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CHANGES OF HEART RATE AND FRACTAL NEURODYNAMICS VARIABILITY INDICATORS UNDER CONTROLLED BREATHING IN THE HEART RATE OSCILLATIONS FREQUENCY SPECTRUM

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Changes of heart rate and fractal neurodynamics variability indicators in the conditions of controlled breathing in the heart rate oscillations frequency spectrum are studied.

It is shown that controlled breathing whose frequency corresponds to the frequency of localisation of the maximum peak of heart rate power in the low-frequency (LF) range is a powerful mechanism for controlling heart rate and modifying functional state as a whole. It is possible to study the properties of the heart rate vegetative control system's own oscillation processes on the basis of the resonance effect in the heart rate spectrum under controlled breathing whose frequency corresponds to the frequency of localisation of the maximum peak of heart rate power in the LF range.

Keywords: controlled breathing, heart rate variability, fractal neurodynamics, heart rate vegetative control system.

INTRODUCTION

Of special interest in recent years has been investigating synchronization of biological rhythms in living organisms whose vital functions are determined by interaction of many complex rhythmic processes [1-3]. A striking example of such an interaction among different physiological rhythms is the functioning of a human cardiovascular system (CVS). The most important oscillation processes determining its dynamics are basic heart rate (HR), breathing as well as processes of slow HR and blood pressure regulation, whose natural frequency is near 0.1 Hz [4]. The majority of physiological oscillations are however not strictly periodic, with rhythms usually varying irregularly under the influence of varying external factors and noise perturbations [2]. Heart rate is not an exception. The CVS regulation mechanism mediated by the vegetative nervous system (VNS) action is modulated by a number of various external influences (such as breathing, physical activity, body position modifications, psychoemotional changes etc.) [2]. As a result of their interaction, these rhythms manifest themselves in various signals such as electrocardiogram (ECG), blood pressure, blood stream and heart rate variability (HRV) [5].

It has recently been revealed that the CVS basic rhythms can be synchronised among themselves [6-9], the finding being in line with the present-day ideas about the functioning of complex systems [2]. Besides, it has been revealed that the system setting the basic HR, or the heart vegetative control system (HVCS), can be considered as a self-oscillator under the external influence represented in this case by breathing [9, 10]. Application of controlled breathing (CB) can therefore be viewed as an introduction of a periodic component in the external noise signal entering the HVCS.

According to the present-day ideas about the CVS vegetative control system organization, the said system is characterised by the presence of a basic self-oscillation process at the frequency of about 0.1 Hz (low-frequency spectrum range) [11-16]. This oscillation process, which varies under external influences and determines the dynamics of an organism's vegerative status, is generally considered to characterize the basic properties of the HVCS central part [17-20]. It has been proved that breathing and vascular tonus regulation rhythms are synchronized at the frequency of 0.1 Hz [9]. The choice of a CB perturbation frequency is therefore often made on the basis of de Boer's model, where the presence of a system's natural oscillations at the frequency of 0.1 Hz allows using the resonance response in the low-frequency range of HR oscillations with the period of 10 seconds [11-15]. The resonance effect is in this case caused by physical coincidence of the frequencies of the two harmonious oscillation processes: exterior respiratory perturbation and the system's natural oscillations. However, individual variability of the wave peak in the low-frequency range (from 0.05 Hz to 0.15 Hz) is widely known, therefore it is a shortcoming of the existing approaches that the respiration rate of 1 inspiration/6 seconds (0.1 Hz) [11-15] does not always have a resonance response in the HVCS.

Hence, the use of the CB method at an individually fitted frequency [21] has good prospects. Yet, most commonly used procedures do not provide any criteria to assess adequacy and efficiency of using CB parametres from the point of view of the functional state of the CVS as a whole and interactions among its parts, which depend on the quality and concordance of functioning vegetative regulation mechanisms, i.e. while using the CB method we face a situation which is quite typical in science, when new ideas are put in practice before any insights into the action mechanisms of the factor underlying these ideas are reached. Thus, the possibility of modifying HVCS parameters and an organism's functional state as a result of CB at an individually fitted frequency remains unstudied. The aim of the present research is therefore to detect changes in the heart rate and fractal neurodynamics variability indicators under the conditions of controlled breathing in the heart rate oscillations frequency spectrum.

MATERIALS AND METHODS

42 conditionally healthy female students aged between 18 and 21 have been examined in the research. All the examinees have volunteered to participate in the examination.

A preliminary HRV record made with the help of an Omega M hardware-software complex (HSC) (produced by *Dynamica* Research Laboratory, St. Petersburg) revealed individually typological differences among the examinees, related, among other things, to stress index values (Si or Ii intensity index [22]): Si values did not exceed 50 arbitrary units in 21% of the examinees, were between 50 and 200 arbitrary units in 50%, and exceeded 200 arbitrary units in 29%.

Only the voluneers showing Si values between 50 and 200 arbitrary units were admitted to the experiment (n = 21). This kind of selection was made because, first, it enabled us to form a homogeneous sample of examinees and, second, because such values prevailed among the examined students, which suggests that these examinees developed the most typical reaction to CB.

