	2001	56
3	BS	782	Nitsche et al	2008	98
4	CN	549	Gandiga et al	2006	55
5	B	536	Hummel et al	2005	49
6	B	495	Liebetanz et al	2002	35
7	JPL	457	Nitsche et al	2003	35
8	PNA	435	Reis et al	2009	62
9	EBR	400	Fregni F et al	2005	36
10	JCN	375	Nitsche et al	2003	29
11	JN	373	Siebner et al	2004	31
12	NR	367	Fritsch et al	2010	61
13	BRB	363	Poreisz et al	2007	40
14	LN	334	Hummel et al	2006	33
15	NS	332	Stagg et al	2011	66
16	EJN	323	Lang N et al	2005	29
17	NCP	300	Fregni et al	2007	33
18	CN	298	Miranda et al	2006	30
19	JPL	290	Nitsche et al	2005	26
20	CN	286	Nitsche et al	2003	22
21	NR	283	Fregni F et al	2005	26
22	JN	280	Nitsche A et al	2007	31
23	P	278	Fregni F et al	2006	28
24	BS	275	Datta et al	2009	39
25	ARP	273	Wagner et al	2007	30
26	BS	263	Brunoni et al	2012	66
27	RNN	234	Boggio S et al	2007	26
28	JN	228	Stagg et al	2009	33
29	JNS	227	Boggio S et al	2006	23
30	BS	225	Ziemann et al	2008	28
31	NI	217	Wagner et al	2007	24
32	AR	207	Fregni et al	2006	21
33	EBR	204	Jacobson et al	2012	51
34	JN	202	Marshall et al	2004	17
35	S	194	Baker et al	2010	32
36	IJN	187	Boggio et al	2008	23
37	JN	187	Fecteau et al	2007	21
38	BP	182	Lang N et al	2004	15
39	N	181	Lindenberg et al	2010	30
40	JNN	177	Monti A et al	2008	22
41	JPL	175	Ardolino et al	2005	16
42	JCN	174	Antal et al	2004	15
43	IOV	174	Antal A, Nitsche et al	2004	15
44	IJN	173	Brunoni et al	2011	35
45	CC	167	Joseph M et al	2011	33
46	RNN	167	Nitsche et al	2011	33
47	JN	131	Fecteau et al	2007	15
48	NP	160	Kincses TZ et al	2004	13
49	PO	159	Zaehle et al	2010	27
50	JCN	157	Floeel et al	2008	20

It is also worth noting that even Pascual-Leone A and Boggio PS have published the same number of articles; however, Pascual-Leone A has received higher number of citations (6663) as compared to Boggio PS (5281

citations). It is worth noting too that the four most productive and highly cited authors (Nitchi MA, Paulus W, Fregni F and Pascual-Leone A) have more than 43000 citations in WOS which implies that they are very highly ranked in the tDCS research field worldwide. It is also noted that most of the influential and productive authors (62.5 %) are working in Germany, USA and Australia only.[12,8,5]

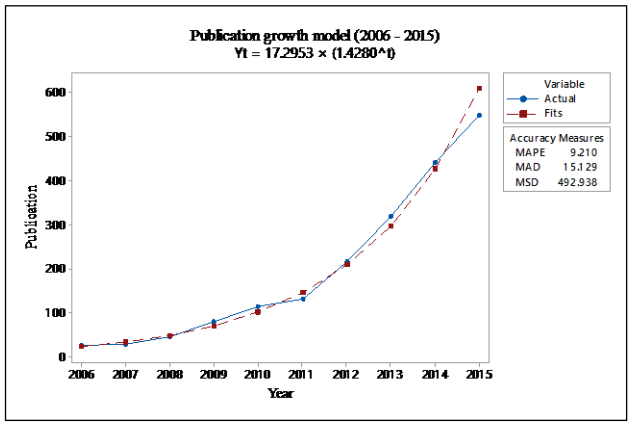


Figure 2: Publications trend analysis.

