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 Eigen Factor (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.

1 Introduction

Brain-Computer Interface (BCI) is one recent field of research which is multidisciplinary. 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 reviews provide more 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 2, we describe the data collection procedure. In Section 3, a briefly update on the BCI literature is presented, while in Section 4 the international collaborations at countries and researchers level are detailed, and journals publishing BCI research in Section 5. Finally, in Section 6, we conclude the paper.

2 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 NOT Document Type=(Proceedings Paper) Timespan=AllYears. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCIS,CPCI-SSH.

3 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 ($R^2 = 0.9981$).



Fig. 1. Growth of the BCI research literature

Fig. 2. BCI researchers' collaborations

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



Fig. 3. Growth of the BCI research literature

Fig. 4. IF versus EF for BCI journals

3.2 BCI Researchers

In Table 1 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 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, Tubingen, Germany), C. Neuper (Laboratory of Brain-Computer Interfaces, Graz, Austria) and G. Schalk (Wadsworth Center, USA).

4 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 appears). Due to space restriction we limited the network to the first 100 researchers. 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 researchers are co-authors.

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
ő	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
12	BIRCH G	16	3 467	6 267
13	GUGER C	13	3.406	7.667
14	VAUGHAN T	10	3 346	7.007
15	COVIED	19	2 202	5 250
10	ALLISON D	0	2 204	5.230
19	ALLISON, B	9	2.04	6 750
10	CAO X	17	2.941	6.750
20		17	2.099	6.092
20	SCHLOGI A	15	2.803	6.060
21	SUN S	13	2.803	4.000
22	SUIN, S NIELIMANINI NI	12	2.750	4.000
25	NEUMANN, N	12	2.032	5.607
24	WANG, I	10	2.642	5.450
25	GUAN, C	13	2.591	5.476
20	KRUSIENSKI, D	12	2.508	5.894
27	MILLER, K	11	2.304	0.307
20	OKAIMAININ, B	10	2.300	5.555
29	100,5	9	2.485	5.985
30	MULLER, K	17	2.424	5.300
31	BRUNNER, C	8	2.412	5.007
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, K	9	2.280	5.083
36	ROBERTS, S	/	2.276	4.083
37	MILLAN, J	10	2.274	4.850
38	VIDAURRE, C	2	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	OBERMAIER, B	5	2.103	4.143
43	LEE, P	6	2.101	5.000
44	IOWNSEND, 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	HUNG, B	10	1.967	4.250
50	GAU, S	17	1.949	4.183

 Table 1. BCI researchers ranked by harmonic counting



BCI research collaboration matrix

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

5 Journals Publishing BCI

In Table 2, we present 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 the *Proceedings of the National Academy of Sciences of the USA* (IF: 9.432), followed by the *Journal of Neurosciences* (IF: 7.178), *NeuroImage* (IF: 5.739), followed by *Neurorehabilitation and Neural 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 Eigen Factor(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]).

Table 2. BCI core journals

IEEE Transactions on Riomedical Engineering 75 9,14% 2,147 0.00413 12 IEEE 2 IEEE Transactions on Neural Systems and 59 8,30% 2,417 0.00570 6 IEEE 3 Journal O Neural Engineering 55 7,47% 0.00570 12 Elsevier 4 Clinical Neurophysiology 46 6,47% 3,122 0.00576 12 Springer 6 Medical and Biological Engineering and Computing 24 3,38% 1,737 0.00576 12 Springer 7 TINSRE) 18 2,35% 5,739 0.16330 20 Elsevier 9 Biomedizinische Technik 11 1,55% 0.525 0.00108 6 Walter de Grayter 11 Journal of Neurosciences 10 1,41% 7,178 0.4843 52 Society for Neuroscience 12 Neuroscience Letters 10 1,41% 1,925 0,672 Elsevier 13 Ananak of Biomedical Engineering 7	Rank	Name of the journal	NP	0%	IF	FF	PF	Publisher
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6 Conclusions

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 BCI researchers. 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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