VEGETATIVE CORRELATES OF CONSCIOUS REPRESENTATION OF EMOTIONAL STRESS

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The aim of the investigation was to search vegetative correlates of subjective level of emotional disadaptation in the study of heart rate variability (HRV) combined with the projective-verbal monitoring of the subjective level of emotional stress.

Materials and Methods. The study included 60 people aged from 19 to 23 years. We used the method of determining a subjective level of emotional disadaptation and telemetric recording of cardiorhythmography. The measurements were performed under natural activity 4 times a day. The results were processed using the methods of parametric statistics, cluster analysis. HRV was examined using the methods of spectral analysis — the periodogram and the continuous wavelet transform. The analysis results enabled to obtain spectral parameters of the second order, which characterize a modulating effect of higher suprasegmental levels of heart rate regulation.

Results. The total power of the HRV spectrum and the power of LF and HF frequency bands, as well as the modulation of sympathetic and parasympathetic nervous system activity were found to be statistically significantly higher ($p<0.05$) in the absence of emotional stress (low emotional maladjustment). Negative estimate of their own emotional states were associated with the decrease in suprasegmental modulating effects on autonomic regulation of the heart rate. Personalized monitoring data indicate the necessity of studying individual and typological features of the relationship between emotional status change and the dynamics of autonomic regulation in health and disease.

Key words: emotional stress; heart rate variability; wavelet analysis.

Emotional stress plays a key role in the development of the variety of somatic and neurological diseases. The term “stress” serves to denote both strong unfavorable physical and/or psychogenic environmental effects, and the developing under their influence extreme psychological load, originally designed for adaptation of a human being to new environmental conditions. Chronic emotional stress can provoke manifestation or exacerbation of disease symptoms, be one of the risk factors, or aggravate the severity of the ailment. Emotional stress reduces the efficiency and quality of the work being done by a person. Psychosomatic diseases, connected with anxiety and depression, which greatly reduces the quality of person’s life, are also clinical correlates of chronical emotional stress [1].

It is chronic emotional stress that affects people’s health in the negative way, and this influence mediates unfavorable endocrine, neuromuscular and vegetative changes [2]. Everyday psychic stress causes numerous common serious diseases, including hypertension, strokes, infarcts, oncopathology, etc.

While the origin of acute psychological stress is associated, first of all, with unexpected negative external effects and life changes, the development of chronic stress is determined mostly by personal features of a person and insufficient functioning of his psychologic adaptation mechanisms.

The first step on the way of overcoming chronic emotional stress is realization by the person himself of his being in the state of psychological overload. Emotions are a subjective phenomenon, and their diagnosis depends on the ability of a person to be adequately aware of them and to describe them verbally. But the ability to realize emotions and put them into words is not the same in different people [3]. Of great importance is the definition of those individual, registered in everyday life, physiological markers, which could serve indicators of emotional stress, i.e. emotional overload and emotional exhaustion. Knowledge of these markers will allow a person to obtain a feedback, demonstrating the level of his psychological stress, and helping him to relieve temporarily the condition by switching

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to physical or to some other kind of activity. Such feedback is especially useful for people who experience problems with self-control of emotional state.

The aim of the work is the investigation of vegetative correlates of the conscious representation of emotional stress.

Materials and Methods. When measuring the dynamics of psycophysiologic system, we used a scheme of parallel control of the vegetative regulation parameters according to the values of heart rhythm variability (HRV) and testing, using the methods of determining the emotional disadaptation level (EDL) [4]. Measurements were done four times a day at 8.00, 12.00, 16.00 and 20.00 during patients' usual activity. 60 people at the age of 19–23 years (gender differences were not assessed) participated in the study.

