

Editorial: Investigation of brain functional connectivity from electroencephalogram data

*Original*

Editorial: Investigation of brain functional connectivity from electroencephalogram data / Chiarion, Giovanni; Safaei, Soroush; Valizadeh, Alireza; Bashivan, Pouya; Yeh, Chien-Hung; Zhang, Chuting; Wang, Yufei; Mesin, Luca. - In: FRONTIERS IN PHYSIOLOGY. - ISSN 1664-042X. - 13:(2022). [10.3389/fphys.2022.1058683]

*Availability:*

This version is available at: 11583/2972728 since: 2022-11-01T10:38:35Z

*Publisher:*

Frontiers Media S.A.

*Published*

DOI:10.3389/fphys.2022.1058683

*Terms of use:*

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

(Article begins on next page)



## OPEN ACCESS

EDITED AND REVIEWED BY  
Raimond L. Winslow,  
Northeastern University, United States

\*CORRESPONDENCE  
Luca Mesin,  
luca.mesin@polito.it

SPECIALTY SECTION  
This article was submitted to  
Computational Physiology and  
Medicine,  
a section of the journal  
Frontiers in Physiology

RECEIVED 30 September 2022  
ACCEPTED 12 October 2022  
PUBLISHED 31 October 2022

CITATION  
Chiarion G, Safaei S, Valizadeh A,  
Bashivan P, Yeh C-H, Zhang C, Wang Y  
and Mesin L (2022), Editorial:  
Investigation of brain functional  
connectivity from  
electroencephalogram data.  
*Front. Physiol.* 13:1058683.  
doi: 10.3389/fphys.2022.1058683

COPYRIGHT  
© 2022 Chiarion, Safaei, Valizadeh,  
Bashivan, Yeh, Zhang, Wang and Mesin.  
This is an open-access article  
distributed under the terms of the  
[Creative Commons Attribution License  
\(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or  
reproduction in other forums is  
permitted, provided the original  
author(s) and the copyright owner(s) are  
credited and that the original  
publication in this journal is cited, in  
accordance with accepted academic  
practice. No use, distribution or  
reproduction is permitted which does  
not comply with these terms.

# Editorial: Investigation of brain functional connectivity from electroencephalogram data

Giovanni Chiarion<sup>1</sup>, Soroush Safaei<sup>2</sup>, Alireza Valizadeh<sup>3,4</sup>,  
Pouya Bashivan<sup>5</sup>, Chien-Hung Yeh<sup>6</sup>, Chuting Zhang<sup>6</sup>,  
Yufei Wang<sup>6</sup> and Luca Mesin<sup>1\*</sup>

<sup>1</sup>Mathematical Biology & Physiology, Department Electronics and Communications, Politecnico di Torino, Turin, Italy, <sup>2</sup>Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand, <sup>3</sup>Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran, <sup>4</sup>Pasargad Institute for Advanced Innovative Solutions (PIAIS), Tehran, Iran, <sup>5</sup>Department of Physiology, McGill University, Montreal, QB, Canada, <sup>6</sup>School of Information and Electronics, Beijing Institute of Technology, Beijing, China

## KEYWORDS

brain, functional connectivity, EEG, electroencephalogram, graph theory, machine learning

## Editorial on the Research Topic

**Investigation of brain functional connectivity from electroencephalogram data**

Neuroimaging and electrophysiological recordings have revealed coordinated activity of anatomically separated brain regions. Several brain functions are dependent on the integration of the information processed in functionally specialized regions and the coordination between the activities of the brain regions controls the communication and integration of information in the brain circuits (Fries, 2005). A variety of methods are used to determine the functional connectivity (FC), which is constructed upon statistical interrelations between brain regions and quantifies communication and the functional similarity between them (Park and Friston, 2013). Consequently, study of the functional networks is deemed crucial for understanding the mechanisms of brain-wide information processing in healthy brains (Nentwich et al., 2020) and for developing treatments for many of the most complex brain disorders (Chiarion and Mesin, 2021). FC methods span a variety of disciplines including mathematics, computer science, signal processing, medicine, neuroscience, physiology, physics, electrophysiology, and psychology.

Functional connectivity is usually inferred from the correlation in the activity of the nodes based on the BOLD or synchrony in the EEG or MEG signals. The present Research Topic focuses on the investigation of FC using electroencephalography (EEG) that, thanks to its high temporal resolution, enables recording brain activity patterns that could appear in short timescales and allows to conduct spectral analysis, which is not possible with

BOLD signals. On the other hand, EEG signal is often noisy and highly affected by volume conduction and common source issues. For this reason, appropriate methodologies for processing the EEG data are of utmost importance, to assure reliable evaluation of the FC measurements (Shi et al., 2019).

The articles in the current Research Topic investigate various applications, using different approaches. The following is a brief introduction to the contributions.

