Estimation of heart rate irregularity during day and night

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Introduction. When the heart rate is recorded over extended periods of time, it displays significant fluctuations. This means that it contain nonlinear contributions. The several methods of nonlinear dynamics, such as Lyapunov exponent, correlation dimension, Kolmogorov entropy, Poincare plot, etc. have generated a new view into heart rate variability under various physiological and pathological conditions [1]. Not in the least instance the interplay between the sympathetic and parasympathetic nervous system caused the complexity of RR intervals. The structure of heart rate dynamics in passive phase (sleep) and active phase (wakeful) is different. Surely the mechanism of fluctuations depends from daily regimen.

The aim of research. This study is the quantitative assessment of the heart rate variability by means of nonlinear dynamics methods at various day times.

Methods. This paper is the continuation of our work [2], where the methods of calculation of such nonlinear characteristics as entropy H (in terms as measure of complexity) and parameters from Poincare plots are described. All these parameters have been compared among themselves. In present article the detrended fluctuation analysis (DFA) method, which was proposed by Peng et al. in 1995 [3], is added. It quantifies the presence or absence of fractal correlation properties in non-stationary time series. The DFA method in short is described below.

The first step of DFA is the calculation of the integrated time series of RR intervals (of total length N) according by equation:

$$y(k) = \sum_{i=1}^{k} [(RR)_i - \overline{(RR)}] \quad , \tag{1}$$

where k=1, 2…N, $(RR)_i$ is the i^{th} RR interval, $\overline{(RR)}$ is the average of RR interval.

Then these integrated time series $y(1)$, $y(2)$,…$y(N)$ are divided into ranges of equal length n. In each range of length n, a least-squared line is fitted to the data, representing the trend in that range. The y coordinate of the straight line segments is denoted by $y_n(k)$. Then, the integrated time series are detrended by subtracting the local trend $y_n(k)$ in each range. The root mean-square fluctuation of this integrated and detrended series is calculated by:

$$F(n) = \sqrt{\frac{1}{N}\sum_{k=1}^{N}[y(k) - y_n(k)]^2} \quad , \tag{2}$$

This computation is repeated over all time ranges to obtain the relationship between $F(n)$ and the range size n. Then the graph of log F vs log n is created. The fluctuations can be characterized by the slope of the line relating $F(n)$ to log n – a scaling exponent α.

We computed separately scaling exponent over the range of $4 \leq n \leq 16$ heartbeats and over the range of $16 \leq n \leq 64$ heartbeats in order to describe short – range scaling exponent α_1 and long – range scaling exponent α_2 for RR intervals. Thus calculated scaling exponent α (self-similarity parameter) represents the fractal correlation properties in *RR* intervals.

Results. We recorded 24h *RR* intervals of 60 subjects and divided these records into two segments: day (active phase, 9.00 – 17.00) and night (passive phase, 22.00 – 6.00). For each data set we calculated means of *RR* intervals, parameters from Poincare plots (*SD1*, *SD2*, *SD1*/*SD2*), entropy *H*. Applying DFA method were calculated scaling exponents α_1 and α_2. The means of these all parameters are presented in Table. 1. A sample of double logarithmic graph log $F(n)$ vs log n is shown in Fig. 1.

Table 1. Descriptive statistics

	Day (active phase)		Night (passive phase)	
Parameter	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**
RR (ms)	884.27	144.004	986.18	133.452
SD1	23.22	17.601	27.34	23.263
SD2	161.33	31.955	194.35	44.794
SD1/SD2	0.133	0.070	0.133	0.073
H	0.015	0.006	0.011	0.005
α_1	1.13	0.158	1.06	0.109
α_2	0.57	0.063	0.69	0.097

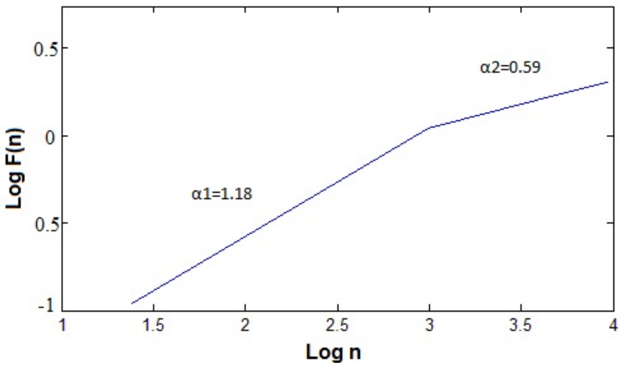

Fig. 1. Scaling exponent (short – range scaling exponent and long-range scaling exponent) for an example RR intervals. The slope of line defines the scaling exponent.

The comparative pair analysis of nonlinear characteristics of heart rate during day and night has shown their essential distinction. The standard Poincare descriptor *SD1* reflecting heart rate short-term variability and standard Poincare descriptor *SD2* responsible for maximal amplitude of fluctuations are smaller in passive phase. At the same time the descriptors *SD1*/*SD2* showing the relationship between these components practically do not differ. In day as well the means of *RR*-intervals and long-range scaling exponent α_2 are smaller. In active phase index of complexity – entropy *H* and short-range scaling exponent α_1 prevail. The statistical analysis of these data is presented in Table 2. Good distinct separation between day and night reflect scatter plot of scaling exponent α_1 vs α_2 (Fig. 2).

Fig. 2. Scatter plot of scaling exponents α_1 vs α_2 for 60 subjects in active phase (wakeful) and passive phase (sleep)

Table 2. Paired Samples Test. Paired differences

Active - passive pairs	Mean	Std. Deviation	Std. Error Mean	p<0,05
RR (ms)	101,914	69,950	9,030	*
SD1	4,119	11,502	1,485	*
SD2	-33,025	34,144	4,408	*
SD1/SD2	-0.001	0,035	0,004	
H	0,004	0,005	0,001	*
$\boldsymbol{\alpha_1}$	0,065	0,208	0,027	*
$\boldsymbol{\alpha_2}$	-0.118	0,118	0,015	*

Discussion and conclusion. The structure of heart rate in active phase is characterized by higher degree of complexity rather than in passive (values of parameter H shows it). A difference in nonperiodic processes during day and night conducts to a difference in so-called fractal components of the structure. The research, performed with DFA, evidenced the existence of two scaling regions. At long distances the RR intervals resemble a white noise (scaling exponent $\alpha_2 \approx 0.5$). At short distances it is observed 1/*f* noise (scaling component $\alpha_1 \approx 1$), that indicates fractal-like signal. Thus the received distinctions of parameters describing RR intervals dynamics during day and night confirm that correlation properties of heart system depend on mode of heart functioning status.

References

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The goal of study was the comparison of heart rate parameters such as RR-interval mean, Poincare plot descriptors, entropy and scaling exponent. RR-intervals records of 60 subjects in active phase (wakeful) and passive phase (sleep) was investigated. The results evidenced that there is a difference in data at day time and data at night time.