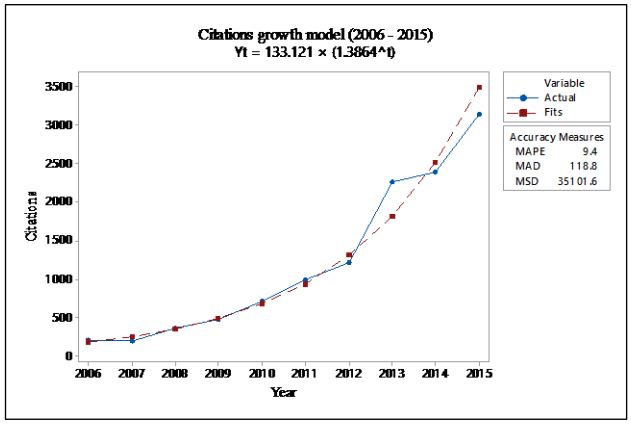


Figure 3: Citations trend analysis.

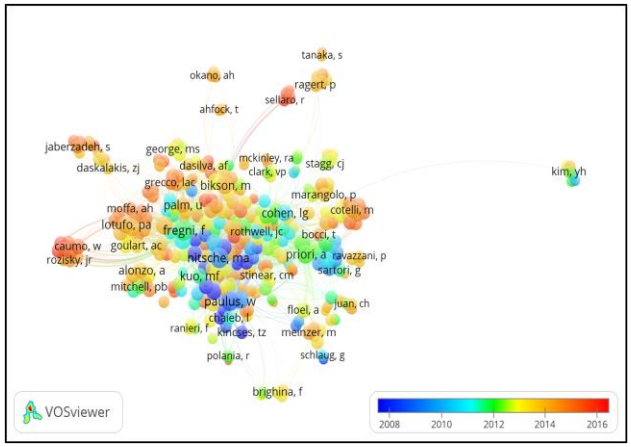


Figure 4: Authors published papers in transcrinal direct current stimulation field.

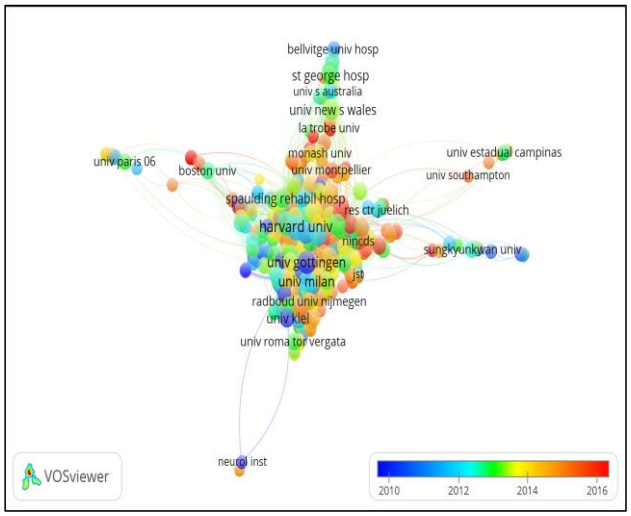


Figure 5: Authors published papers in transcrinal direct current stimulation field and link between organizations.

Next, let us look into the productivity of the leading authors throughout the selected time period in the top most productive list of six (refer Table 4) journals. For doing so, Table 8 presents the evolution of the publications of the most productive authors in the tDCS appeared in the top selected journals. In Table 8, we have selected only those ten influential authors which have published ten or more than 10 articles in the selected list of eight influential journals. Figure 5 provides an overview of the authors which are focusing on specific journals to publish their research articles and those who tend to publish in various scientific journals.

Results reveal that the top three authors (Fregni F, Nitchi MA and Paulus W) maintain their leading publishing position in the tDCS research as well as have published in all six selected journals; however, their highest number of articles are published in the BS journal. Next to them is Bikson M, who holds the fourth position and also publish in all the selected journals with the highest number of articles published in the BS journal too.[14] This has strong evidence that most of the influential authors are publishing their work in the Brain Stimulation journal.

