Multifractal Analysis of Human EEG: Link with Sleep Stages

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PURPOSE:

We aim to study intracranial electroencephalographic (icEEG) recordings and look for markers of stages based on multifractal theory.

METHOD:

We applied the Chhabra-Jensen [1] approach to the study of the data. This method derives the multifractal spectra directly from the equations bellow, without the use of a Legendre transform.

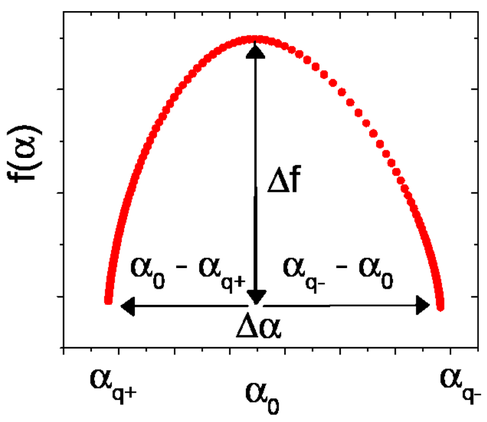
$$\alpha(q) = \lim_{\epsilon \to 0} \frac{\sum_i \mu_i(q,\epsilon) \log P_i(\epsilon)}{\log \epsilon}$$

$$f(q) = \lim_{\epsilon \to 0} \frac{\sum_i \mu_i(q,\epsilon) \log \mu_i(q,\epsilon)}{\log \epsilon}$$

$$\mu_i(q,L) = \frac{P_i(L)^q}{\sum_j P_j(L)^q}$$

Multifractal approaches describe objects in terms of a spectrum of singularities instead of a single dimension, as in fractal analyses.

The geometric features of the spectra are compared as they provide information about the studied object.

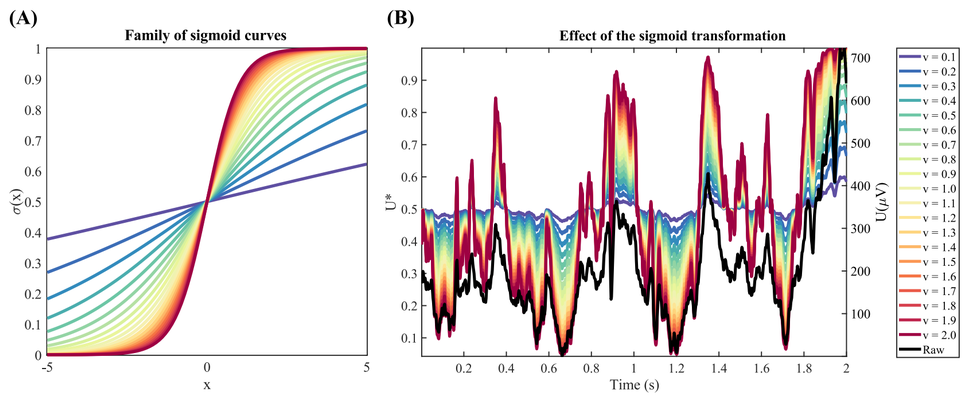


STANDARD DEVIATION AND SIGMOID TRANSFORMATION:

We normalise the EEG epochs and then transform with a sigmoid function according to the equations below:

