The interface between the brain microwave radiation and autonomic nervous system

V.S. Kublanov, V.I. Borisov, A.Y. Dolganov

Abstract— **The features of the application of multifractal analysis to assess the interrelation of the short-term signals of microwave radiation of the human brain and heart rate variability (HRV) are described. Data are presented for periods (20, 40) s of microwave radiation signals and periods (6.5, 25) s of HRV showing low level of systematic divergence. Similar properties for periods (50, 70) s of microwave radiation signals and periods (25, 300) s of HRV are found. The results indicate the interface between microwave radiation fluctuations of the human brain and HRV signals, which represent autonomic nervous system activity.**

I. Introduction

Human brain is a part of central nervous system (CNS). It is the most complex biological structure. Neuron networks, glia, arachnoid and pia maters, systems of cerebrospinal fluid and blood circulation compose the interrelated dynamic systems which organize brain functioning. Sensory information processing, planning, decision making, coordination, movement management, positive and negative emotions, attention, memory and thinking, these are processes that are provided by brain activity.

Researches of the brain behavior and cognitive activity have inexhaustible large number of topics for investigation [1]. Complexity of the task enforces to search adequate models that could represent specific physiological artefacts. But at what level and in what precise sense might these models be used? Mostly, the general principles of these models are determined by instrumental methods applied to brain function study. The most common of instrumental methods are electroencephalography, magnetoencephalography, positron emission tomography, functional magnetic resonance imaging and single-photon emission computed tomography.

Study of microwave radiation of human brain tissues is a relatively new method, although, the first works on this approach appeared in the 70s of the last century. In earlier works search techniques of organic structures including cancerous cells were investigated [2-5].

What is a role of the autonomic nervous system (ANS) in the mentioned processes? Mechanisms of interaction of the ANS and microwave radiation of brain have not been sufficiently described in prior studies, however this knowledge might improve efficiency of the brain disorders treatment.

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The aim of this article is to detect physiological such artefacts in microwave radiation of brain that reflect variations of the ANS.

Biomedical signals are formed by complex dynamic regulation systems. One can suppose statistical self-similarity of their time series (TS). Characteristic properties of such TS's correspond to requirements of multifractal theory [6-7].

II. Methodology of multifractal analysis

Nowadays, the multifractal detrended fluctuation analysis method (MFDFA) is one of the most promising methods in analysis of non-stationary TS [8].

Let us describe features of application of MFDFA for short-term TS of biomedical signals. The short-term signals are recorded during functional studies and are the most common in clinical practice.

First, TS are obtained by uniform linear interpolation of data points of the original biomedical signals. Then, TS are detrended using the sliding window method. After that the values of interpolated TS $y[i]$, $i = 1, 2, ..., N$ are divided into integer number $N_s = [N/s]$ of nonoverlapping segments of equal length s.

According to methodology of MFDFA method [9], the least-square fit of the series is used to calculate polynomial $y_{\mathrm{v}}[i]$:

$$y_{\mathrm{v}}(i) = \sum_{\mathrm{k}=0}^{m} C_{\mathrm{k}}\, i^{\mathrm{m-k}}, \qquad (1)$$

where m - degree of the polynomial (usually $m = 2$). In general, degree of polynomial is chosen to ensure the interpolation error does not exceed a predetermined limit. Next, the variance is counted:

$$F^2(v,s) = \frac{1}{s}\sum_{\mathrm{i}=1}^{s} |y\{(v-1)s+i\} - y_{\mathrm{v}}(i)|^2 \qquad (2)$$

The fluctuation function $F_{\mathrm{q}}[s]$ is averaged over all segments obtained for each of the q-th order [8]:

$$F_{\mathrm{q}}(s) = \left\{\frac{1}{N_s}\sum_{\mathrm{v}=1}^{\mathrm{N}_s} |F^2(v,s)|^{\frac{q}{2}}\right\}^{\frac{1}{\mathrm{q}}}. \qquad (3)$$

