Publication trends in transcranial magnetic stimulation: a 30-year panorama

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ABSTRACT

Background: Transcranial magnetic stimulation (TMS) is a non-invasive neuromodulatory technique that has broad diagnostic and therapeutic potential across a range of neurological and psychiatric diseases.
Objective: This study utilises a bibliometric approach to systematically and comprehensively evaluate the literature on TMS from the last three decades.
Methods: The Scopus citation database was used to identify all peer-reviewed journal articles concerning TMS over the period 1988—2017. Frequency-distribution, cross-tabulation and keyword analyses were performed to determine the most prolific researchers, institutions, nations, journals and the foremost studied disease entities within the TMS field. Given recent heightened awareness of gender bias across many fields of biomedicine, female representation among the most prolific authors was determined. Open-access publication rates and types of study design utilised were also quantified.
Results: 17,492 TMS-related articles were published during the study period 1988—2017. The annual TMS research output has increased dramatically over this time, despite a recent levelling-off of publications per year. The most prolific institutions were based in the United Kingdom, the United States and Canada. The top disease entities studied were stroke, depression and Parkinson's disease. Only 4/52 of the most productive researchers during the study period were female. A minority (4.81%) of publications were published as gold open-access.
Conclusion: This study implemented a systematic, bibliometric approach to quantitively assess the breadth of the TMS literature base and identify temporal publication and authorship trends. Drawing on these insights may aid understanding of historical progress in TMS over the last 30 years and help identify into unmet needs and opportunities to improve scientific and publishing practices to contribute to the future health of the field. These findings are likely to be relevant to researchers, clinicians, funders, industry collaborators and other stakeholders.

Introduction

Transcranial magnetic stimulation (TMS) uses a time-varying magnetic field induce electric current to selectively modulate neuronal activity over discrete brain regions via electromagnetic induction. When applied to the cortex, the painless induction of currents in cortical neurons can lead to neuronal depolarisation, which is thought to influence cortical excitability and thereby function [1—3]. Since Anthony Barker and colleagues built the first practical electromagnetic device for human use at the University of Sheffield in 1985, TMS has become a potent, non-invasive diagnostic tool to evaluate nervous propagation from the primary motor cortex along the corticospinal tract, spinal roots and peripheral nerves [4]. It has found use as a research tool for mapping and elucidating cortical function in a variety of neuropathological states and it allows for intraoperative neurophysiological monitoring, for example during tumour resections and epilepsy surgery [5—8]. It has also found a place in the therapeutic armamentarium against neurological conditions such as headache and other forms of chronic pain, spasticity, post-stroke deficits and Parkinson's disease (PD), among others [9—17]. In recent years and beyond

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these roles, the efficacy of TMS has been tested against a wide range of psychiatric conditions, predominantly major depressive disorder and treatment-resistant depression, and it has been shown to provide some benefit in the setting of post-traumatic stress disorder (PTSD), obsessive-compulsive disorder (OCD), addiction disorders, and in ameliorating the negative symptoms of schizophrenia, with a well-established safety and tolerability profile [18–30].

A 2014 consensus position statement on the therapeutic use of repetitive TMS (rTMS) issued by a group of European experts found level A or B evidence supporting the efficacy of rTMS protocols in major depressive disorder, pain, rehabilitation of motor function after stroke, and schizophrenia [31]. Examples of more recent evidence synthesis through meta-analysis have confirmed the durability of the antidepressant effect of TMS in depression, to efficacy against motor symptoms and refractory depression in PD, and against tic and obsessive-compulsive symptoms in Tourette syndrome [32–35]. In contrast, similarly recent meta-analyses have demonstrated that assertions of TMS efficacy in conditions such as Alzheimer's disease, obsessive-compulsive disorder, PTSD, autism spectrum disorder and seizure control in epilepsy are not yet justified [36–42]. Poor primary study design and clinical and methodological heterogeneity contribute to uncertainties regarding efficacy [43]. Nevertheless, as the breadth of both experimental and clinically established indications for TMS expands, the array of TMS techniques available (such as high-frequency, navigated and repetitive TMS) and the nature of the studies undertaken have also evolved, with a number of large-scale, multisite randomised controlled trials completed in recent years [44–52].

Bibliometric analysis is a widely used quantitative method to examine the knowledge structure and development of specific research fields [53–56]. Although there exist publications that provide a general overview of TMS with respect to specific health states to our knowledge none have utilised a bibliometric approach to provide a whole-field panorama [57]. Accordingly, this study takes a bibliometric approach to systematically and comprehensively evaluate the vast literature on TMS that has accumulated over the past three decades (1988–2017).

Materials and methods

A search of the Scopus scientific citation indexing service (https://www.scopus.com/; Elsevier, Amsterdam, Netherlands) was performed on 11th April 2018 to identify research outputs on the subject of TMS. Scopus, introduced in 2004, is the largest abstract and citation database of peer-reviewed literature, containing over 1.4 billion cited references dating back to 1970. The database covers 5000 publishers and over 12 million unique author profiles. Scopus covers a wider range of journals than the similar Web of Science bibliometric database (Clarivate Analytics, Philadelphia, PA, USA) while still permitting in-depth citation analysis and cross-tabulation and, for these reasons, it was chosen for the present study [58,59].

The terms for TMS in English, French, German, Spanish, Portuguese, Italian and Dutch were used. The search was designed to detect publications where TMS was mentioned in the title, abstract or keywords of publications. The following search string was used: TITLE-ABS-KEY ("Transcranial magnetic stimulation" OR "Transkranielle Magnetstimulation" OR "Estimulación magnética transcranean" OR "Estimulação magnética transcraniana" OR "Stimulation magnétique transcrânienne" OR "Stimolazione magnetica transcranica" OR "Transcraniële magnetische stimulatie") AND (EXCLUDE (PUBYEAR, 2018)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "le") OR LIMIT-TO (DOCTYPE, "no") OR LIMIT-TO (DOCTYPE, "sh") OR LIMIT-TO (DOCTYPE, "ip") OR LIMIT-TO (DOCTYPE, "ed")) AND (LIMIT-TO (SRCTYPE, "j")).

Publications of the source type "journals" were included; those of the types "conference proceedings", "book series", "books", "trade publications" and "undefined" were excluded. The following document types were included: article, article in press, review, letter, editorial, note and short survey; the following document types were excluded: conference paper, book, book chapter, erratum, and conference review. No geographic or language restrictions were applied. In order to allow for evaluation of only full publication years, publications from the current year (2018) were excluded; no further date restrictions were applied.

The dataset of publications identified by the above search was explored, quantified and subject to keyword analysis within the Scopus online environment. The most prolific authors, institutions and nations were identified. Further statistical analysis and graphical visualisation was performed using Microsoft Excel for Mac (version 16.11.1; Microsoft, Redmond, WA, USA) and Prism for Mac OS X (version 7.0a; GraphPad Software, Inc., San Diego, CA, USA). The number of individual authors in the dataset was computed using the R package bibliometrix (version 2.0.2; Department of Economics and Statistics, University of Naples Federico II, Naples, Italy) [60]. Contemporary journal and author metrics were obtained from the online databases Scopus and Journal Citation Reports (http://jcr.incites.thomsonreuters.com/; Clarivate Analytics, Philadelphia, PA, USA) on 11th April 2018. The coverage in each of the top ten journals in the field within the Sci-Hub service, as of March 2017, was determined using the Sci-Hub Stats Browser (https://greenelab.github.io/scihub/#/journals; Greene Laboratory, University of Pennsylvania, Philadelphia, PA, USA) [61].