Examinations were made daily within a 10-day period as well as 7 days after the termination of the CB course (17th day of the experiment) in order to record the aftereffect at the same time of the day, thereby eliminating any impact of circadian HRV variations on the reasearch results [23, 24].

Examinations began with recording an ECG signal in the first standard lead by means of the Omega M HSC, which had been developed on the basis of an essentially new method for discrete dynamic analysis of heart and brain rhythms. Rhythmograms obtained as a result of processing the electrocardiosignal are basically sequences of time intervals between contiguous heart excitations. Five rhythms were identified on the basis of the electrocardiosignal for the software-hardware implementation of the method: *R-R* intervalogram (sequence of *R-R* intervals), *R-T* intervalogram (sequence of *R-T* intervals), ratios of *R* and *T* wave amplitudes (sequences of *R* and *T* ratio amplitudes) and off-duty ratio of the electric signal (sequence of ratios of the cardiocomplex period to its duration). Each rhythm is used as a basis for identifying first-order waves, enveloping the said rhythms. Thus, a proper transition from rhythmograms to time functions is carried out.

Recordings were made with examinees sitting and breathing quietly within 5 minutes, i.e. the time needed to get 300 cardiocomplexes. To achieve the set goal, we applied the basic methods of HRV analysis (in the assessment system recommended by the standards of the European Cardiological Society and the North American Society of Pacing and Electrophysiology [25]): statistical methods (RMSDD, SDNN, pNN50), geometrical methods (Aмо, Mo, Dx), spectral methods (HF, LF, VLF, TOTAL, LF/HF) and FND (A, B, C, D, Health), which are explicitly featured in literature and our previous investigations [26].

It is known that time series oscillations of cardiointervals are characterized by self-similarity, i.e. there is repeatability of their properties in different time scales [27]. Since the human CVS is self-organized in such a way that it has no characteristic duration or time scale, it would be reasonable to expect its structure to distort as a result of any deflection in one’s functional state. Therefore fractal analysis of biorhythms provides moreexhaustive information on the state of biological objects and can be an important supplement to the traditional methods of HR analysis.

The neurodynamic method of processing rhythmograms is a means of transforming the signals $f_1(t)$, $f_2(t)$, $f_3(t)$, $f_4(t)$ and $f_5(t)$ into a binary code combination, which consists of a sequence of impulses whose parameters are all identical.

On the first day of the experiment background records of HRV and FND indices were made during spontaneous breathing to obtain control records. The electrocardiogram records were being monitored against any forced inspirations and breath holdings so as to eliminate any arbitrary breathing influences on an examinee’s CVS, i.e. examinations were made in relatively standard conditions.

On the experimental days that followed, records of HRV and FND indices were made during CB whose frequency corresponded to the frequency of localisation of the maximum peak of HR power in the LF range.

During a CB session, each examinee breathed in his or her individual rhythm set by a "respiratory sphere", whose parameters were calculated on the basis of the rhythmogram recorded immediately before the breathing session on the Omega HSC (fig. 1, 2).

The depth of breathing corresponded to the size of the sphere: the bigger the sphere the deeper the inspiration, the smaller the sphere the fuller the expiration.

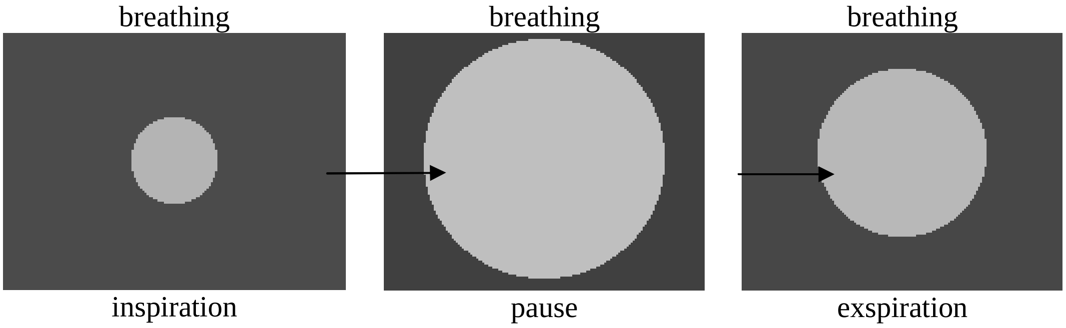

Fig. 1. Controlled breathing phases set by the Omega HSC.

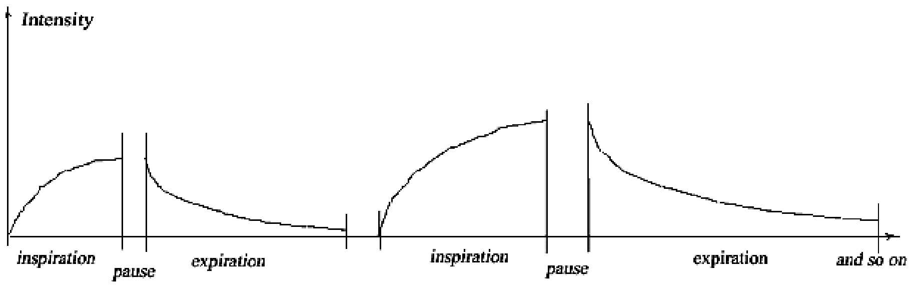

Fig. 2. Graph of controlled breathing phases in the Omega-M HSC.