The scaling behavior of the $F_{\mathrm{q}}[s]$ is determined by analyzing equation (4) for each value of $q = [-5, ..., 5]$, see [9]:

$$log_2\, F_{\mathrm{q}}(s) = h(q) \cdot log_2 s + Const. \qquad (4)$$

In the general case, the multifractal set is characterized by a multifractal scaling exponent:

$$\tau(q) = q \cdot h(q) - 1. \qquad (5)$$

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The width of the multifractal spectrum is determined by a function of the probability distribution of the spectrum *D*. *D* is obtained by the Legendre transformation applied to scaling exponent $\tau[q]$:

$$D(\alpha) = q \cdot \alpha - \tau(q), \qquad (6)$$

where $\alpha = \frac{d\tau}{dq}$ is the Hölder exponent [10]. The spectrum borders, corresponding to extreme and smooth events, are, respectively, equal to:

$$\frac{d\tau}{dq}\Big|_{q=-5} = \alpha_{\min}; \qquad \frac{d\tau}{dq}\Big|_{q=5} = \alpha_{\max}. \qquad (7)$$

Thus, width of the multifractal spectrum (*W*) is equals to:

$$W = \alpha_{\max} - \alpha_{\min} \qquad (8)$$

Another value estimated by *MFDFA* is the generalized Hurst exponent (*H*), so-called self-similarity index [8]:

$$H = \alpha|_{q=0} \, . \qquad (9)$$

Fig. 1 represents typical multifractal spectrum with common multifractal values described above.

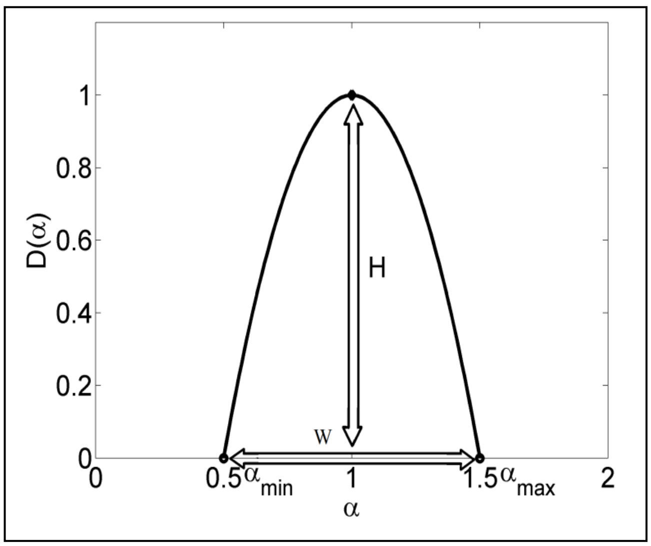

Figure 1. Typical values estimated by MFDFA method

W and H are quantitative measures of self-similarity of the TS. They can characterize functional changes in regulation of the CNS and the ANS [11, 12].

III. Comparison Ranges

It is known that microwave radiation processes in brain tissues are accompanied by fluctuations of thermodynamic temperature $T_{td}[t]$ and variations of the liquid circulation, which are defined absorption coefficient $\chi[t]$:

$$T_{br}(t) = \frac{k}{2\pi\lambda^2} \cdot \chi(t) \cdot T_{td}(t), \qquad (10)$$

where T_{br} is radio brightness temperature, k is the Boltzmann constant, λ is the wavelength of radiation [13].

Results of theoretical and experimental researches of the brain own microwave radiation in a band of frequencies from 650 to 850 MHz show that its fluctuations of the microwave radiation are objectively reflect the physiological changes in brain tissues. The frequency spectrum of these fluctuations ranges from 0.02 to 0.013 Hz. This spectrum mainly reflects changes of the dielectric permeability in tissues in depth more than 10 mm and is a consequence of the humoral processes. In the band of frequencies below 0.013 Hz, intensity of fluctuations of the brain microwave radiation is defined by thermodynamic changes in its tissues that are stimulated by metabolic processes [14].

Based on the mentioned frequencies, the following time scale boundaries are chosen for investigation of multifractal properties of the microwave radiation: $\delta[\varepsilon]$ – (20, 40) s and T_{td} – (50, 70) s.

Three main spectral components are distinguished from HRV short-term signals [15]: the high frequencies (HF) that correspond to the ranges of tidal waves; the low frequencies (LF), so-called slow waves of the first order, and the very low frequencies (VLF), i.e., slow waves of second order. According to domestic and foreign standards the following frequency bands are considered: HF – (0.4, 0.15) Hz; LF – (0.15, 0.04) Hz; VLF – (0.04, 0.003) Hz. Previously it was shown that multifractal analysis of HF component is not informative [16].