The h-index, an author-level metric defined as the maximum value of h such that the given author/journal has published h papers that have each been cited at least h times, was computed for the most prolific authors. The gender of each of the top 100 most productive authors in the field over the study period was evaluated based on a review of each author's given names. When this information was not decisive, gender was determined by review of the websites of affiliated institutions and social media sources (e.g., ResearchGate). The most prolific institutions were identified based on the affiliations of all authors contributing to a given manuscript, not just those of the first or corresponding authors. Open access availability was quantified according to the following categorisation scheme:

- Gold open access, where an author publishes their article in an online open-access journal or under an open-access license
- Green open access, where an author publishes their article in a journal and then self-archives a copy in a freely accessible institutional or specialist online repository or on a website, as permitted by relevant copyright legislation
- Promotional open access, where subscription-based journals provide open access to individual articles or entire issues sporadically until further notice or temporarily with a predetermined access-withdrawal date [62].

As this bibliometric analysis drew on publicly available data and did not directly involve human participants, ethical review by an institutional review board was not required.

Results

A total of 17,492 unique publications were identified, 4.81% (n = 842) of which were published as gold open-access, which allows papers to be accessed by readers cost-free immediately upon publication. The remaining 95.19% (n = 16,650) publications were

published in subscription, green open-access or promotional open-access sources. The median number of publications per year was 438 (mean 583, interquartile range 857; Fig. 1). The mean year-on-year growth in field publications count was 127.18% during 1988–1992, 30.95% during the period 1993–1997, 16.36% during 1998–2002, 13.04% during 2003–2007, 9.31% during 2008–2012, and 3.06% during 2013–2017. The original Barker et al. Lancet publication from 1985 has to date been cited a total of 2298 times according to the Scopus database [4].

The total number of individuals authoring publications was 31,240, with a total of 81,883 authorship positions seen in the dataset. The mean number of authors per publication was 4.67. Overall, the top five most productive authors in the field of TMS are, in descending order, Alvaro Pascual-Leone (Harvard University, USA), John C. Rothwell (University College London, UK), Walter Paulus (University of Göttingen, Germany), Mark Hallett (National Institute of Neurological Disorders and Stroke, USA), and Paul B. Fitzgerald (Monash University, Australia). These five authors alone account for 8.03% (n = 1405) of TMS publications. The top 52 most productive authors in the field overall (representing the top 50 places with three authors tied for 50th place) are outlined in Table 1. The median h-index across this group of 52 authors was 53 (95% confidence interval 50.83–65.63). Notably, only four of these top 52 most productive authors in the field during 1988–2017 were female; they were Sarah H. Lisanby, Janet L. Taylor, Andrea Antal and Cathy M. Stinear.

Focussing on more recent developments in the field, Table 2 shows the top 20 most productive authors during the period 2008–2017. Among the top 50-placed authors (represented by 53 individual authors owing to tied positions) by publication count in the period 2008–2017, five were women: Sarah H. Lisanby, Andrea Antal, Faranak Farzan, Mervi Könönen and Cathy M. Stinear.

The top ten most productive institutions across the period 1988–2017 are shown in Table 3, with each of these top ten institutions producing a mean of 13 TMS publications per year (median 16 publications per year) over the 30-year study period. This list is headed by University College London (UK), Harvard University (USA) and the National Institutes of Health (USA; incorporating the National Institute of Neurological Disorders and Stroke and the National Institute of Mental Health, among others) and their respective affiliated academic and clinical institutions. The most prolific ten institutions by publication count accounted for 23.72% (n = 4149) of the total publication dataset. A total of 160 institutional affiliations were represented in the 17,492-paper dataset (based on the affiliations of all contributing authors).

From 1988 to the close of 2007, 5521 TMS-related research outputs had been published. The USA was the most productive

country during this timeframe, accounting for 25.01% of all TMS research during this period (Table 4), followed by Germany (20.36%) and the UK (12.24%) in the standings. The top 10 most-productive countries represented 81.11% (n = 4478/5521) of research outputs during 1988–2007. In line with this, the top 10 most-productive countries represented 81.51% (n = 9757/11,971) of research outputs during 2008–2017. The Netherland (formerly eleventh-place, now tenth) and the People's Republic of China (formerly seventeenth-place, now ninth) entered the top ten during this more recent time period, while Switzerland (formerly ninth-place, now thirteenth) and Spain (formerly tenth-place, now twelfth) exited the top ten. The most common languages of publications overall were English (93.69%; n = 16,388), German (1.90%; n = 333), Chinese (0.99%; n = 174), French (0.88%; n = 154) and Japanese (0.73%; n = 128).

Clinical Neurophysiology was the most popular journal for publishing TMS research with 828 publications (4.73% of total TMS research output), followed by *Brain Stimulation* (3.22%) and *Experimental Brain Research* (3.04%). The top ten highest-output journals represented in the dataset are shown in Table 5 along with journal-specific metrics. The median journal impact factor (JIF, defined as the average number of times that articles in a particular journal, published during the last two preceding years, were cited over the last year by new publications) of the top 10 journals was 3.538 (mean 4.187, range 1.917–7.592). The median CiteScore, which is a comparable metric to the JIF but which uses a three-year citation window, was 3.25 (mean 3.64, range 1.97–6.31) among the top 10 journals. The mean coverage of this cohort of journals in the Sci-Hub database, which allows cost-free access to the scientific literature (while being illegal or of questionable legality in some jurisdictions; cf. the original incarnation of Napster in the music industry [63]) was 84.4% (median 98.7%, interquartile range 74.1–99.6).

73.79% of all TMS publications were of the document type "article"; the remaining publications were reviews or systematic reviews (16.03%), letters (3.76%), editorials (2.80%), notes (2.14%) or short surveys (1.10%). Articles in press accounted for 0.38% of the publication set and were from the following years: 2015 (n = 1), 2016 (n = 1) and 2017 (n = 64).

Overall, depression and its subtypes formed the main disease entity investigated within the TMS literature, followed by stroke, Parkinson's disease, schizophrenia and other motor dysfunction. The major disease entities studied in the TMS literature remained largely stable across the periods 1988–1997, 1998–2007 and 2008–2017 (Table 6). There was no discernible increase in the field-wide publication rate following early reports of repetitive or navigated TMS, although the proportion of papers describing studies utilising these techniques increased over time, from 18% in 2000 to 33% in 2017, and from less than 1% in 2000 to 3.9% in 2018, respectively.

Based on the age groups subject to research within the TMS literature, demonstrated by keyword analysis of publications over the entire 1988–2017 period, the following publication counts per age group were seen: child (2.75%, n = 482), adolescent (7.35%, n = 1286), young adult (15.52%, n = 2714), adult (54.99%, n = 9619) middle-aged adult (22.11%, n = 3868), and aged adult (14.65%, n = 2563). Again based on keyword analysis and with respect to research subject gender breakdown, the keyword "male" was recorded for 55.95% of publications, and "female" was coded for 52.10% of publications. Case reports (n = 1959) accounted for 6.00% research outputs. Controlled studies (n = 6627) and randomised controlled trials (n = 1066) represented 37.89% and 6.09% of TMS research outputs, respectively.

