Oscillatory synchrony between GP neurons and the cortical EEG in the parkinsonian animals

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Abstract

Parkinson's disease patients exhibit abnormal oscillations of neuronal activity (Beta oscillation) in the basal ganglia. A recent study showed that there were two neural populations in the Globus pallidus (GP) synchronized with cortical EEG during slow wave activity in anesthetized rats. In this study, we aim to quantify the oscillatory synchrony between GP neurons and the cortical EEG in parkinsonian rats in activated and slow wave states.

1. Introduction

Parkinson disease (PD) is a heterogeneous movement disorder caused by progressive neurodegeneration of dopaminergic neurons in the substantia nigra pars compacta (SNpc) of the midbrain [1]. Using Electroencephalograph (EEG) on Parkinsonian patients and animal models has shown the existence of abnormal oscillations in the beta range (12-30 Hz) in the basal ganglia-thalamo-cortical network. This activity may be closely related to an oscillation between the subthalamic nucleus (STN) and globus pallidus that caused abnormally strong synchrony with cortical EEG in the beta range (the increase of beta frequency waves in the EEG) [2]. Mallet et al. observed two neural populations in external globus pallidus (GPe) which correspond to the synchrony of their activity to cortical EEG during slow wave activity in anesthetized rats. The first population spiked in-phase with the cortical rhythm and the second population was in anti-phase [3].

The aim of this study is to investigate the oscillatory synchrony between GP neurons and the cortical EEG in parkinsonian rats in two condition states, the slow wave and activated states in order to characterize the difference in their firing pattern during beta oscillations.

2. Material and Methods

We used EEG data which are extracted from electrophysiological recordings in anesthetized rats [3]. We have four sets of data corresponding to different spike trains which are classified into four groups and are as follows: 1)ActivePark, the binary data of the patient in active mode; 2) SWAPark, the binary data of the patient in sleep mode; 3)ActivCtrl, the binary data of the control participant in active mode; and 4)SWACtrl, the binary data of control participant in sleep mode. All analyses were performed on 100s duration.

In order to process and analyze the data we used a set of Python scripts in Jupyter Notebook. There are two distinctive neuronal populations in the GPe that synchronize at different low

frequencies (1Hz) with cortical EEG in a slow wave state. To demonstrate the difference in their firing pattern during beta oscillations, we characterized the synchrony between GP neurons and EEG at a beta frequency (12-30 Hz). Also, we used two other datasets as control data to verify the difference between healthy and disease conditions.

3. Results

3.1. Spectral power density histogram

We applied the Welch method that uses the fast Fourier transform for the estimation of spectral power density (PSD). The results of PSD of parkinsonian and control animals in both active and SWA states are shown in Figure 1. The abnormality in the frequency of ~20-30 HZ was observed in the parkinsonian data set compared with the control data set in the active state.