It is well-known that the LF band characterizes the activity of the sympathetic nervous system and the vascular tone regulation. This regulation is determined by the sympathetic division of the ANS and sympathetic centers. The VLF band reflects the activity of central ergotropic and humoral-metabolic mechanisms of heart rate regulation [15].

Accordantly, time scales boundaries are chosen for the multifractal analysis: for LF – (6.5, 25) s, for VLF – (25, 300) s. The scale of the entire spectrum of the signal is defined as: Total – (2.5, 300) s [12, 16].

IV. Results

As test material, we used biomedical data of radiophysical complex MRTRS-40 [17] in Research Medical and Biological Engineering Centre of High Technologies of Ural Federal University (Yekaterinburg, RF). The MRTRS-40 is used for real-time functional study of the brain. This complex includes one multichannel microwave radiothermograph, which measures microwave radiation of two parts of human brain in a band of frequencies from 650 to 850 MHz. For registration of the HRV signal the separate channel of electroencephalograph-analyzer "Encephalan-131-03" was used.

The study group consisted of 31 psychologically healthy patients-volunteers with age of 18 – 20 years. Research was conducted in two functional states: before load (functional rest) and during the passive orthostatic load (functional load). Both states were recorded for approximately 5 minutes (300 seconds).

The Bland-Altman criterion was used for comparison of multifractal estimates of simultaneously recorded signals of the microwave radiation and HRV [18]. For each pair of the mentioned estimates differences (W_{HRV}–W_{MR}) and (H_{HRV}–H_{MR}) were counted. Mean value of difference characterizes systematic divergence. Standard deviation of difference characterizes the results' scatter degree. Further, difference is

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plotted against average of estimates to evaluate the dependence of divergence on numerical value of estimate.

Tables 1 and 2 represent the mean and the standard deviation of difference of values *W* and *H*, calculated for δ[ε] and T_{td} bands of microwave radiation signals and for LF, VLF, Total bands of HRV signals.

TABLE 1. MEAN AND STANDARD DEVIATION OF DIFFEERENCE OF W

<*ΔW*> rest					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	-0.381	-0.358	-0.341	**-0.009**
LF	-0.381	*	**0.023**	**0.04**	0.371
Total	-0.358	**0.023**	*	**0.018**	0.349
δ[ε]	-0.341	**0.04**	**0.018**	*	0.331
***T*td**	**-0.009**	0.371	0.349	0.331	*
σ(*ΔW*) rest					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	0.433	0.199	0.327	0.223
LF	0.433	*	0.273	0.165	0.029
Total	0.199	0.273	*	0.3949	0.283
δ[ε]	0.327	0.165	0.394	*	0.349
***T*td**	0.223	0.029	0.283	0.3497	*
<*ΔW*> orthostatic load					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	-0.341	-0.288	-0.309	**0.015**
LF	-0.341	*	**0.053**	**0.032**	0.356
Total	-0.288	**0.053**	*	**-0.021**	0.303
δ[ε]	-0.309	**0.032**	**-0.021**	*	0.323
***T*td**	**0.015**	0.356	0.303	0.323	*
σ(*ΔW*) orthostatic load					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	0.501	0.290	0.361	0.366
LF	0.501	*	0.261	0.088	0.071
Total	0.290	0.261	*	0.260	0.346
δ[ε]	0.361	0.088	0.260	*	0.385
***T*td**	0.366	0.071	0.346	0.385	*

TABLE 2. MEAN AND STANDARD DEVIATION OF DIFFERENCE OF H

<*ΔH*> rest					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	-0.241	-0.237	-0.174	**0.022**
LF	-0.241	*	**0.004**	**0.067**	0.263
Total	-0.237	**0.004**	*	**0.063**	0.259
δ[ε]	-0.174	**0.067**	**0.063**	*	0.196
***T*td**	**0.022**	0.263	0.259	0.196	*
σ(*ΔH*) rest					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	0.204	0.097	0.133	0.120
LF	0.204	*	0.117	0.109	0.107
Total	0.097	0.117	*	0.127	0.106
δ[ε]	0.133	0.109	0.127	*	0.082
***T*td**	0.120	0.107	0.106	0.082	*
<*ΔH*> orthostatic load					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	-0.178	-0.203	-0.172	**0.027**
LF	-0.178	*	**-0.025**	**0.006**	0.205
Total	-0.203	**-0.025**	*	**0.031**	0.230
δ[ε]	-0.172	**0.006**	**0.031**	*	0.199
***T*td**	**0.027**	0.205	0.23	0.199	*
σ(*ΔH*) orthostatic load					
	VLF	**LF**	**Total**	**δ[ε]**	***T*td**
VLF	*	0.271	0.169	0.161	0.194
LF	0.271	*	0.117	0.077	0.031
Total	0.169	0.117	*	0.082	0.114
δ[ε]	0.161	0.077	0.082	*	0.072
***T*td**	0.194	0.031	0.114	0.072	*