According to keyword analysis (publications matching any of the keywords "animal", "animals", "animal tissue", "animal
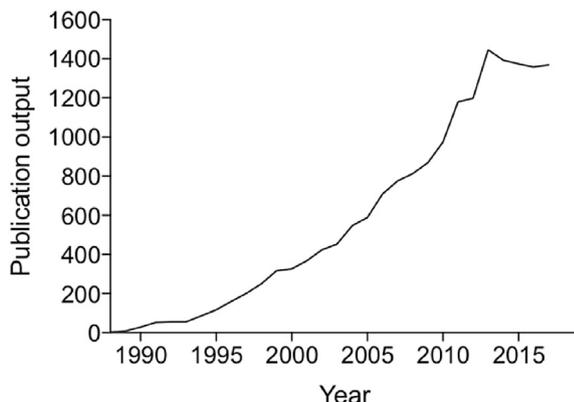

Fig. 1. Publication output per year 1988–2017.

Table 1
Ranking of authors by total number of TMS research outputs during the period 1988–2017 inclusive (top 50 places with 52 individual researchers owing to three authors being tied for 50th place). The publication and citation metrics and the author h-index values shown were extracted from Scopus on 11th April 2018.

Rank	Author	Total outputs (n)	Total outputs (% of 1988–2017 dataset)	Author h-index based on their entire publication history
1	Pascual-Leone, A.	434	2.48	127
2	Rothwell, J.C.	424	2.42	135
3	Paulus, W.	231	1.32	97
4	Hallett, M.	228	1.30	150
5	Fitzgerald, P.B.	215	1.23	57
6	Ziemann, U.	211	1.21	75
7	Fregni, F.	206	1.18	78
8	Daskalakis, Z.J.	200	1.14	57
9	George, M.S.	190	1.09	81
10	Cohen, L.G.	187	1.07	108
11	Chen, R.	156	0.89	67
12	Siebner, H.R.	147	0.84	65
13	Walsh, V.	136	0.78	68
14	Nitsche, M.A.	133	0.76	85
15	Rossini, P.M.	130	0.74	84
16	Koch, G.	128	0.73	43
17	Ugawa, Y.	120	0.69	48
18	Di Lazzaro, V.	119	0.68	59
19	Langguth, B.	115	0.66	43
20	Berardelli, A.	111	0.63	68
21	Wassermann, E.M.	106	0.61	72
22	Ridding, M.C.	104	0.59	42
23	Lisanby, S.H.	99	0.57	53
24	Lefaucheur, J.P.	94	0.54	53
25	Caltagirone, C.	93	0.53	70
26	Byblow, W.D.	87	0.50	40
27	Miniussi, C.	84	0.48	54
28	Nardone, R.	83	0.47	23
29	Oliveri, M.	82	0.47	38
30	Hajak, G.	78	0.45	57
30	Zangen, A.	78	0.45	41
32	Taylor, J.L.	77	0.44	53
33	Liepert, J.	76	0.43	39
34	Nahas, Z.	74	0.42	54
35	Oliviero, A.	73	0.42	46
36	Hanajima, R.	70	0.40	35
36	Rossi, S.	70	0.40	43
38	Antal, A.	66	0.38	48
38	Thickbroom, G.W.	66	0.38	38
40	Classen, J.	65	0.37	48
40	Manganotti, P.	65	0.37	37
40	Terao, Y.	65	0.37	34
43	Kiernan, M.C.	64	0.37	54
43	Quartarone, A.	64	0.37	35
45	Dileone, M.	63	0.36	33
45	Gandevia, S.C.	63	0.36	89
45	Padberg, F.	63	0.36	42
45	Pilato, F.	63	0.36	36
49	Silvanto, J.	61	0.35	28
50	Sack, A.T.	60	0.34	31
50	Stinear, C.M.	60	0.34	33
50	Vucic, S.	60	0.34	34

experiment", "animal model" or similar), in vivo or in vitro animal research accounted for 7.05% (n = 54/766), 10.52% (n = 500/4755) and 6.92% (n = 828/11,971) of TMS research in the time periods 1988–1997, 1998–2007 and 2008–2017, respectively.

Discussion

This study has used a novel bibliometric approach to comprehensively quantify and delineate the most prolific researchers, institutions, nations, journals and the leading disease entities studied within the TMS field over the past 30 years, during which time the field has grown remarkably in scope, depth and translational applicability. While previous systematic and narrative reviews of the role of TMS have been limited to exploring its use in specific disease settings, this study takes a whole-field, bibliometric approach that explores 30 years of accumulated TMS literature.

The predominant disease entities studied across epochs were mostly neurological rather than psychiatric conditions, although the most productive researchers in the TMS field came from a mix of psychiatric and neurological research and clinical backgrounds. Furthermore, a novel keyword analysis approach was applied to characterise the subject groups and study types featured in the TMS evidence base, finding that while controlled studies are well-represented in the publication cohort, subject randomisation techniques are less frequently applied with important implications for the reproducibility of results [64–67].

The finding that eight authors published an average of ≥10 TMS papers per year during the period 2008–2017 demonstrates a noteworthy level of peak productivity in this highly specialised

Table 2
Ranking of authors by total number of TMS research outputs during the more recent 2008—2017 period.

Rank	Author	Outputs during 2008—2017 (n)	Outputs during 2008—2017 (% of entire 2008—2017 dataset)
1	Pascual-Leone, A.	244	2.04
2	Rothwell, J.C.	216	1.80
3	Fitzgerald, P.B.	174	1.45
4	Daskalakis, Z.J.	172	1.44
5	Paulus, W.	145	1.21
6	Fregni, F.	142	1.19
7	Ziemann, U.	111	0.93
8	Koch, G.	100	0.84
9	George, M.S.	94	0.79
10	Chen, R.	90	0.75
11	Nitsche, M.A.	89	0.74
12	Siebner, H.R.	83	0.69
13	Langguth, B.	81	0.68
14	Hallett, M.	73	0.61
15	Zangen, A.	72	0.60
16	Ugawa, Y.	70	0.58
17	Landgrebe, M.	47	0.39
18	Golaszewski, S.	46	0.38
18	Rossi, S.	46	0.38
20	Antal, A.	43	0.36

field, particularly given the finding by Amaral and colleagues that only about 1% of all researchers, across all scientific disciplines, published at least one paper per year over the 16-year period 1996—2011 [68].

