

International Collaborations in Brain-Computer Interface (BCI) Research

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Abstract—The strength and quality of a research field can be depicted from its literature. In this paper, the Brain-Computer Interface (BCI) research literature is examined for collaborations at the individual level (i.e. researchers) and international level (i.e. countries). Records from the Web of Science (WoS) (Thomson Reuters) are examined to form an updated picture of the BCI research worldwide and in particular its international collaboration. Results indicate strong collaboration between Germany, USA, Austria, and Italy. At the BCI researcher level, this is less prominent. Furthermore, a research quality proxy, based on both Impact Factor (IF) and EigenFactor (EF), is also examined for journals publishing BCI research. These results, updated regularly, will be published online to help to improve the BCI research community visibility.

Keywords—Brain-Computer Interface; Research collaborations; Impact Factor; Eigenfactor

I. INTRODUCTION

Brain-Computer Interface (BCI) is one recent field of research which is multi-disciplinary. It makes use of sensor to record biosignals (typically using electroencephalogram (EEG) [1] or Near Infrared Spectroscopy (NIRS) [2]) mapping response from subjects (healthy [3] or disabled [4]) by extracting features to be mapped onto control signals for a variety of applications including spelling words [5], controlling wheelchair [6], music composition [7], to name few. Few recent review provide details, see [8] and [9].

The focus of this paper, follow-up on a previous bibliometric study [10], was on assessing the current state of international collaboration in BCI research at a researcher level and country level.

The remainder of the paper is organized as follows. In Section II, we describe the data collection procedure. In Section III, a briefly update on the BCI literature is presented, while in Section IV the international collaborations at countries and researchers level are detailed. Finally, in Section VI, we conclude the paper.

II. PROCEDURE

The analysis procedure is similar to the one used in previous bibliometric studies [10]. Briefly, the online interface of the Web of Science (WoS) (Thomson Reuters) was used to obtain full records of articles on BCI (with abstract plus references), subsequently processed using MATLAB scripts. A typical WoS query used for the year 2009 for e.g., was of the form *Topic=(Brain-computer interface) AND Year Published=(2009) AND Language=(English)*

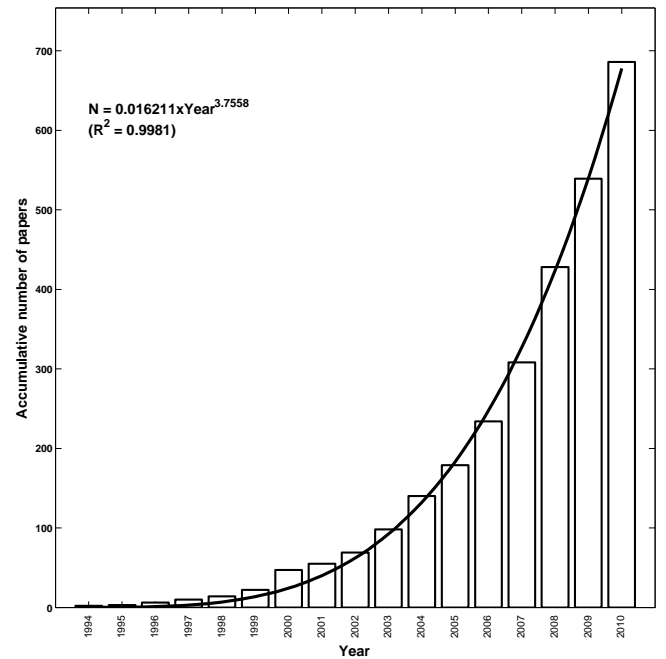


Figure 1. Growth of the BCI literature

NOT Document Type=(Proceedings Paper) Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH..

III. BCI LITERATURE

The growth of the BCI literature has shown some power law curve [10], as shown in Figure 1. Its characteristic was fitted with a power-law curve with the following $N = a \times x^b$, with $a = 0.016211$ and $b = 3.7558$ ($R^2 = 0.9981$).