Fig. 2 and 3 represent the Bland-Altman plots of estimates of two signals in different time scales boundaries with low value of mean difference.

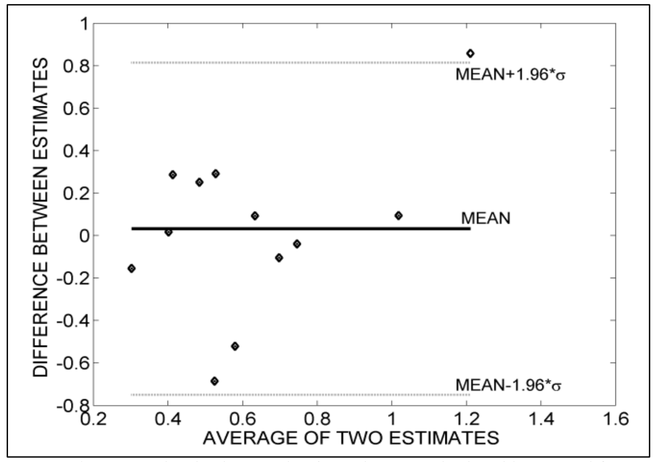

Figure 2. Bland-Altman plot for value *W*, calculated in LF and δ[ε] boundaries

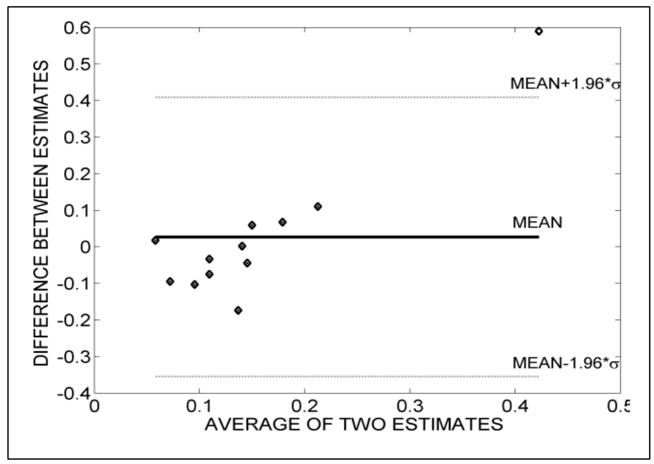

Figure 3. Bland-Altman plot for value *H*, calculated in VLF and T_{td} boundaries

Represented results show low level of systematic divergence between VLF and T_{td} bands, as well as for LF and δ[ε] bands. The σ values for mentioned bands are lower, then sample average values <*W*>=0.49 and <*H*>=0.25. So, it is possible to suppose that multifractal estimates W_{HRV}, W_{MR} and H_{HRV}, H_{MR} have close numerical values. This in turn implies interface between processes corresponding to respective bands of two signals.

In [19, 20], it was shown that dynamic organization of the ANS is of monofractal type in some bands (LF,VLF,ULF).The self-similarity index of this process is about $H≈0.2$. In our studies average values of *H* for both types of signals are <*H*>=0.25. This suggests that microwave radiation signal in δ[ε] and T_{td} bands can be described as a monofractal process.

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V. Conclusion

The MFDFA method was used to obtain statistically significant prove that fluctuations of microwave radiation of human brain is of self-similarity type.

Multifractal estimates of the LF band, which is designated by regulation of vascular tone, are connected with the δ[ε] band, characterized by dynamics of liquid transport in intercellular and intracellular areas of brain tissues. On the other hand, the VLF band reflected in central ergotropic and humoral-metabolic mechanisms is related to the T_{td} band, which is described by thermodynamic fluctuations in brain tissues.

Obtained results may confirm interface between microwave radiation and fluctuations of the ANS activity. In future works interface between microwave radiation and other biomedical signals such as electroencephalography, will be investigated.

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