During recent decades, understanding of gender- and sex-related differences and gender bias in many fields of medicine has increased. Concurrently, a large body of literature has emerged on the gender gap in the research and clinical workforces, in career progression to leadership roles and high-ranking academic positions, and in relation to funding acquisition, conference presentation and journal publication rates and authorship prominence [69—78]. This study has systematically mapped the gender diversity among the most prolific authors in the TMS field, finding that only 5/53 in the period 2008—2017 were women. While the reasons for this situation cannot be elucidated by this study, the present findings provide support the need for further research to determine the underlying basis of this gender gap and to investigate its impact on the field. Indeed, the gender gap in this study accords with findings from Hoy's investigation of gender imbalance among speakers at brain stimulation conferences, which provoked much recent discussion in the brain stimulation literature. Hoy reported that only 2/39 of invited speakers at the first International Brain Stimulation Conference in 2015 were female, with a gender gap also evident at the sixth International Conference on Transcranial Brain Stimulation in 2016, where 9/55 invited speakers were female and she suggested that the lack of gender balance in the field may impact on female researchers' collaboration opportunities, career advancement, and likelihood of receiving funding and awards [79]. A similar speaker gender gap has been demonstrated at critical care, emergency medicine, palliative care and evolutionary biology conferences and in the academic medicine, surgery and global health workforces, with male faculty outnumbering female faculty [80—86]. There seems to be agreement within academia generally, including the field of brain stimulation, that balanced gender representation with enhanced female participation is desirable and novel practices to promote and this have been proposed [70,87—94]. In addition to the impact on women researchers, gender disparities in the workforce may impact on research priorities, the conditions and outcomes investigated in studies, and on female study enrolment and participation as research subjects [95—99]. A cross-field systematic assessment of the TMS literature base similar to that employed by Süßenbacher et al. within academic psychiatry or Holman et al. across the science, technology, engineering, mathematics and medicine (STEMM) literature base would be a useful complementary approach to better evidence and more closely quantify any gender gap that exists among TMS researchers [100—103].

Table 3
Ranking of the most productive research institutions in the field of TMS according to total research outputs during the period 1988 to 2017 inclusive. Where institutions were closely affiliated with one another, where one institution formed part of another, or where institutions represented constituent bodies within the same organisation, their publication counts were de-duplicated and merged, with the leading organisation or the principal name of the organisation displayed in this table.

Rank	Institution	City	Country	Total TMS research outputs (n)	Proportion of entire TMS publication dataset (%)
1	University College London	London	UK	895	5.12
2	Harvard University	Boston (MA)	USA	820	4.69
3	National Institutes of Health	Multiple locations	USA	593	3.39
4	University of Toronto	Toronto (ON)	Canada	487	2.78
5	Institute for Research and Health Care — Santa Lucia Foundation	Rome	Italy	429	2.45
6	Sapienza University of Rome	Rome	Italy	350	2.00
6	University of Göttingen	Göttingen	Germany	350	2.00
8	French National Institute of Health and Medical Research (Inserm)	Paris	France	318	1.82
9	University of Oxford	Oxford	UK	283	1.62
10	Monash University	Melbourne	Australia	277	1.58

Table 4
Ranking of the most productive countries in TMS research according to total research outputs during the period 2008–2017 inclusive. The country rank for the period 1988–2007 is show in parenthesis in the first column.

Rank	Country	Total outputs (% of dataset) during 2008–2017 inclusive	Total outputs (n) during 2008–2017 inclusive	Fold-change in total number of outputs (1988–2007 vs 2008–2017)
1 (1)	USA	18.77	3284	2.38
2 (2)	Germany	9.28	1624	1.44
3 (4)	Italy	9.24	1619	2.46
4 (3)	UK	8.55	1495	2.21
5 (7)	Canada	5.63	984	3.53
6 (6)	Australia	5.62	983	3.15
7 (8)	France	4.14	724	3.51
8 (5)	Japan	3.66	641	1.44
9 (17)	People's Republic of China	2.69	471	8.12
10 (11)	Netherlands	2.52	440	3.52

In addition, there exists geographic imbalance of the field, with no World Bank-defined low-income countries and only one middle-income country (People's Republic of China) featured in the list of the top 10 countries for any of the periods studied. The drivers for the observed geographical trends seen are unclear and could potentially reflect the priorities or incentives of national research systems and funders, perceived relevance, editorial policies, or other academic and publication practices [104]. Perhaps unsurprisingly, none of the top 10 institutions by publication output was based in a low- or middle-income country (LMIC), while it is known that institutions in these countries often have trouble affording journal access [105–108]. Nevertheless, despite the more limited research capacity and scientific and clinical infrastructure in LMIC countries, the burden of neurological and psychiatric disease that could potentially be amenable to TMS therapy is higher [104,109–111]. Given this unmet need, it is a point of criticism that only 4.81% of the detected TMS literature is freely and legitimately available in gold open-access journals, whereby the research is available without cost directly from the publisher's website (cf. green open-access, where a publication is made available on an author's institutional website or in a repository via self-archiving). Based on our findings, which are the first to report on publication trends in the field as a whole and which demonstrate a potential barrier to literature access, it seems fitting that TMS researchers should be encouraged to submit their work to open-access journals or to journals that have author- or funder-paid options for open-access. Researchers should be helped to recognise the benefits of publishing their work in open-access journals, especially to low-income countries. Still, it is relevant to note that the vast majority

of TMS research produced during the past 30 years is likely to be available to researchers without personal or institutional subscriptions via the online Sci-Hub service, which has a mean coverage of 84.4% for the top 10 journals publishing TMS research. In addition, the World Health Organisation's HINARI Access to Research in Health Programme, which supports access to the scientific literature for researchers in low-income countries, may help ensure that scientists and clinicians in these countries have access to the full range of TMS literature [105,112,113].

Bibliometric analyses such as this study have potential to provide valuable insights into academic research in the field of TMS and non-invasive neuromodulation, allowing topics of interest and methodological trends to be detected. Moreover, analysis of personal and demographic metadata about who is performing the research, which institutions and geographies are involved and in which journals it is being published should be of interest to researchers, their institutions, national and transnational funding bodies, and systems that evaluate research outputs and their impact such as the UK's Research Excellence Framework (REF). Moreover, bibliometric studies can be repeated at intervals to detect changing research, clinical application and publication trends. The ease with which such analyses can be performed has only been enhanced by the recent growth and feature optimisations seen in citation databases such as Scopus (Elsevier), Web of Science (Clarivate Analytics), Dimensions (Digital Science) and Microsoft Academic along with developments in the underlying technologies that support them [114].

Naturally, a bibliometric analysis such as this, concerning itself with what *has* happened in the field, has a limited ability to forecast

Table 5
Ranking of journals according to number of TMS-related research outputs published during the period 1988 to 2017 inclusive. The journal impact factors (JIF) and Eigenfactor scores were obtained from Clarivate Analytics Journal Citation Reports (JCR). The SCImago journal rank (SJR) and CiteScore measures were obtained from Scopus. The Sci-Hub coverage of the content of each journal, as of March 2017, was determined using the Sci-Hub Stats Browser. Both journals marked (†) are gold open-access journals and their content is made freely accessible online by their publishers.

