FRACTAL ANALYSIS OF RAT CEREBELLAR ELECTROCORTICAL ACTIVITY AT SAMPLING FREQUENCIES OF 64-512 Hz

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Abstract - *The aim of this study was to investigate the effects of brain injury by fractal analysis of rat cerebellar electrocortical activity recorded at varying sampling frequencies up to 4096Hz. Applying Higuchi's algorithm, we calculated fractal dimension (FD) values of cerebellar signal before and after brain injury in anesthetized rats. Following the acute injury, we found a reversible increase of FD values of cerebellar signals at sampling frequencies of 64, 128, 256 and 512 Hz. We concluded that changes of FD values before vs. after brain injury were similar irrespective of sampling frequency.*

1. INTRODUCTION

Fractal dimension (FD) analysis provides a fast computational tool to track complexity variations of biosignals. Applying Higuchi's algorithm [1], we have recently calculated FD values [2], [3] of cerebral and cerebellar electrocortical activity recorded at sampling frequency of 256Hz in brain injured rats. The aim of this study was to investigate FD values of cerebellar signals recorded at varying sampling frequencies up to 4096Hz.

2. METHODS

Experimental procedure and data acquisition

The experiments were performed on anesthetized adults male Wistar rats under Nembutal (operative procedure was described in [4]). The electrocortical activity was recorded bilaterally over cerebellar paravermal cortex in different experimental conditions: before and after focal injuring of the cortex above the left parietal cerebral cortex. Each recording sequence before and after injury lasted 30 s while pauses between acquisition sessions were 5-10 min long. The signals of cerebellar electrocorticogram (ECoG) were amplified and analog to digital conversions were obtained at the sampling rate of 2048 and 4096 Hz. Thereafter we reduced the sampling frequencies to 64-512 Hz and formed new signals.

Fractal dimension and data analysis

We used one of the most frequently applied methods - Higuchi's algorithm [1], [5], [6] for estimating FD of biosignals. Briefly, if we consider rat electrocortical signal as a time sequence x(1), x(2)…, x(n), we may construct k new self-similar (fractal) time series x(k,m) as:

$x(k,m)=\{x(m), x(m+k), x(m+2k),\ldots,x(m+int[(N-m)/k]k)\}$,

for m=1, 2,…,k and int[.] as an integer function. We computed the length L(m,k) for each of the k time series or curves x(k,m):

$$L(m,k)=\left\{\frac{\sum_{i=1,\,int[(n-m)/k]}|x(m+ik)-x(m+(i-1)k)|(n-1)}{int[(n-m)/k]k}\right\}\frac{1}{k}$$

L(m,k) was averaged for all m forming the mean value of the curve length L(k), for each k. Thus, we obtained an array of mean values L(k), and then from the plot of log(L(k)) versus log(1/k), we estimated the fractal dimension (FD) as the slope of least squares linear best fit, i.e.

$$FD = \log(L(k))/\log(1/k).$$

Each biosignal was divided into 9 – 77 epochs (or windows) as shown on Table 1. Parameter n=200 (window width) was within the range already used by other authors [5], [6] and corresponding epoch's durations and sampling frequencies are shown on Table 1.

n	Sampling frequency [Hz]	Duration of epoch [s]	Number of epochs
200	512	0.390625	76.8
200	256	0.78125	38.4
200	128	1.5625	19.2
200	64	3.125	9.6

Table 1. Parameters of fractal analysis of ECoG signals.

We used [2] the maximum value of k, k_{max} = 8, and calculated FD values for each epoch, without overlap. FDs of signals, obtained under particular experimental conditions (before and after first and repeated injuries), were calculated using MATLAB routines.

2. RESULTS

Electrocortical activity of the left and right cerebellar paravermal cortex was analyzed before and after acute brain injury in anesthetized rats. The computed FDs of these signals, recorded in B1 rat, 30-60 minutes after first acute injury, are shown on Fig. 1. Means of FDs of signals,

recorded from the same B1 rat obtained at three different times (5-30 min before first injury, 30-60 min after the first injury, 5-30 min before second repeated injury and after 15-40 min after second injury) are shown on Fig 2. Signals denoted (Fig 2.) as b300 and b301 were reduced from 4096 Hz, while signals denoted as b290 and b291 were reduced from 2048 Hz to low frequencies.

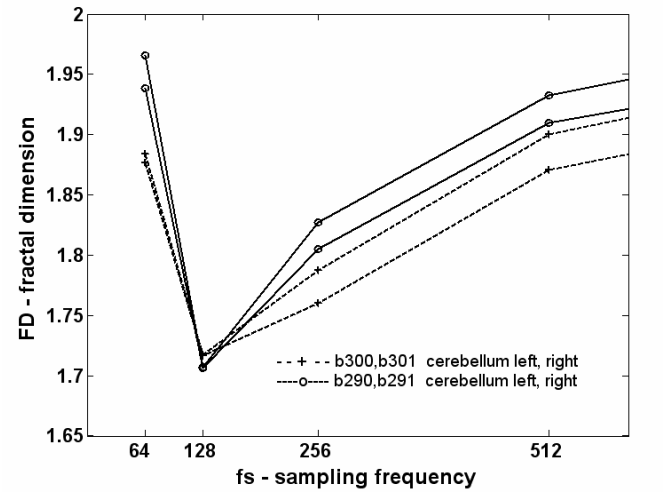

Fig. 1. *Dependence between computed FD and sampling frequencies of cerebellar signals, recorded in one rat (B1) after first acute injury.*

