ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXVI Cycle

Functional connectivity analysis in neuroscience

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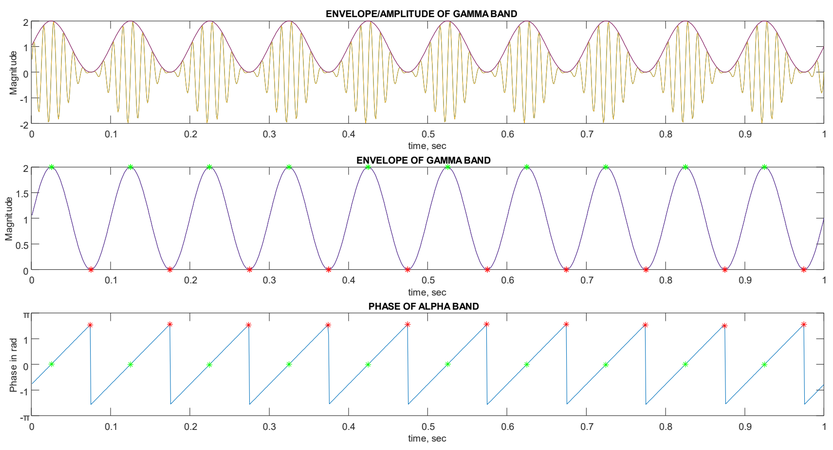
Research context and motivation

Understanding the mechanisms behind human brain functions is nowadays defined as crucial to treat many of the most complex neurological diseases. There are numerous disorders that still don't have a cure: not only neurodegenerative disorders, like Alzheimer's (AD) and Parkinson's disease (PD), but also auto-immune ones, like Amyotrophic Lateral Sclerosis (ALS) and Diabetes.

Moreover, mood illnesses like Depression (DD) and Bipolar Disorders (BD) often are not diagnosed rapidly and with precision.

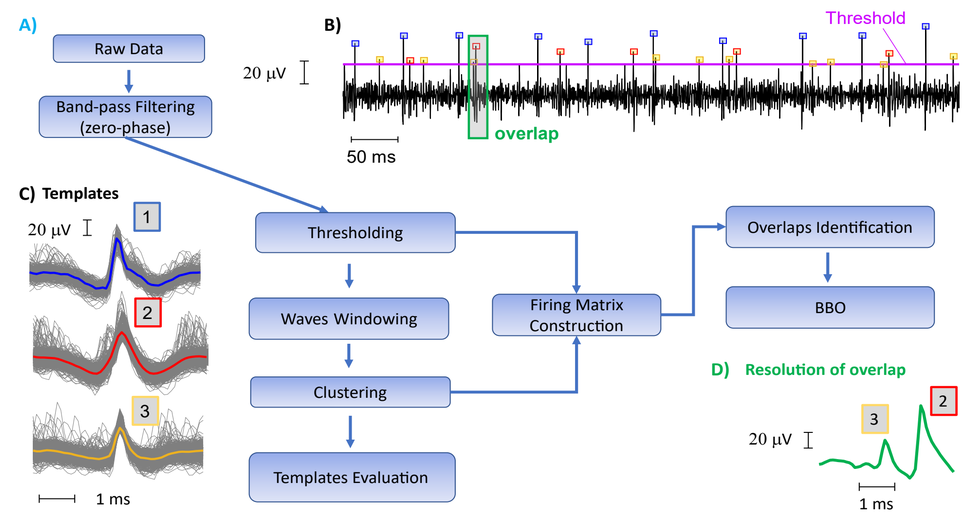
It is proved that patients affected by these conditions have different brain mechanisms with respect to healthy people. In particular, different brain areas are connected (or better, *synchronized*) in different moments. Functional Connectivity (FC) Analysis is inserted in this context. It tries to quantify these synchronizations in terms of the temporal coincidence of spatially distant neurophysiological events (Friston, 1994).



It is possible to use data from different sources to assess FC, from temporal series data like Electroencephalogram (EEG) or Magnetoencephalogram (MEG), to image data like functional Magnet Resonance Images (fMRI). It is also possible to combine both data sources to acquire more information.