The ratio of inspiration and expiration time intervals was constant – 38% of inspiration and 62% of expiration, which complies with the "golden section" rule [28]. The breathing periods showed exponential growth at the beginning and exponential decrease in the completion phase.

The duration of a CB session was about 5 minutes. The next rhythmogram record was made not earlier than 5 minutes after the end of the CB session.

Changes in the HRV and FND indices against the control record obtained on the first (background) day of the experiment were considered as a criterion of efficiency of the method applied. Statistical treatment of the data was carried out with the help of Omega-M and Statistics 6.0 software packages. Reliability of the differences between the obtained data sets was assessed by means of Wilkokson's criterion.

RESULTS AND DISCUSSION

Statistical methods of HR analysis showed a reliable ($p < 0.05$) increase of PNN50, RMSSD and SDNN indices in the examinees during a ten-day individually fitted frequency CB course, starting from the 2nd, 3rd and 5th observation days, respectively (fig. 3).

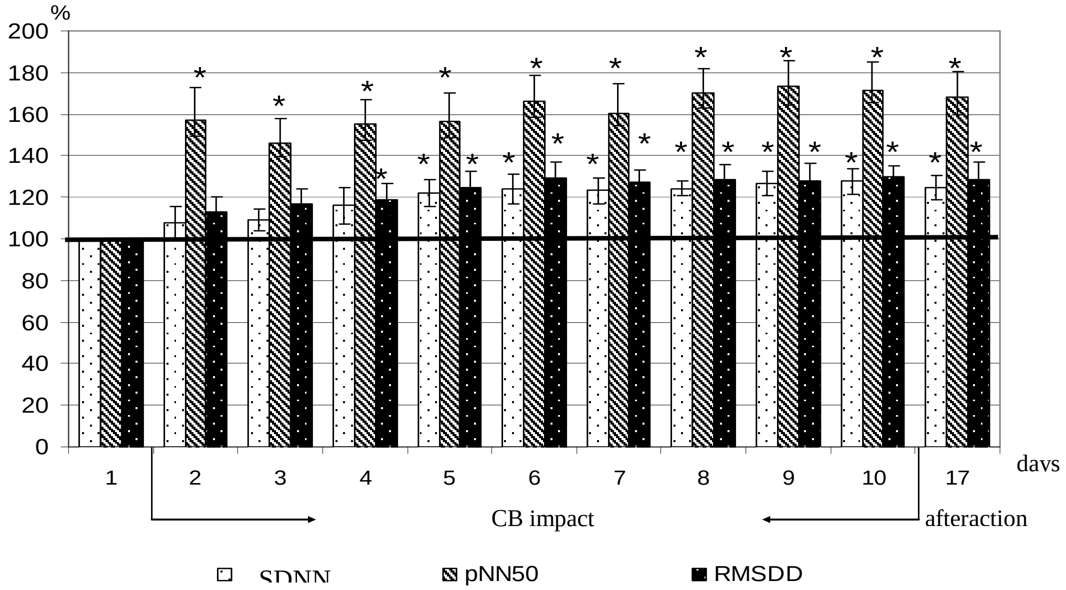

Fig. 3. Modifications of the heart rate statistical analysis indices induced by controlled breathing at an individually fitted frequency in examinees in different stages of the experiment (percentage wise agaist the initial values taken as 100 %).

Note: * - reliability of differences is $p < 0.05$ according to Wilkokson's criterion against the initial values of the indices under study.

On the 10th day of our examination the values of RMSSD, SDNN and PNN50 indices increased by 30% ($p < 0.05$), 28% and 71% ($p < 0.01$) respectively against the background values.

It is known that SDNN is a cumulative index showing variability of ranges of R-R intervals over the entire period under consideration, which describes the HRV as a whole [29], and an increase of the SDNN suggests intensification of autonomic regulation. Values of the RMSSD index are calculated on the basis of the times series of value differences of consecutive pairs of cardiointervals and do not contain any slow-wave HR components [26]. Any augmentation of the difference between the cardiointervals results in an increase in the RMSSD value, which suggests activization of the parasympathetic VNS.

Along with stabilisation of SDNN and RMSSD indices starting from the 5th or 6th day of the observation, we registered the earliest (since the 1st controlled breathing session) and most significant increase of the pNN50, most evident on the 9th day (by 73% ($p < 0.05$) against the initial values). The pNN50 index provides information similar to the one offered by RMSSD. Yet, since we take into account only difference values exceeding 50 ms when calculating it, this index is more sensitive to high-frequency HR respiratory oscillations and therefore reflects the activity of the autonomic regulation circuit and the VNS tonus more efficiently.

Thus, the increasing values of HRV statistical indices (SDNN, pNN50 and RMSSD) testify to the effect that the CB course induced intensification of the autonomic circuit, in particular intensification of the parasympathetic part of HR regulation, and therefore optimized regulation of living functions.

Besides, it should be noted that 7 days after the termination of the CB sessions the values of HRV statistical indices remained reliably higher than the initial values, suggesting that the course in question had a pronounced aftereffect.