A. Countries of origin

There are in total 37 countries contributing to the BCI literature include USA (211, 30.10%), Germany (85, 12.13%), Austria (70, 9.99%), China (56, 7.99%), U.K. (33, 4.71%), Canada (31, 4.42%), Japan (25, 3.57%), Italy (19, 2.71%), Taiwan (18, 2.57%), France (16, 2.28%), Spain (14, 2.00%), Ireland (12, 1.71%), Switzerland (12), Denmark (11, 1.57%), Netherlands (11), Singapore (11), Korea (9, 1.28%), Israel (7, 1.00%), Australia (5, 0.71%), etc. Using these countries as nodes of authors' affiliation, an international collaboration

Table I
BCI RESEARCHERS RANKED BY HARMONIC COUNTING

Rank	Name	NP	Harmonic	Arithmetic
1	PFURTSCHELLER, G	82	18.054	35.573
2	MCFARLAND, D	36	11.848	22.243
3	WOLPAW, J	50	10.590	19.598
4	BIRBAUMER, N	48	7.195	13.232
5	NEUPER, C	30	6.127	12.969
6	SCHALK, G	26	5.597	12.187
7	SCHERER, R	22	5.378	11.833
8	MULLER-PUTZ, G	17	5.092	10.250
9	BLANKERTZ, B	19	4.790	10.450
10	KUBLER, A	26	4.734	10.876
11	HINTERBERGER, T	18	4.236	10.683
12	MASON, S	10	4.044	7.333
13	BIRCH, G	16	3.467	6.267
14	GUGER, C	13	3.406	7.667
15	VAUGHAN, T	19	3.346	7.275
16	COYLE, D	6	3.302	5.250
17	ALLISON, B	9	3.204	6.833
18	LIN, C	9	2.941	6.750
19	GAO, X	17	2.899	6.250
20	LI, Y	9	2.863	6.083
21	SCHLOGL, A	15	2.803	6.060
22	SUN, S	4	2.758	4.000
23	NEUMANN, N	12	2.652	5.867
24	WANG, Y	10	2.642	5.450
25	GUAN, C	13	2.591	5.476
26	KRUSIENSKI, D	12	2.568	5.894
27	MILLER, K	11	2.564	6.367
28	GRAIMANN, B	10	2.506	5.333
29	YOO, S	9	2.485	5.983
30	MULLER, K	17	2.424	5.300
31	BRUNNER, C	8	2.412	5.667
32	SEPULVEDA, F	9	2.361	3.833
33	VUCKOVIC, A	3	2.333	3.000
34	LEUTHARDT, E	10	2.295	5.378
35	LEEB, R	9	2.280	5.083
36	ROBERTS, S	7	2.276	4.083
37	MILLAN, J	10	2.274	4.850
38	VIDAURRE, C	5	2.232	5.000
39	LOTTE, F	5	2.187	4.500
40	RON-ANGEVIN, R	4	2.152	3.500
41	HSU, W	3	2.147	3.000
42	OVERMAIER, B	5	2.103	4.143
43	LEE, P	6	2.101	5.000
44	TOWNSEND, G	4	2.099	4.000
45	BOGUE, R	2	2.000	2.000
46	FREEMAN, W	2	2.000	2.000
47	CHASE, S	6	1.979	4.000
48	BASHASHATI, A	6	1.975	4.333
49	HONG, B	10	1.967	4.250
50	GAO, S	17	1.949	4.183

NP: number of publications

matrix was computed and rendered visually as shown in Figure 3.

B. BCI Researchers

In Table I the top 50 BCI researcher are shown. Their ranking is based on harmonic counting [11] which provides a more objective (and fair) measure than the number of publications or geometric counting (which suppose all authors having equal contribution) which are know to be biased [12].