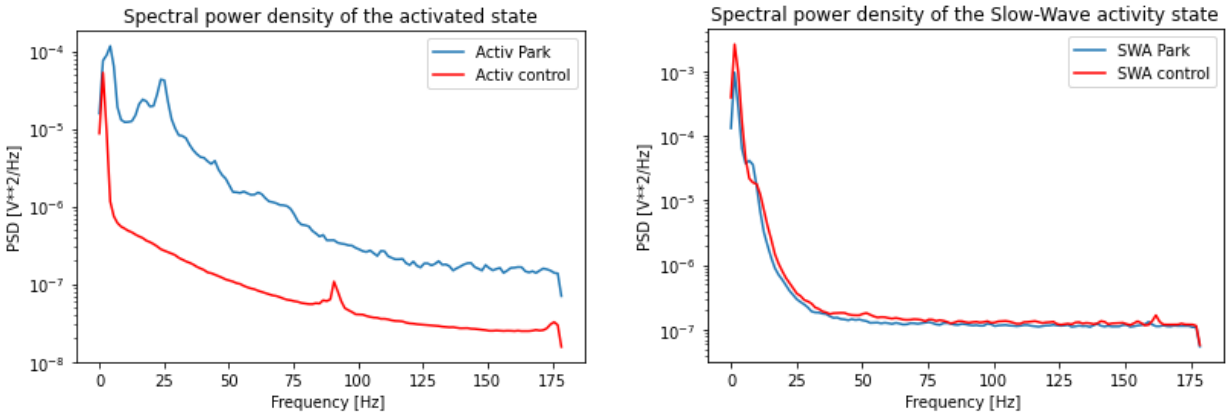

Figure 1: (a) PSD in an activated state, (b) PSD in a slow wave activity state in the parkinsonian and control animals.

3.2. Crosscorrelogram and Coherence

We made an instantaneous firing rate (IFR) in bins of 1 ms of two consecutive spike trains (STs) of parkinsonian data set in an activated state. The cross-correlation of the IFR of ST1 and IFR of ST2 for delays from -250ms to +250ms is shown in Figure 2a. Also in order to smooth the signals we used a Gaussian window by averaging each value with neighboring values. The plot of the filtered signal is shown in Figure 2b.

Also, in Figure 2c, we plot the coherence of IFR between two consecutive spike trains which is used to characterize common inputs that drive motor unit synchronization. And at the end, in Figure 2d, we showed the coherence of IFR with the EEG.