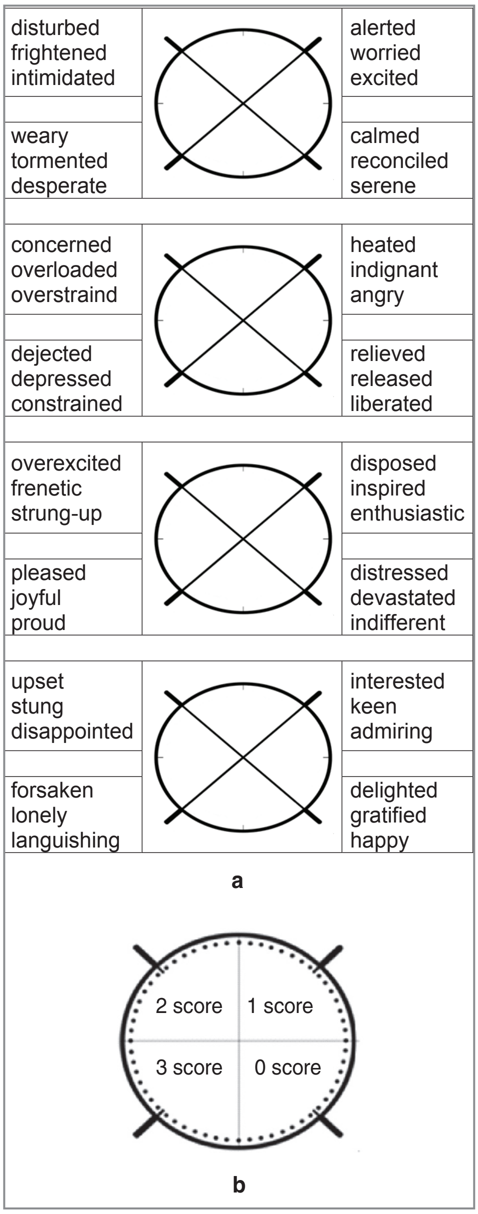

Fig. 1. Method of determining the level of emotional disadaptation [4]: *a* — a form for testing; *b* — a dial for evaluation of satisfaction level according to basic demands

The study was carried on according to the Helsenki's Declaration (adopted in June 1964, (Helsinki, Finland) and revised in October 2000 (Edinburgh, Scotland)) and approved by the Ethic Committee of Nizhny Novgorod State Medical Academy (Russia). A written consent was obtained from each patient.

Test of verbal associations for actual emotional state and value of emotional stress (emotional disadaptation level — EDL). In order to assess EDL, each participant of the test was suggested to indicate a zone of his current state in the circular condition space (Fig. 1, *a*). The borders of the space are determined by the four points where diagonals cross the circumference. The borders represent sets of synonymous adjectives describing emotions in accordance with the modality (positive/negative) and activity level (tension/relaxation) relative to four basic personality demands: a) in safety; b) in independence; c) in achievements; d) in unity (closeness). Depending on the position of the indicated zone a number of scores, obtained by a person for each demand (Fig. 1, *b*) is determined. The degree of emotional disadaptation is judged by an average score as follows:

0 scores — absence of emotional disadaptation (physiological relaxation);

1 score — slightly expressed emotional disadaptation (physiological strain);

2 scores — moderately expressed emotional disadaptation (pathological strain);

3 scores — sharply expressed emotional disadaptation (pathological relaxation).

Heart rhythm variability monitoring. Telemetric measurements of HRV were made using the developed soft- and hardware complex, consisting of a miniature wireless ECG sensor (HxM; Zephyr Technology, USA) and a smartphone with a specialized software. ECG sensor construction provides its reliable fixation on the human body, the electrodes are located in I and II chest leads.

Batch data transmission from the sensor to the mobile device is done through the wireless protocol Bluetooth. Realization of communication, data transmission and storage is performed in the mobile device by the original software HR-Reader. HR-Reader program medium provides on-line visualization of the registered R–R-interval dynamics for the record control.

Analysis of spectral values of heart rhythm variability. The calculation and analysis of the spectral values of HRV were carried on using the program complex RhythmService 1.2 (Photon-test Company, Nizhny Novgorod, Russia).

Methods of HRV spectral analysis allow one to separate from the complex oscillating process to which RR interval data is referred, more simple reference oscillations, composing it, to determine their frequency, intensity and, in some cases, to trace the evolution of the revealed frequency rhythms in time. Two methods of RR interval data spectral analysis were used in this work:

periodogram method (Fourier transformation and Welch periodogram);

method of continuous wavelet-transformation.

When periodogram method was used, the following HRV characteristics were used according to the existing methodological recommendations [5]:

TP, ms^2 — total power of HRV spectrum;

VLF, ms^2 — a spectrum power in very low frequency region;

LF, ms^2 — a spectrum power in low frequency region;

HF, ms^2 — a spectrum power in high frequency region;

LF/HF — relationship of spectrum powers in low and high frequency regions (vegetative balance index).

The method of continuous wavelet-transformation is used to analyze amplitude modulations of RR interval data spectral components. This method makes it possible to isolate and assess the participation of the highest suprasegmental regulatory components in the control of the cardiac rhythm (Fig. 2).