Rank	Journal	Total TMS outputs (n)	Total TMS outputs (% of TMS dataset)	JIF (2017)	Eigenfactor score (2017)	CiteScore (2016)	SJR (2016)	Sci-Hub article coverage (%)
1	*Clinical Neurophysiology*	828	4.73	3.866	0.021920	2.81	1.379	98.2
2	*Brain Stimulation*	564	3.22	6.078	0.013020	4.40	2.487	79.5
3	*Experimental Brain Research*	531	3.04	1.917	0.018910	1.97	0.964	99.6
4	*Journal of Neuroscience*	334	1.91	5.988	0.319910	5.96	4.682	99.7
5	*Neuroscience Letters*	308	1.76	2.180	0.035070	2.23	0.978	99.1
6	*NeuroImage*	305	1.74	5.835	0.173210	6.31	3.823	99.7
7	*PLOS One*	273	1.56	2.806	1.924690	3.11	1.201	2.7 †
8	*Journal of Neurophysiology*	268	1.53	2.396	0.046140	2.40	1.615	41.6
9	*Neurology*	257	1.47	7.592	0.115120	3.81	3.539	57.7
10	*Frontiers in Human Neuroscience*	249	1.42	3.209	0.056590	3.38	1.739	2.3 †

Table 6
Most common disease entities investigated in the TMS literature in the periods 1988–1997, 1998–2007 and 2008–2017 and identified by keyword analysis. Where multiple keywords referred to the same broad disease state (e.g., stroke and cerebrovascular accident, depression and depressive disorder), counts were de-duplicated and merged. Disease-specific percentage proportions in relation to the total number of TMS publications published during each period are shown in parenthesis.

Rank	1988–1997	1998–2007	2008–2017	1988–2017 (overall)
1	Stroke (5.87%)	Depression (14.07%)	Depression (13.50%)	Depression (13.53%)
2	Depression (4.44%)	Stroke (7.21%)	Stroke (9.85%)	Stroke (8.93%)
3	Multiple sclerosis (3.79%)	Parkinson's disease (4.88%)	Parkinson's disease (4.69%)	Parkinson's disease (4.68%)
4	Epilepsy (3.52%)	Epilepsy (3.83%)	Schizophrenia (4.42%)	Schizophrenia (4.07%)
5	Parkinson's disease (3.26%)	Schizophrenia (3.68%)	Headache (3.39%)	Motor dysfunction (3.16%)
6	Facial nerve paralysis (3.13%)	Motor dysfunction (3.41%)	Motor dysfunction (3.22%)	Epilepsy (3.09%)
7	Spinal cord injury (2.87%)	Mental disease (3.05%)	Cognitive defect (3.20%)	Headache (2.85%)
8	Amyotrophic lateral sclerosis (2.35%)	Dystonia (2.63%)	Pain (3.05%)	Pain (2.80%)
9	Brain injury (1.83%)	Pain (2.57%)	Epilepsy (2.77%)	Cognitive defect (2.76%)

future trends and developments. A complementary approach such as topic modelling, citation graph and network analysis, patent trend analysis, reference publication year spectroscopy or the newly developed progressive scholarly acceptance method may prove useful in this regard [115–117]. Such approaches may also be considered to explore the factors underlying the here observed levelling off and slight decline in the rate of annual publication increases in the TMS field. A limitation of this study is that it focusses on research outputs (articles, reviews and editorials mostly) identifiable in one citation database. This may not reflect the full range of research undertaken in the field, some of which is published in books, reports and non-indexed journals. In addition, although Scopus is the largest citation database in existence and has excellent non-English language coverage, it has its own areas of lesser concentration; for example, a small 2009 study found that it detected fewer citations from articles, editorials, and letters than the rival Web of Science service among three leading general medical journals [59]. This study purposefully did not set out to measure parameters such as publication novelty or quality or evaluate the level of evidence or degree of intra- or interdisciplinary collaboration, although these represent worthwhile endeavours that could be investigated by scientometric means.

Conclusion

In summary, this is the first study to implement a systematic, bibliometric approach to assess the breadth of the TMS literature base, assessing developments over the last 30 years and temporally quantifying global publication and authorship trends. Drawing on these insights may aid understanding of historical progress in TMS over the last 30 years and provide guidance regarding best scientific and publishing practices for the future health of this scientific field.

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Author contributions

A.L.M. conceived and designed the study, acquired the data, analysed and interpreted these data, drafted the manuscript, critically revised the manuscript for important intellectual content and approved the final, submitted version of the manuscript.

Potential conflicts of interest

A.L.M. declares that he has no financial or non-financial conflicts of interest related to the subject matter or materials discussed in this article.

Data availability

The data that support the findings of this study are available within the online, subscription-based Scopus database by entering the search query identified in the methods section of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brs.2019.01.002.

References

[1] Barker AT, Shields K. Transcranial magnetic stimulation: basic principles and clinical applications in migraine. Headache 2017;57(3):517–24.
[2] Klooster DCW, de Louw AJA, Aldenkamp AP, Besseling RMH, Mestrom RMC, Carrette S, et al. Technical aspects of neurostimulation: focus on equipment, electric field modeling, and stimulation protocols. Neurosci Biobehav Rev 2016;65:113–41.
[3] Wagner T, Valero-Cabre A, Pascual-Leone A. Noninvasive human brain stimulation. Annu Rev Biomed Eng 2007;9(1):527–65.
[4] Barker AT, Jalinous R, Freeston IL. Non-invasive magnetic stimulation of human motor cortex. Lancet 1985;1(8437):1106–7.
[5] Krieg SM, Shiban E, Buchmann N, Gempt J, Foerschler A, Meyer B, et al. Utility of presurgical navigated transcranial magnetic brain stimulation for the resection of tumors in eloquent motor areas. J Neurosurg 2012;116(5):994–1001.
[6] Huberfeld G, Trebuchon A, Capelle L, Badier JM, Chen S, Lefaucheur JP, et al. Preoperative and intraoperative neurophysiological investigations for surgical resections in functional areas. Neurochirurgie 2017;63(3):142–9.
[7] Sakreida K, Lange I, Willmes K, Heim S, Binkofski F, Clusmann H, et al. High-resolution language mapping of Broca's region with transcranial magnetic stimulation. Brain Struct Funct 2018;223(3):1297–312.
[8] Papanicolaou AC, Rezaie R, Narayana S, Choudhri AF, Abbas Babajani F, Boop FA, et al. On the relative merits of invasive and non-invasive pre-surgical brain mapping: new tools in ablative epilepsy surgery. Epilepsy Res 2017;142:153–5.
[9] Gao F, Chu H, Li J, Yang M, Du L, Li J, et al. Repetitive transcranial magnetic stimulation for pain after spinal cord injury: a systematic review and meta-analysis. J Neurosurg Sci 2017;61(5):514–22.
[10] Lawson McLean A, Frank S, Zafar N, Waschke A, Kalff R, Reichart R. Time course of the response to navigated repetitive transcranial magnetic stimulation at 10 Hz in chronic neuropathic pain. Neurol Res 2018:1–9.
[11] Zhang L, Xing G, Shuai S, Guo Z, Chen H, McClure MA, et al. Low-frequency repetitive transcranial magnetic stimulation for stroke-induced upper limb motor deficit: a meta-analysis. Neural Plast 2017;2017:2758097.
[12] Goodwill AM, Lum JAG, Hendy AM, Muthalib M, Johnson L, Albein-Urios N, et al. Using non-invasive transcranial stimulation to improve motor and cognitive function in Parkinson's disease: a systematic review and meta-analysis. Sci Rep 2017;7(1):14840.
[13] Khan F, Amatya B, Bensmail D, Yelnik A. Non-pharmacological interventions for spasticity in adults: an overview of systematic reviews. Ann Phys Rehabil Med 2017. https://doi.org/10.1016/j.rehab.2017.10.001.
[14] Fan J, Li Y, Yang Y, Qu Y, Li S. Efficacy of noninvasive brain stimulation on unilateral neglect after stroke: a systematic review and meta-analysis. Am J Phys Med Rehabil 2018;97(4):261–9.
[15] Lan L, Zhang X, Li X, Rong X, Peng Y. The efficacy of transcranial magnetic stimulation on migraine: a meta-analysis of randomized controlled trails. J Headache Pain 2017;18(1):86.
[16] Salazar APS, Vaz PG, Marchese RR, Stein C, Pinto C, Pagnussat AS. Noninvasive brain stimulation improves hemispatial neglect after stroke: a

systematic review and meta-analysis. Arch Phys Med Rehabil 2018;99(2):355–366 e1.

