Report

Issues of health evaluation during simulated space mission to Mars

Part 3. Assessment of adaptation reactions in the participants of the long-term medical & ecological investigations during the experiment Mars-500

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Abstract

The paper presents the results of the long-term medical & ecological investigations conducted during the experiment Mars-500. Methodology of conducting the long-term medical & ecological investigations and the applied methods are considered. The results are presented in the materials of the research conducted in Russian Federation and Republic of Belarus (Moscow, Syktyvkar, Yekaterinburg, Izhevsk, Magadan and Minsk). For comparative evaluation of the functional state of different reference groups the notion of "ecological stress" was introduced. It depends upon the degree of dominance of the activity of the sympathetic member of the regulatory system over the parasympathetic member. Application of probabilistic approach to the assessment of the functional state and adaptation level with the FR (functional reserve) and the DT (the degree of tension) of the regulatory mechanisms proved the detected peculiarities of the heart rhythm vegetative regulation. Clear dependency of the functional state of the volunteers on geographic location of regions and climatic parameters is observed. Almost every HRV indicator is characterized by seasonal dynamics. Seasonal dynamics data is exemplified by the research conducted in Yekaterinburg and Syktyvkar.

Keywords

Medical and ecological investigations • Research • Adaptation • Prenosological diagnostics • Functional state • Heart rate variability • Ecological stress

Imprint

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Introduction

During the experiment "Mars-500" flight conditions to Mars and space crew life were simulated. Simultaneously satellite investigations of the reference groups of volunteers living and working in natural social and work environment were conducted. These investigations were important for scientific analysis of the health changes in the crew of Mars-500 experiment. The group of people spent almost two years being isolated and experiencing the influence of different factors (isolation, hypomobility, psychological and emotional tension, etc.). These factors produced significant influence on the human body, its adaptive abilities and regulatory mechanisms. Test experiments are to be conducted where similar groups of people would be under natural conditions influenced by different environmental factors, e.g., climatic and geographical, working, social and living conditions. Health criteria and pathology risks can be identified only when comparing the adaptive reactions of the groups of people being put under simulated and regulated environmental conditions, with the reactions of the similar groups under natural conditions.

In this connection the project "Long-term medical and ecological investigations" supported by General Committee of the Russian Academy of Science was developed. As in case of the basic experiment conducted with the participation of the European Space Agency, parallel international investigations were conducted in Russia, in Europe (the Czech Republic and Germany) and in America (Canada and the USA). Thus, a set of adaptive reactions determined by climatic, ethnical, geographical, working and social differences was obtained. The conducted investigations can be called medical & biological as both the inner risk factors and environmental stress influence are considered. One of the main objectives of the present research work was the development and scientific rationale of the evaluation criteria of health and health risks with practically healthy people under different social and ecological conditions. Of great importance in the conducted investigations is examination of the novel methods of assessment and forecasting of health and adaptive abilities. These methods are developed in cosmic medicine with regard to problems of practical healthcare and applied physiology. Investigations with groups of practically healthy people in different climatic and geographical regions provides information for future application of the results of MARS-500 experiment.

In the present paper the main attention is given to the results of medical & ecological investigations conducted in the cities of Russian Federation and Republic of Belarus (Moscow, Yekaterinburg, Syktyvkar, Izhevsk, Magadan and Minsk).

Materials and methods

152 volunteers (13 groups) participated in the investigations. 6 participants (the first group) were put in a sealed ground-based facility. The other (satellite) groups (6 – 18 people in each group) were situated in 12 cities around the world (s. Table 1). The groups included mainly the intellectual workers (research laboratory staff, engineers, economists, teachers).