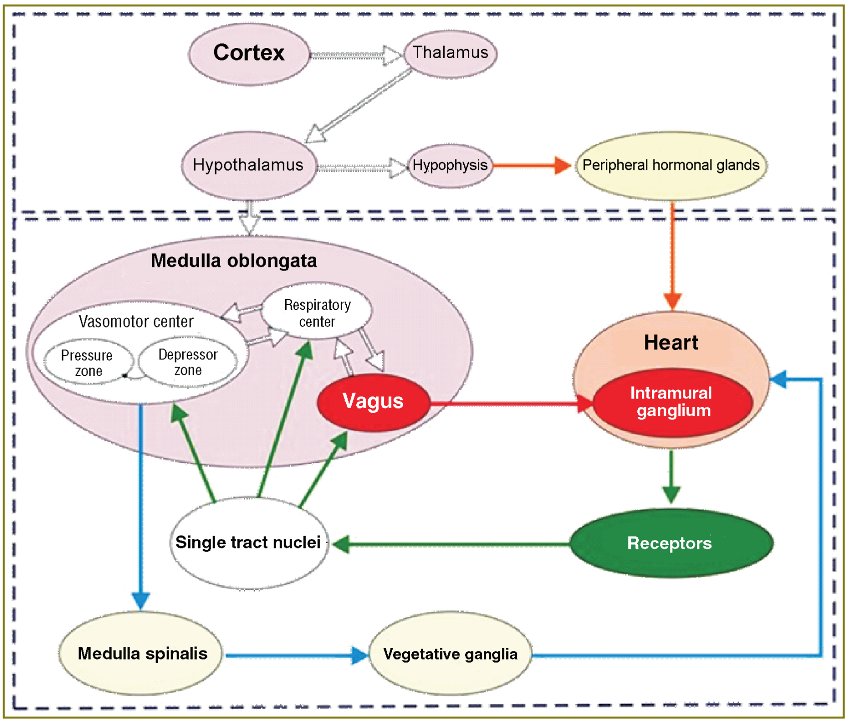

Fig. 2. Scheme of blood circulatory system regulation

The phenomenon of modulating parasympathic and sympathic activity on the part of suprasegmental structures is described in the literature [6, 7]. A regulatory effect of the suprasegmental link is suggested to be investigated indirectly by a modulating action on the parasympathetic (HF) and sympathetic (LF) HRV components.

An algorithm of separation and assessment of amplitude modulation includes the following steps:

1) analysis of RR interval data using the method of continuous wavelet-transformation, obtaining, as a result, a wavelet-spectrogram;

2) separation of narrow frequency bands (0.005 Hz) on the wavelet-spectrogram in LF- and HF-range, in which the relation of wavelet-coefficients (W2) and time is considered;

3) statistical and spectral assessment of the time series of wavelet-coefficients — W2(t), in this case periodogram method is an additional assessment method.

A RR interval data (Fig. 3, *a*) and wavelet-spectrogram (Fig. 3, *b*) of the examined patient P. is presented. On the wavelet-spectrogram narrow frequency bands (0.005 Hz) in LF- and HF-ranges are marked, in which relations of wavelet-coefficients (W2) and time are considered (Fig. 4). The time series obtained characterize changes of the instantaneous power of the given spectral signal component by the time. These relations may be used to assess low-frequency modulating effects.

The degree of modulating effects is determined by a statistical method according to the spread of the instantaneous power time series relative to its mean value, i.e. according to the mean square deviation.

The periodogram method serves to determine modulating frequencies and their power by the amplitude peaks in the spectrum obtained (Fig. 5).

The presented spectrums contain the main modulating frequencies — 0.03 Hz for HF-component and 0.025 Hz for LF-component. At the same time, several more modulators (minimum one) are defined. It is clearly seen on the spectrograms, that more expressed predominance of the main modulating frequency in the spectrum is characteristic of the spectrum of the time series of the LH-component instantaneous power. According to the relationship of the total power of all modulating frequencies to the power of the main modulating frequency the degree of power concentration of the modulating effect near the main modulating frequency was calculated.

As the result of the spectral and statistical analysis of the time series of the instantaneous power of the LF- and HF-components in the narrow frequency band the following criteria for the assessment of the degree of the modulating effect of the suprasegmental level in the regulation of the cardiac activity (spectral characteristics of the second order) were obtained:

index of the degree of sympathetic activity modulation — is determined by the spread of the mean square deviation of the time series of the LF-range instantaneous power;

index of the degree of the parasympathetic activity modulation — by the spread of the mean square deviation of the time series of the HF-range instantaneous power;

the degree of power concentration of the modulating effect near the main modulating frequency — the relationship of the total power of all modulating frequencies to the power of the main modulating frequency — $A(f_{tot})/A(f_{max})$ in the modulation of the sympathetic activity (LF-range);

the degree of power concentration of the modulating effect near the main modulating frequency — $A(f_{tot})/A(f_{max})$ in the modulation of the parasympathetic activity (HF-range).

The spectral analysis of the time series of the HF- and LF-component power revealed in various cases a different