[17] O'Connell NE, Marston L, Spencer S, DeSouza LH, Wand BM. Non-invasive brain stimulation techniques for chronic pain. Cochrane Database Syst Rev 2018;4:CD008208.

[18] Trevizol AP, Shiozawa P, Cook IA, Sato IA, Kaku CB, Guimaraes FB, et al. Transcranial magnetic stimulation for obsessive-compulsive disorder: an updated systematic review and meta-analysis. J ECT 2016;32(4):262–6.

[19] Berlim MT, Neufeld NH, Van den Eynde F. Repetitive transcranial magnetic stimulation (rTMS) for obsessive-compulsive disorder (OCD): an exploratory meta-analysis of randomized and sham-controlled trials. J Psychiatr Res 2013;47(8):999–1006.

[20] Kozel FA, Motes MA, Didehbani N, DeLaRosa B, Bass C, Schraufnagel CD, et al. Repetitive TMS to augment cognitive processing therapy in combat veterans of recent conflicts with PTSD: a randomized clinical trial. J Affect Disord 2018;229:506–14.

[21] Karsen EF, Watts BV, Holtzheimer PE. Review of the effectiveness of transcranial magnetic stimulation for post-traumatic stress disorder. Brain Stimul 2014;7(2):151–7.

[22] Osoegawa C, Gomes JS, Grigolon RB, Brietzke E, Gadelha A, Lacerda ALT, et al. Non-invasive brain stimulation for negative symptoms in schizophrenia: an updated systematic review and meta-analysis. Schizophr Res 2018. https://doi.org/10.1016/j.schres.2018.01.010.

[23] Makani R, Pradhan B, Shah U, Parikh T. Role of repetitive transcranial magnetic stimulation (rTMS) in treatment of addiction and related disorders: a systematic review. Curr Drug Abuse Rev 2017;10(1):31–43.

[24] Razza LB, Moffa AH, Moreno ML, Carvalho AF, Padberg F, Fregni F, et al. A systematic review and meta-analysis on placebo response to repetitive transcranial magnetic stimulation for depression trials. Prog Neuro-Psychopharmacol Biol Psychiatry 2018;81:105–13.

[25] Allen CH, Kluger BM, Buard I. Safety of transcranial magnetic stimulation in children: a systematic review of the literature. Pediatr Neurol 2017;68:3–17.

[26] Pereira LS, Muller VT, da Mota Gomes M, Rotenberg A, Fregni F. Safety of repetitive transcranial magnetic stimulation in patients with epilepsy: a systematic review. Epilepsy Behav 2016;57(Pt A):167–76.

[27] Perera T, George MS, Grammer G, Janicak PG, Pascual-Leone A, Wirecki TS. The clinical TMS society consensus review and treatment recommendations for TMS therapy for major depressive disorder. Brain Stimul 2016;9(3):336–46.

[28] Hong YH, Wu SW, Pedapati EV, Horn PS, Huddleston DA, Laue CS, et al. Safety and tolerability of theta burst stimulation vs. single and paired pulse transcranial magnetic stimulation: a comparative study of 165 pediatric subjects. Front Hum Neurosci 2015;9:29.

[29] Muller PA, Pascual-Leone A, Rotenberg A. Safety and tolerability of repetitive transcranial magnetic stimulation in patients with pathologic positive sensory phenomena: a review of literature. Brain Stimul 2012;5(3):320–329 e27.

[30] Chen R, Spencer DC, Weston J, Nolan SJ. Transcranial magnetic stimulation for the treatment of epilepsy. Cochrane Database Syst Rev 2016;8:CD011025.

[31] Lefaucheur J-P, André-Obadia N, Antal A, Ayache SS, Baeken C, Benninger DH, et al. Evidence-based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (rTMS). Clin Neurophysiol 2014;125(11):2150–206.

[32] Senova S, Cotovio G, Pascual-Leone A, Oliveira-Maia AJ. Durability of antidepressant response to repetitive transcranial magnetic stimulation: systematic review and meta-analysis. Brain Stimul 2019;12(1):119–28.

[33] Yang C, Guo Z, Peng H, Xing G, Chen H, McClure MA, et al. Repetitive transcranial magnetic stimulation therapy for motor recovery in Parkinson's disease: a Meta-analysis. Brain Behav 2018;8(11).

[34] Hsu C-W, Wang L-J, Lin P-Y. Efficacy of repetitive transcranial magnetic stimulation for Tourette syndrome: a systematic review and meta-analysis. Brain Stimul 2018;11(5):1110–8.

[35] Lesenskyj AM, Samples MP, Farmer JM, Maxwell CR. Treating refractory depression in Parkinson's disease: a meta-analysis of transcranial magnetic stimulation. Transl Neurodegener 2018;7(1).

[36] He H, Lu J, Yang L, Zheng J, Gao F, Zhai Y, et al. Repetitive transcranial magnetic stimulation for treating the symptoms of schizophrenia: a PRISMA compliant meta-analysis. Clin Neurophysiol 2017;128(5):716–24.

[37] Chen K, Dong X, Yan L, Huang L, Guan X, Dong C, et al. Repetitive transcranial magnetic stimulation for the treatment of Alzheimer's disease: a systematic review and meta-analysis of randomized controlled trials. PLoS One 2018;13(10).

[38] Cheng CPW, Wong CSM, Lee KK, Chan APK, Yeung JWF, Chan WC. Effects of repetitive transcranial magnetic stimulation on improvement of cognition in elderly patients with cognitive impairment: a systematic review and meta-analysis. Int J Geriatr Psychiatry 2018;33(1):e1–13.

[39] Barahona-Corrêa JB, Velosa A, Chainho A, Lopes R, Oliveira-Maia AJ. Repetitive transcranial magnetic stimulation for treatment of autism spectrum disorder: a systematic review and meta-analysis. Front Integr Neurosci 2018;12.

[40] Yan T, Xie Q, Zheng Z, Zou K, Wang L. Different frequency repetitive transcranial magnetic stimulation (rTMS) for posttraumatic stress disorder (PTSD): a systematic review and meta-analysis. J Psychiatr Res 2017;89:125–35.

[41] Chen R, Spencer DC, Weston J, Nolan SJ. Transcranial magnetic stimulation for the treatment of epilepsy. Cochrane Database Syst Rev 2016;(8).

[42] Liao X, Li G, Wang A, Liu T, Feng S, Guo Z, et al. Repetitive transcranial magnetic stimulation as an alternative therapy for cognitive impairment in alzheimer's disease: a meta-analysis. J Alzheim Dis 2015;48(2):463–72.