Most influential institutions in tDCS research

tDCS research is conducted by several leading institutions. Many of these institutions are productive and influential because the leading authors and researchers are working in these institutions. However, sometimes, there are some institutions which maintain a long list of productive and leading authors making them more influential.

A list of twenty-five (25) most influential and productive institutions in tDCS research is presented in Table 9 which are ranked according to the total number of article's citations published in six selected journals by

these institutions. Figure 6 showed the last three columns also provide other bibliometric information (TP, TC and H-index) regarding all tDCS research articles published elsewhere in the WOS.

Table 6: Most influential authors in TDCS research.

R	Name	Country	tDCS						All		
			TP	TC	H-index	TP10	TC10	T50	TP	TC	H
1	Nitsche MA	Germany	147	14538	66	105	5968	17	232	16150	69
2	Paulus W	Germany	130	13376	62	94	5608	4	1557	52383	106
3	Fregni F	USA	169	8529	47	159	6613	7	414	15365	62
4	Pascual-Leone A	USA	71	6663	39	63	4939	3	663	31649	97
5	Boggio PS	Brazil	71	5281	33	63	3514	5	114	6717	39
6	Antal A	Germany	66	4910	34	51	2947	4	296	7702	41
7	Cohen LG	USA	31	4164	22	28	2745	4	515	33577	99
8	Liebetanz D	Germany	29	3411	23	16	1079	1	77	4165	29
9	Tergau F	Germany	16	3030	15	3	470	1	82	5591	35
10	Priori A	Italy	49	2725	25	48	2550	0	277	8476	47
11	Rothwell JC	England	30	2536	18	23	1040	0	875	50860	118
12	Bikson M	USA	65	2003	23	65	2003	0	143	4498	35
13	Floel A	Germany	33	1646	17	32	1110	0	159	5035	40
14	Ferrucci R	Italy	30	1541	19	29	1314	1	70	1642	20
15	Brunoni AR	Brazil	65	1366	20	65	1366	2	136	2187	22
16	Datta A	USA	30	1360	19	30	1360	1	3534	52693	91
17	Kuo MF	Germany	23	1292	16	22	1262	0	123	1938	24
18	Schlaug G	USA	21	1155	16	19	1000	0	331	15282	70
19	Celnik P	USA	15	1136	11	14	600	1	65	4960	27
20	Fecteau S	USA	18	1069	11	18	1069	3	71	2638	26
21	Bolognini N	Italy	21	773	11	21	773	1	200	2730	25
22	Vergari M	Italy	16	732	11	16	732	0	57	972	16
23	Loo CK	Australia	24	571	11	24	571	0	209	2445	26
24	Lavidor M	Israel	23	563	11	23	563	0	101	1651	25
25	Fink GR	Germany	17	517	8	17	517	0	893	67713	138
26	Miniussi C	Italy	23	513	13	23	513	1	186	7261	48
27	Byblow WD	New Zealand	15	501	10	15	501	0	129	3875	35
28	Alonzo A	Australia	20	479	10	20	479	0	1161	2520	25
29	Bensenor IM	Brazil	29	450	13	29	450	0	215	2586	22
30	Fitzgerald PB	Australia	24	450	9	24	450	0	387	8531	46
31	Padberg F	Germany	23	417	8	23	417	0	334	10012	48
32	Lang N	Germany	26	413	22	14	1540	3	1666	59279	118
33	Lotufo PA	Brazil	26	406	11	26	406	0	264	4918	27
34	Meinzer M	Australia	17	366	9	17	366	0	66	1441	22
35	Palm U	Germany	22	362	7	22	362	0	210	1297	19
36	Plewnia C	Germany	16	355	8	16	355	0	92	1614	22
37	Lefaucheur JP	France	19	342	9	19	342	0	292	8581	47
38	DE Ridder D	Belgium	16	334	11	16	334	0	803	13992	57
39	Cotelli M	Italy	16	247	8	16	247	0	125	1809	23
40	Jaberzadeh S	Australia	16	173	7	16	173	0	43	411	12