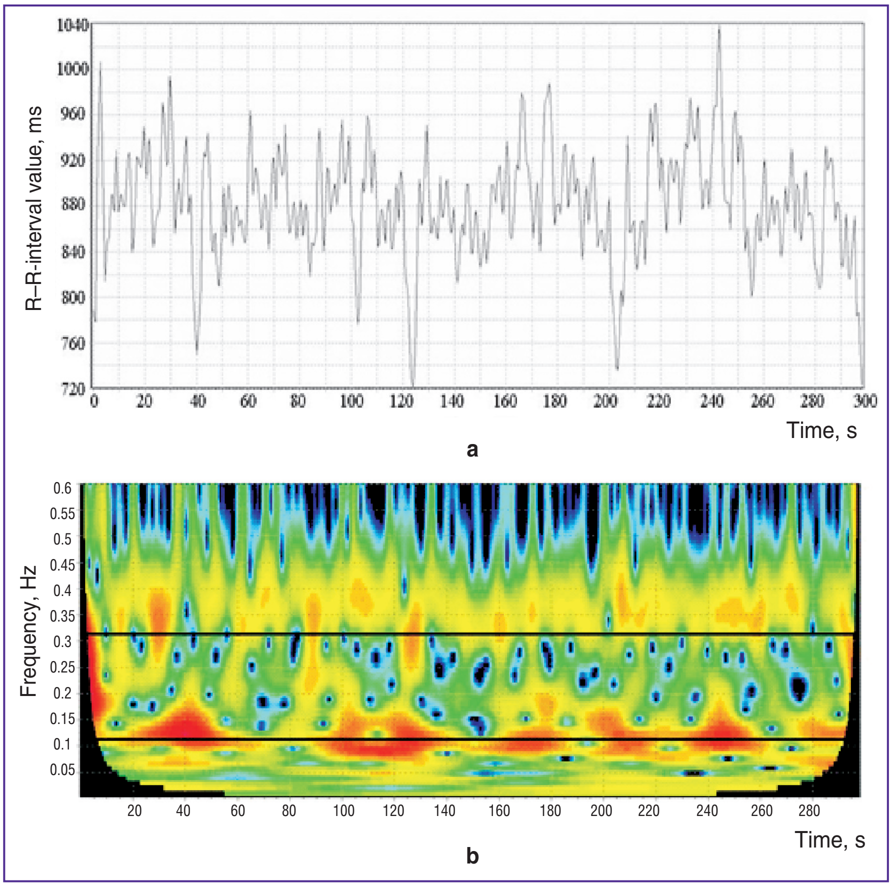

Fig. 3. RR interval data (*a*) and wavelet-spectrogram (*b*) of the examined patient P., 21 years old, taken at rest; black lines on the wavelet-spectrogram mark the frequency bands (0.005 Hz), in which time series of the relation of the spectral component power of the cardiac rhythm and central frequency of 0.31 Hz for HF component and 0.11 Hz for LF component were taken

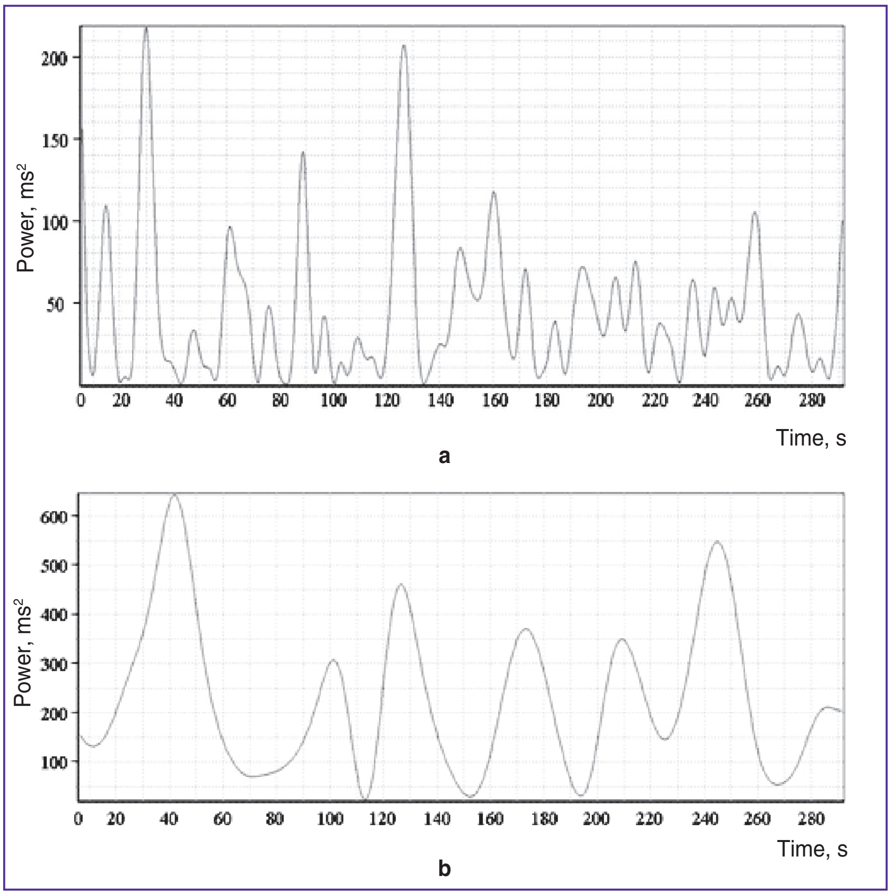

Fig. 4. Time series of the instantaneous power: *a* — HF-component (at the frequency of 0.31 Hz); *b* — LF-component (at the frequency of 0.11 Hz)