Table 1. *Participants of experiment MARS-500*

City	Number of participants	Number of investigations
Moscow (MARS-500)	6	120
Moscow	16	139
Voronezh	14	61
Syktyvkar	17	232
Yekaterinburg	12	146
Magadan	20	254
Izhevsk	11	103
Minsk (Republic of Belarus)	10	127
Almaty (Kazakhstarn)	18	221
Berlin (Germany)	10	75
Prague (Czech Republic)	8	61
Toronto (Canada)	6	98
Poulsbo (USA)	4	114

Similarity of investigations in all regions was provided by application of the hardware and software complex Ecosan-2007 [1]. Only in Canada and the USA the "Heart Wizard" device (product of the American company "Biocom Technologies") was applied instead [2]. The device is used for analysis of HRV using the photoplethysmographic ear sensor with the application of Internet technology. The computer software of the device was modified to obtain the results answering the data recorded with the hardware and software complex Ecosan-2007.

Research report of the investigations of all reference groups covered monthly ECG recording during 5 minutes at rest and 15 minutes with respiratory tests, filling the special question form concerning lifestyle, loads and possible complaints during the month. Arterial pressure, height and weight were measured. All experiment participants signed the informed consent statement. The research reports were approved by Commission on Bioethics. To provide the uniformity of the investigations in all regions a special procedure manual was prepared [3].

The examination resulted in preliminary findings and formation of the file containing the results of the conducted investigation in the individual database with its further communication to Analytical Center. For exchange of the information as well as methodological and technical support a special website was designed [4]. During the investigations the average results for the cities and weather conditions were displayed.

Prenosological approach described in publications [5, 6, 7] was used when assessing the results.

Results and discussion

Figure 1 shows distribution of the satellite groups from several regions of Russia and Republic of Belarus according to age and body mass index (BMI). We can observe minor but significant ($p<0.001$ according to F-ratio test) differences of age (from 28.9 in Minsk to 35.1 in Moscow) and body mass index (from 23.6 in Minsk to 26.4 in Moscow). When comparing the results of physiological and medical investigations these differences should be taken into account. The exception is the group from Izhevsk which is younger and has minor age differences (its participants are students).

Average group values of certain indicators of functional state evaluation in the groups are represented in Table 2. It can be observed that in Minsk, Syktyvkar and Moscow heart rate variability tends to rise. The highest arterial pressure rate (systolic and diastolic) is observed in Magadan and Moscow.

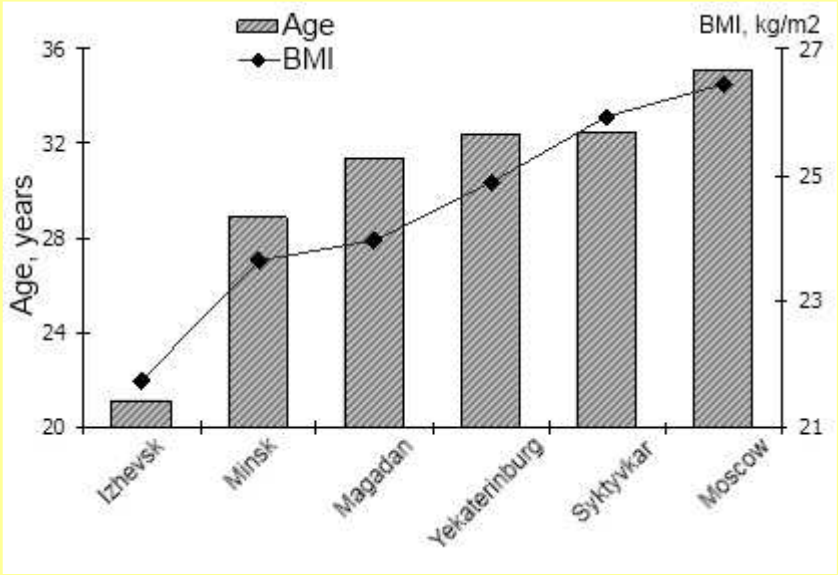

Figure 1. *Age and body mass index (BMI) in the satellite groups during experiment MARS-500.*

In Yekaterinburg the lowest heartbeat rate and arterial pressure values are observed. When comparing the data on functional state of cardiovascular system with age and body mass index it can be supposed that the observed differences in cardiovascular homeostasis are connected

not only with age and body peculiarities. This speculation can be proved when comparing the indicators of self-regulation in the examined groups. Index of stress reflects the sympathetic regulation level and degree of tension whereas pNN50 reflects the parasympathetic level. The most favourable state of regulatory mechanisms is observed with the group form Yekaterinburg (the group has average indicators of age and BMI- body mass index), the most unfavourable state is with the group from Magadan (its indicators of age and BMI are the second among the groups). The group from Minsk shows the highest stress index values but activity of parasympathetic regulatory member remains (pNN50). The group from Izhevsk showed quite high stress-index, the parasympathetic regulation indicator was the highest.