The obtained data are further proved by HR geometrical analysis data, which show that realiable changes in the studied indices occurred as early as after the 5th CB session (fig. 4), and on the 10th day of our observation Dx index values were 17% higher ($p < 0.01$) and Amo index values were 19% lower ($p < 0.05$) than their initial values.

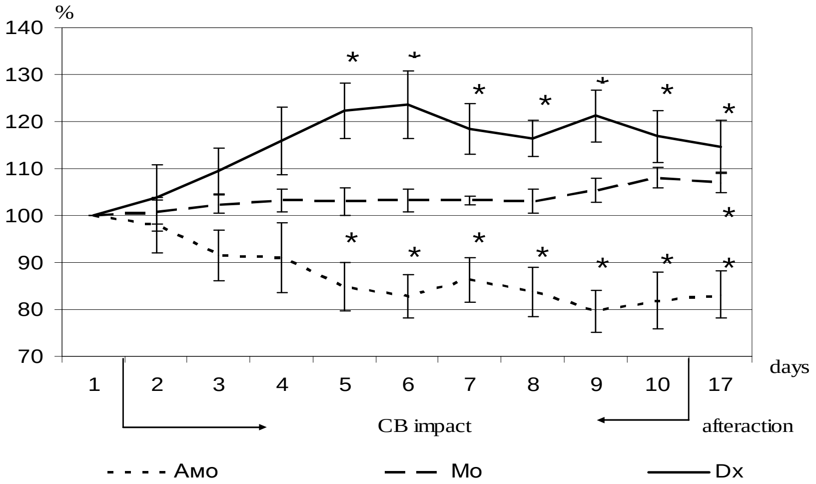

Fig. 4. Modifications of the heart rate geometrical analysis indices induced by controlled breathing at an individually fitted frequency in examinees in different stages of the experiment (percentage wise agaist the initial values taken as 100 %).
Note: the notations are identical to the ones in fig. 3.

It is known [22] that geometrical methods of HRV analysis are basically mathematical analysis of histograms of R-R interval distributions. Thus, dilation of the R-R histogram base and flattening of its dome are characterized by falling Amo values and growing Dx and Mo values and can suggest activation of the parasympathetic VNS and decreased impact of its sympathetic part on HR as well as be indicative of increased activity of the CVS autonomic regulation circuit regulation [25], as was registered in our examinees undergoing the CB course at the frequency within the HR oscillation low-frequency range.

Furthermore, seven days after the CB course, biological responses were reliably different from the initial values: Amo - 83%, Dx - 114% ($p < 0.05$; fig. 4).

Geometrical analysis data can be expressed quantitatively in terms of variational pulsometry indices, the most common and informative method of variational pulsometry being analyzing the Si stress-index of an organism’s regulatory systems.

Under the influence of CB, on the 5th day of the experiment Si decreased sharply by 31% ($p < 0.05$) against the background values of this index (fig. 5).

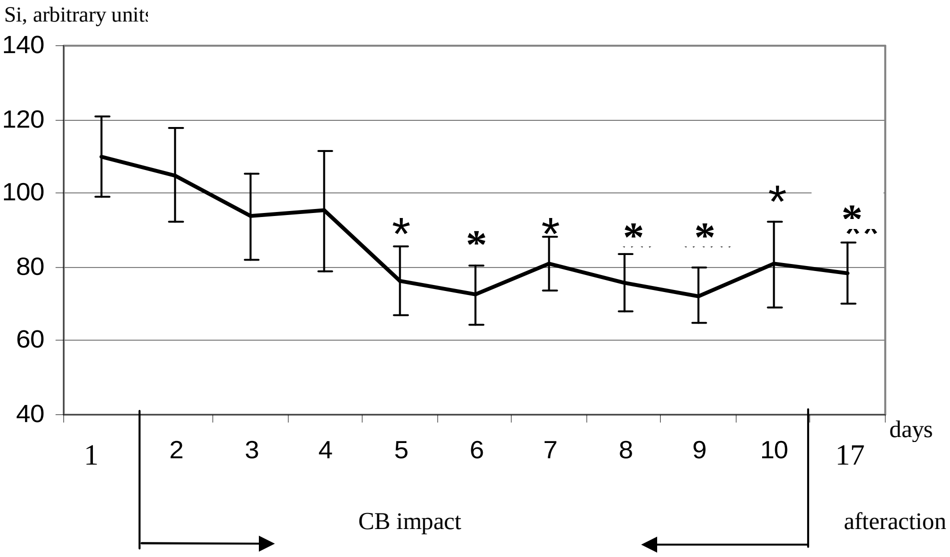

Fig. 5. Si modifications (arbitrary units) induced by controlled breathing at an individually fitted frequency in examinees in different stages of the experiment.
Note: the notations are identical to the ones in fig. 3.

It should be noted that after the subsequent CB sessions the values of this index remained in the range between 75 and 80 arbitrary units, suggesting that Si values had reached a “plateau” (fig. 5). Si still remained at this level 7 days after the termination of the CB course.

As is known [30], Si characterises a degree of predominance of sympathetic effects over parasympathetic ones as well as a stress level of regulatory systems [22]. The decrease of Si values as a result of CB at the frequency of maximum peak localisation in the LF HR range is therefore yet another evidence of increased vagal actions on HR and reduced stress levels of examinees’ regulatory systems.