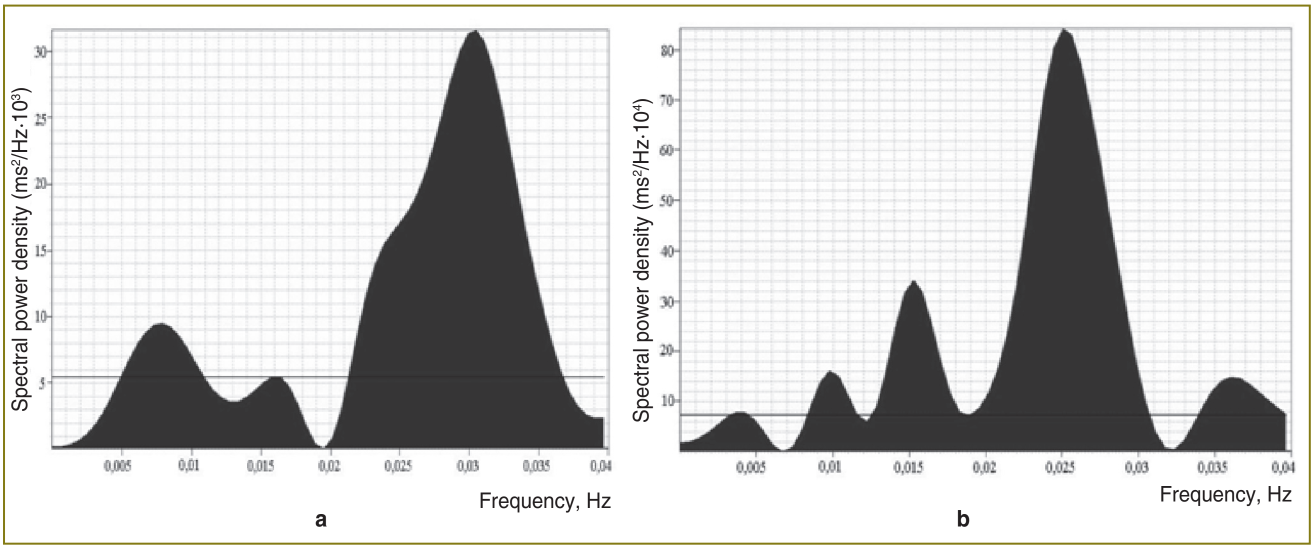

Fig. 5. Fourier spectrums of instantaneous power time series of HF-component (*a*) and LF-component (*b*); reliability threshold of signal separation from the noise with the probability of $p \geqslant 0.9$

number of modulating frequencies, reliably present in the signal (from 1 to 6), which were in the range of 0.003 to 0.04 Hz. And among all frequency peaks the most powerful one was always observed, which was defined as a basic source of frequency modulations (the main modulating frequency). If the power of the main modulating frequency exceeds significantly the value of the total power of all modulation sources, a resonance effect of power amplitude increase in case of synchronization of the modulation source frequencies may be suggested. For the analyzed frequency components it means capture of all modulator frequencies by the frequency of the main source [8, 9]. Thus, index of the degree of power concentration of the modulating effect near the main modulating frequency reflects the degree of submission of all components, modulating tonic and physical activity of the vagus and sympathetic nerves.

Statistical data processing was made using a program complex Statistica 6.0. To divide the sample into clusters we applied k-means method.

Statistical assessment of reliability of intergroup differences and differences of the indexes within the clusters was made according to Student t-criterion.

Results and Discussion. For searching vegetative correlates of verbal presentation of the emotional stress, a spectral analysis of power dynamics of LF- and HF-components of HRV was carried out. Modulations of sympathetic and parasympathetic system activity are considered by us to be manifestations of suprasegmental level of cardiac rhythm regulation. According to the EDL indexes and spectral characteristics of the second order a group of the examined patients was divided into two clusters. The clusters differed significantly according to both emotional disadaptation indexes and indexes of vegetative regulation dynamics. Sharply expressed emotional disadaptation, corresponding to the state of emotional stress, agrees with the low level of suprasegmental control (Fig. 6).