Table 2. *Basic indicators of the operational evaluation of functional state of volunteers in different regions*

	Izhevsk n=103	Minsk n=129	Magadan n=251	Yekaterinburg n=146	Syktyvkar n=232	Moscow n=140
heartbeat rate, BPM	72.5±1.2	79.3±1.1	72.8±0.7	70.4±0.6	74.0±0.5	74.1±0.8
systolic arterial pressure, mmHg	117.9±1.9	123.2±0.9	129.4±0.6	118.5±0.7	121.0±0.6	124.4±0.6
diastolic arterial pressure, mmHg	76.0±0.9	79.11±0.7	80.6±0.6	76.5±0.6	75.9±0.4	78.8±0.7
load index, c.u.	108.3±9.2	135.6±11.6	135.0±5.7	82.6±5.1	127.0±4.3	125.3±8.6
pNN50, %	22.7±2.3	13.8±1.3	8.7±0.7	20.9±1.4	11.4±0.8	10.7±0.9
ecological stress	37.5±7.6	70.6 ±12.4	67.2±6.3	18.8±3.9	27.2±2.9	38.9±7.2

For comparative evaluation of functional state of different reference groups the notion "ecological stress" (ES) was introduced. It is identified by degree of dominance of activity of sympathetic member of regulatory system over parasympathetic member. Correlation of pNN50 and SI, concentration index as well as heartbeat rate and arterial pressure values enable considering ecological stress. Ecological stress is the body's response to combined influence of environmental factors, it is the result of the body's adaptability to environmental conditions. Table 3 shows the average values of some indicators in 6 reference groups studied in Russia and Republic of Belarus, as well as the values of ecological stress indicators calculated from the formula SI/pNN50. Significant differences between the cities with different environmental conditions can be observed. Thus, in Minsk and Magadan the highest ecological stress level is observed. These cities have the highest average values of systolic and diastolic arterial pressure and SI whereas Magadan has the lowest pNN50 value. Probably the degree of ecological stress depends not only on geographical location of the studied group but on the complex of social, working, psychological and living conditions. Thus, Izhevsk, Syktyvkar and especially Yekaterinburg which are situated in the northern part of Russia differ from Magadan

in many parameters, whereas in Minsk which is situated southward diastolic arterial pressure and SI values hardly differ from those recorded in Magadan. It is well illustrated by the ecological stress data presented in table 2. Comparing the average SI data in the groups it is observed that the differences are determined mainly by the pNN50 value, i.e., by the degree of activity of parasympathetic member of regulatory system.

Application of probabilistic approach for evaluation of functional state and adaptability level according to FR and DT data proved the revealed peculiarities of vegetative regulation of heart rhythm and allowed to make a conclusion about the revealed differences.