The fact that examinees show a significant decrease of Si values as early as after the 5th CB session opens up possibilities for practical application of this method to reduce stress caused by psychoemotional or physical exertion. It can be mentioned that Si increases 1.5 to 2.0 times under physical sress [31.], 1.1 to 3.9 times under emotional pre-examination stress in students and schoolchildren [32], 1.4 to 1.7 times in cosmonauts during a magnetic storm [33], and 20 to 30 times in sportsmen during sports events such as games and single combats, suggesting a grave functional stress state “on the verge of adaptation breakdown” [34].

Spectral analysis of drive characteristics of bioelectric signals, which is widely used as a noninvasive method in heart vegetative regulation examinations, revealed reliable changes of the studied indices in the examinees, starting from the 2nd or 3rd day of the experiment (fig. 6). Yet, maximum value increases of the indices under study were registered on the 10th day of CB, when spectrum power values in the LF and HF HR ranges had grown by 112 and 69% ($p < 0.01$) respectively against the background values of these indices. It must be noted that this growth was mostly accounted for by growing power of the LF-component of the spectrum. Changes in the VLF-component of the spectrum proved to be unreliable.

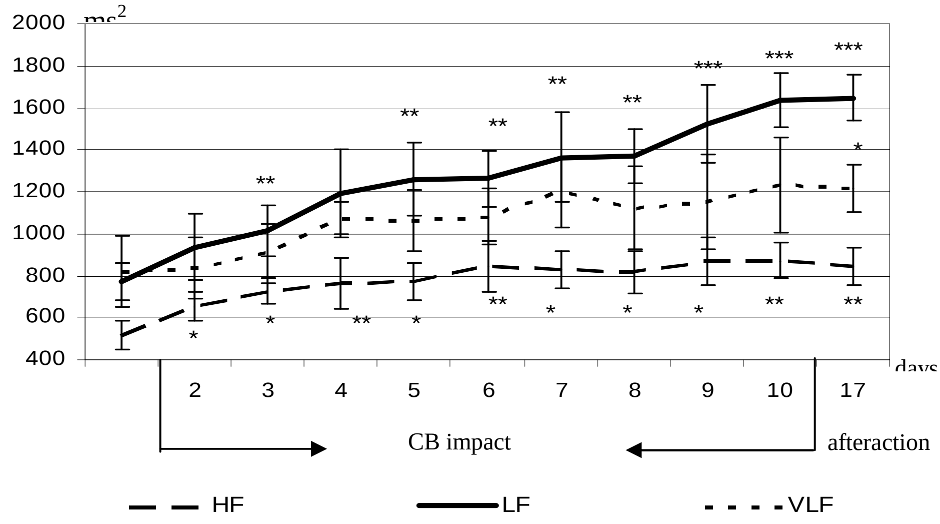

Fig. 6. Modifications of heart rate spectral components power (ms^2) induced by controlled breathing at an individually fitted frequency in examinees in different stages of the experiment.

Note: the notations are identical to the ones in fig.1.

There are numerous experimental data showing that the HRV spectrum obtained by analyzing short (3-to-5-minute) rhythmogram fragments has a solely neurogenic nature, for the high-frequency component as well as the both low-frequency components of the HRV spectrum disappear after heart denervation [35], are missing in transplanted heart patients [36] as well as in anencephalic foetuses [37].

It is nowadays generally acknowledged that HF-components of the spectrum (0.15 – 0.4 Hz) are related to respiratory movements and reflect the HR vagal control whereas LF-components characterize the condition of the sympathetic VNS [25], and, in particular, that of the vascular tonus regulation system (activity of the vasculomotor centre). Besides, some authors have shown that increased power of the HR LF-component is indicative of improved baroreflex regulation of haemodynamics [19].

Furthernore, the sympathovagal LF/HF interaction coefficient showed a tendency ($p>0.05$) to change under the CB influence. Thus, starting from the 4th day of our reserach we registered an increase in the LF/HF coefficient, which reached its maximum values by the 9th day – 2.57 arbitrary units, or 135% against the control values.

It is known that the dynamics of this index is indicative of changing balance between the sympathetic and parasympathetic parts of the VNS [29]. Yet, under the CB influence, the LF/HF ratio in the spectrum approached 3, suggesting predominance of low-frequency rhythms, intensified baroreflex regulation and intensified sympathetic effects on our examinees' HR.

Consequently, the obtained data revealing increased power of both LF- and HF-components of the HR spectrum as well as the LF/HF coefficient in examinees practising

CB at a frequency within the low-frequency HR spectrum component can suggest intensifying vagal effects and intensifying baroreflex regulation of the HVCS.

Along with changes in the power of individual HRV spectrum components, CB induced an increase in the aggregate power of the spectrum (TP) (fig. 7).

