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Unlocking Neural Patterns: A Graph Neural Network Model to Classify and Analyze EEG Connectivity in Parkinson's Disease

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***Introduction**:* Recent advances in brain-computer interfaces (BCIs) have shown their potential for diagnosing and rehabilitating Parkinson's disease (PD) patients by promoting neuroplasticity [1]. These results support the development of personalized therapeutic interventions through techniques like motor imagery-based BCIs, enabling rehabilitation by recording electroencephalographic (EEG) signals during imagined movements. Unfortunately, traditional methods of analyzing EEG signals struggle to capture the complex neural patterns associated with PD [2]. Geometric deep learning network approaches such as graph neural networks (GNNs) have been used to express non-Euclidian spaces representing how information flows between brain regions observed by EEG electrodes [3].

***Material, Methods, and Results**:* We developed a deep learning pipeline using graph neural networks to classify the brain signals as PD or healthy. Data were collected from 15 PD patients and 14 healthy subjects using a 128-channel EEG system. They were instructed to visually imagine walking on a straight pathway and crossing a hurdle. EEG data was preprocessed and transformed into graph representations - each node represented an EEG electrode, and edges represented connections between electrodes. We split the dataset into training and test sets and trained our model with a two-layer graph convolutional network (GCN). Then, we performed hyperparameter optimization using Optuna and extracted weights from the first and second convolutional layers. The strength of each neural pathway was calculated by summing the absolute values of the weights for each electrode pair. The proposed GNN model achieved a mean test accuracy score of 83% in classifying EEG signals. The model demonstrated a mean precision of 0.88, a mean recall of 0.76, and a mean F1 score of 0.79. Figure 1 shows the connections between EEG electrodes critical for the model to make accurate predictions: the connection between the frontal midline electrode (Fz) and the right occipital electrode (O2) showed the highest importance for the model.

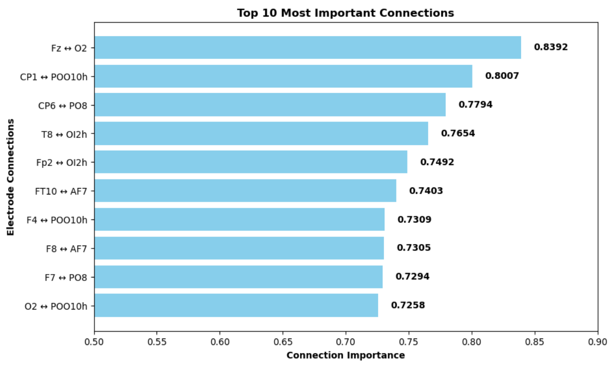

Fig 1. Connections between brain regions identified by our model as critical for classifying Parkinson's Disease during motor imagery.

***Conclusion**:* This study demonstrates the potential of using GNNs to identify PD patients using EEG signals recorded during motor imagery tasks. Finding specialized populations such as those with PD is a limiting factor for training conventional large-scale models because of the lack of a large quantity of high-quality data. Our model performed to a high degree of accuracy after training on only 29 patients. Our findings suggest that connectivity between the occipital and parietal lobes may play a more prominent role in motor imagery affected by PD than was previously known [4], [5]. Our work could help develop BCIs with improved diagnostic capabilities, reduced response times, and enable personalized therapeutic interventions. In particular, this deep learning model framework could help develop tools to support the rehabilitation of PD patients by identifying regions in real time that may be implicated in motor control with a high degree of accuracy.

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