Normal intracranial encephalographic activity: oscillations, scale-free behavior and neural network classification

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Abstract

In this work, normal intracranial electroencephalographic (iEEG) activity is analyzed in different states of wakefulness and sleep. For this, the database Atlas of iEEG normal activity [1] is used, which compiles iEEG temporal series of patients with refractory epilepsy, during periods free of epileptic seizures, ranging from the waking state and three sleep states: non-REM N2, non-REM N3 and REM.

The aim of the work is to characterize the different states using a variety of tools including frequency bands analysis, the study of scale-free behavior, and classification with neural networks.

The main methods and results are illustrated below, together with the database used.

Database: The Atlas of iEEG normal activity

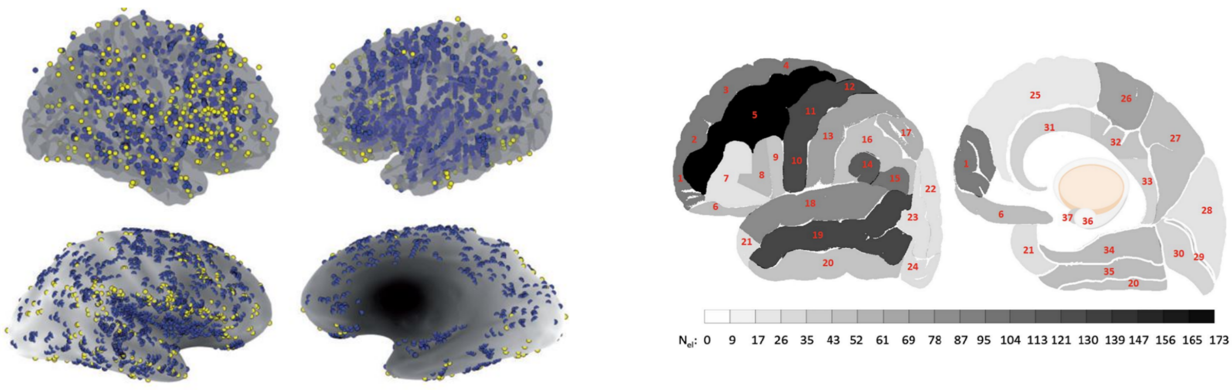

Figure 1. Left: Localization of the 1772 EEG channels with normal physiological activity analyzed for this study. Right: Location of each region and number of electrodes available. The brain areas are labeled in the lateral view (left schematic) and in the medial view (right schematic). See [1] for further details.

Spectral analysis

In the oscillatory analysis (fig. 2) it is observed a very important increase in the spectral power of slow waves during sleep REM, with the N2 phase being more marked. There is a large preponderance of waves in the alpha band during wakefulness, which are not observed during sleep. During non-REM sleep, there is the presence of slow waves in the hippocampus.

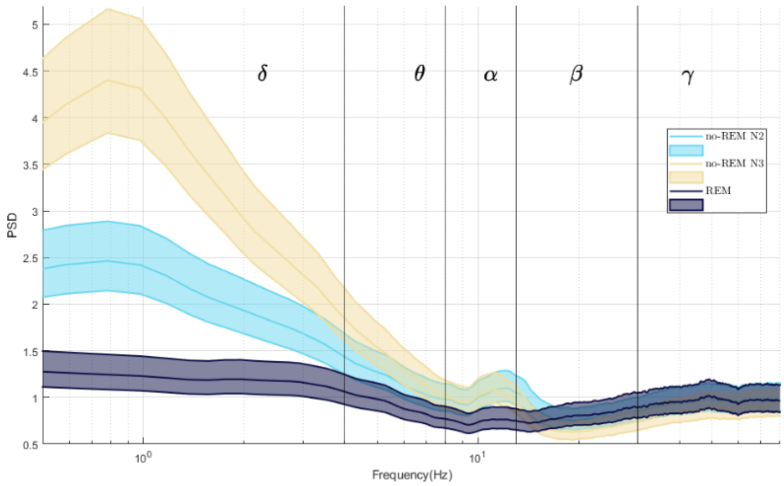

Figure 2: Power spectral density averaged over all subjects for each state of wakefulness and sleep.