Negative assessments of one's own emotional state are connected with the decrease of variability of vegetative

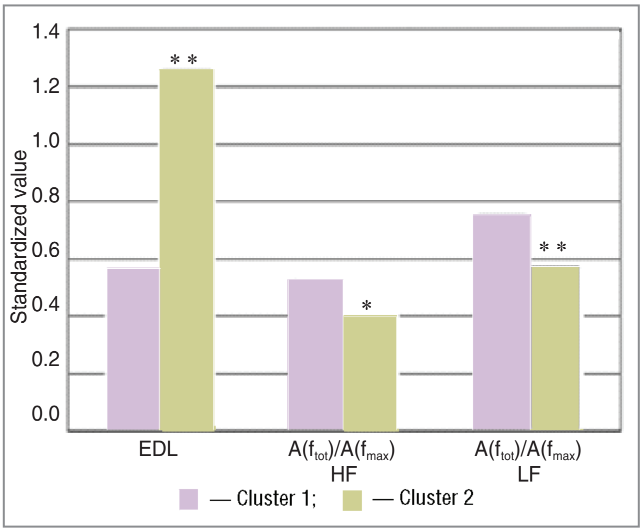

Fig. 6. Comparison of clusters according to EDL and degree of concentration $A(f_{tot})/A(f_{max})$ of modulating effect power near one frequency when modulating parasympathetic (HF-range) and sympathetic (LF-range) activity; intergroup differences are statistically significant: differences * — $p<0.05$; ** — $p<0.01$

regulation and reduction of localization of suprasegmental modulating source action (Fig. 7). Such reduction (dissociation) of the modulation source localization is reproduced in a number of mathematic models of the heart work control and is interpreted as hierarchy destruction in the organization of regulation [10–12].

The analysis of vegetative regulation of the cardiac rhythm in the outlined clusters points out at the statistically significant differences in the indexes of activities of both sympathetic and parasympathetic systems. In the low level of emotional disadaptation (cluster 1) the total spectrum power and the power for frequency ranges, corresponding to the activity of the sympathetic (LF) and parasympathetic (HF) nervous system, is higher (Fig. 8). Thus, the increase

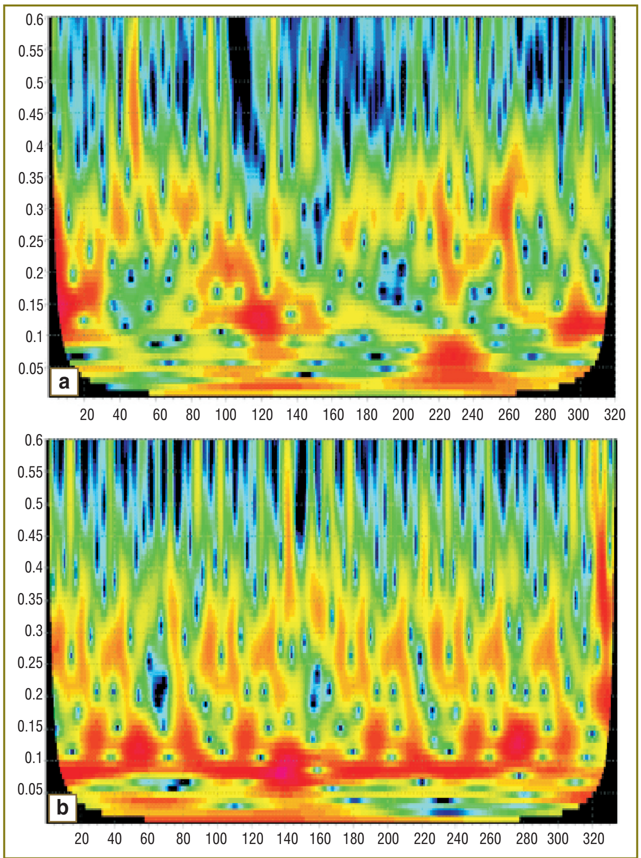

Fig. 7. Wavelet-spectrogram at high (*a*) and low (*b*) levels of suprasegmental control

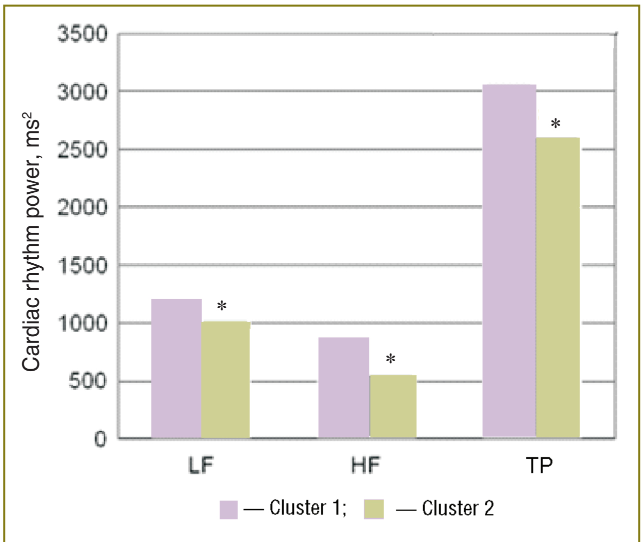

Fig. 8. Comparison of clusters according to the spectrum values of heart rhythm variability; TP — total power spectrum; * — statistical significance of intragroup differences, p<0.01

of the emotional stress level correlates with exhaustion of regulatory system resources.

