

Recurrence Network Analysis Uncovering Biomarkers of Depression from Nonlinear Dynamics Underlying EEG Signals

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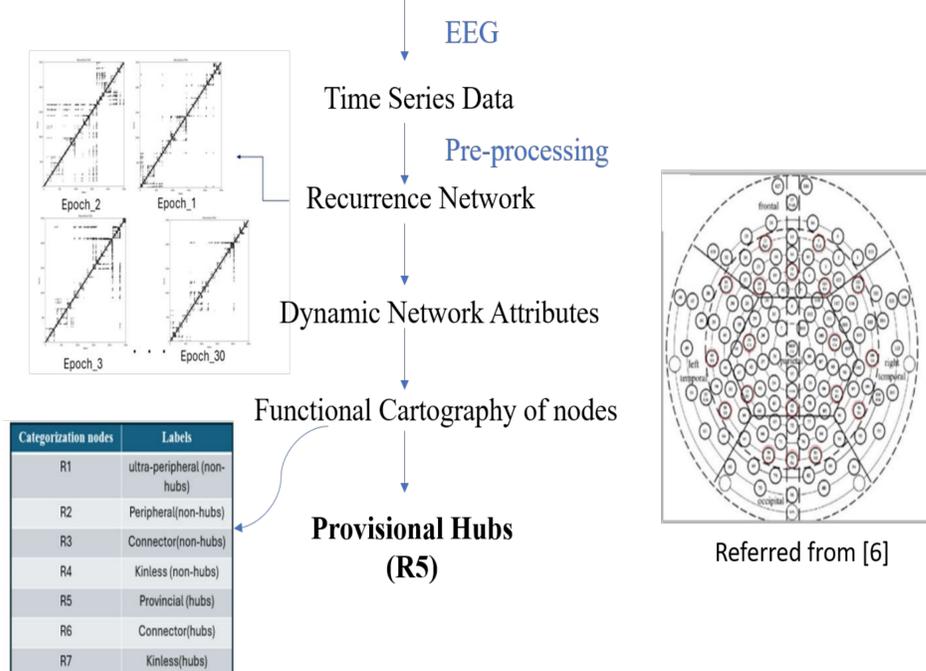
INTRODUCTION & AIM

- Major Depressive Disorder (MDD) is one of the most prevalent and severe mental health condition, affecting millions of individuals worldwide and often leading to significant cognitive and emotional dysfunction.
- MDD is characterized by persistent low mood, loss of interest or pleasure, and impaired cognitive and physical functioning.
- Our objective is to apply advanced complexity and recurrence network analysis approaches to investigate underlying changes in the functional brain connectivity using electroencephalographic (EEG) signals.

METHOD

- We have used the multi-modal open dataset for mental-disorder analysis (MODMA), consisting of 128-channel resting-state EEG recordings of individuals with MDD and that of healthy controls.
- Our study included 24 subjects from each group (MDD and healthy controls).
- We have particularly focussed on 30 channels in the frontal brain region as it is known to play a crucial role in the emotional and cognitive processing.

Multimodal Open Dataset for Mental Disorder Analysis

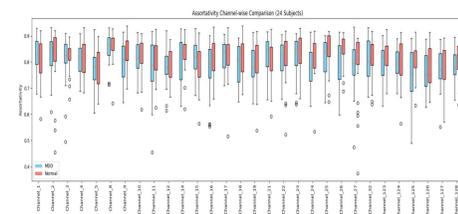


- To capture the nonlinear temporal dynamics of the EEG signals, we analyzed the PSD time series using recurrence plots (RPs) and recurrence networks (RNs). Recurrence plots were constructed using the supremum (maximum) norm with a threshold set to 0.05 standard deviations of the time series.
- We then computed various network measures, including Recurrence Quantification Analysis (RQA), recurrence rate (RR), determinism (DET) and laminarity (LAM)[3].
- Recurrence networks were then created by treating the recurrence matrix as an adjacency matrix, where nodes represent time points and edges indicate recurrences between states.
- For each network, we computed several topological measures using NetworkX, including clustering coefficient, transitivity, assortativity, density, average path length, diameter, and degree centralization.
- Further, we performed functional cartography of nodes based on modularity to quantify network hubs[4].
- To examine the modular organization of the recurrence networks, we applied Louvain community detection.
- We classified nodes based on their participation coefficient (P_i) and within-module degree (Z -score), using a Z -score threshold of 1.5 to distinguish hubs from non-hubs[5].