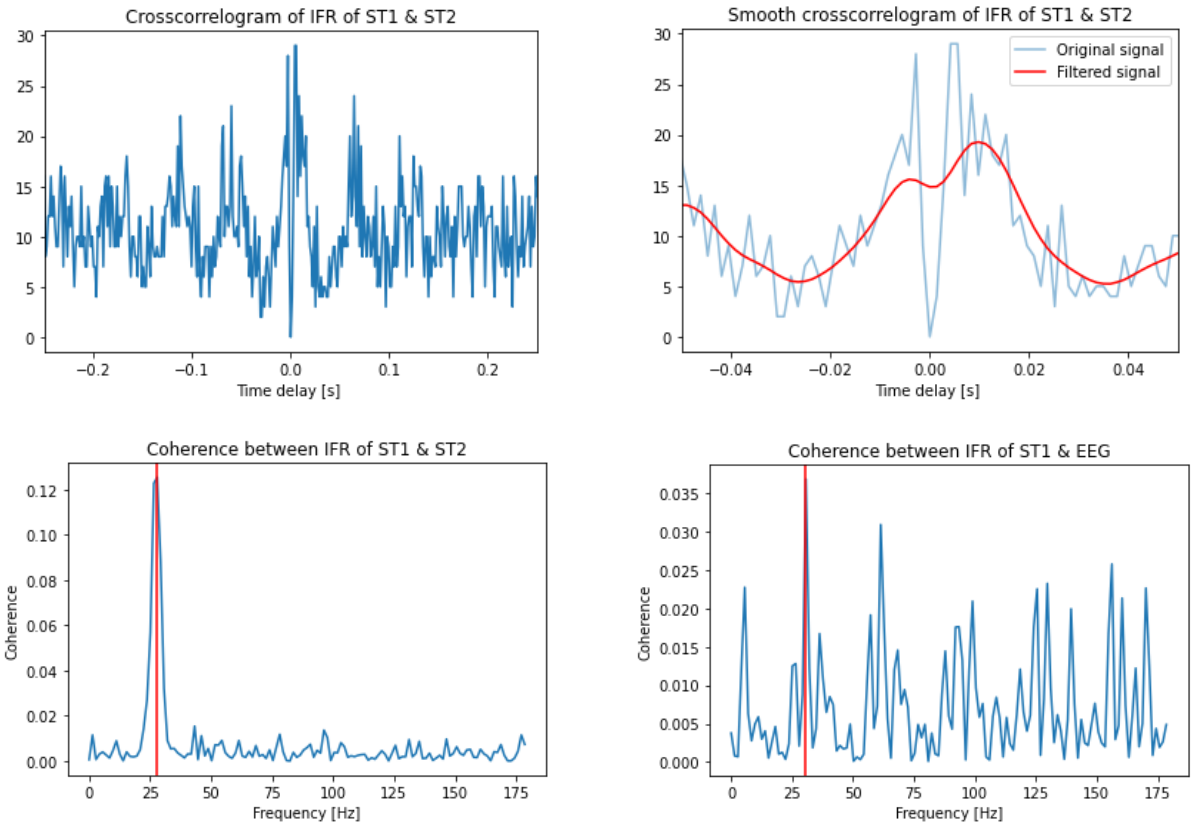

Figure 2: (a) Cross-correlation is the correlation between two signals on different delays; (b) Smooth the cross-correlogram of two signals; (c) Coherence between IFR of two spike trains; (d) Coherence between IFR of a spike train and the EEG.

3.3. Spike-triggered averages and Mean Firing Rate

After we made a bandpass filter with [0.5 1.5] Hz band for EEG, we computed the spike-triggered average (STA) of the EEG trace with the first spike train of the parkinsonian data set in slow wave activity state. The plot of the STA of all spike trains is shown in Figure 3a. Then we made a scatter plotted the mean firing rate of the spike trains vs the value of the spike-triggered average at 0-time lag which showed the two different firing rates in the positive and negative mean STA. We can conclude the existence of two different populations of neurons that spike at different time points in the slow wave activity.

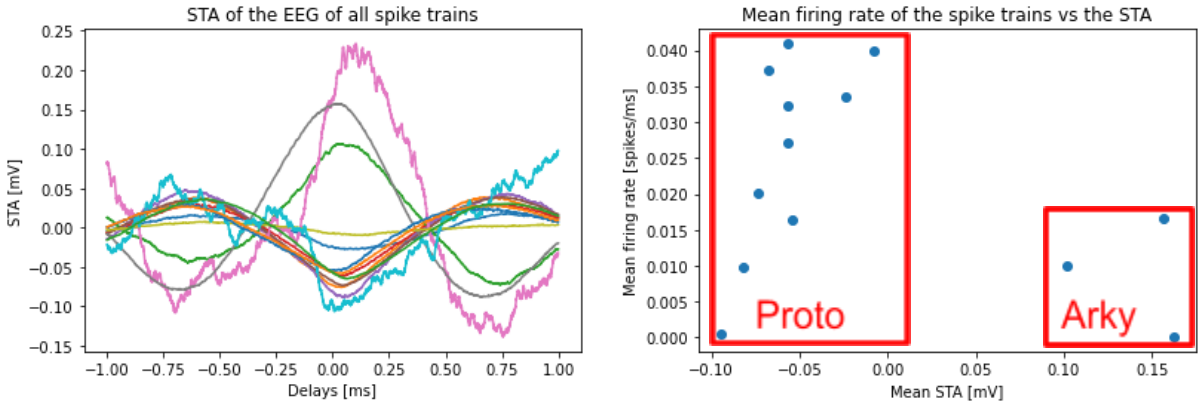

Figure 5: (a) Plot of the spike-triggered average of the EEG of all spike trains in the slow wave activity state; (b) The plot of the mean firing rate of the spike trains vs the value of the spike-triggered average at 0-time lag.

4. Conclusion/Discussion

In this work, we studied the oscillatory synchrony between GP neurons and the cortical EEG in parkinsonian rats in two states: Active and Slow Wave Activity. According to our results, two major populations of GPe neurons are distinguished by their distinct temporal activities (such as firing at different phases) shown in the slow wave activity of parkinsonian animals. We were limited by the datasets we had, however, more precise results could be achieved by changing the datasets, the number of patients, the type of patient, etc. The anatomic analysis could be interesting to confirm the presence of two different cell populations.

In spite of the mentioned limitations, since the prepared processing and analysis scripts are generic, it would be easy to change datasets, apply all the functions, and get proper results corresponding to the new datasets. The scripts are publicly available and accessible[1].

References

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