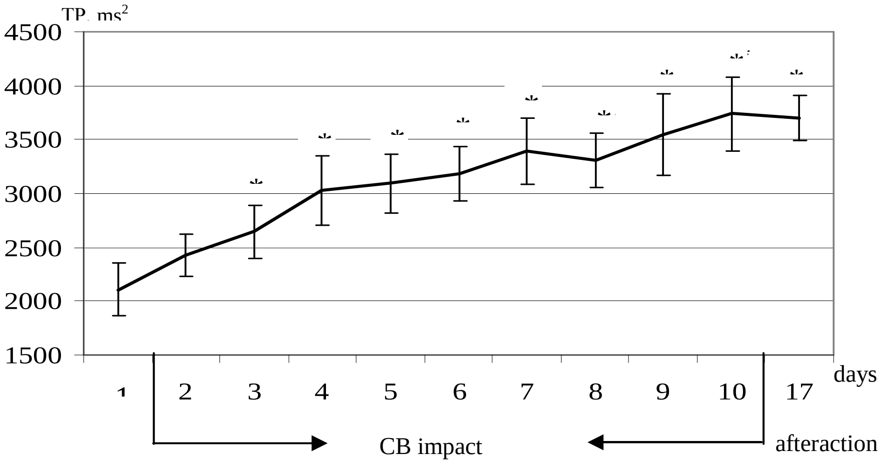

Fig. 7. Modifications of the aggregate spectrum power index (ms^2) induced by controlled breathing at an individually fitted frequency in examinees in different stages of the experiment.

Note: the notations are identical to the ones in fig. 3.

Thus, on the 10th day of CB our examinees registered maximum TP values, which made 177% ($p < 0.001$) against the background values of the same index.

TP is known to reflect aggregate vegetative effects on HR. Vagal activation is usually accompanied by a TP increase [25]. Therefore, a TP increase in examinees practising CB at an individually fitted frequency can be put down to activation of the vegetative circuit and decreased action of the central circuit of HVCS regulation.

At the same time, it is known that the higher the aggregate power of the spectrum is the more pronounced the organism’s adaptive capabilities are [25]. A conclusion can therefore be made that CB increases examinees’ adaptive potential, which agrees with the reference literature data [21].

Since applied physiology and clinical medicine use HRV not only for studying HVCS, but also for assessing an organism’s functional reserves, regulation characteristics and adaptive reactions, the next stage of our research was analyzing CB-induced changes in HRV derivative parameters – integral FND indices, which make it possible to pool all information about different levels of body regulation.

The CB course resulted in growth of all studied FND indices in our examinees by 17 to 23% ($p < 0.01$) on average against the background values (see the Table).

Of particular interest are findings obtained as a result of analyzing dynamic changes of HRV and FND indices depending on the CB course duration. Differences were found in most HRV and FND indices. Reliable changes of the parameters under consideration were recorded as early as after the 3rd CB session although the maximum effects of the CB course were registered by the 9th or 10th day. Thus, our research shows that at the early stages the CVS and the organism as a whole respond to CB rather slowly, but their response intensifies under repeated exposure and persists for a long time, which suggests the presence of a cumulative CB effect at the LF HR frequency.

Table

Dynamics of integral indices of examinees' functional state

Days	Indices				
	A	B	C	D	Health
1	61,21 ± 2,83	66,94±4,33	56,42 ±3,58	57,94±2,75	60,63 ±3,10
2	69,48±4,03 $p<0,05$	70,70±4,82	62,41±3,31	63,91±3,12	66,62±3,53 $p<0,05$
3	65,03 ± 3,37 $p<0,05$	74,38±4,52	64,52 ±2,62 $p<0,05$	63,47 ±2,69	66,85 ±2,86 $p<0,05$
4	66,08±4,74	74,33±5,49	59,97±4,02	62,38±4,41	69,50±3,37 $p<0,01$
5	70,07± 3,83 $p<0,05$	79,64± 3,91 $p<0,05$	65,67 ±4,16 $p<0,05$	66,24 ±3,48 $p<0,05$	70,41 ±3,63 $p<0,05$
6	72,06±3,53 $p<0,01$	81,53±3,38 $p<0,01$	65,98±3,35 $p<0,05$	67,18±2,98 $p<0,05$	71,69±3,04 $p<0,01$
7	70,08±2,87 $p<0,01$	77,24±,21 $p<0,01$	66,30 ±3,44 $p<0,05$	68,53 ±2,91 $p<0,01$	70,54 ±2,83 $p<0,01$
8	71,44±3,26 $p<0,05$	81,42±3,28 $p<0,01$	65,59±2,65 $p<0,05$	68,15±2,74 $p<0,05$	71,65±2,62 $p<0,05$
9	73,80±3,05 $p<0,01$	82,44±3,21 $p<0,01$	69,48±2,62 $p<0,01$	69,97±2,10 $p<0,01$	73,92±2,37 $p<0,001$
10	71,87 ± 3,26 $p<0,05$	80,14± 4,60 $p<0,01$	69,07 ±2,88 $p<0,01$	71,13 ±3,20 $p<0,01$	73,39 ±3,29 $p<0,01$
17 fteractio	74,05 ± 3,74 $p<0,01$	81,53± 3,74 $p<0,05$	71,48 ±3,49 $p<0,01$	72,08 ±3,66 $p<0,01$	73,60 ±3,61 $p<0,01$

These data largely refute the ideas of those authors [27] who have proved that CB can be effectively used for the purpose of raising the anaerobic threshold and obtaining the "doping effect". The said "doping effect" is however transient and fails to produce the long-term aftereffect obtained when using the method under study and therefore fails to bring about any persistent changes in the organism's functional state.

