FRACTAL AND MULTIFRACTAL PROPERTIES OF HEARTBEAT INTERVAL SERIES IN EXTREMAL STATES OF THE HUMAN ORGANISM

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Abstract. *The fractal and multifractal properties of human heart rate fluctuations in 2 extremal (but not yet pathological) states are investigated in this study: 1) sleep deprivation and 2) alcohol intoxication. Namely these states are dangerous in traffic - accidents, car crushes are an epiphenomenon of tired, angry, sleep deprived or (in the worst case) drunken car drivers. Results of our first pilot experiments are quite promising; it's possible to distinguish between the vigilant and sleep deprived (or alcohol intoxicated) person on the basis of fractal analysis of the heartbeat interval series signal.*

Keywords: *fractal analysis, heart rate variability, sleep deprivation, alcohol intoxication*

1. Introduction

Though some physiological signals may contain an important information, classical methods (such a statistical or spectral analysis and also methods arising from low-dimensional chaos) do not imply unambiguous results - till this time no universal and easy to calculate descriptor for these purposes exists. Especially in the last 20 years, properties of interbeat interval sequences (measured as the distance between two successive R-waves on an ECG record, RR) have attracted the attention of researchers, and it has been shown that heart rate fluctuations carry much more information about neuro-autonomic control than had previously been supposed. There is a clear evidence that most physiological signals under healthy conditions may have a fractal temporal structure - time series generated by certain physiological control systems may be members of a special class of complex processes, called multifractal (Ivanov 1999, Thurner 1999). One of the most interesting questions is how the fractal properties of heart rate fluctuations are altered in the mentioned physiological states - at least a partial answer is the main goal of this work.

2. Experiments

Alcohol intoxication. 9 men, 25-30 years old min. 500 ml of 40 percent ethanol distillate applied p.o. The blood alcohol concentration is a very relative indicator, so I have chosen an alternative approach, developed by psychologists: the goal state we can explain as a "confusion, staggering, unable to stand upright, slurred speech, blurred vision, impaired judgement of distance". Considering the human circadian rhythms all experiments were carried out in the same time in the evening and kept no more than 3 hours; then 80 minutes ECG record was measured (sampling rate 250 Hz, A/D resolution 10 bits, modified bipolar lead "I").

Sleep deprivation. 2 different sources of data were used: **(A)** 6 records from the project "Sleeping Driver, Vigilant car" (CBME CTU Prague, 1998-2000). The goal of this project was design and development of the automatic classifier of the fatigue states of a car driver.

All experiments were performed on-the-road, we measured selected technical and physiological signals, including ECG (polygraph Brainscope MI). Duration of each record is approximately 60 minutes, sleep deprivation was 24-48 hours. **(B)** 8 records obtained from the laboratory experiments: 80 minutes long ECG records were measured in the evening after 2-3 days of the sleep deprivation. Measuring equipment was the same as in case of the alcohol intoxication. I have also obtained the control record in the provable vigilant state from all tested persons.

3. Methods

The experimental data were preprocessed (filtration, segmentation) and heart rate variability (HRV) signal was extracted. The basic idea of the fractal analysis of time-series is self similarity of rescaled segments of the signal. Visual verification of the presence of self-similar structures in the integrated HRV was the first step of the analysis. The integration (or accumulation) is the step that can be interpreted as the mapping of the original (bounded) time series to an integrated signal with a fractal behavior. In fractal signals the distribution is scale-dependent. This dependence can be quantified using so called self-similarity indexes; in monofractal signals is exponential and it's possible to calculate the self-similarity exponent. On the contrary for the multifractal signals one and only exponent of self-similarity is not sufficient. I have used 3 different methods for these purposes in this work:

(A) the DFA-estimator (Detrended Fluctuation Analysis , Havlin & Goldberger 1994), (B) the WAV-estimator (based on dispersion of the wavelet transform coefficients) and (C) the WTMM-estimator (Wavelet Transform Modulus Maxima), which represents so called multifractal formalism. Finally, some tests with the surrogate data with randomized order of samples were performed. This type of surrogate data preserves the distribution but disturbs the long-range correlations, 1/f-noise etc., simply fractal properties of the original signal.

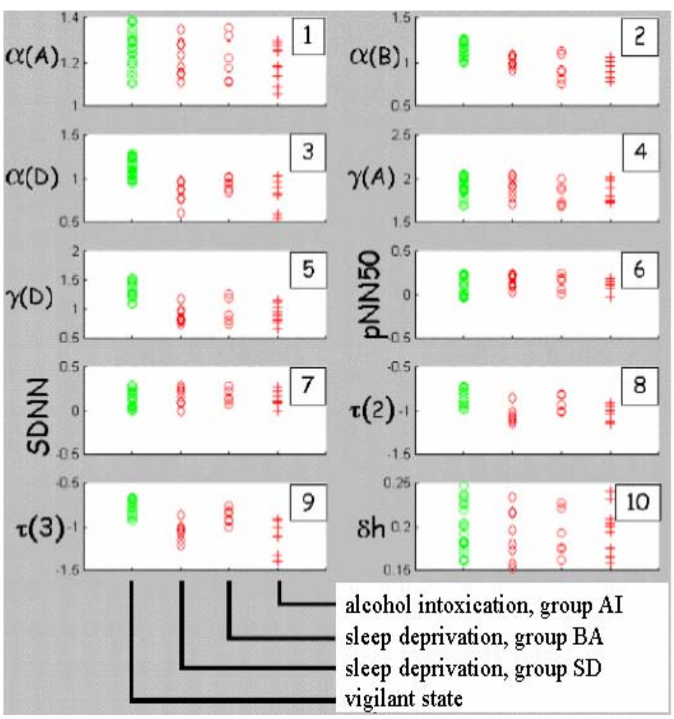

Fig 1. Visualisation of results

Legend. In each white box you can see 4 groups of points (see text in yellow box). On the vertical axis in each white box are values of tested descriptors. In some cases it's possible to distinguish between the vigilant state and other states (boxes 2, 3, 5, 8, 9).

4. Results

(1) Distinguishing between the vigilant and sleep deprived (alternatively vigilant and alcohol intoxicated) persons using the fractal and multifractal analysis of heart interbeat time series is possible (see fig .1)

(2) On the other hand I have found no significant differences between the states of sleep deprivation and alcohol intoxication together.

(3) The length of fluctuations on which the discrimination area occurs coincides with the pink noise - characteristic scales from hundreds to thousands heart beats. One important practical limitation emerges from this fact: at least 40-60 minutes of the ECG record are necessary for the sufficient discrimination.

(4) The best results were given by the multifractal descriptor derived from the 3rd order distribution function. Well known and favorite "Gaussian formalism" with the 2nd order statistical moments gives only the suboptimal results in case of the heart rate fluctuations signal analysis.

Proposed interpretation comes from the analysis of 23 datasets, so no far going generalizations are convenient. In the near future it will be necessary to carry out more experiments in order to verify this methodology and, especially, its accuracy. For the first experimental group the results are quite promising.

We believe this methodology can be utilized in practical situations, f.e. in personal monitors of the alertness or vigilance in the traffic and industry. The main advantage of introduced methodology may be in an automatic, absolutely noninvasive procedure and relatively easy accessible source signal (ECG).

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