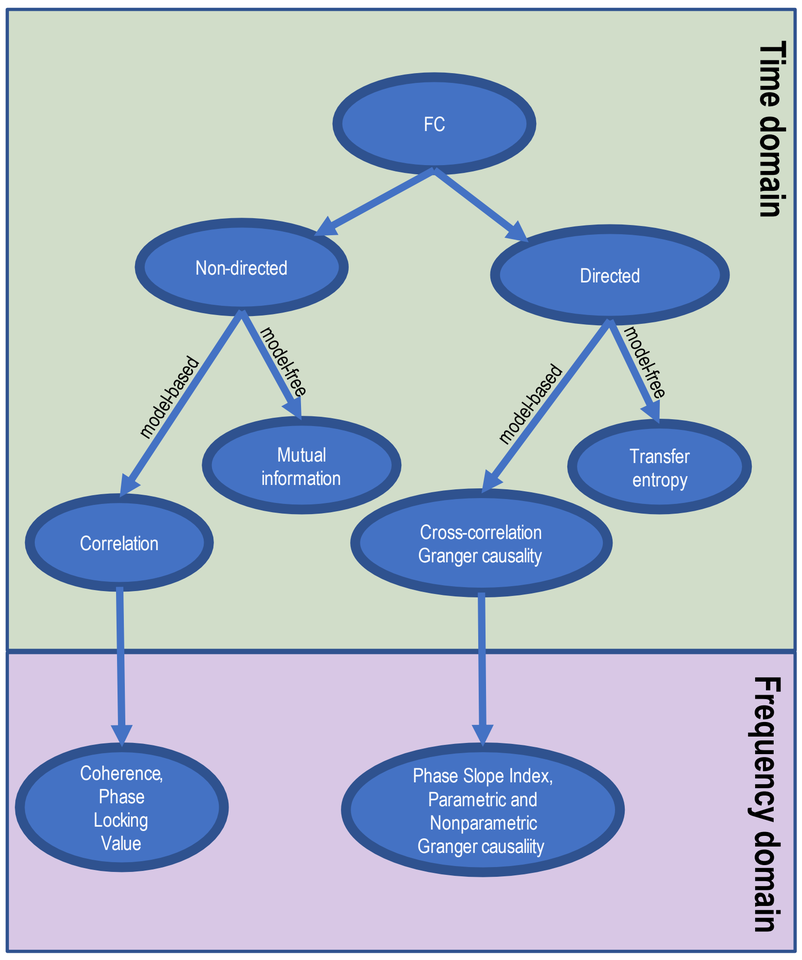
Novel contributions

- Applications of new methods for the assessment of functional connectivity
- Use of algorithms generally not applied in neuroscience field (Biogeography-Based Optimization Algorithm for spike detection) with good results
- Automatic detection of significant structures on EEG signal for encephalitis patients (Slow Biphasic Complexes)
- Exploration of the changes of brain connectivity patterns in proximity of focal events for epileptic patients
- Training of machine learning classifiers with FC topological indices as features to evaluate the severity of a disease (e.g, epileptic patients)



Addressed research questions/problems

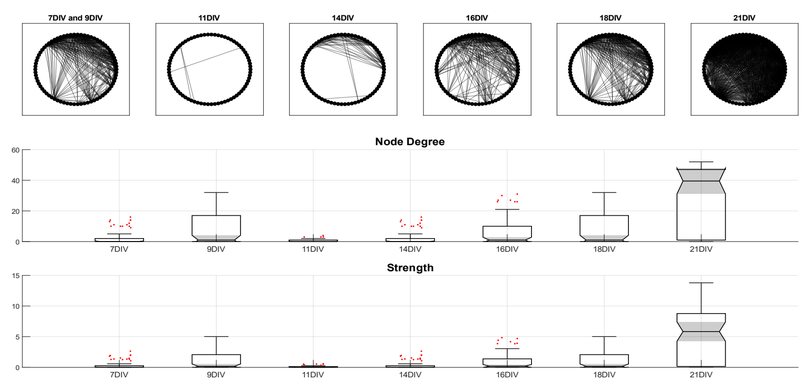
- Since brain is extremely complex, how is it possible to identify and quantify (in the least invasive way) the activities that regulate its processes?
- The use of surface EEG data, for example, let us obtain information about the overall tasks performed by the brain with minimal discomfort by the subjects. However, the signals obtained are generally very noisy due to various reasons: volume conduction problems, common sources, independent electromagnetic noise added in the signal, etc… How could we lower the noise interferences without losing useful information?