Results in Table 9 reveal that Gottingen University, Germany is highly influential in the tDCS research which has obtained the higher number of citations (4644 in selected journals whereas 16538 in all WOS journals). The Harvard University, USA has received the 2nd position with higher number of citations (3654 in selected journals whereas 11148 in all WOS journals) in the field of tDCS. It is worth noting that among 25 institutions, western institutions are leading in the tDCS research. Furthermore; 56.0 % institutions belong to Germany and USA only followed by 16.0 % institutions belong to Australia.

Table 7: Total papers classified by selected journals.

Rank	Author	BS	FHN	PO	NL	CN	JN	Total
1	Fregni F	18	4	5	9	6	3	45
2	Nitsche MA	16	3	1	2	6	8	36
3	Paulus W	14	1	2	2	8	8	35
4	Bikson M	14	5	3	0	2	0	24
5	Boggio PS	5	2	4	6	1	1	19
6	Pascual-Leone A	9	0	2	1	1	2	15
7	Antal A	8	1	1	1	3	0	14
8	Brunoni AR	5	0	3	3	2	0	13
9	Priori A	6	1	1	2	2	0	12
10	Kuo MF	4	0	0	0	0	6	10

Table 8: The most influential institutions in TDCS research.

R	Name	Country	tDCS articles in selected six journals			tDCS articles in all WOS journals		
			H	TP	TC	TP	TC	H
1	Univ Gottingen	Germany	33	64	4644	183	16538	72
2	Harvard Univ	USA	29	68	3654	235	11148	56
3	Ninds	USA	12	13	2417	38	4674	24
4	Beth Israel Deaconess MED CTR	USA	11	17	2004	48	3221	25
5	Univ Kiel	Germany	6	8	1547	25	2590	18
6	Univ Milan	Italy	9	13	1389	55	2942	26
7	UCL	Germany	15	25	1337	77	2742	25
8	Univ Prebiteriana Mackenzie	Brazil	12	19	1268	58	2830	27
9	Cuny City Coll	USA	16	31	1222	60	1914	23
10	Univ Sao Paulo	Brazil	11	22	923	103	4198	29
11	Univ Tubingen	Germany	7	17	853	38	1687	13
12	Univ Oxford	England	10	15	570	41	1500	17
13	Johns Hopkins Univ	USA	7	9	466	30	1535	17
14	Univ Munich	Germany	7	10	405	29	500	10
15	Spaulding Rehabil	USA	8	9	397	20	536	11
16	Charite	Germany	10	17	373	45	842	14
17	Univ Penn	USA	10	20	336	35	670	17
18	Univ Auckland	New Zealand	5	6	333	28	602	13
19	Monash Univ	Australia	8	17	315	36	489	10
20	Univ Brescia	Italy	8	13	285	29	526	13
21	Univ New S Wales	Australia	7	11	126	38	696	14
22	Max Planck Inst Human Cognit Brain	Germany	6	9	106	21	209	9
23	Univ Queensland	Australia	5	11	100	29	313	10
24	ST George HOSP	Australia	6	6	98	23	535	11
25	Bar Ilan Univ	Israel	3	5	93	26	518	10

In general; out of twenty-five selected institutions; 18 institutions are Germany, American and Australian based institutions. Asian institutions are totally absent in the top 25 list.

Most influential countries in tDCS research

Figure 7 showed an interesting bibliometric indicator is to classify the authors and institutions by countries.

Thus, we can see the regions where tDCS research is more active and influential. For doing this, Table 9 presents the 30 most productive countries in the tDCS.

