Complexity of EEG During Sleep Onset Process

Kristína Šušmáková

Institute of Measurement Science, Slovak Academy of Sciences, Dúbravská cesta 9, 842 19 Bratislava, Slovak Republic

umersusm@savba.sk

Abstract

This study was concentrated on changes of complexity of EEG signals during the transition from relaxed state to sleep onset. The ability of correlation dimension D_2 and fractal exponent γ to discriminate these slightly distinct states was examined. Both measures indicated that brain was less complex system during sleep onset than during the relaxation; however, γ appeared to be more sensitive and better in characterizing various states of brain.

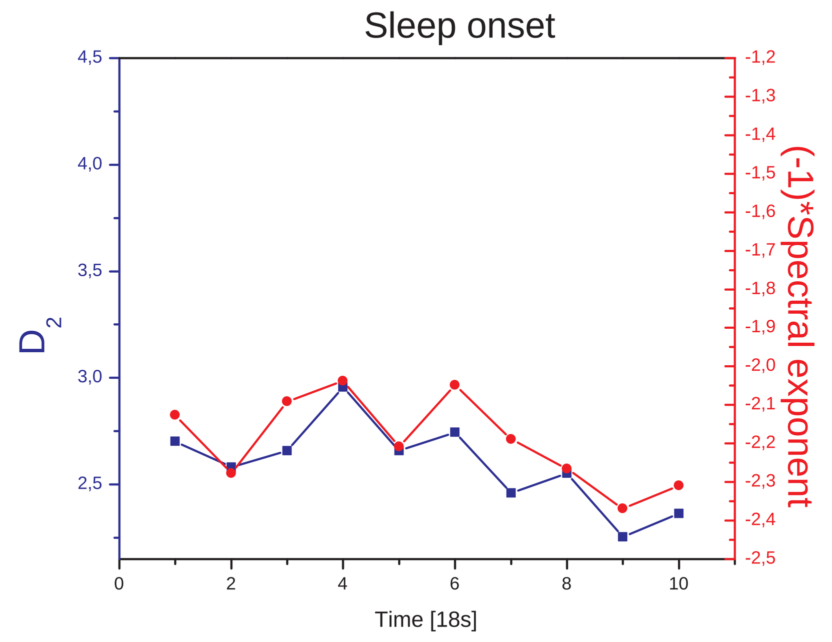

Figure 1: *Evolution of D_2 and $(-1)\gamma$ during sleep onset process; average from 12 signals and over all derivations of EEG*

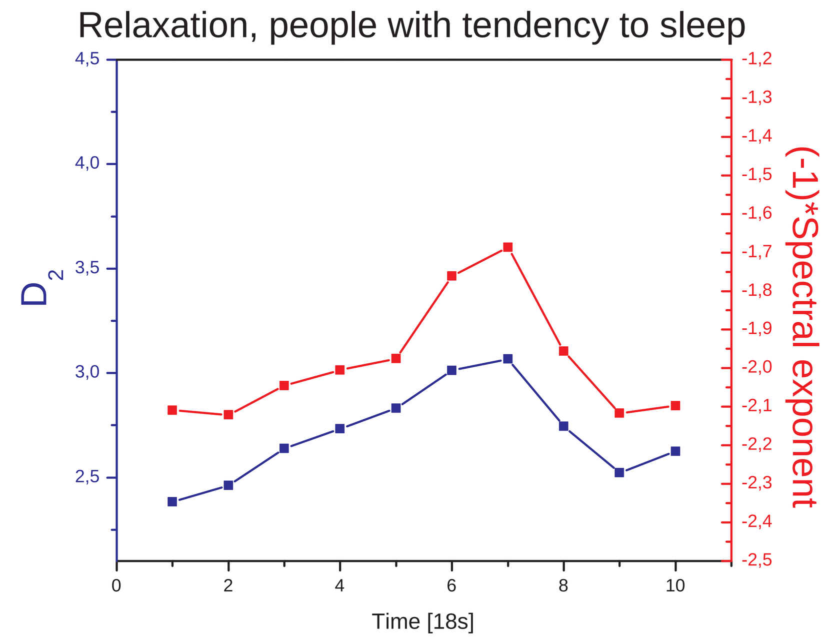

Figure 2: *Evolution of D_2 and $(-1)\gamma$ during relaxation, people with tendency to oversleep; average from 12 signals and over all derivations of EEG*