[43] Razza LB, Moffa AH, Moreno ML, Carvalho AF, Padberg F, Fregni F, et al. A systematic review and meta-analysis on placebo response to repetitive transcranial magnetic stimulation for depression trials. Prog Neuro Psychopharmacol Biol Psychiatr 2018;81:105–13.

[44] Herwig U, Fallgatter AJ, Hoppner J, Eschweiler GW, Kron M, Hajak G, et al. Antidepressant effects of augmentative transcranial magnetic stimulation: randomised multicentre trial. Br J Psychiatry 2007;191:441–8.

[45] Carpenter LL, Aaronson ST, Clarke GN, Holtzheimer PE, Johnson CW, McDonald WM, et al. rTMS with a two-coil array: safety and efficacy for treatment resistant major depressive disorder. Brain Stimul 2017;10(5):926–33.

[46] Hasan A, Guse B, Cordes J, Wölwer W, Winterer G, Gaebel W, et al. Cognitive effects of high-frequency rTMS in schizophrenia patients with predominant negative symptoms: results from a multicenter randomized sham-controlled trial. Schizophr Bull 2016;42(3):608–18.

[47] Leuchter AF, Cook IA, Feifel D, Goethe JW, Husain M, Carpenter LL, et al. Efficacy and safety of low-field synchronized transcranial magnetic stimulation (sTMS) for treatment of major depression. Brain Stimul 2015;8(4):787–94.

[48] Hosomi K, Morris S, Sakamoto T, Taguchi J, Maruo T, Kageyama Y, et al. Daily repetitive transcranial magnetic stimulation for poststroke upper limb paresis in the subacute period. J Stroke Cerebrovasc Dis 2016;25(7):1655–64.

[49] Abo M, Kakuda W, Momosaki R, Harashima H, Kojima M, Watanabe S, et al. Randomized, multicenter, comparative study of NEURO versus CIMT in poststroke patients with upper limb hemiparesis: the NEURO-VERIFY study. Int J Stroke 2013;9(5):607–12.

[50] Teng S, Guo Z, Peng H, Xing G, Chen H, He B, et al. High-frequency repetitive transcranial magnetic stimulation over the left DLPFC for major depression: session-dependent efficacy: a meta-analysis. Eur Psychiatry 2017;41:75–84.

[51] Brunoni AR, Chaimani A, Moffa AH, Razza LB, Gattaz WF, Daskalakis ZJ, et al. Repetitive transcranial magnetic stimulation for the acute treatment of major depressive episodes. JAMA Psychiat. 2017;74(2).

[52] Kaster TS, Daskalakis ZJ, Noda Y, Knyahnytska Y, Downar J, Rajji TK, et al. Efficacy, tolerability, and cognitive effects of deep transcranial magnetic stimulation for late-life depression: a prospective randomized controlled trial. Neuropsychopharmacology 2018;43(11):2231–8.

[53] Thompson DF, Walker CK. A descriptive and historical review of bibliometrics with applications to medical sciences. Pharmacotherapy 2015;35(6):551–9.

[54] Hu X, Rousseau R. A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries. Scientometrics 2009;81(2):475–91.

[55] Thompson DF, Walker CK. A descriptive and historical review of bibliometrics with applications to medical sciences. Pharmacotherapy 2015;35(6):551–9.

[56] Ellegaard O, Wallin JA. The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 2015;105(3):1809–31.

[57] Bersani FS, Minichino A, Enticott PG, Mazzarini L, Khan N, Antonacci G, et al. Deep transcranial magnetic stimulation as a treatment for psychiatric disorders: a comprehensive review. Eur Psychiatry 2013;28(1):30–9.

[58] Falagas ME, Pitsouni EI, Malietzis GA, Pappas G. Comparison of PubMed, scopus, Web of science, and google scholar: strengths and weaknesses. FASEB J 2008;22(2):338–42.

[59] Kulkarni AV. Comparisons of citations in Web of science, scopus, and google scholar for articles published in general medical journals. Jama 2009;302(10).

[60] Aria M, Cuccurullo C. Bibliometrix : an R-tool for comprehensive science mapping analysis. J Inform 2017;11(4):959–75.

[61] Himmelstein DS, Romero AR, Levernier JG, Munro TA, McLaughlin SR, Greshake Tzovaras B, et al. Sci-Hub provides access to nearly all scholarly literature. eLife 2018;7.

[62] Laakso M, Björk B-C. Hybrid open access—a longitudinal study. J Inform 2016;10(4):919–32.

[63] Greshake B. Looking into pandora's box: the content of sci-hub and its usage. F1000Research 2017;6.

[64] Ioannidis JPA, Greenland S, Hlatky MA, Khoury MJ, Macleod MR, Moher D, et al. Increasing value and reducing waste in research design, conduct, and analysis. Lancet 2014;383(9912):166–75.

[65] Berlim MT, Van den Eynde F, Jeff Daskalakis Z. Clinically meaningful efficacy and acceptability of low-frequency repetitive transcranial magnetic stimulation (rTMS) for treating primary major depression: a meta-analysis of randomized, double-blind and sham-controlled trials. Neuropsychopharmacology 2012;38(4):543–51.

[66] Brunoni AR, Fregni F. Clinical trial design in non-invasive brain stimulation psychiatric research. Int J Methods Psychiatr Res 2011;20(2):e19–30.

[67] Neugebauer EAM, Rath A, Antoine S-L, Eikermann M, Seidel D, Koenen C, et al. Specific barriers to the conduct of randomised clinical trials on medical devices. Trials 2017;18(1).

[68] Amaral LAN, Ioannidis JPA, Boyack KW, Klavans R. Estimates of the continuously publishing core in the scientific workforce. PLoS One 2014;9(7).

[69] Aakhus E, Mitra N, Lautenbach E, Joffe S. Gender and byline placement of Co-first authors in clinical and basic science journals with high impact factors. Jama 2018;319(6).

[70] Handley IM, Brown ER, Moss-Racusin CA, Smith JL. Quality of evidence revealing subtle gender biases in science is in the eye of the beholder. Proc Natl Acad Sci Unit States Am 2015;112(43):13201–6.

[71] de Melo-Martín I, Intemann K. Interpreting evidence: why values can matter as much as science. Perspect Biol Med 2012;55(1):59–70.

[72] Kavathas P, Soong L. Gender inequity: challenging business as usual. Nat Immunol 2001;2(11):985–7.

[73] Mühlenbruch B, Jochimsen MA. Only wholesale reform will bring equality. Nature 2013;495(7439):40–2.

[74] Ceci SJ, Williams WM. Understanding current causes of women's under-representation in science. Proc Natl Acad Sci Unit States Am 2011;108(8):3157–62.

[75] Shen H. Inequality quantified: mind the gender gap. Nature 2013;495(7439):22–4.

[76] Rochon PA, Davidoff F, Levinson W. Women in academic medicine leadership. Acad Med 2016;91(8):1053–6.

[77] Reuben E, Sapienza P, Zingales L. How stereotypes impair women's careers in science. Proc Natl Acad Sci Unit States Am 2014;111(12):4403–8.

[78] Sheltzer JM, Smith JC. Elite male faculty in the life sciences employ fewer women. Proc Natl Acad Sci Unit States Am 2014;111(28):10107–12.