In this list, not surprisingly, the most eminent BCI

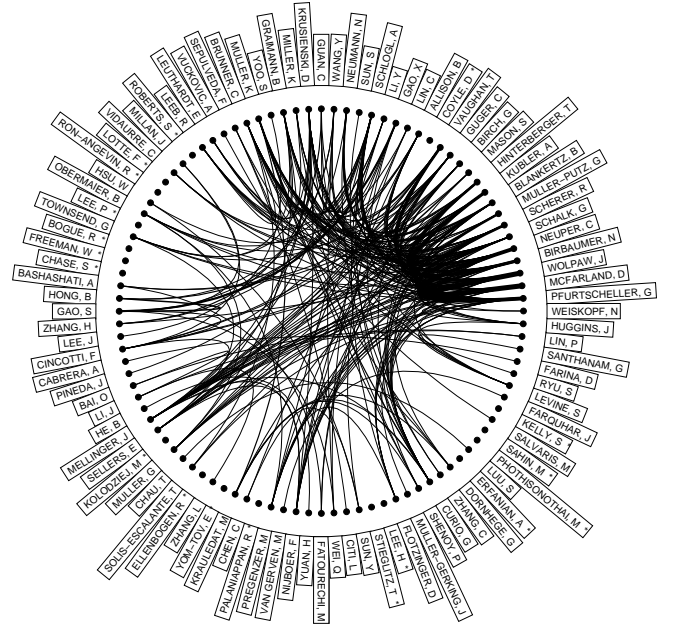


Figure 2. BCI researchers collaborations

researchers are G. Pfurtscheller (Laboratory of Brain-Computer Interfaces, Institute for Knowledge Discovery, Graz University of Technology, Graz, Austria), D. McFarland (Wadsworth Center, NY State Health Department, NY, USA), J. Wolpaw (Wadsworth Center, USA), N. Birbaumer (Institute of Medical Psychology and Behavioral Neurobiology, Tübingen, Germany), C. Neuper (Laboratory of Brain-Computer Interfaces, Graz, Austria) and G. Schalk (Wadsworth Center, USA).

IV. BCI RESEARCH COLLABORATIONS

Records were used to identify BCI article co-authorship in order to form BCI network, shown in Figure 2, a visual representation of the collaboration between BCI researchers. Each node is a research and connections are coded by the strength of the collaboration (i.e. number of papers on which both researchers' name appear). Due to space restriction we limited the network to the first 100 research. One can notice the dense connections between the top eminent BCI researchers, more obvious in Figure 5 were the number of papers in which these research are co-authors.

V. JOURNALS PUBLISHING BCI

In Table II, a list all top 50 core journals publishing BCI research. The additional amount publications from last two years (2009 and 2010) changed slightly the top order of the table compared to a previous a study [10]. The journals with the highest Impact Factor (IF) [13][14] include *Proceedings of the National Academy of Sciences of the USA* (IF: 9.432), followed by *Journal of Neurosciences* (IF: 7.178), *NeuroImage* (IF: 5.739), followed by *Neurorehabilitation and Neural*

