MULTIFRACTAL ANALYSIS OF NARROW BAND
FILTERED EEG SIGNALS *

P. DOJNOW
Institute of Inorganic and General Chemistry
Bulgarian Academy of Sciences.
Akad. G. Bonchev Str., Bl. 11, BG-1113 Sofia, Bulgaria.
e-mail: dojnow@svr.igic.bas.bg

ABSTRACT. The electroencephalograms (EEG) are multifractal time series with power-law decaying frequency spectrum from 0Hz to over 100Hz. In clinical practise the narrow-band filtered brain waves δ, θ, α, β, γ are used but their multifractal analysis is meaningless because as is shown here the correlation type of multifractality is connected with a broad frequency spectrum and the phase changes which are diminished in the case of separation of the EEG signal into the brain waves.

Резюме. Електроенцефалограмите EEG) са сигнали, даващи информация за мозъчните вълни. Тези сигнали представляват мултифрактални времеви редове, чийто честотен съкът намалява по степенен закон с увеличаване на честотата от 0 до над 100 херца. В клиничната практика се използва анализ на δ, θ, α, β, γ мозъчни вълни. Тук показваме, че мултифракталният анализ на всяка една от тези вълни е безсмислен, тъй като честотният спектър, свързан с отделните мозъчни вълни е твърде тесен, а фазовите разлики, характерни за корелационната мултифракталност се премахват при прехода от сумарния сигнал към сигнали, свързани с отделните мозъчни вълни.

KEY WORDS: MDFA; EEG; correlation multifractality; power spectrum; 1/fβ noise; singular spectrum

1. Introduction

The electroencephalography and the electroencephalograms (EEG) are still a basic method and a source for diagnostics of the brain activity. In the clinical analysis the frequency spectrum of the EEG from 0Hz over 100Hz EEG is separated in narrow-band filtered brain waves in the following frequency ranges: δ = 1...3Hz, θ = 4...7Hz, α = 8...12Hz, β = 18...30Hz, γ =

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35...40Hz. A typical characteristics of the measured EEG in the frequency domain is the power-law decay of the power spectrum density: $PSD(f) = 1/f^\beta$. As time series, EEG have two kinds of characteristics: (I). EEGs are anharmonic, aperiodic and nonstationary, and (II). They possess also long-range correlations and scaling function with power-law. This hints on fractal properties.

In the last years we observe a fast spreading of the methods of the nonlinear dynamics and chaos theory to different scientific areas [1] - [5]. Especially large amount of research is devoted to the nonlinear time series analysis [6] and its applications to hydrodynamic and biological systems [7], [8] and even in the economics [9], [10]. The application of these modern methods to analysis of biological signals EEG led to revealing of their multifractal nature: in cardio-pulmonary system [11] or the heart rate variability in human and animals [12], [13]. In previous studies [14], [15] it was revealed that EEG are multifractal time series too. Their expressive nonstationarity impose upon analysis with appropriate multifractal methods. The problems we shall investigate below are as follows:

- Do the narrow-band filtered brain waves retain the multifractality as the initial EEG signal?
- Is the multifractal analysis of brain waves meaningful?

2. Methods

The investigated below EEGs are recorded during performance of cognitive task. The investigated time series are recorded for 16 right-hand volunteers. For each person 17 electrodes are positioned on selected points of the head and the EEG signals are recorded at sampling rate 256 Hz and the frequency interval of the signal between 0.3 and 70 Hz (the 50 Hz electric network frequency has been filtered out by a special filter that does not changes the phase of the signal). The blinking and other artifacts are removed by ICA (independent component analysis) algorithm of the EEGLAB package. The task performed by the students is visual tracking of a moving spot on a map of Sofia with constant step (the corresponding quantities are denoted as \( \text{reg} \)). Brownian movement step (the quantities are denoted as \( \text{br} \)), or freely given by the subject (the quantities are denoted as \( \text{im} \)).

Two principal methods for multifractal analysis of nonstationary time series such as EEG are Wavelet Transform Modulus Maxima method (WTMM) [16] - [18] and Multifractal Detrended Fluctuation Analysis (MDFA) [19] - [21]. It is easier for implementation and will be used below. The other methods used in this study are the Hilbert transformation [22], surrogate time series method
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[23] and fractional binomial model for synthesis of multifractal signals. The numeric parameters of the scaling and the multifractality, obtained by MDFA or WTMM are the generalised (local) $h(q)$ Hurst (Hölder) exponent, scaling exponent $\tau(q)$, singular spectrum $f(\alpha)$ and multifractal spectrum width $D_{mf}$. We can perform additional analysis of correlation properties by additional refining the concept of multifractality. The multifractality can be separated into two types:

1. Multifractality determined by different long-range correlations for small and for large fluctuations.
2. Multifractality determined by broad probability density function of distribution for the values of time series.

We compare the obtained EEG signals to the following kinds of artificial signals: (I). Multifractal long-range correlated series with a given multifractality generated by means of the fractional binomial model; (II). Amplitude and phase time series obtained from the EEG signal by means of a Hilbert transformation and (III). Surrogate time series obtained by Schreiber and Schmitz method.

3. Results

The main result of this study is that the separation of the EEG signal into traditional narrow-band brain waves signals influences severely the multifractal properties of the signal. A characteristic behaviour of the spectrum of EEG signal and signals connected to brain waves is shown in Fig. 1. There is a local maximum of the power spectrum of the EEG at $\alpha$-brain-wave $= 8 \ldots 12 \text{Hz}$. With two exceptions (reminiscence of the influence of the electricity network frequency) the EEG power spectrum decays at high frequencies. We observe that the power spectra of the filtered signals are different from the power spectrum of the entire signal. This hints on the fact that the filtering changes the correlation properties and probably affects severely the multifractality of the signal. In the Table 1 are presented the obtained by the MDFA method mean results for the width of the singular spectrum $f(\alpha)$ of the originating signal, the amplitude and the phase of the analytical signal (obtained by Hilbert transformation from the originating signal) and of the randomly-permutated initial signal and of the amplitude and the phase of the analytical signal. The phase spectrum width is over two times then the amplitude one. This result implies multifractality originated mainly from phase changes rather then amplitude changes. The frequency spectrum of the phase-modulated signal is significantly broader then amplitude-modulated signal. Narrow-band filtration diminishes phase changes which causes shrinkage of the multifractal
Figure 1: Power spectrum density of EEG and brain waves

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Table 1: Mean values of the width of the singular spectrum $f(\alpha)$ of the originating signal, the amplitude and the phase of the analytical signal and of the randomly-permutated initial signal and of the amplitude and the phase of the analytical signal.

spectrum. The surrogate data method destroys possible correlations in the time series. Correlation coefficient $h(2)$ for EEG is estimated to be $h(2) 1$ while it is $h(2) 0.5$ for the randomly permuted EEG. This define correlation type of multifractality. It is characterised by a broad power spectrum which
condition in case of narrow-band filtration is disturbed.

4. Conclusion

In this study combination of MDFA, Hilbert transformation, Fourier filtering and surrogate data methods are used to reveal the narrow-band filtering on the multifractality of EEG and test signals. It was estimated that correlation type of multifractality is presented. The spectrum with is mainly based on phase component. This result is in favor about multifractality originated mainly from phase changes. Narrow-band filtering vanishes phase modulation which means the destruction of multifractality.

REFERENCES