[79] Hoy K. Gender imbalance at brain stimulation conferences: we have a problem and it is everyone's problem. Brain Stimul 2017;10(1):155–6.

[80] Sleeman KE, Koffman J, Higginson IJ. Leaky pipeline, gender bias, self-selection or all three? A quantitative analysis of gender balance at an international palliative care research conference. BMJ Supportive & Palliative Care; 2017.

[81] Mehta S, Rose L, Cook D, Herridge M, Owais S, Metaxa V. The speaker gender gap at critical care conferences. Crit Care Med 2018;46(6):991–6.

[82] Downs JA, Reif LK, Hokororo A, Fitzgerald DW. Increasing women in leadership in global health. Acad Med 2014;89(8):1103–7.

[83] Webster F, Rice K, Christian J, Seemann N, Baxter N, Moulton C-A, et al. The erasure of gender in academic surgery: a qualitative study. Am J Surg 2016;212(4):559–65.

[84] Schroeder J, Dugdale HL, Radersma R, Hinsch M, Buehler DM, Saul J, et al. Fewer invited talks by women in evolutionary biology symposia. J Evol Biol 2013;26(9):2063–9.

[85] Débarre F, Rode NO, Ugelvig LV. Gender equity at scientific events. Evol Lett 2018;2(3):148–58.

[86] Shishkova E, Kwiecien NW, Hebert AS, Westphall MS, Prenni JE, Coon JJ. Gender diversity in a STEM subfield — analysis of a large scientific society and its annual conferences. J Am Soc Mass Spectrom 2017;28(12):2523–31.

[87] Hinder MR, Fujiyama H, Vallence A-M. Response to "Response to Hoy, 'Gender imbalance and brain stimulation conferences: we have a problem and it is everyone's problem'". Brain Stimul 2017;10(1):158–9.

[88] George MS, Sackeim HA. Response to Hoy, 'gender imbalance at brain stimulation conferences: we have a problem and it is everyone's problem'. Brain Stimul 2017;10(1).

[89] Antal A. Letter to the editor: a late response from a female scientist to Hoy, 'gender imbalance at brain stimulation conferences: we have a problem and it is Everyone's problem'. Brain Stimul 2017;10(4).

[90] Travis EL, Doty L, Helitzer DL. Sponsorship. Acad Med 2013;88(10):1414–7.

[91] Westring A, McDonald JM, Carr P, Grisso JA. An integrated Framework for gender equity in academic medicine. Acad Med 2016;91(8):1041–4.

[92] Bucknor A, Kamali P, Phillips N, Mathijssen I, Rakhorst H, Lin SJ, et al. Gender inequality for women in plastic surgery. Plast Reconstr Surg 2018;141(6):1561–77.

[93] Dwyer KM, Clark CJ, MacDonald K, Paraskeva MA, Rogers N, Ryan J, et al. Gender equity in transplantation. Transplantation 2017;101(10):2266–70.

[94] Casadevall A, Handelsman J. The presence of female conveners correlates with a higher proportion of female speakers at scientific symposia. mBio 2014;5(1).

[95] Ovseiko PV, Greenhalgh T, Adam P, Grant J, Hinrichs-Krapels S, Graham KE, et al. A global call for action to include gender in research impact assessment. Health Res Policy Syst 2016;14(1).

[96] Mazure CM, Jones DP. Twenty years and still counting: including women as participants and studying sex and gender in biomedical research. BMC Women's Health 2015;15(1).

[97] Hoyt MA, Rubin LR. Gender representation of cancer patients in medical treatment and psychosocial survivorship research. Cancer 2012;118(19):4824–32.

[98] Jagsi R, Motomura AR, Amarnath S, Jankovic A, Sheets N, Ubel PA. Under-representation of women in high-impact published clinical cancer research. Cancer 2009;115(14):3293–301.

[99] Cislak A, Formanowicz M, Saguy T. Bias against research on gender bias. Scientometrics 2018;115(1):189–200.

[100] Süßenbacher S, Amering M, Gmeiner A, Schrank B. Gender-gaps and glass ceilings: a survey of gender-specific publication trends in Psychiatry between 1994 and 2014. Eur Psychiatry 2017;44:90–5.

[101] Jagsi R, Guancial EA, Worobey CC, Henault LE, Chang Y, Starr R, et al. The "gender gap" in authorship of academic medical literature — a 35-year perspective. N Engl J Med 2006;355(3):281–7.

[102] Fishman M, Williams WA, Goodman DM, Ross LF. Gender differences in the authorship of original research in pediatric journals, 2001-2016. J Pediatr 2017;191:244–249.e1.

[103] Holman L, Stuart-Fox D, Hauser CE. The gender gap in science: how long until women are equally represented? PLoS Biol 2018;16(4).

[104] Ergin I, Cash-Gibson L, Rojas-Gualdrón DF, Pericàs JM, Benach J. Inequalities in global health inequalities research: a 50-year bibliometric analysis (1966-2015). PLoS One 2018;13(1).

[105] Doughty K, Rothman L, Johnston L, Le K, Wu J, Howard A. Low-income countries' orthopaedic information needs: challenges and opportunities. Clin Orthop Relat Res 2010;468(10):2598–603.

[106] Derbew M, Beveridge M, Howard A, Byrne N. Building surgical research capacity in africa: the ptolemy project. PLoS Med 2006;3(7).

[107] Smith H, Bukirwa H, Mukasa O, Snell P, Adeh-Nsoh S, Mbuyita S, et al. Access to electronic health knowledge in five countries in Africa: a descriptive study. BMC Health Serv Res 2007;7(1).

[108] Noordin S, Wright JG, Howard AW. Global relevance of literature on trauma. Clin Orthop Relat Res 2008;466(10):2422–7.

[109] Feigin VL, Abajobir AA, Abate KH, Abd-Allah F, Abdulle AM, Abera SF, et al. Global, regional, and national burden of neurological disorders during 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet Neurol 2017;16(11):877–97.

[110] Vigo D, Thornicroft G, Atun R. Estimating the true global burden of mental illness. Lancet Psychiat 2016;3(2):171–8.

[111] Forloni G, Whiteford HA, Ferrari AJ, Degenhardt L, Feigin V, Vos T. The global burden of mental, neurological and substance use disorders: an analysis from the global burden of disease study 2010. PLoS One 2015;10(2).

[112] Burton A. Sharing science: enabling global access to the scientific literature. Environ Health Perspect 2011;119(12):a520–3.

[113] Davis PM, Walters WH. The impact of free access to the scientific literature: a review of recent research. J Med Libr Assoc : JMLA 2011;99(3):208–17.

[114] Bar-Ilan J. Informetrics at the beginning of the 21st century—a review. J Inform 2008;2(1):1–52.

[115] Batagelj V, Ferligoj A, Squazzoni F. The emergence of a field: a network analysis of research on peer review. Scientometrics 2017;113(1):503–32.

[116] Vincenot CE. How new concepts become universal scientific approaches: insights from citation network analysis of agent-based complex systems science. Proc Biol Sci 2018;(1874):285.

[117] Schnurman Z, Kondziolka D. Evaluating innovation. Part 1: the concept of progressive scholarly acceptance. J Neurosurg 2016;124(1):207–11.