Avalanches

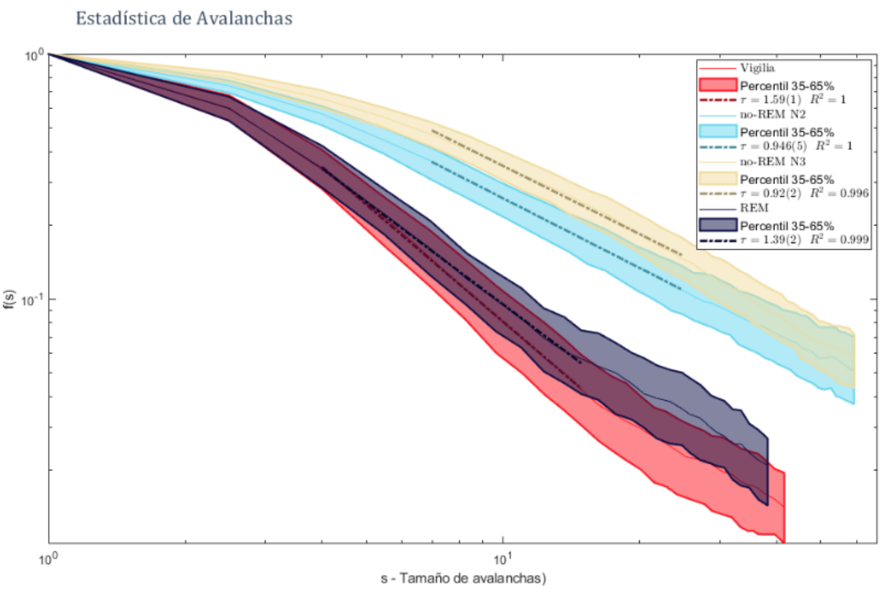

Figure 3: Avalanche distribution for the stages of wakefulness, non-REM N2, non-REM N3 and REM sleep.

The size of an avalanche in iEEG recordings is measured by the number of active electrodes (above a threshold) between instances of inactivity [2]. Figure 3 shows the mean avalanche size distribution on a log-log scale for the different states. The linearity in these curves indicates a trend of scale-free behavior (limited by the accessible scales). As it can be observed, during deep sleep (non-REM) the avalanches are large, covering a large number of electrodes. On the other hand, during wakefulness, there are a large number of small and local avalanches. Finally, REM sleep has a scale-free behavior very similar to the waking state.

Neural networks
We have used different neural networks to classify sleep-wake states from portions of the iEEG time series or its spectrogram. Figure 4 shows the results of the classification with a convolutional neural network (CNN) [3]. CNN's performance is shown here by means of the Confusion Matrix. The horizontal axis shows the actual states, while the vertical axis shows the predicted states. The best performance here is in predicting the wake state with almost 80% (top left corner). On the other hand, in the last column it can be seen how CNN "confuses" between REM and wakefulness (54% of the REM states are effectively identified as such, but 33% confuse it with wakefulness). This makes sense according to the neurophysiological similarity of both states and is consistent with the results of the other techniques used.

Figure 4. Confusion matrix for state prediction using a convolutional neural network. See text above for description.

Conclusions: Using spectral techniques, scale-free analysis and neural networks we have characterized the different states of wakefulness and sleep in iEEG time series of normal activity. Each technique has its own strengths and limitations, but together they provide a consistent framework that allows classify and identify similarities and differences between states.

References:

[1] von Ellenrieder, N., Gotman, J., Zelmann, R., Rogers, C., Nguyen, D. K., Kahane, P., Dubeau, F., and Frauscher, B. (2020). How the human brain sleeps: direct cortical recordings of normal brain activity. Annals of neurology, 87(2):289–301.
[2] Plenz D. and Niebur, E. (2014). Criticality in Neural Systems. Wiley-VCH Verlag.
[3] Goodfellow I., Bengio Y. and Courville A. Deep Learning. MIT Press, 2016.