Table 9: The most influential countries in TDCS research.

Rank	Name	TP	TC	>500	>100	>50	TP10	TC10	H
1	Germany	492	25137	5	60	61	440	14012	84
2	USA	651	20535	3	40	64	634	16698	70
3	Italy	278	7271	1	14	20	273	6356	42
4	Brazil	201	7043	1	17	16	191	5117	39
5	England	226	6820	0	19	19	218	5254	42
6	Australia	185	2753	0	2	12	185	2753	28
7	Spain	61	2441	0	7	5	60	2160	26
8	France	75	1478	0	4	4	75	1478	20
9	South Korea	68	1191	0	1	6	68	1191	19
10	Canada	87	1163	0	2	4	5117	1142	18
11	Switzerland	48	981	0	2	5	47	917	16
12	Japan	76	946	0	1	5	75	854	17
13	Hungary	15	667	0	2	3	13	475	11
14	New Zealand	37	660	0	1	2	37	660	14
15	Israel	33	600	0	1	3	33	600	11
16	Portugal	18	600	0	1	3	17	301	9
17	Netherlands	62	443	0	0	1	62	443	11
18	Denmark	15	350	0	0	1	15	350	10
19	Taiwan	22	296	0	0	2	22	296	8
20	China	47	272	0	0	0	47	272	9
21	Austria	20	230	0	0	2	20	230	7
22	Russia	8	119	0	0	1	7	116	4
23	Belgium	81	114	0	0	5	81	114	20
24	Poland	13	92	0	0	0	13	92	6
25	Iran	14	80	0	0	0	14	80	4
26	Thailand	9	80	0	0	0	9	80	3
27	Turkey	10	76	0	0	1	10	76	3
28	India	15	69	0	0	0	15	69	5
29	Ireland	8	63	0	0	0	8	63	5
30	Wales	9	38	0	0	0	9	38	3

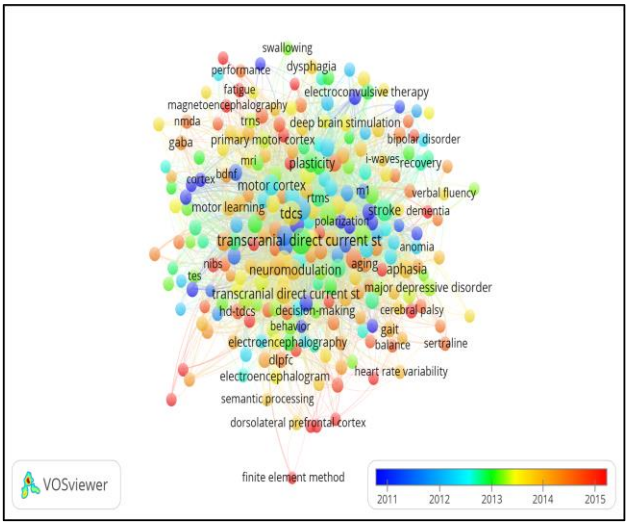


Figure 6: Authors published papers in transcrinal direct current stimulation (tDCS) field and co-occurrence with key words of tDCS.

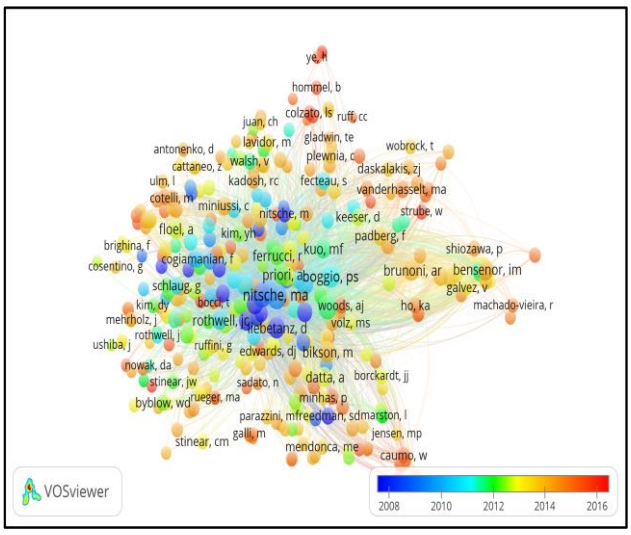


Figure 7: Citation graph between authors papers in transcrinal direct current stimulation field.