Thus, according to our research results, a ten-day CB course at an individually fitted frequency brings about reliable changes in the HRV indices under study as well as its derivaties. It is known [30] that HRV is an integral index showing interactions of three HR regulating factors: reflex sympathetic factor, reflex parasympathetic factor and humoral-metabolic-mediator medium. Changing HR is a universal prompt response of the whole organism to any external stimulus and characterizes a balance between the sympathetic tonus and the parasympathetic tonus. Therefore our findings showing reliable changes in HRV and FND indices suggest that CB at the maximum peak frequency in the HR LF range normalizes examinees’ sympathovagal balance. The CB course had a pronounced effect on the activity of both the parasympathetic VNS (RMSSD, pNN50, Dx) and the sympathetic VNS (Amo) as well as contributed to the cumulative effect of vegetative regulation (SDNN). The CB course also effected considerable changes in the stress-index of regulatory systems (Si), which is indicative of adaptive changes in the examinees’s organisms. It is important to emphasize that CB also brought about significant changes in the HRV wave indices reflecting the internal structure of a number of cardiointervals and providing insights into the mechanisms underlying the observed final effect of regulatory influences. The mentioned changes concerned both the HRV spectrum aggregate power indices (TP) and its components (HF and LF), i.e. autonomic and segmenal HR regulation levels. The most significant increase of the spectrum power (if compared to the same indices during sponteneous breathing) occurred in the LF HR range on the frequency of about 0.1 Hz as a response to CB. According to A.R.Kiselyov et al. [38, 39], HRV spectral components characterize the HVCS state in any particular time point, the low-frequency (LF) range of the HRV spectrum being a result of functioning of central SVUS mechanisms and the high-frequency (HF) range reflecting interactions between the cardiovascular and respiratory regulation centres during spontaneous breathing. It seems fair to suppose that the recorded phenomenon of LF-component increasing more significanly than the HF component under CB can be put down to central and vegetative respiration-dependent synchronization between the respiratory system and the CVS and suggests increased baroreflex regulation based on the resonance effect in the HR spectrum under CB at frequencies corresponding to oscillation frequencies of the said spectrum.

Thus, the LF-component of the HRV spectrum is a marker of the HVCS functional state, which should be investigated under CB at a frequency that corresponds to the frequency of localisation of the maximum peak of HR power in the low-frequency range.

It must be noted that the reliable increase of HRV derivative indices, which have been obtained using the FND method, indicates that CB at an individually fitted frequency ensures regulation of HR controlling functions at different levels (autonomic, vegetative, hypothalamohypophysial and central ones) and, hence, helps to improve adaptive capabilities of the organism as a whole.

Consequently, the dynamics of HRV and FND indexes suggests that an individually fitted frequency CB course can selectively modify basic HR regulation mechanisms important for adaptation, restoring intersystem connections (largely due to normalization of vegetative regulation), which brings about activation of the organism’s inner reserves, nonspecific resistance mechanisms, neuroendocrinal regulation optimisation and enhancement of physiological reserves as well as helps to normalize the functional state of the organism as a whole.

This can probably be explained by the fact that a feedback system is of great importance for proper functioning of any oscillatory control circuit, and HVCS is an oscillatory control circuit, too [10] The nature of an efferent signal will depend on the characteristics of the afferent information entering the oscillatory circuit control centre. Qualitative diversity of afferent information, which is related to manifold factors surrounding the system, generates an efferent signal corresponding to specific conditions, which is an optimum way of functioning of a control system. Introduction of a harmonic component whose frequency coincides with the basic frequency of the control centre oscillations into an afferent signal causes certain standardization of afferent information during a time interval in this circuit, i.e. synchronization of control mechanisms in line with environment conditions is possible. It is therefore possible to modify characteristics of the organisms's own oscillatory processes based on the resonance effect in the HRV spectrum by means of CB in the HR oscillation frequency range.

Thus, using CB at a frequency selected individually on the basis of the previously made HRV record can be viewed as introduction of a periodic component into the external signal for the purpose of harmonizing a human being's vegetative control system, and reliable positive changes in examinees' HRV and FND indices take place due to the fact that endogenous rhythms adjust themselves to the external CB-set rhythm. Indeed, many investigations show cardiorespiratory synchronization, i.e. synchronization between the basic HR and the respiratory rhythm [6]. Meanwhile, increasing synchronization of heart and respiratory rhythms is viewed as an improvement of adaptive capabilities of the CVS and the organism as a whole. Yet, it will be possible to make any final conclusions regarding synchronization changes of the rhythmic processes under study only when simultaneous records of the HRV and the pneumogram are made and the crosscorrelation coefficient is calculated, which is the object of our subsequent research. If synchronization is detected, it will be evidence of adequate interaction of CVS functinoal components when adapting to CB at an individually fitted frequency.