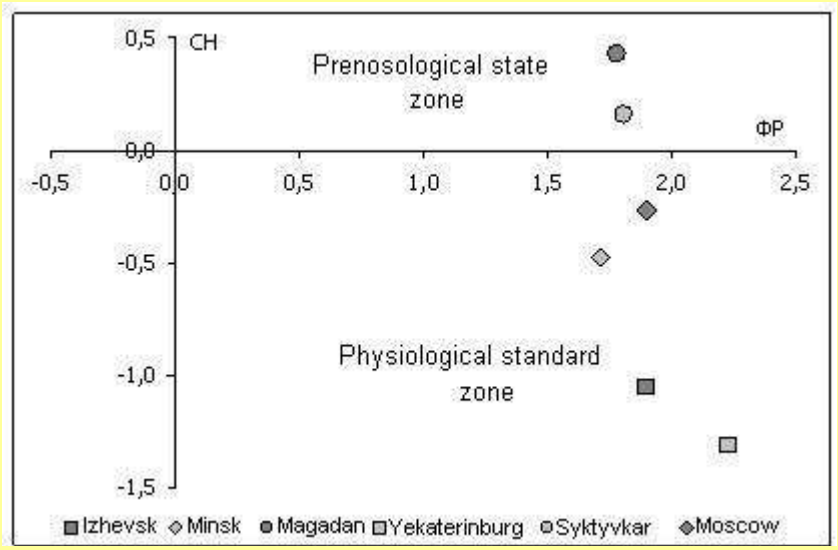

Figure 2. *Functional state in satellite groups during experiment Mars-500.*

Figure 2 shows the averaged points of functional state in functional reserve (FR) and degree of tension (DT) data recorded in different regions over a 1.5-year monitoring period. At first three zones can be identified where the functional states of regions are grouped. The first is physiological standard zone (Yekaterinburg and Izhevsk), the second is the upper limit of the norm zone and prenosological state zone (Moscow and Minsk), the third is the lower limit of prenosological state zone and physiological standard zone. The main differences are connected with increase of regulatory mechanisms tension, the exception is the group from Yekaterinburg where the lowest tension of regulatory systems was recorded whereas the FR indicator was higher compared with the other groups. During pair-wise comparison of groups using these parameters, differences ($p \leq 0.001$) by F-criterion are significant. The exceptions are groups from Syktyvkar and Magadan ($p=0.20$) and to some extent groups from Syktyvkar and

Moscow (p=0.06) as well as from Minsk and Izhevsk (p=0.03). We can assume that agreeing closely functional states recorded with groups from Syktyvkar and Magadan are due to influence of unfavourable environmental factors such as long severe winter, short summer, short daylight hours in winter and white nights in Magadan in summer. Magadan is situated in the permafrost zone. The functional states of the Moscow and Syktyvkar groups are comparatively similar. This fact can be explained by the similar age range (this indicator is the highest among the groups) and body mass index (s. Fig.1). On the contrary, groups from Minsk and Izhevsk are the youngest.

Table 3 offers the averaged probability estimate of functional states and risks of adaptation disorders in different cities. It is not surprising that the highest probability of prenosological states and adaptation health risks are observed in groups from Magadan and Syktyvkar. The second is the group from Minsk which participants are younger. In can be connected with reduction of functional reserve (the lowest FR value among all groups) due to high level of ecological stress.

Table 3. *Probability estimate of functional states and risks of adaptation disorders of volunteers in different regions*

	Izhevsk n=103	Minsk n=129	Magadan n=251	Yekaterinburg n=146	Syktyvkar n=232	Moscow n=140
Probability of prenosological state, %	24±3	24±2	36±2	16±2	32±2	24±2
Probability of normal state, %	74±3	73±3	63±2	83±2	68±2	75±2
Average risk category	1,99±0,14	2,04±0,13	2,41±0,09	1,55±0,08	2,16±0,08	1,91±0,10

The participants of the research were divided into 4 risk groups according to their average individual risk evaluation recorded during 1.5 years. The average value of the risk category (M) scores 2.09, standard deviation (SD) scores 1.34. Value 0.5 SD was taken as classification interval.

The average risk category value for the first group of people was M-0.5 SD, for the second group – up to M+0.5 SD, for the third group – up to M+1.0 SD, for the fourth group – higher than M+1.0 SD.

Estimation of the average risks of adaptation disorders in different regions proved that the most unfavourable distribution of people according to risk categories (s. Fig.3) is observed in Magadan and Syktyvkar. If in Yekaterinburg more than a half of the studied volunteers refer to the 1st risk group, in Magadan and Syktyvkar more than 70% of the volunteers refer to the

second risk group with prenosological states dominating, and probability of development of premorbid states is high.