The countries are ranked by total number of citations received as well as by their research productivity; although some other bibliometric indicators are also considered including the total number of citations, H-index, the number of articles and citations received in last 10 (TP10 and TC10) as well as the number of articles which have received more than >500, >100 and >50 citations. Germany, USA and Italy are the leading countries in tDCS research. Note that England, Brazil, Australia and Canada are also obtaining promising results in regards to total number of citations. It is also noted that some Asian countries are also starts appearing in the selected list in recent years as well.

Bibliometric coupling and graphical analysis

The graphical representation of the tDCS research articles is conducted in this section. Figure 8 showed the graphs are giving a visualized picture of the common work and occurrence of authors, organizations, and documents. For doing so, we use the VOS viewer software that visualizes the bibliographic material through co-authorship, co-occurrence, citation, bibliographic coupling and co-citation analysis. Note that the graph visualizes those variables mostly meet the bibliographic parameters. In the bibliometric coupling graphs, circles are representing the set (authors, organizations, etc.), so the bigger the circle means that this corresponding set has a more link strength, Link strength represents the number of times a corresponding set has been repeated in the relevant field (co-authorship, co-occurrence, etc.). The lines between the authors, organizations, and so on, represent repetitions; thus, the thickest line provides the strongest relation.[43]

Co-authorship coupling analysis

Co-authorship illustrates the volume of publications by authors, organizations, and countries and shows how they are connected. First, Co-authorship shows the volume of publications of a set of variables (authors, organizations, and countries) and how they are connected between them. Regarding the co-authorship between authors in tDCS, Figure 4 reveals that Fregni F has the greatest co-authorship among all other authors. Fregni F exits 539 times (total link strength according to VOS Viewer analysis) with other authors in all his 169 published articles, for example he published 54 articles with Pogo PS.

Note that the total link strength is represent the relation of co-authorship of a set with all other, and it doesn't equal to the number of publications, because the set may have more than one co-authorship in the same paper and then will be counted more than one. Then, Nitsche MA comes in the second position having greatest co-authorship with 479 total link strength, and the most partner for Nitshce MA is Paulus W who is also having the third strongest link strength. Nitshce and Paulus published 86 papers together in the tDCS field. Furthermore, most of the papers by Nitsche and Paulus are published early in 2008, whereas most of papers published by Fregni are around 2014 as shown below in the color key in the right down of the figure. It is worth noting that all top authors in TDCS are mostly publishing as two more authors.

Co-authorship organizational analysis

Furthermore, inter-organization co-authorship is shown in Figure 5. Among all organizations publishing in tDCS, Harvard University has the strongest co-authorship with other organizations. It has 578 co-authorships with all other organizations, and the most partner was Sao Paulo University, which is also comes second with 321 total link strength.

Co-occurrence analysis

Co-occurrence measures the number of times that a keyword appears in the documents considered. Figure 4 presents the keywords mostly used in the tDCS field. Author keywords (the keywords that appear in the first page of many journals) are considered to visualize the existing of our related keywords and their common existing in the same paper.

Figure 6 shows that keyword "Transcranial direct current stimulation" and its abbreviation used in this research study are the strongest occurrence (existence in papers considered) and have the strongest link (common existing with other keywords), which are placed in the core of the graph. Transcranial direct current stimulation has 1707 common occurrences with other keywords, and the keyword "Transcranial magnetic stimulation" has the most common occurrence with it, which also comes in the third position. "Brain stimulation" also comes fourth with 1322 link strength.