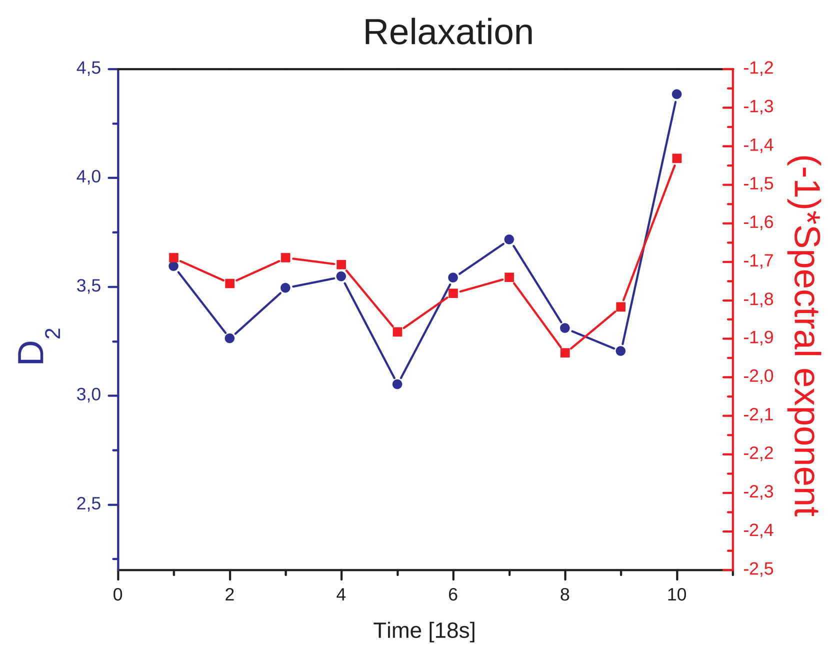

Figure 3: *Evolution of D_2 and $(-1)\gamma$ during relaxation; average from 12 signals and over all derivations of EEG*

1. Introduction

In sleep research and also in clinical practice Rechtschaffen and Kales system [1] for scoring sleep states and vigilance is widely used. In the case of sleep - wakefulness transition three states of vigilance are important: wakefulness, Stages 1 and 2 of non rapid eyes movement sleep. Hori et al. [2] subclassified these three classical stages into 9 novel stages that described more precisely the process of sleep onset. After Hori's system sleep onset process begins with reduction of alpha activity below 50 % of the scored epoch and ends with appearance the wave patterns sleep spindles or K-complex in the Stage 2. In this study the ability of two complexity measures correlation dimension and fractal (spectral) exponent to catch the process of sleep onset was examined.

2. Methods

- *Correlation dimension* D_2 was computed after Grassberger - Procaccia algorithm [3]. After embedding signals into the phase space the correlation sum is computed:

$$C_2(\epsilon) = \frac{2}{(N)(N-1)} \sum_{i=0}^{N} \sum_{j>i}^{N} \Theta(\epsilon - \|\mathbf{x}_i - \mathbf{x}_j\|), \quad (1)$$

where $\mathbf{x}_i$, $\mathbf{x}_j$ are vectors in the phase space, N is the number of vectors and $\Theta(\epsilon - \|\mathbf{x}_i - \mathbf{x}_j\|)$ is the Heaviside function, which is equal one if the pair of vectors $\mathbf{x}_i$, $\mathbf{x}_j$ are less than a geometrical distance ϵ and zero otherwise. Then, D_2 is defined as:

$$D_2 = \lim_{\epsilon \to 0} \lim_{N \to \infty} \frac{\ln C_2(\epsilon)}{\ln \epsilon} \quad (2)$$

C_2 is computed for several values of embedding dimension m. For deterministic signals $C_2(\epsilon)$ shows a power-law behavior, so if the local slope of ln C_2 is taken against ln ϵ, then the value of the plateau gives the estimate of D_2.

- *Fractal exponent* γ: power spectra of fractal stochastic signals show power-low behavior with $1/f^{\gamma}$. So, γ is computed as the slope of linear fit of the power spectrum density in the double logarithmic graph. Fractal exponent γ was found to be negatively correlated with D_2, so for less complex signal D_2 shows lower value and γ higher value [4].

3. Data

Data came from a relaxation experiment, in which 8 healthy subjects were trained in relaxation during 25 sessions. Four subjects overslept several times. 3 min. long EEG from 6 channels was recorded, EEG derivations were: C3P3, C4P4, F3C3, F4C4, P3O1, and P4O2 after international 10-20 electrode placement system. EEG was sampled at 500 Hz and filtered from 0,75 Hz. After subjective scoring the records were selected into two groups: records of sleep onset (36 files) and records of relaxation state (339 files).

4. Results and Conclusions

- The whole mean over 8 subjects and all EEG derivations:
  D_2 = 4,41 $\pm$ 0,6 for relaxed data and D_2 = 3,95 $\pm$ 0,46 for sleep onset data
  γ = 2,24 $\pm$ 0,34 for relaxed data and γ = 2,59 $\pm$ 0,21 for sleep onset data
- With regard to topographic characteristics of brain D_2 and γ were averaged over signals with the same EEG derivation. The highest relative difference between relaxation and sleep onset appeared in the occipital area (especially in p4o2); for D_2 it was and 14,27% and for γ -21,48%.
- With the aim to reveal possible intersubject differences D_2 and γ were averaged over all channels for individual subject. Interesting findings were observed; subjects with tendency to oversleep (four subjects) showed lower D_2 during relaxation than subjects that had never overslept. Subjects were divided into two subgroups after this tendency to oversleep, the averaged value of D2 and γ for these two subgroups are in Table 1.