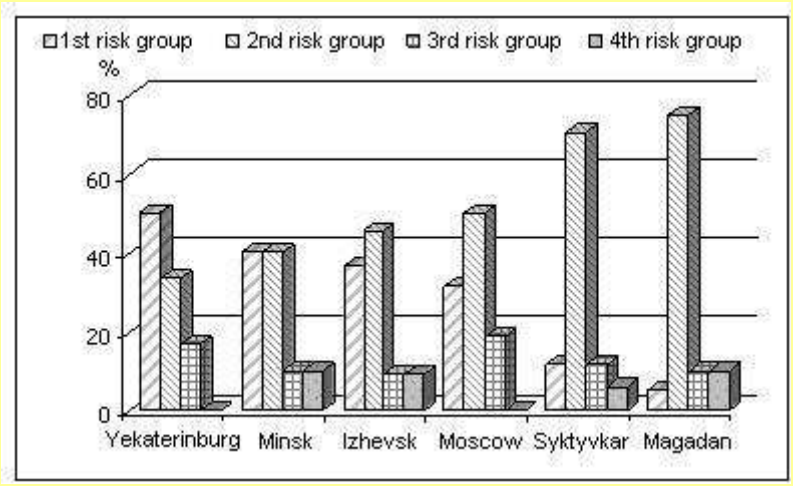

Figure 3. *Disposition of the participants of satellite investigations from different regions in experiment Mars-500 according to risk categories.*

Thus, dependency of functional states of volunteers on geographical location of the regions and climatic conditions is revealed. In this connection seasonable changes of the basic functional indicators should be considered. Figure 4 represents the graphs of average monthly values of the basic anthropometric and cardiological data for all investigations conducted in Russia and Republic of Belarus (1006 investigations). There can be observed a trend of autumn increase of arterial pressure indicators (in October and November) as well as increase of stress index and "myocardium" index. Body weight and pulse rate increase in October and July. In winter time increase of systolic arterial pressure, body weight and total power of HRV spectrum is observed. In July increase of the stress index value is observed. Thus, we should note that almost every indicator is characterized by seasonal dynamics.

Let us consider the results of investigations in certain cities. The data from Yekaterinburg (ecological stress=18.8, the average risk category = 1.55) and Syktyvkar (ecological stress=27.2, the average risk category = 2.16) are presented below. Dynamics of changes of physiological parameters in groups in these cities reveals seasonality of functional state.