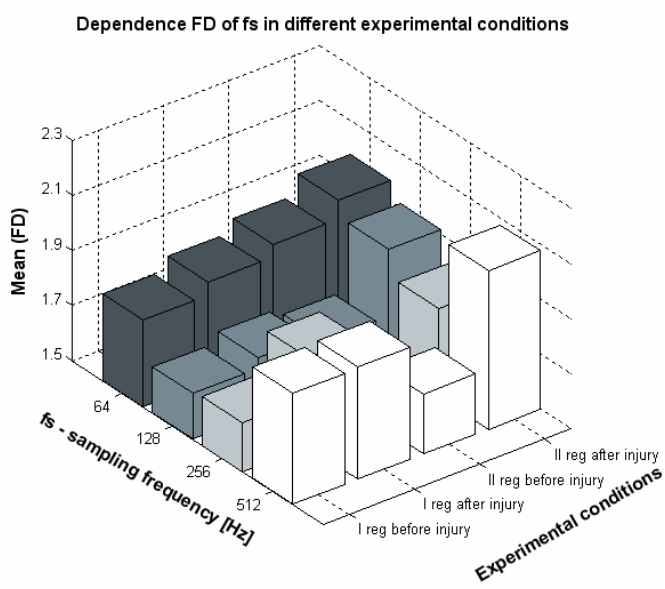

Fig. 2. *Means of FD values of cerebellar signals from a rat (from fig.1) at sampling frequencies of 64, 128, 256 and 512Hz in different experimental conditions.*

Following the acute injury, we found a reversible increase of mean FD of cerebellar electrocortical activity at sampling frequencies of 64, 128, 256 and 512 Hz. In addition, we found that relative changes of FD values (before vs. after injury) are similar at the different sampling frequency. There is almost a linear dependence between sampling frequency within the range of 128-512 Hz and FD of analyzed ECoG signals (in particular experimental condition). We do not have the explanation of relatively high values of FD at sampling frequency of 64 Hz.

4. DISCUSSION AND CONCLUSION

Various tools were used in establishing a measure for the degree of complexity of EEG signal in brain injury. It is known [1], [5], [6], [7], [8] that fractal dimension may be used as an indicator of various states of brain activity. Our recent results [3] suggest that the increase of FDs of cerebral and cerebellar signals may be an indicator of discrete acute brain injury. Obviously, the enthusiasm for estimating fractal dimension depends on how is this measure discriminative for different functional states of the brain although we do not understand the underlying physiological mechanisms.

However, recent experience with the feasibility of chaos theory shows that we must be cautious when trying to apply results of this theory to human and animal physiology. Further studies require richer database concerning particularly various pathophysiological states. We suggest fractal dimension analysis of signals with varying sampling rate of brain activity in order to screen different states (brain injury, epilepsy, stroke). We plan to enlarge our study of FD biosignal analysis in wider range (64-16384 Hz) of sampling frequencies.

REFERENCES

[1] T. Higuchi, *Approach to an irregular time series on the basis of the fractal theory.* Physics D 31, pp.277-283., 1988.

[2] S. Spasić, A. Kalauzi, M. Culić, G. Grbić and Lj. Martać, *Estimation of parameter k_{max} in fractal analysis of rat brain activity.* Ann. N.Y. Acad. Sci., Vol. 1048, (In press), 2005.

[3] S. Spasić, A. Kalauzi, M. Culić, G. Grbić and Lj. Martać, *Fractal analysis of rat brain activity after injury*. Medical & Biological Engineering & Computing **43**, Issue 4, (In press). 2005.

[4] M. Ćulić, Lj. Martać, G. Grbić, S. Spasić, B. Janković and A. Kalauzi, *Spectral changes of cerebellar activity after acute brain injury in anesthetized rats.* Acta Neurobiol. Exp. 65, Pp.11-14. 2005.

[5] R. Esteller, G. Vachtsevanos, J. Echauz, and B. Litt, *A comparison of fractal dimension algorithms using synthetic and experimental data.* Proc. IEEE International Symposium on Circuits and System, Adaptive Digital Signal Processing, Orlando, Fl, III**,** pp. 199-202. 1999.

[6] R. Esteller, *Detection and Prediction of seizures in epileptic EEG records, Ph Thesis,* Georgia Institute of Technology, Atlanta, GA., 2000.

[7] W. Klonowsky, E. Olejaczyk, R. Stepien and W. Scelenberger, *New methods of nonlinear and symbolic dynamics in sleep EEG-signal analysis*, in: Modelling and Control in Biomedical Systems, D. D. Feng, E. R. Carson (Eds.), Proc. 5th IFAC Symposium, Melbourne, Australia, Elsevier, pp. 241-244. 2003.

[8] C.C. King, *Fractal and chaotic dynamics in nervous systems.* Prog Neurobiol, **36**, pp. 279-308., 1991.