This finding is in line with the studies in which stress situations and emotional strain are simulated [13–15]. The study of the patients with depressive and anxiety disorders showed the reduction of statistical indexes of HRV (SDNN, RMSSD) in the given group in comparison with the control one [16, 17].

The connection between the dynamics of the emotional state and that of vegetative regulation during 24 hours was revealed (Fig. 9).

In cluster 1 in the stable emotional wellbeing during 24 hours redistribution of the vegetative balance from sympathotonia in the morning to normotonia in the evening was registered. The transition of the physiological system from the strained condition at the beginning of the working day to the low energetic level in the evening can provide the capability of recovering the energy resources of the regulatory systems and the organism as a whole. And the value of EDL in this case varies near 1, which tells about the absence of emotional stress. In cluster 2, where EDL is higher, during all daily samples the index of the vegetative

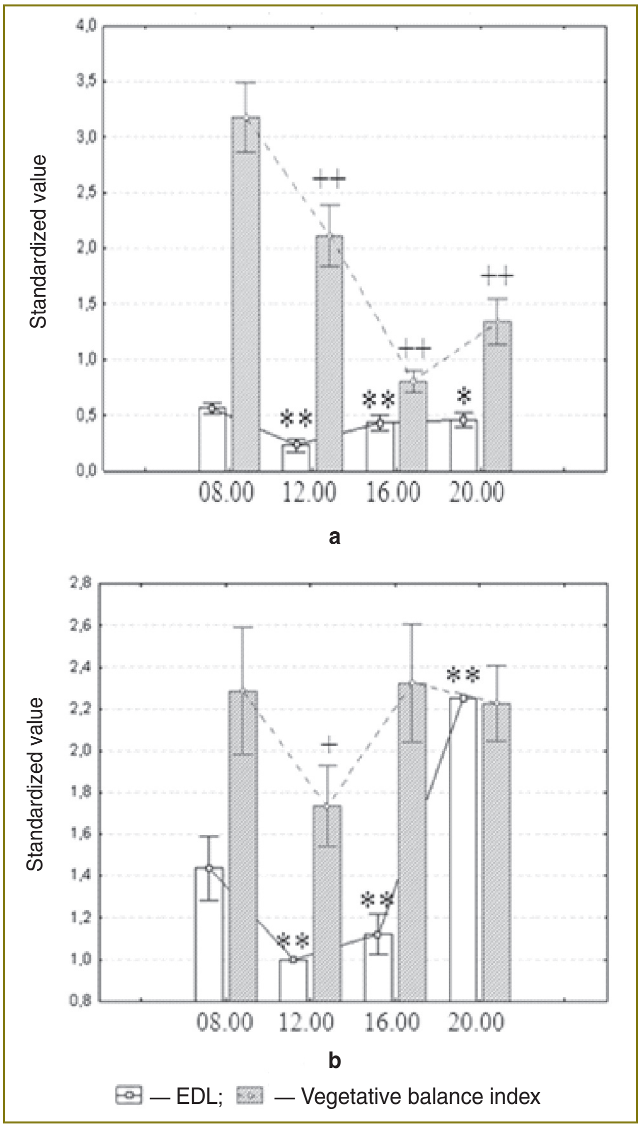

Fig. 9. Daily dynamics of EDL value and vegetative balance index in the marked clusters: *a* — cluster 1; *b* — cluster 2; * — statistically significant differences relative to the reference EDL value, p<0.05; ** — relative to the reference value LF/HF ($^{+}$ — p<0.05; $^{++}$ — p<0.01)