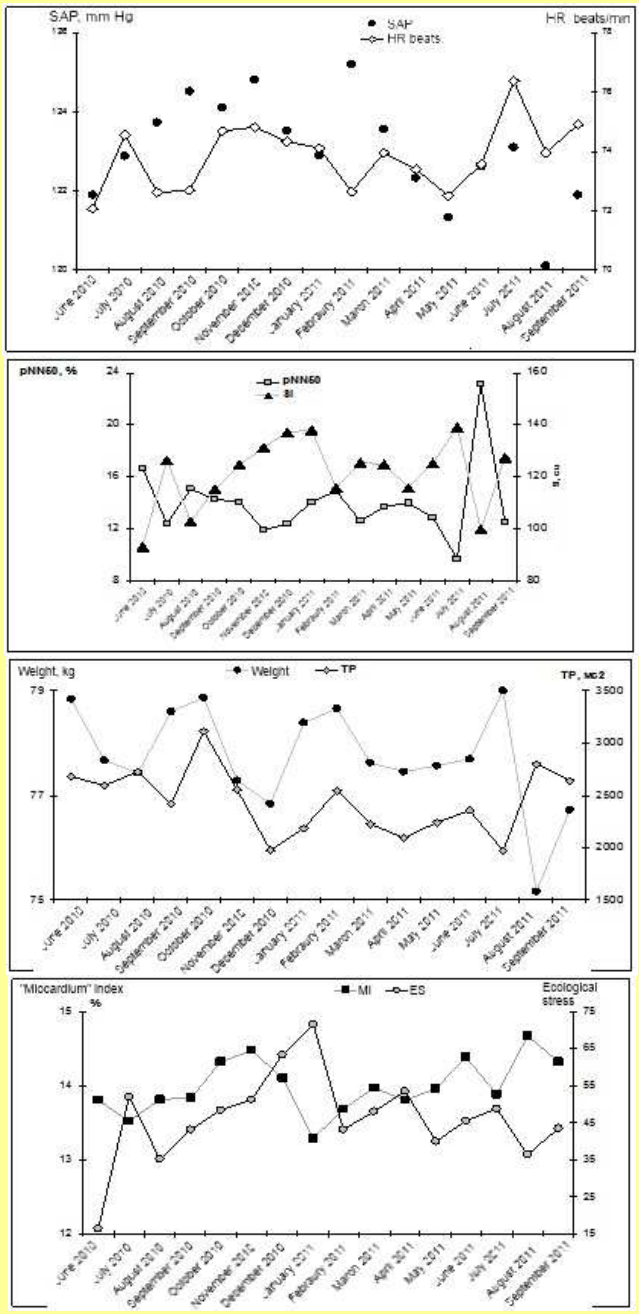

Figure 4. *Graphs of average monthly values of anthropometric and cardiological parameters.*

Investigation results in Yekaterinburg

Table 4 provides average monthly values of the parameters of cardiovascular system functional state from June 2010 to September 2011. Changes of average values of all

parameters were within the physiological norm. Changes of heartbeat rate during the year were insignificant (within 67-74 BPM) and reached maximum values in winter months (December). They decreased in summer and autumn months (from June to November).

Table 4. *Results of medical and ecological investigations in Yekaterinburg*

Month, year	heartbeat rate	pNN50	SI	TP	myocardium	RSAI
June 2010	68.67	19.99	83.35	2699.44	14.58	3.67
July 2010	69.75	21.09	75.60	4227.56	13.08	5.33
August 2010	69.55	25.05	68.14	3912.33	14.55	4.36
September 2010	70.25	20.93	91.68	4017.11	14.92	4.75
October 2010	69.90	17.40	73.78	2759.98	13.30	4.00
November 2010	69.89	22.37	68.58	3807.65	14.22	4.44
December 2010	74.40	17.44	111.42	3407.14	13.90	4.90
January 2011	70.80	24.65	78.70	3811.98	13.40	4.70
February 2011	68.00	27.99	61.15	4219.91	14.10	4.40
March 2011	73.80	17.97	89.35	3233.73	14.30	3.60
April 2011	71.50	18.52	79.89	3189.21	13.70	3.50
May 2011	67.40	27.19	64.54	3524.88	14.40	3.80
June 2011	71.25	21.45	88.19	2949.67	14.25	4.00
August 2011	71.13	24.09	83.99	2969.34	14.50	4.50
September 2011	69.78	22.48	95.00	3402.22	13.22	4.11

It should be noted that in December increase of activity of sympathoadrenal member of regulatory system was noted (increase of stress index, increase of RSAI and decrease of pNN50). In spring (March) and autumn (September) activity of this member of regulatory system was less significant. We should note that RSAI as an integral indicator changed its values smoothly from the summer period to winter period and vice versa. Besides, there was sharp increase of RSAI in July 2010 which was probably caused by extremely hot weather for that period.

Dynamics analysis of pNN50 appears to be of interest. It mainly reflects the state of the parasympathetic member of regulatory system and characterizes protective and restoring role of regulatory mechanism. As can be seen from the table, increase of pNN50 was noted in May, August and February. These are the months preceding the beginning of summer, autumn and winter seasons. There may exist two explanations of the mentioned phenomenon. We either observe the defense reaction of the body as a response to energy consumption necessary for changing the functions during the preceding season, or the body "foresees" its change to the new function level and prepares for the forthcoming loads.

"Myocardium" index is an integrative indicator of energy and metabolic changes in myocardium. It monitors seasonal changes of the functional state. Its minimum values in July, September (2011), October (2010), January and April characterize the optima of seasonal adaptive body reactions.

Results of investigations in Syktyvkar.

In Fig.5 annual dynamics of the basic indicators HRV are shown. These indicators are used to calculate the FR (functional reserve) and DT (degree of tension) for phase plane construction. An increase in the heart rate during the autumn months and reduction during the winter months is observed.