BCI research collaboration matrix

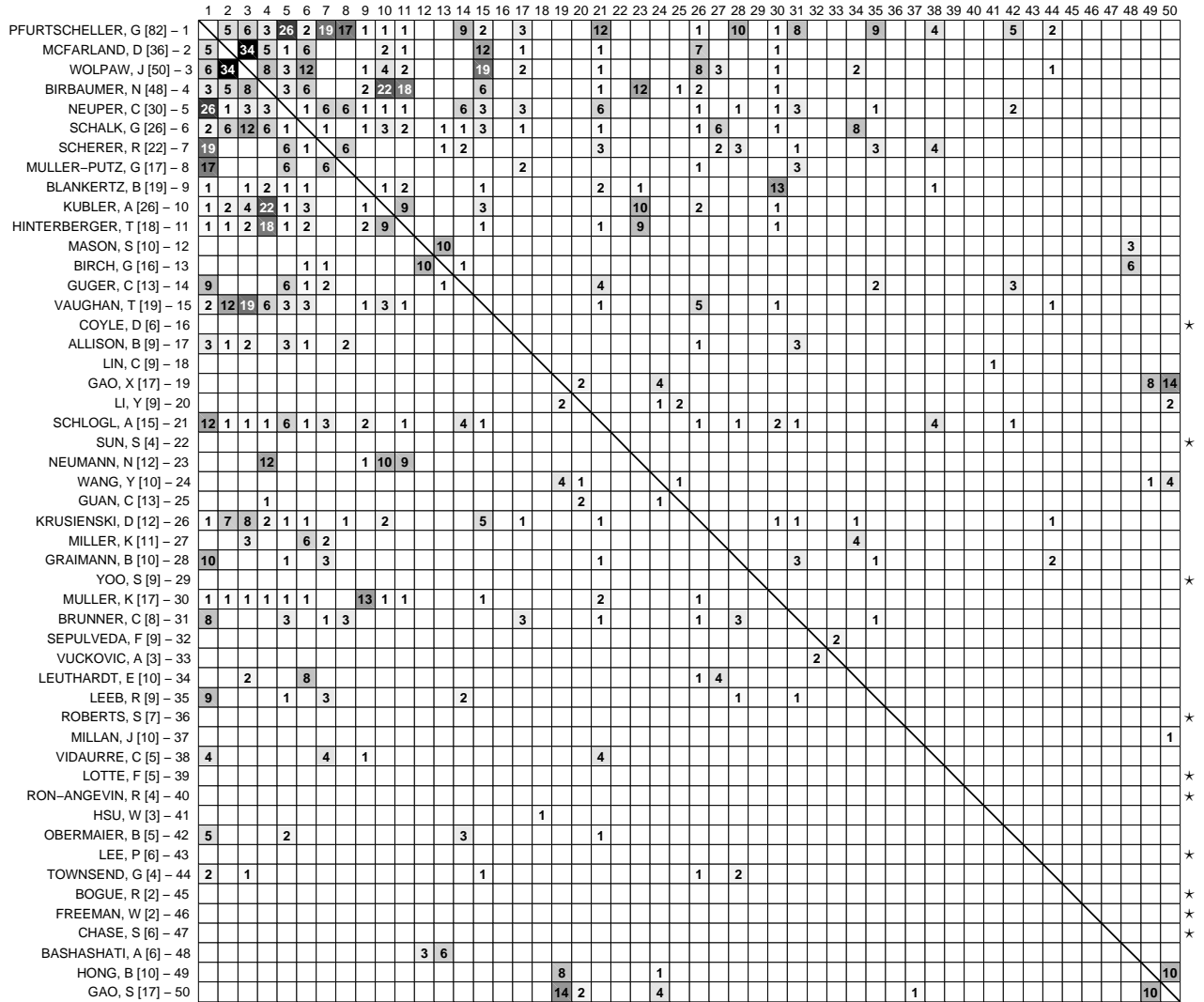


Figure 5. BCI research collaboration matrix based on articles' co-authorship

Repair (IF: 5.398), *IEEE Signal Processing Magazine* (IF: 4.914) and *Biological Psychology* (IF: 4.363).

As another useful indicator, a plot to assess these journals' influence and quality is shown in Figure 4, with each journal ranked by their Impact Factor (IF) versus their EigenFactor (EF) [15]. Based on their EF score [16], one can observe a spread relative to the thick line (1:1 line) and outside the outer lines representing a score different of 5 between the two rankings (as in [17]).

VI. CONCLUSION

Extending a previous bibliometric study on the BCI research literature [10], this paper was focused on the current state of international collaborations in BCI research. This was depicted based on co-authorship information, extracted

from the BCI research literature, from both researchers and their country of origin. Overall, strong research collaborations links exist between Austria, Germany, USA and Italy. One can also find sustained collaborations between researchers in particular the most eminent BCI research.

The identification of BCI *rising star* researchers, with other important scientometric issues such as self-citation rate and plagiarism, are left for future studies.

