

Fractal regulation of electroencephalography fluctuations during wake and sleep

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1 Introduction

A hallmark of living organisms is their extraordinary complexity [1]. In particular, the complex behavior of the biological signals that these systems produce is often due to their nonlinearity and nonstationarity (*i.e.*, the statistical properties change with time). Under healthy conditions, the fluctuations of these signals, although resembling “noise”, appear to show long-range power-law (fractal) correlations over a wide range of time scales [1, 2]. Quantification of these fractal correlations in healthy conditions and detecting subtle alterations with disease and/or aging has already been performed on many biological signals, including neural activity, but mostly during the awake state [1–3]. However, the neural activity exhibits two very distinct states during wake and sleep both at a macroscopic and microscopic level. At a macroscopic level, wake is often associated with low amplitude and high frequency signals while (non-REM) sleep is associated with high amplitude and low frequency signals. At a cellular level, wake is associated with tonic firing while sleep is associated with bursting [4]. These distinct states might therefore show different fractal correlation properties [1, 2]. In this work, we aim at understanding whether a change in arousal state (wake vs. sleep) implies a change in fractal regulation of electroencephalography (EEG) signals.

2 Detrended fluctuation analysis

In 1994, Peng *et al.* proposed a fluctuation analysis of a one-dimensional random walk process modeling the DNA sequence [5]. This analysis, called *detrended fluctuation analysis* (DFA), has since been applied to the various biological signals, and has been used to detect and summarize using a single exponent the long-range power-law correlations embedded in the observed fluctuations.

The goal of this method is therefore to obtain a relationship between $F(n)$, the average fluctuation as a function of box size n , and the box size n that is the number of data points inside an observation window of width n [2, 3]. A linear relationship on a $\log_{10}(n) - \log_{10}(F(n))$ graph (*i.e.*, getting $F(n) \sim n^\alpha$ with α , the scaling exponent corresponding to the linear slope on the graph) demonstrates the presence of scaling. The observed fluctuations of the time series can then be classified according to the value of the exponent α .

3 Case study

In this study, the EEG signals consist of 15 minutes of wake followed by 15 minutes of non-REM (NREM) slow wave sleep (stages N2 and/or N3) in 28 healthy men. Only the signal recorded at the frontal electrode F_z is analyzed since it best detects the K -complexes and is thus suitable to discriminate between the awake or sleep state [6]. We apply the DFA method to the δ (0.4 Hz–4 Hz), α (8 Hz–12 Hz), and σ (12 Hz–15 Hz) components of the temporal EEG signals.

4 Perspectives

Future work will focus on modeling at the cellular level a population of neurons that can exhibit a fractal behavior at a macroscopic level. Necessary and/or sufficient conditions on the cellular properties that would give such a fractal behavior will be searched.

References

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