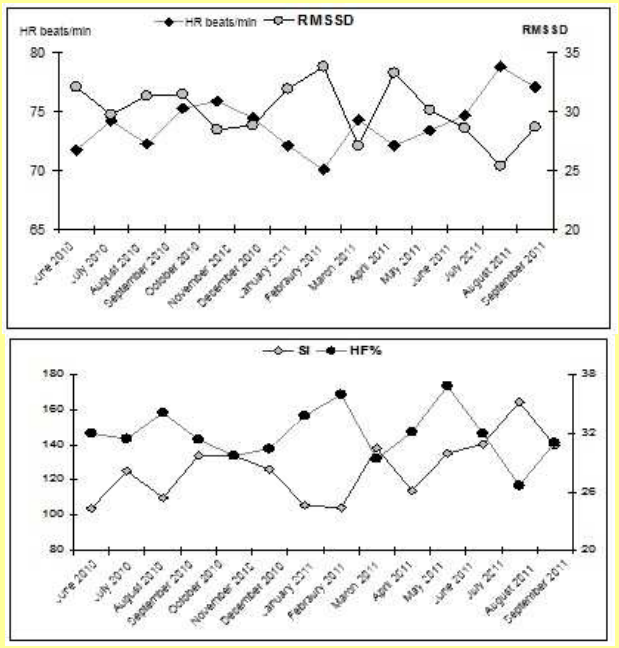

Figure 5. *Annual dynamics of the average group values of heartbeat rate, SI, pNN50 and HF.*

In October and November increase in activity of the sympathetic member of regulatory system is observed. It is evident as increase in stress index (SI), decrease in RMSSD and relative power of high-frequency content of the spectrum (HF). In January and February the stress index decreases and RMSSD and HR increase.

Figure 6 shows the phase plane constructed with the results of mathematic modeling with calculation of monthly DT and FR values presented by the points on the phase plane. Series-connected average monthly group indicators of the functional state create the phase tracking. It reflects the seasonal functional state changes. Four loops can be distinguished: autumn loop (on the right), winter loop (on the left), spring loop (in the center), summer loop (it is partly laid on the winter loop).

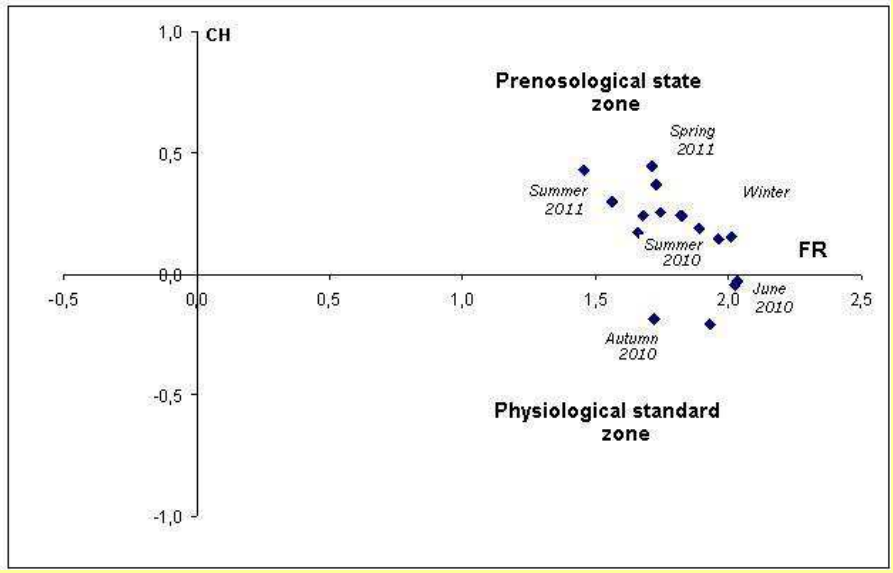

Figure 6. *Phase tracking of the 1.5-year dynamics of the functional state of the reference groupparticipants in Syktyvkar constructed according to results of the monthly HRV analysis.*

In Fig.6 geometric centers of the seasonal loops of the solution curve are shown. The centers of all loops (except autumn 2010) are situated in prenosological state zone. They differ in DT and FR values. Spring and autumn centers differ in DT values. In spring the degree of tension of regulatory systems is higher than in autumn. Centers of the summer and winter loops are similar to DT in coordinates. Though in winter the degree of tension of regulatory systems is slightly higher in case the level of functional reserves is high.