	Relaxation		Sleep onset	
	D_2	γ	D_2	γ
Tendency to oversleep	4,04 $\pm$ 0,46	2,45 $\pm$ 0,21	3,95 $\pm$ 0,46	2,59 $\pm$ 0,21
No tendency to oversleep	4,68 $\pm$ 0,46	2,09 $\pm$ 0,24	-	-

Table 1: *Mean and standard deviation of D_2 and γ for subgroups of subjects with and without the tendency to oversleep.*

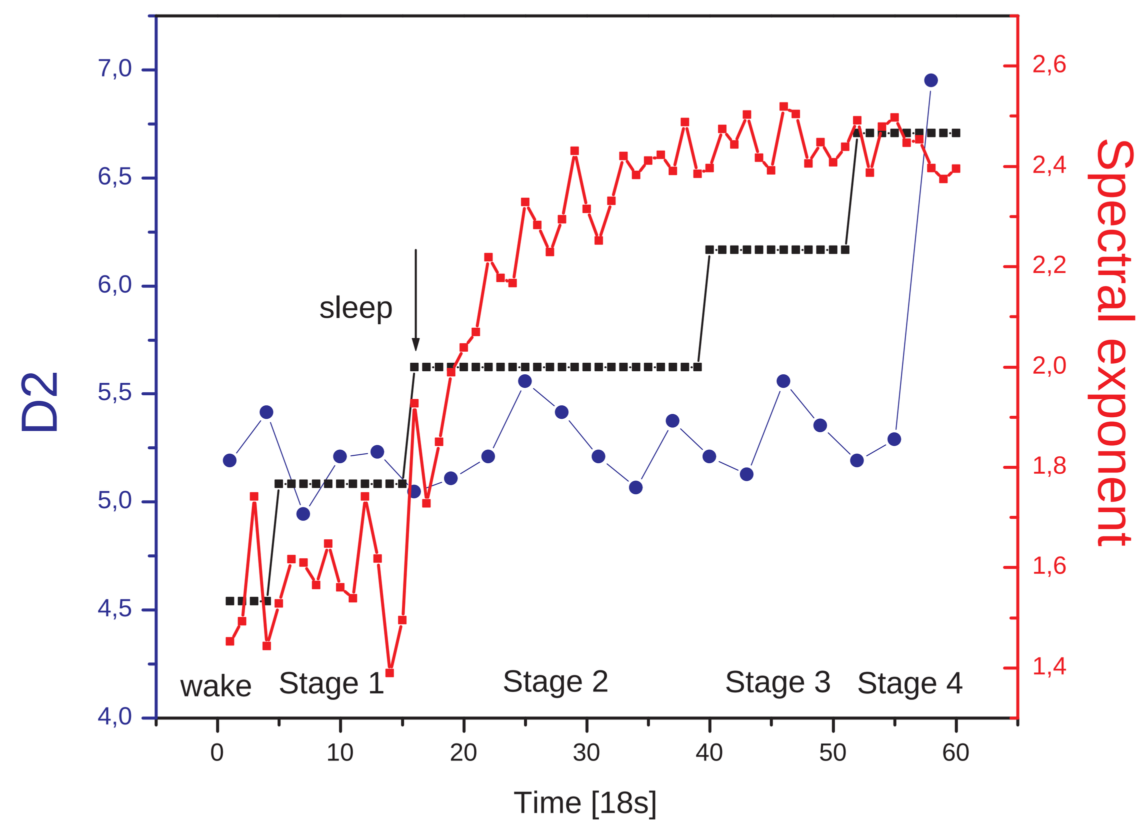

Figure 4: *D_2 and γ computed for first 60 epochs epochs of 30s, scored EEG, EEG Stages are labeled with black squares*

- Furthermore the ability of both measures to catch the process of sleep onset was examined. D_2 and γ were computed for EEG fragmented into 10 equal epochs, so 1 epoch was 18s long and has 8700 points. The average behaviors of D_2 and γ for all three groups of signals - with sleep onset, relaxation of the subjects with and without the tendency to oversleep are on Figures 1-3. During the sleep onset D_2 is evidently decreasing from the 4. epoch in contrast with both relaxations. The unusual differences in D_2 and γ between subgroups with and without tendency to oversleep were confronted with the ability to improve the relaxation during the training process (25 sessions). Several authors found that long-term averaged decrease of D_2 was a sign of improving relaxation. In this study the tendency not to oversleep was highly correlated with higher trend in improving the relaxation.
- Finally, the behaviour of D_2 and γ was tested on data scored for sleep stages provided by Prof. G. Dorffner, received by The Siesta Group Schlafanalyse GmbH. γ was computed from 30s long EEG signals, D_2 was computed from 90s long signals, from less points it was not possible to determine D_2. The results can be seen on Figure 4. It is evident that γ catches the process of sleep onset much better than D_2; the correlation coefficient between γ and values of sleep stages was 86%.

References

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[3] Grassberger, P. and Procaccia I. Measuring the strangeness of strange attractors. Physica 9D, pp. 189, 1983.

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Acknowledgement

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