Dynamics of Brain Functional Networks and Epileptic Seizures

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Legend: Red – Epileptic Focus

The data consists of 0.25Hz of iEEG voltage recordings. Sliding window is 4s.

Introduction:

- Epileptic seizures are associated with a state of the brain in which too many neurons are synchronized for the brain to function correctly. Being able to predict the inception of the seizure and notify the person would remove many dangers of its current unpredictability and be a safe temporary solution, while the success rate of brain surgeries and medicine improves.
- There has been a significant success in utilizing the network reconstruction to predict and identify seizure onset zones using Granger causality[1]. Researchers have also studied the transitions in network topology acquiring some interesting results[2]. Yet, a complete understanding of a global picture of how abnormal synchrony emerges in epileptic brain networks is lacking and requires studies that take into account the interplay between the intrinsic properties of individual neurons and the evolving functional network structures.

Methods:

Network Reconstruction:

- **Outline:** The iEEG data contains voltage readings from electrodes connected directly to the brain, n=120. Since neurons are interconnected, one can analyze these voltage recordings through **a statistical measure** that gives a numerical value to the strength of connection between different electrodes. **Sliding-window** is utilized since the connections are generally not completely connected through all of time. After applying a statistical measure, **a threshold is used** to drop nodes with weak uncorrelated connections[3].

Graph Theoretical Measures:

- **Average Betweenness Centrality: The betweenness centrality is the sum of shortest paths that pass through a node V. We average all of these at time t:**

$$g = \frac{1}{N}\sum_{v\in G} C_{B(v)}, C_{B(v)} = \sum_{s,t\in V}\frac{\sigma(s,t|v)}{\sigma(s,t)}$$

- **Average Clustering: The average clustering coefficient is given as:**

$$C = \frac{1}{N}\sum_{v\in G} c_v$$

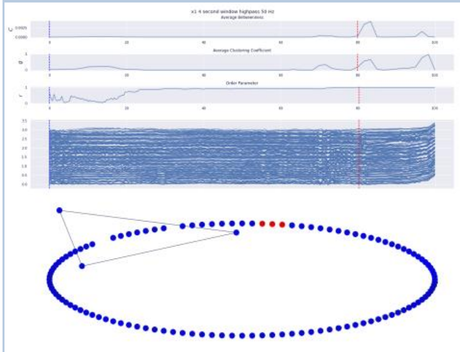
Dynamical Systems Measures:

- **Order Parameter: The Kuramoto order parameter was used to measure synchrony in the functional network. The order parameter *r (r=1* coherence, *r=0* incoherence*)* is calculated from the iEEEG data using*:***

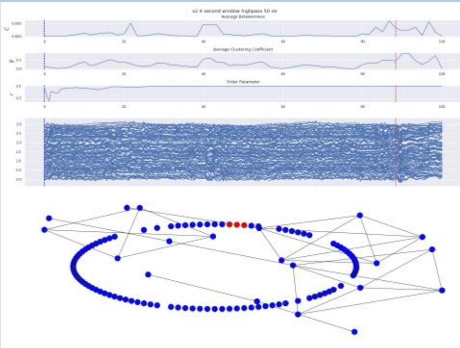
$$re^{i\psi} = \frac{1}{N}\sum_{j=1}^{N} e^{i\theta_j}$$

Reconstruction of brain functional networks from iEEG recordings of epileptic episodes: abrupt structural changes and decreased coherence forecast the onset of a seizure

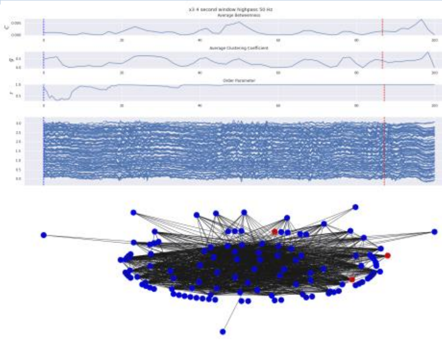
Recording 1:



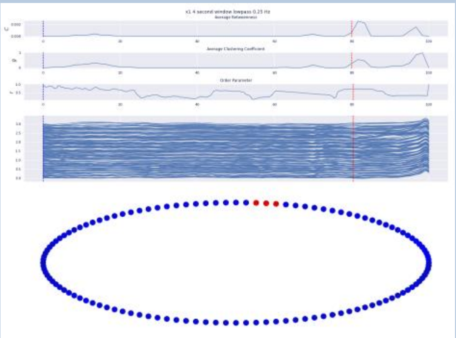
Recording 2: The generalized seizure episode. The network sustains average connectivity right up until a few moments before the epileptic episode where the connectivity drops and then quickly rises signifying the intense neuron synchronization and seizure onset.

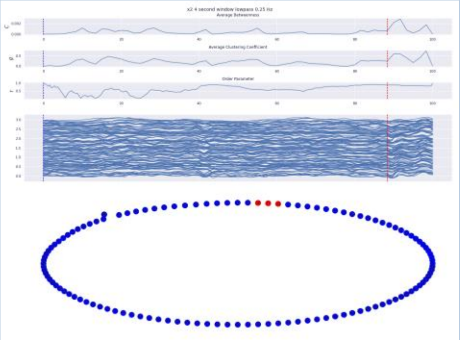


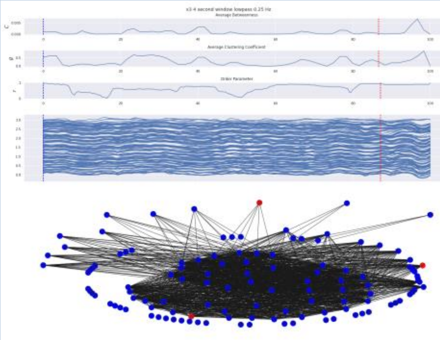
Recording 3:



Comparison: The animations show the changes in the network topology over the various episodes for low frequency lowpass filters at 0.25 hz. Compare those to the pictures below that are high pass filters at 50hz.







Conclusions:

We have used intracranial electroencephalography (iEEG) recordings of epileptic episodes to reconstruct brain functional networks by applying cross-correlation and calculating graph theoretical measures. By using the graph theoretical measures we have discovered that there were common features to all three episodes even though the episodes were fundamentally different. More specifically, the onset of an epileptic seizure (a severe, generalized seizure in Episode 1, and localized seizures in Episodes 2 and 3) is preceded by a well pronounced episode of decreased coherence and abrupt changes in functional connectivity. These changes can be used to forecast the onset of a seizure.

References:

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[2] Wang Z., Tian C., Dhamala M., Liu Z. (2017) A smal change in neuronal network topology can induce explosive synchronization transition and activity propagation in the entire network. *Scientific Reports*. doi:10.1038/s41598-017-00697-5DO

[3] Papo, D., Zanin, M., & Buldú, J. M. (2014). Reconstructing functional brain networks: have we got the basics right?. *Frontiers in human neuroscience*, *8*, 107. doi:10.3389/fnhum.2014.00107