Conclusion

The results of the long-term medical and ecological investigations conducted simultaneously with the earth-bound experiment Mars-500 showed that health changes with the practically healthy people usually remain within the prenosological state zone. Although, risk of pathology development with different people changes significantly. It follows that within the same functional state of the body, the higher is the probability of pathology development, the more serious should the precautionary measures be. One of the important results of the Mars-500 experiment is successful testing of prenosological diagnostics which is a new trend in modern medicine and physiology [7].

Prenosological diagnostics studies the states on the boundary of norm and pathology, and is aimed mainly at studying healthy people having no signs of pathology. This scientific field developed in cosmic medicine to evaluate the degree of the body adaptability to spaceflight

conditions. The methods of prenosological diagnostics came into operation in 1980s during preventive examinations [8, 9], and in recent years are used to evaluate the risks of pathology development in bus drivers and pilots [1, 10]. Experiment Mars-500 offered a unique opportunity to verify effectiveness of prenosological approach for evaluation of the long-term dynamics of the functional state of healthy people living in different environmental conditions. As a conventional reference group the Martian crew was considered. The volunteers lived in controlled ecological environment. The investigations results showed that despite differences in sensitivity to ecological factors with different populations, in all cases there was observed a correlation of prenosological and premorbid state development and changes in social and working environment, seasonal changes or health problems.

Results of the long-term medical & ecological investigations prove that prenosological state zone is a place where the body interacts with environment, and problems of further development are considered [7]. Prenosological state is an unstable equilibrium between health and pathology supported by tension of regulatory mechanisms and utilization of information, energy and metabolic body reserves. Consequently further development of prenosological approach for evaluation of health and pathology development is an upcoming trend both for cosmic and preventive medicine.

Statement on ethical issues

Research involving people and/or animals is in full compliance with current national and international ethical standards.

Author contributions

R.M.B., A.P.B., I.N.S. and A.G.C. developed the concept, prepared the manuscript and analyzed the data, A.G.C. drafted the manuscript. All authors read and met the ICMJE criteria for authorship. All authors read and approved the final manuscript.

Conflict of interest

None declared.

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References

1. Baevsky RM, Berseneva AP, Bersenev EY, Denisov KF, Eshmanova AK. Problems of monitoring and forecasting of the cardiovascular system state in bus drivers. Diagnostics and treatment of cardiovascular regulatory system. Moscow2008. p. 263-86.

2. Berseneva AP, Pugachev VI, Baevsky RM, Baevsky AR, Zhirnov EN, Gribkov EN, et al. Individual dynamic prenosological monitoring based on heart rate variability analysis using «HEART WIZARD» device. Vestnik of Udmurt University. 2012:32-41.

3. Baevsky RM, Berseneva AP, Luchitskaya ES, Slepchenova IN, Chernikova AG. Assessment of health level in practically healthy people. Moscow2009. 100 p.

4. www.iki.rssi.ru/mars500.

5. Baevsky RM, Bersenev EY, Chernikova AG. Issues of health evaluation during simulated space mission to Mars. Part 1. Research methodology and methods used in experiment Mars-500. Cardiometry. 2013(2).

6. Grigoriev AI, Baevsky RM. Concept of health and space medicine. Moscow2007. 208 p.

7. Baevsky RM, Berseneva AP. Introduction into prenosological diagnostics. Moscow2008. 208p.

8. Adamovich BA, Baevsky RM, Berseneva AP. Contemporary problems of automatic assessment of the body functional state in astronautic science and preventive medicine. Space biology and aerospace medicine. 1990(6):23-31.

9. Kaznacheev VP, Baevsky RM, Berseneva AP. Prenosological diagnostics in population screening. Leningrad1981. 196 p.

10. Ushakov IB, Kniga VV, Zipa OM, Chernikova AG, Baevsky RM. Problem of prenosological control in flying assessment. 5th Russian national conference "Heart rate variability"; Izhevsk2011. p. 165-7.