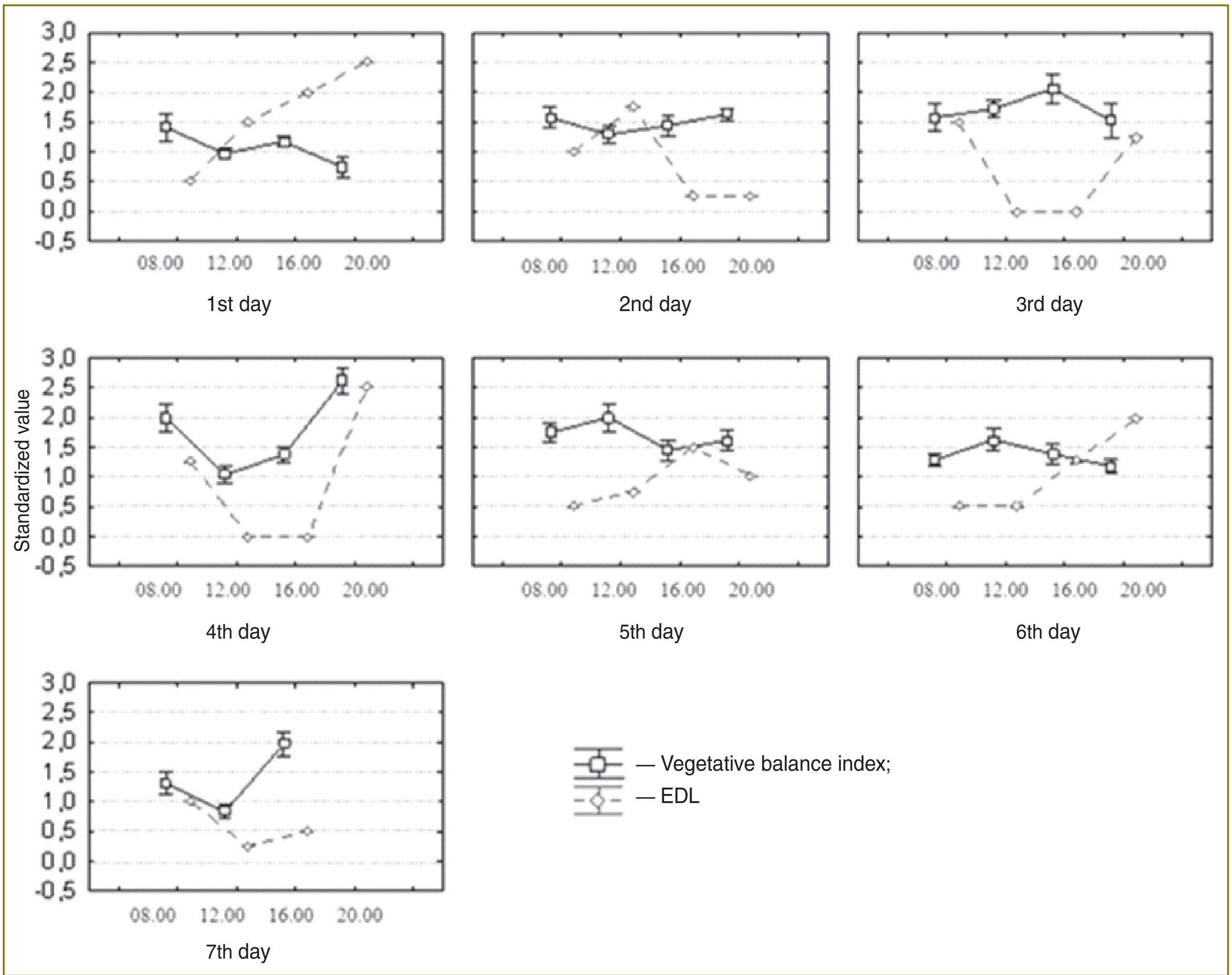

Fig. 10. Daily dynamics of EDL value and vegetative balance index during 7 days in patient P.

balance shows prevalence of sympathetic regulatory influences (index does not drop below 1.6). The level of emotional stress in this case has a maximum value by the end of the day. Thus, we may conclude, that emotional stress is accompanied by the steady exhaustion the organism regulatory systems.

Investigations, reflecting daily dynamics of HRV indexes, as a rule, consider "day–night" samples. In this case reduction of variability in the day time compared to the period of sleeping is observed in all patients independently on their age and activity specificity [18]. And the jobs, reflecting the variability dynamics during the day, demonstrate significant possibilities of classification of patient circadian profiles in order to make a prognosis of the disease course [19, 20].

The results of individual longitudinal investigation during 7 days are presented in Fig. 10.

It was estimated that 24-hour dynamics of EDL and vegetative balance index in 5 cases of 7 is of the reverse correlation character. In the individual profile of daily dynamics, increase of the emotional stress occurs together with the reduction of sympathetic activity. This finding of personified monitoring attracts special attention, as it contradicts the results of data sample analysis. It is obvious that investigations of individual and typological association between the emotional status dynamics and that of the vegetative regulation both in norm and pathology are of great importance. Notably, the necessity of individual dynamic analysis has been discussed since the XX-th century [21] and is still going on nowadays in the current literature, as the contradiction of individual data and sample mean values is frequently noted. But even methods of solving these problems have not yet been developed. The attempts being taken now to determine the vegetative status of a man [22], in spite of the high degree of dynamic characteristics and sensitivity of the tested parameters to the external and internal signals, as well as search of universal norms [23] for the state evaluation, tell only about insufficient development of the dynamic approach to the determination of the physiological parameters and physical components of the biological system.

Conclusion. It has been estimated that vegetative correlates presenting verbally emotional stress may be spectral indexes of heart rhythm variability, the influence of the highest regulatory contours displaying itself in the spectrum characteristics of the second order. The spectrum of the second order is a principally new method of evaluating the level of suprasegmental regulation of cardiac rhythm.

Circadian dynamics of emotional disadaptation level indexes and vegetative balance index in the sampling study is characterized by a steady dominance of the sympathetic activity with a high level of subjective representation of emotional stress. However, in case of the individual longitudinal investigation, an association of increase of emotional disadaptation level with the reduction of the vegetative balance index was revealed. Personified monitoring acquires great practical value in the study of the connection of emotional and vegetative contexts of the man's life activity.

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