CONCLUSION

1. Controlled breathing whose frequency corresponds to the frequency of localisation of the maximum peak of heart rate power in the low-frequency range is a powerful mechanism for controlling heart rate and modifying functional state as a whole.
2. It is possible to investigate HVCS own oscillatory processes based on the resonance effect in the HRV spectrum during controlled breathing at a frequency corresponding to the frequency of localisation of the maximum peak of heart rate power in the low-frequency range.
3. Increased values of indices obtained by means of statistical analysis of HRV SDNN (by 28%), pNN50 (by 71%; $p < 0.01$) and RMSSD (by 30%; $p < 0.05$) suggest that, as a result of a CB course whose frequency corresponds to the frequency of localisation of the maximum peak of heart rate power in the low-frequency range, the activity of the autonomic circuit and the parasympathetic regulation system intensified and regulation of living functions was optimized.
4. HRV geometrical analysis methods showed that CB at an individually fitted frequency caused an increase in the values of Dx index (by 17%; $p < 0.01$) accompanied by a decrease in the values of Amo index (by 19 %; $p < 0.01$), indicating activation of the parasympathetic VNS, activation of the autonomic regulation circuit and reduced centralization of heart rate control.
5. The CB course at an individually fitted frequency brought about a significant Si decrease (by 26 %), which suggests increased vagal effects on the heart rate as well as reduced stress level of regulatory sustems.

6. An increase of the aggregate spectrum power (by 77 %; p <0.001) induced by CB at the frequency coinciding with the frequency of heart rate spectrum LF-component oscillations is evidence of intensified vegetative effect on heart rate. The increase of the LF spectrum component power (by 112%) is much more significant than the increase of the HF component power (by 69 %; p <0.01), which can be put down to central and vegetative respiration-dependent synchronization between the respiratory system and the cardiovascular system and suggests increased baroreflex regulation on the basis of the resonance effect in the heart rate spectrum under CB at frequencies corresponding to oscillation frequencies of the said spectrum.
7. The LF-component of the HRV spectrum is a marker of the functional state of the heare rate vegetarive control system, which should be investigated during controlled breathing at a frequency that corresponds to the frequency of localisation of the maximum peak of heart rate power in the low-frequency range.
8. The reliable increase of HRV derivative indices, which have been obtained by means of fractal neurodynamics method, indicates that controlled breathing ensures regulation of heart rate controlling functions at different levels (autonomic, vegetative, hypothalamohypophysial and central ones) and, hence, helps to improve adaptive capabilities of the organism as a whole.
9. Changes in the indices of heart rate variability and biorhythms fractal neurodynamics in examinees practising controlled breathing at the heart rate spectrum oscillation frequency depend on the duration of the controlled breathing course: reliable changes were registered in the parameters under study only after the 3rd CB session and the maximum effects of the CB course were recorded only by the 9th or 10th day.
10. A CB course has a marked aftereffect, as is suggested by a reliable change in the indices of heart rate variability and fractal neurodynamics 7 days after the termination of the course.

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Чуян Е.Н. Изменение показателей вариабельности ритма сердца и фрактальной нейродинамики в условиях управляемого дыхания на частоте колебаний спектра сердечного ритма / Е.Н. Чуян, Е.А. Бирюкова, Т.В. Заячникова // Ученые записки Таврического национального университета им. В.И. Вернадского. Серия «Биология, химия». – 2012. – Т. 25 (64), № 2. – С.176-190.

Изучены изменения показателей вариабельности сердечного ритма и фрактальной нейродинамики в условиях управляемого дыхания на частоте колебаний спектра сердечного ритма. Показано, что управляемое дыхание, частота которого соответствует частоте локализации максимального пика мощности сердечного ритма в низкочастотном (LF) диапазоне является мощным механизмом управления сердечным ритмом и изменением функционального состояния организма в целом. Изучение свойств собственных колебательных процессов системы вегетативного управления ритмом сердца возможно на основе эффекта резонанса в спектре сердечного ритма при воздействии управляемого дыхания с частотой, соответствующей частоте локализации максимального пика мощности сердечного ритма в низкочастотном (LF) диапазоне.

Ключевые слова: управляемое дыхание, вариабельность сердечного ритма, фрактальная нейродинамика, система вегетативного управления ритмом сердца.

Чуян О.М. Зміна показників варіабельності ритму серця і фрактальної нейродинаміки в умовах керованого дихання на частоті коливань спектру серцевого ритму / О.М. Чуян, О.О. Бірюкова, Т.В. Заячнікова // Вчені записки Таврійського національного університету ім.В.І. Вернадського. Серія „Біологія, хімія”. – 2012. – Т. 25 (64), № 2. – С. 176-190.

Вивчені зміни показників варіабельності серцевого ритму і фрактальної нейродінаміки в умовах керованого дихання на частоті коливань спектру серцевого ритму. Показано, що кероване дихання, частота якого відповідає частоті локалізації максимального піку потужності серцевого ритму в низькочастотному (LF) діапазоні є потужним механізмом управління серцевим ритмом і зміною функціонального стану організму в цілому.

Вивчення властивостей власних коливальних процесів системи вегетативного управління ритмом серця можливо на основі ефекту резонансу в спектрі серцевого ритму при дії керованого дихання з частотою, відповідній частоті локалізації максимального піку потужності серцевого ритму в низькочастотному (LF) діапазоні.

Ключові слова: кероване дихання, варіабельність серцевого ритму, фрактальна нейродинаміка, система вегетативного управління ритмом серця.

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