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Table II
BCI CORE JOURNALS

Rank	Name of the journal	NP	%	IF	EF	PF	Publisher
1	IEEE Transactions on Biomedical Engineering	65	9.14%	2.154	0.02413	12	IEEE
2	IEEE Transactions on Neural Systems and Rehabilitation Engineering	59	8.30%	2.417	0.00579	6	IEEE
3	Journal of Neural Engineering	55	7.74%	3.739	0.00616	6	IOP Publishing
4	Clinical Neurophysiology	46	6.47%	3.122	0.03073	12	Elsevier
5	Journal of Neuroscience Methods	31	4.36%	2.295	0.02638	18	Elsevier
6	Medical and Biological Engineering and Computing	24	3.38%	1.757	0.00576	12	Springer
7	IEEE Transactions on Rehabilitation Engineering (now TNSRE)	18	2.53%	2.036	0.00049	4	IEEE
8	NeuroImage	17	2.39%	5.739	0.16330	20	Elsevier
9	Biomedizinische Technik	11	1.55%	0.525	0.00108	6	Walter de Gruyter
10	Neural Networks	11	1.55%	1.879	0.01187	10	Elsevier
11	Journal of Neurosciences	10	1.41%	7.178	0.48433	52	Society for Neuroscience
12	Neuroscience Letters	10	1.41%	1.925	0.06722	57	Elsevier
13	Annals of Biomedical Engineering	7	0.98%	2.409	0.01737	12	Springer
14	Eurasip journal on applied signal processing	7	0.98%	0.885	0.00472	12	Hindawi Publishing
15	Medical Engineering and Physics	7	0.98%	1.674	0.00702	10	Elsevier
16	NeuroReport	7	0.98%	1.805	0.03321	18	Lippincott Williams and Wilkins
17	Neurosurgical FOCUS	7	0.98%	—	—	12	American Association of Neurosurgeons
18	Biomedical Signal Processing and Control	6	0.84%	0.620	0.00038	4	Elsevier
19	Electronics Letters	6	0.84%	0.970	0.04283	25	IET
20	IEEE Signal Processing Magazine	6	0.84%	4.914	0.01375	6	IEEE
21	Presence: Teleoperators and Virtual Environments	6	0.84%	1.241	0.00281	6	MIT Press
22	Electroencephalography and clinical neurophysiology	5	0.70%	3.122	0.03073	12	Elsevier
23	IEEE Transactions on Biomedical Circuits and Systems	5	0.70%	1.741	0.00098	—	IEEE
24	Journal of Clinical Neurophysiology	5	0.70%	1.470	0.00452	6	Lippincott Williams and Wilkins
25	Journal of NeuroEngineering and Rehabilitation	5	0.70%	2.115	0.00257	12	Springer
26	Journal of Neurophysiology	5	0.70%	3.483	0.11207	12	APS
27	Neurocomputing	5	0.70%	1.440	0.01156	18	Elsevier
28	Proceedings of the National Academy of Sciences of the USA	5	0.70%	9.432	1.67820	52	National Academy of Sciences
29	Cognitive Neurodynamics	4	0.56%	2.263	0.00043	4	Springer
30	Computers in Biology and Medicine	4	0.56%	1.269	0.00339	12	Elsevier
31	Event-Related Dynamics of Brain Oscillations	4	0.56%	—	—	—	Elsevier
32	IEICE Transactions on Information and Systems	4	0.56%	0.245	—	12	IEICE
33	International Journal on Psychophysiology	4	0.56%	3.045	0.01030	12	Elsevier
34	Neurosurgery	4	0.56%	2.862	0.04552	12	Lippincott Williams and Wilkins
35	Pattern Recognition Letters	4	0.56%	1.303	0.01310	16	Elsevier
36	PLOS One	4	0.56%	4.351	0.16359	4	PLOS
37	Psychophysiology	4	0.56%	3.926	0.01460	6	Wiley
38	Biological Psychology	3	0.42%	4.363	0.01328	9	Elsevier
39	Experimental Brain Research	3	0.42%	2.256	0.03741	24	Springer
40	Expert Review of Medical Devices	3	0.42%	1.725	0.00333	6	Ingenta
41	Industrial Robot: An International Journal	3	0.42%	1.000	0.00108	6	Ingenta
42	International Journal of Neuroscience	3	0.42%	0.855	0.00369	12	Ingenta
43	Journal of Computational Neuroscience	3	0.42%	2.220	0.00417	—	—
44	Journal of Medical and Biological Engineering	3	0.42%	—	—	6	Chinese Electronic Periodical Services
45	Neurorehabilitation and Neural Repair	3	0.42%	5.398	0.00486	9	Sage Publications
46	Przegląd Elektrotechniczny	3	0.42%	0.196	0.00026	12	Wydawnictwo SIGMA
47	Revista de Neurologia	3	0.42%	1.234	0.00274	12	Cesar Viguera
48	Signal Processing	3	0.42%	1.135	0.01270	—	Elsevier
49	Applied Psychophysiology and Biofeedback	2	0.28%	1.765	0.00114	4	Springer
50	Artificial Intelligence in Medicine	2	0.28%	1.645	0.00349	9	Elsevier