- FC analysis makes use of mathematical methods to assess some relationships between different signals (generated in spatially distant sites). Which are the most informative methods that could capture these relationships?
- There are tons of methods that could be used to assess FC, each one with its own peculiarities, pros and cons. For example, it is known that linear methods, like Cross-Correlation (CC), Coherence (C), Granger Causality (GC), are more robust to noise and simpler with respect to non-linear ones. However they could be used only with the hypothesis of linearity which is often not applicable in a non-linear signal like the EEG. In which circumstances is it possible to consider linear the sources?
- Generally, there are many electrodes from which data is recorded (with EEG data, N ~= 30-128), and metrics are generally calculated for each couple of signals, generating a great number of values (~1000-10000 values) storable as an adjacency matrix. Thus, it is possible to view the problem with a graph theory approach, but, since the number of nodes is high and the graph is initially a clique, how could it be visualized in a useful way? How could the adjacency matrix be thresholded to maintain only the useful connections, discarding the noise?
- An intelligent way to represent and analyse a graph is to assess topological properties of the graph using indices from graph theory. However, the number of indices that could be evaluated is huge: which are the best informative indices that could be used to understand the mechanisms behind the brain connectome? Data visualization is fundamental.

Adopted methodologies

- **Pre-processing of data**
  - Visual deletion of "bad data"
  - Downsampling (if data were oversampled considering the bandwidth of interest)
  - Filtering in a proper frequency band (to extract a specific EEG rhythm)
  - Automatic deletion of "bad data" based on some criteria (e.g, in EEG, std of noise over a threshold for a number of consecutive seconds)
- **Splitting data into epochs**
- **Processing**
  - FC Metric(s) evaluation
  - Adjacency matrix construction
  - Thresholding
  - Topological indices evaluation
- **Statistical Analysis**
  - Evaluation of statistical similarities and differences using proper statistical tests
- **Visualization**
  - Graph visualization
  - Topological indices visualization
- **Results interpretation**



Future work

- Exploration of new FC metrics, in particular multi-variate ones
- Application of source localization techniques on EEG data to reduce the effect of common sources
- Focus on adjacency matrix thresholding problem
- Extension of FC analysis on new fields
- Application of FC techniques to define the efficacy of a new treatment (e.g, trans-cranial stimulation, drug treatment, psychological therapy, etc…)
- Integration of data from multiple acquisition devices (e.g, fMRI) to gain more information about connectivity
- Study of neuro-stimolation effects on connectivity (e.g, trans-cranial magnetic stimulation) and implementation of feedback mechanisms to enhance positive effects

List of external training activities

- 02SIOPQ – Didattica, tecnologia e ricerca educativa (17/06/2022, 60h)
- XXXXXX – Pedagogia della relazione educativa e formativa per la scuola secondaria (16/06/2022, 30h)
- XXXXXX – Psicologia dell'educazione e dell'apprendimento in contesti scolastici (22/08/2022, 30h)
- XXXXXX – Aspetti affettivi e relazionali dei gruppi nel contesto scolastico (22/08/2022, 30h)

Submitted and published works

- Chiarion, G., Mesin, L., 2021a. Functional connectivity of eeg in encephalitis during slow biphasic complexes. Electronics (Switzerland) 10. https://doi.org/10.3390/electronics10232978
- Chiarion, G., Mesin, L., 2021b. Resolution of spike overlapping by biogeography-based optimization. Electronics (Switzerland) 10. https://doi.org/10.3390/electronics10121469
- Hilviu, D., Vincenzi, S., Chiarion, G., Mattutino, C., Roatta, S., Calvo, A., Bosco, F., Gena, C., 2021. Endogenous Cognitive Tasks for Brain-Computer Interface: A Mini-Review and a New Proposal:, in: Proceedings of the 5th International Conference on Computer-Human Interaction Research and Applications. Presented at the 5th International Conference on Computer-Human Interaction Research and Applications, SCITEPRESS - Science and Technology Publications, Online Streaming, pp. 174–180. https://doi.org/10.5220/0010661500003060

List of attended classes

- 01UNXRV – Thinking out of the box (31/12/2020, 1h)
- 01SWPRV – Time Management (10/01/2022, 2h)
- 02LWHRV – Communication (19/01/2021, 5h)
- 01QFFRV – Tecniche innovative per l'ottimizzazione (26/02/2021, 20h)
- 02SFURV – Programmazione scientifica avanzata in Matlab (25/05/2021, 30h)
- 08IXTRV – Project Management (02/08/2021, 5h)
- 02QUBRS – Statistical data processing (04/02/2022, 20h)
- 01UJZIU – Information visualization and visual analytics (30/06/2022, 20h)
- 01SCSIU – Machine Learning for pattern recognition (22/07/2022, 20h)

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