Citation coupling analysis

Citation between authors measures the direct citations between two authors in the set considered (documents, sources, authors, organizations, or countries). For example, with two authors, the connection represents the number of times author X has cited Y plus the number of times that author Y has cited X inside the set of documents considered. Note that here one visualizes the two documents that gives the citation but not the third document that receives the other two citations. Citations between authors are shown in Figure 7 which depict that Nitsche MA is the most authors received and cited others in his 148 papers appeared in this part of analysis. Nitsche received the most citations from Fregni F which is also comes in the third position after Paulus.

Bibliographic coupling analysis

The connections show the variables (documents, sources, authors, organizations, or countries) that cite the same documents. But not necessarily they are co-authors. Note

that the two connected documents appear in the figure but not the third one unless it also has a significant degree of bibliographic coupling through other documents. Figure 8 illustrates the bibliographic coupling between authors. The results again show that Nitsche MA has the most common reference with other authors having 1272472 link strength.

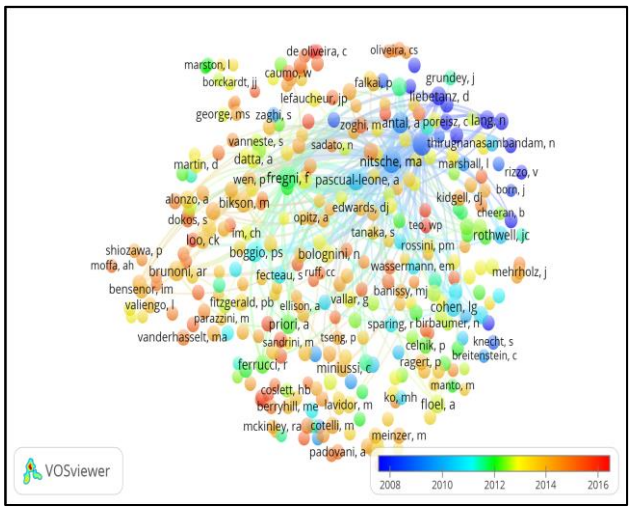


Figure 8: Bibliographic coupling of authors that publish papers in transcrinal direct current stimulation field.

Note that link strength here means the times author number 1 and another author number 2 have cited a third author at the same time, and these number will be counted more than one in the same paper if it is repeated with other authors. For example, Nitsche MA has cited the same authors with Paulus W 79690 times, who come in the third position after Fregni.

CONCLUSION

This study has presented a quantitative analysis and visualization of bibliometric indicators in the field of tDCS research. Initially, analyzing the WOS data; results reveal that since 2011 there is a growing interest by researchers in the field. BI indicators such as total number of publications and citations are increasing exponentially with positive trend. Results also reveal that country wise, Germany is the most influential country with higher number of citations; whereas United States is the most productive country with higher number of publications. It is also observed that some developing countries are also appearing in the list including Brazil, South Korea, India, Iran, Thailand and Turkey. Currently, they do not have significant position; however, it is expected that their contributions will continue to grow significantly in future. Nitsche Ma and Paulus W from Germany appeared as the most active and influential authors followed by Fregni F from USA. Among institutions; University of Gottingen (Germany) holds the most influential institution position, however Harvard University is the most productive institutions in tDCS research. Australia has many influential institutions and researchers, since there are four Australian institutions in the twenty-five most influential institution list, and the same thing occurred in the list of the most influential authors. Among 25 top institutions, western institutions are leading in the tDCS research. 56.0 % institutions belong to Germany and USA only followed by 16.0 % institutions belongs to Australia. Asian institutions are totally absent among the selected twenty-five most influential institution list. Study also reveals that Brain Stimulation journal is the top most productive and influential journal; which publishes 17 % tDCS research papers followed by Frontiers in Human Neuroscience (1.96%) and Neuro-rehabilitation and Neural Repair (1.75%) respectively.

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