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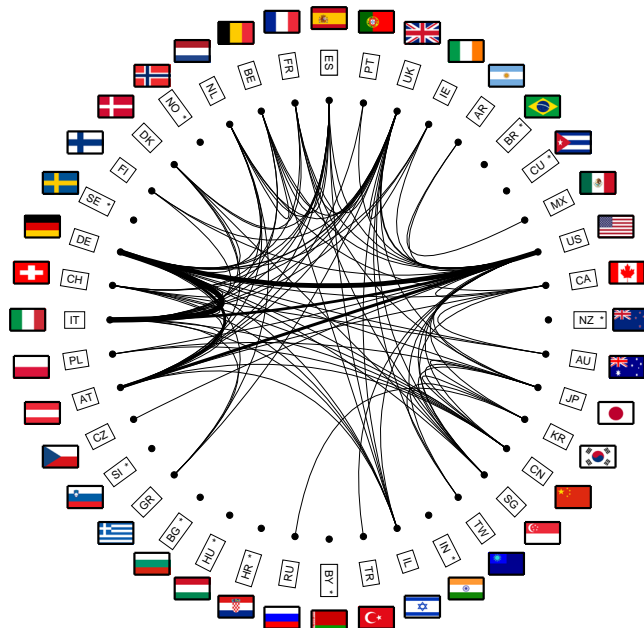


Figure 3. BCI international collaborations

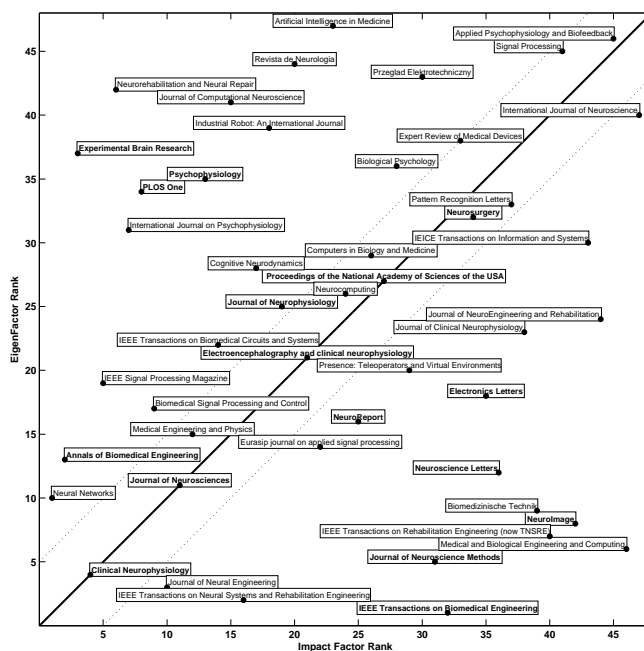


Figure 4. IF versus EF for BCI journals

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