1. Kaminsky and Blinowska, who had previously proposed the widely used Direct Transfer Function (DTF) metric, provide a guide toward future research in FC analysis in EEG. In particular, their paper analyzes different FC approaches (e.g., linear vs nonlinear, bivariate vs multivariate methods, etc.) with respect to the effect that these choices have on addressing issues due to noise, volume conduction, common drive, etc. Characterization of networks is also treated with critical analysis of the definition of “smallworldness”.
2. Song et al. focuses on the analysis of the different brain organization of depressed patients during sleep with respect to controls. The high temporal resolution of the EEG is exploited with dynamic FC analysis (dFC), using the weighted phase lag index (wPLI) as a bivariate metric and dividing the signal epochs by sleep stages and frequency bands. Interestingly, they found that depressed patients exhibit higher node strength and global efficiency than controls in all frequency bands and stages of sleep.
3. Jin et al. applies the adaptive frequency band division to the analysis of gait disturbance in Parkinson’s disease (PD). Cross-frequency coupling (CFC) techniques are used to investigate functional connections under the dynamic gait phase. In particular, the authors evaluated phase-amplitude coupling (PAC), exploring the relationships between the amplitude of high-frequency rhythms (i.e.,  $\beta$  and  $\gamma$ ) and the phase of low-frequency rhythms (i.e., main rhythms of lower frequency) of local field potentials in the subthalamic nucleus (STN) in PD patients. As an important result, they revealed that there is a suppression of exaggerated  $\beta/\gamma$ -band-related PAC and an enhanced gait-phase-related modulation of the high portion of  $\beta$  in the STN, corresponding to the improvement of stepping performance using auditory cues.
4. Ho et al. applies the global synchronization (GFS) metric to predict the outcome of sudden cardiac arrest (SCA) survivors. Since GFS is known to be influenced by noise, they proposed an anti-noise algorithm that reduces its effect showing that patients with a good outcome (GO) have a higher EEG power in all the four analyzed frequency bands (i.e.,  $\delta$ ,  $\theta$ ,  $\alpha$  and  $\beta$ ). Using the severity-of-disease classification system APACHE II, they also found that  $\alpha$  band is the most useful in predicting GO in SCA survivors.
5. Pirovano et al. highlights the importance of assessing the directionality of the information flows in the FC analysis of

stroke patients after rehabilitation. They propose to combine the information of direct and indirect coupling provided by two frequency-domain measures: directed coherence (DC) and generalized partial directed coherence (gPDC). They observed a significant increase in the topographic representation of intra-hemispheric connections as well as an increase in power transfer. In particular, in the  $\alpha$  frequency band, they found an improvement in information flow between the pre-motor cortex (pMC) and primary motor cortex (M1) areas in the ipsi- and contra-lesional hemispheres. As a final result, they found a significant increase in the topographic representation of the connection from supplementary motor area (SMA) to contra-lesional M1 in  $\alpha$  frequency, while a decrease in the contra-lesional pMC  $\rightarrow$  SMA coupling after rehabilitation was observed both in  $\alpha$  and  $\beta$  frequency bands. Considering only the DC, they would not be able to identify changes in SMA connections with contra-lesional motor and pre-motor areas, as well as the enhanced role of the pMC inter-hemispheric coupling in the  $\beta$  band.

In summary, this Research Topic presents novel approaches to various applications of FC analysis on EEG data. Different FC metrics can be useful for exploring brain network connections under different physiological or pathological conditions. Many more applications are expected in the future.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## Funding

PB is supported by the Healthy Brains Healthy Lives (fund No. 253784), Natural Sciences and Engineering Research Counsel of Canada (fund RGPIN-2021-03035), Fonds de Recherche Santé (fund No. 310924), and Canada Foundation for Innovation (fund No. 42730). CHY is supported by the National Natural Science Foundation of China (Grant No. 62171028 and 62001026), and the BIT High-level Fellow Research Fund Program (Grant No. 3050012222022).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated

organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References

Chiarion, G., and Mesin, L. (2021). Functional connectivity of eeg in encephalitis during slow biphasic complexes. *Electronics* 10, 2978. doi:10.3390/electronics10232978

Fries, P. (2005). A mechanism for cognitive dynamics: Neuronal communication through neuronal coherence. *Trends Cogn. Sci.* 9, 474–480. doi:10.1016/j.tics.2005.08.011

Nentwich, M., Ai, L., Madsen, J., Telesford, Q., Haufe, S., Milham, M., et al. (2020). Functional connectivity of eeg is subject-specific, associated with phenotype,

and different from fmri. *Neuroimage* 218, 117001. doi:10.1016/j.neuroimage.2020.117001

Park, H., and Friston, K. (2013). Structural and functional brain networks: From connections to cognition. *Science* 342, 1238411. doi:10.1126/science.1238411

Shi, W., Yeh, C. H., and Hong, Y. (2019). Cross-frequency transfer entropy characterize coupling of interacting nonlinear oscillators in complex systems. *IEEE Trans. Biomed. Eng.* 66, 521–529. doi:10.1109/TBME.2018.2849823