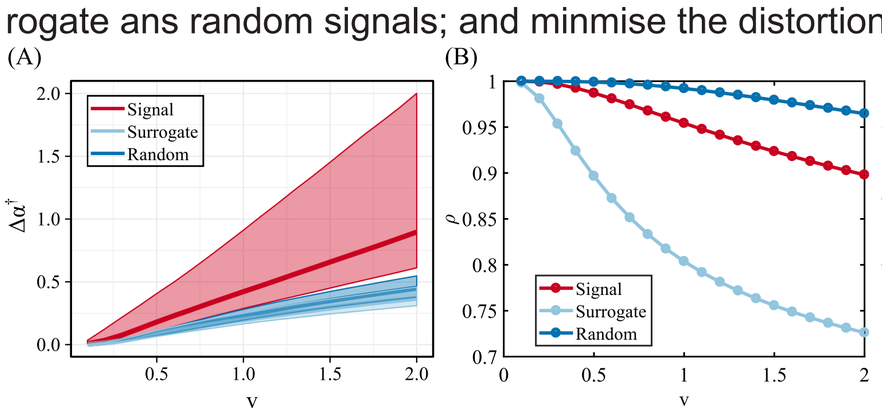
$$x = \frac{t - \overline{ts}}{s}$$

$$\sigma(x) = \frac{1}{1 + e^{\nu x}}$$



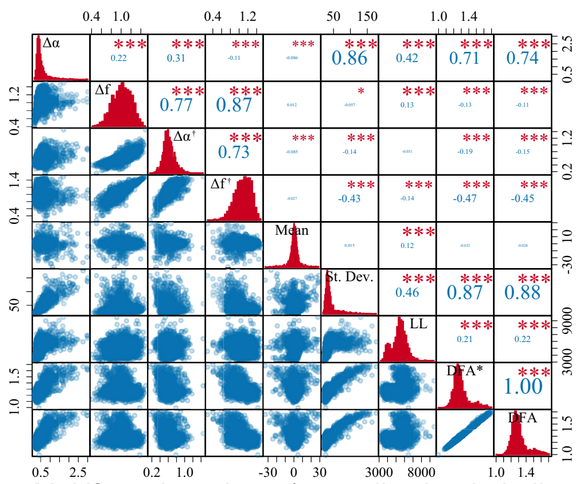
(A) Family of sigmoids with different parameters and (B) the effect on on a signal.

The criteria to choose v are: maximising the difference between real, surrogate ans random signals; and minmise the distortion of the signal.

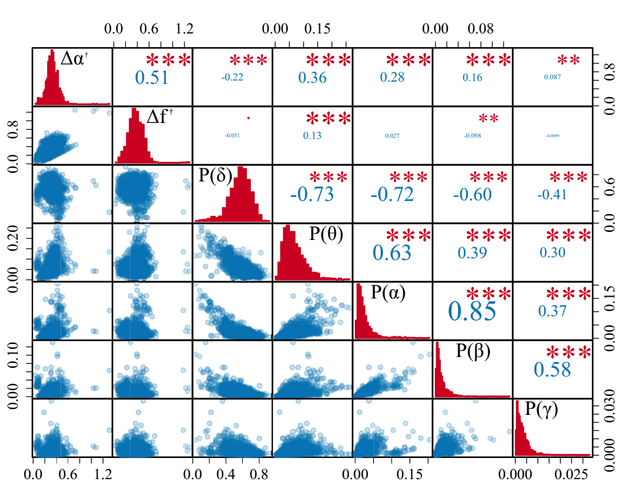


The parameter v was chosen to be 1. It is possible to separate the channels amd the pearson correlation with the original series is still high (~0.95).

MULTIFRACTALS AND OTHER MEASURES:

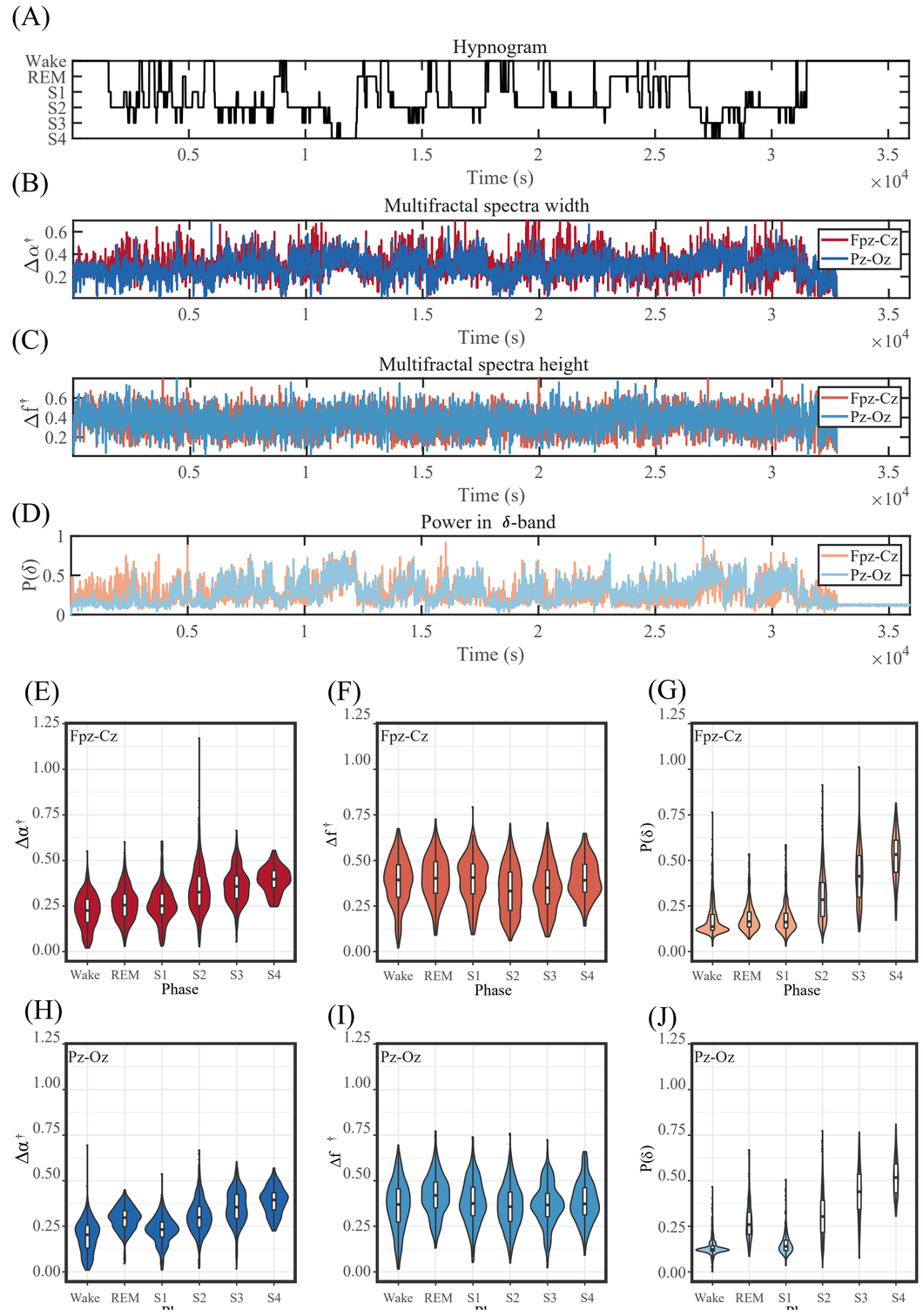


Multifractal markers (normalisation is indicated by the † symbol) and traditional metrics. The normalised multifractal markers show low correlations.



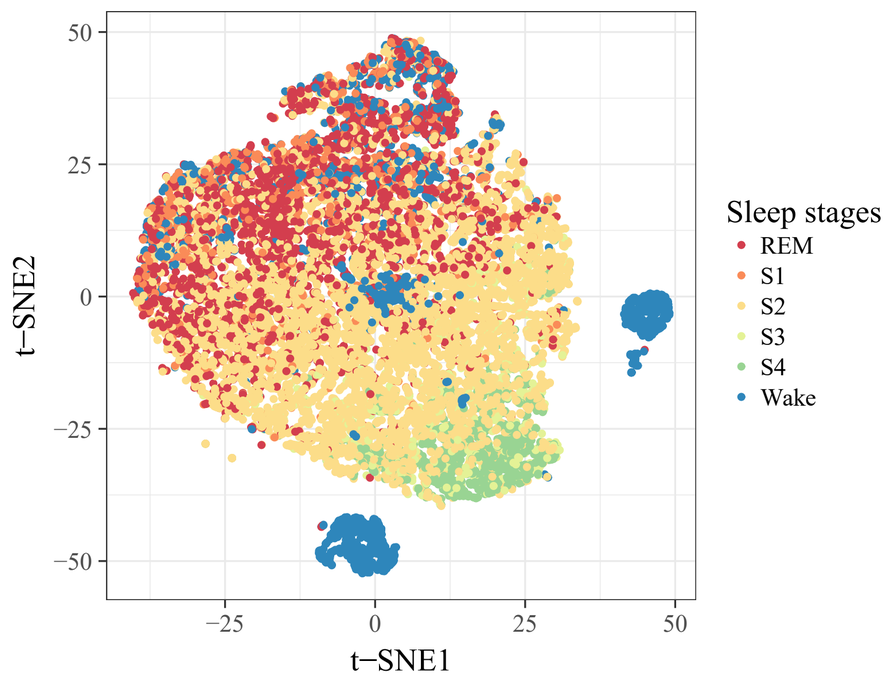
Multifractal markers (normalised) also show low correlations with spectral bands power.

SLEEP STAGES AND MULTIFRACTAL MARKERS:



Multifractal spectra width present similar variations to delta power and suggests some sensitivity to sleep stages. The violin plots show an increase in the marker for both Fpz-Cz and Pz-Oz channels.

t-SNE:



CONCLUSIONS:

- The pre-processing procedure applied removes the effect of the standard deviaton.
- Multifractal markers are able to unearth additional features of the signal.
- Multifractal markers provide information about sleep stages.

REFERENCES:

1 - Chhabra, A., Jensen, R. V., 1989. Direct determination of the f(α) singularity spectrum. Phys. Rev. Lett. 62, 1327–1330. doi:10.1103/PhysRevLett.62.1327

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