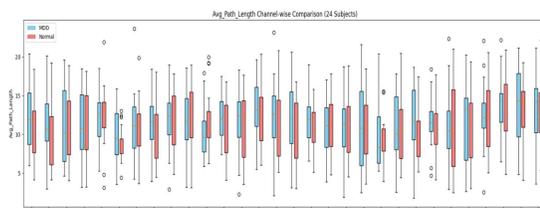
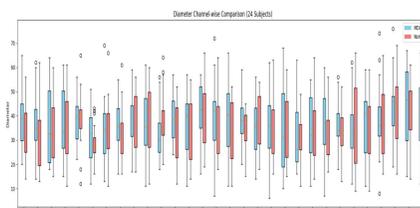
RESULTS & DISCUSSION

Comparison of different network measures:

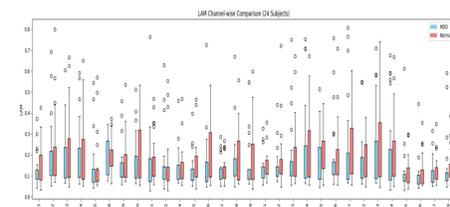
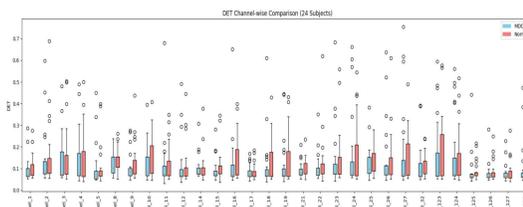
- MDD patients exhibited significantly lower assortativity together with increased dispersion of values, particularly in channels 9, 11, 26, 32, and 125. This pattern suggests altered geometric organization of neural attractors in regionally specific cortical areas.



- Average Shortest Path Length (ASPL) and diameter boxplots (between HC and MDD) show similar patterns to each other. This is a clear indicator that the result is structurally consistent.
- MDD patients exhibited increased ASPL and diameter across frontal channels (except channel 123), indicating reduced global efficiency and increased separation of dynamical states in reconstructed phase space. Concurrent reductions in assortativity, together with these findings, point to both global fragmentation and local destabilization of neural dynamics in depression.

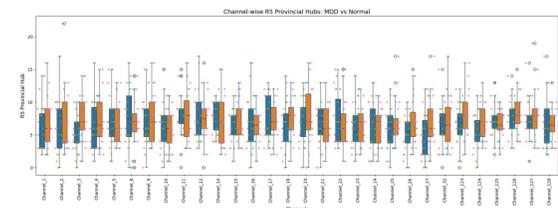


- Determinism (DET) and Laminarity (LAM) boxplots (between HC and MDD) show similar patterns to each other. This indicates internal metric consistency within structural groups.
- Reduced DET and LAM values in MDD indicate diminished deterministic structure and laminar stability of neural dynamics. The exception observed in Channel 8, characterized by increased dispersion in MDD, suggests region-specific heterogeneity in dynamical reorganization.



Mesoscale analysis:

- The reduction in provincial hub strength across the majority of channels in MDD indicates weakening of intra-community dynamical cores, suggesting diminished modular organization.



CONCLUSION

Recurrence-based network analysis reveals multiscale disruption of neural dynamics in MDD. Patients show reduced determinism and laminar stability, weakened provincial hubs, and increased path length and diameter, indicating diminished local coherence and reduced global efficiency. Overall, depression is characterized by a more fragmented and less structured organization, with region-specific heterogeneity.

FUTURE WORK / REFERENCES

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