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HEART RATE VARIABILITY AS THE MAIN METHOD OF ASSESSING THE FUNCTIONAL STATE OF ATHLETES PARTICIPATING IN EXTREME SPORTS

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Annotation. The aim of this study is to develop a model for early diagnosis of the functional state of extreme sports athletes, based on heart rate variability (HRV) data. Athletes had been examined with diagnostic device "Varicard 2.51", linear discriminant analysis was made on HRV data. Statistics were calculated with the "Statistica 7" software. According to discriminant analysis, athletes were divided into 4 groups by their functional state (FS) with a level of classification ability 90,66%. Developed model is precise and accurate: match of calculated results with actual FS is 80,27% for optimal FS, 97,08% for acceptable FS, 84,05% for premorbid condition, 77,08% for critical FS. The change in FS is due to the processes of athletes' adaptation to environmental conditions and the intensity of physical and psycho-emotional stress associated with the readjustment of the regulation mechanisms, which is confirmed by HRV analysis. Significant ($p<0,05$) predictive indicators of HRV (SI, SDNN, HR, CV, pNN50, Xmax, Mean RR, Xmin, AMo50, Mo, MxRMn, HFmx, RMSSD, LF/HF, CC1), which values must be used in developed LDF model, were identified. The developed forecasting model is characterized by a high informational ability (90.1%), which allows reliable ($p<0,05$) forecasting of the FS dynamics in extreme sports athletes. Developed model has a strong correlation ($r>0,70$, $p<0,05$) between FS levels, extreme sports and stress reaction in premorbid and critical state, indicated by stress-hormone concentration in saliva.

Introduction. Currently, a non-invasive method for diagnosing the activity of autonomic circuits of the nervous system, by recording an electrocardiographic (ECG) signal – heart rate variability (HRV) – is widely used in the world [12]. Studies show the association of HRV values with conditions such as pain [14], acute and chronic stress [15, 19, 16], metabolic syndrome [20, 21] depression [18], and psycho-emotional tension [17], which are common in athletes and can cause failure in their sport career and affect their future health status.

Accompanying athletes participating in extreme sports nowadays generates great difficulties for doctors, due to frequent changes in climatic conditions of sports work, leading to depletion of functional reserves of the organism. To increase professional health and improve performance in sports activities, it is necessary to determine the level of functional state of the organism (FS) in a timely and accurate manner with subsequent metabolic correction, providing an opportunity to maintain the necessary level of adaptation reserves of the athlete's organism.

A large number of modern physiologists have studied the processes of human body adaptation to extreme physical loads [1, 2, 3, 4, 5, 11]. Relying on their scientific researches, we decided to develop objective criteria of FS level estimation in athletes participating in extreme sports. The obtained data will clearly increase diagnostic accuracy of HRV method and provide an opportunity to objectively assess the effectiveness of metabolic correction when accompanying athletes participating in extreme sports.

The purpose of this research is to develop a model for early diagnosis of the level of FS of athletes participating in extreme sports, based on significant indices of HRV.

Methods and organization. The prediction model was developed on 60 healthy athletes participating in extreme sports, whose age was 25.1±3.1 years in average, 1521 dynamic examinations were conducted. Sports qualification corresponded to the first adult grade and higher (according to Unified Sports Classification System of the USSR and Russia). The background HRV registration was performed in optimal FS at the location of permanent residence. At the moment of examination, all athletes were healthy, well rested and in a state of maximal working capacity. Dynamic study was conducted during training camp, before and after performance at the competition. The study was designed in accordance with the Helsinki Declaration of 1964, as amended in October 2013.

HRV values were recorded using the “Varicard 2.51” hardware and software complex with the “ISCIM 6.1” (Build 2.8) software installed in accordance with the requirements of the European Society of Cardiology [12]. The examination was performed at rest from 9am to 12am in the sitting position. The recording duration was five minutes in a noise-insulated room at air temperature 22±1 ^{o}C.

The final data analysis did not include athletes who had one of the following criteria at the time of the examination: alcohol consumption, sleeping less than 8 hours in the last 24 hours, eating, or smoking in the last two hours.

Time domain parameters of HRV were recorded and calculated using “Varicard 2.51”: heart rate (HR, beats/minute), mean RR interval duration (MeanRR, ms) maximal RR interval duration (XMax, ms), minimal RR interval duration (XMin, ms), XMax-XMin difference (MxDMn), XMax/XMin ratio (MxRMn), the root mean square of successive differences between normal heartbeats (RMSSD, ms), the number of pairs of RR intervals that differ by more than 50% as a percentage of the total number of RR intervals in the array (pNN50), the standard deviation of NN intervals (SDNN, ms), coefficient of variation (CV, %), dispersion (D, ms2), mode (Mo, ms), amplitude of mode (AMo50, %), autocorrelation function index 1 (CC1), autocorrelation function index 0 (CC0), stress index of regulatory systems (SI) according to R.M. Baevskij [3, 13].

In the frequency domain, after filtering the spectral signal (for a comprehensive visual representation of the filtered frequencies) [13], we calculated the total power of the spectrum (TP, ms2), the absolute power of the high-frequency range (HF, ms2), absolute power of low frequency range (LF, ms2), absolute power of very low frequency range (VLF, ms2), absolute power of ultra-low frequency range (ULF, ms2), maximum high frequency component (HFmx, ms2/Hz), maximum low frequency component (LFmx, ms2/Hz) very low frequency component maximum (VLFmx, ms2/Hz), ultra-low frequency component maximum (ULFmx, ms2/Hz), HF spectrum maximum period (HFt, ms2/Hz), LF spectrum maximum period (LFt, ms2/Hz), VLF spectrum maximum period (VLFt, ms2/Hz) period of ULF maximum spectrum (ULFt, ms2/Hz), relative power of high-frequency range (PHF, %), relative power of low-frequency range (PLF, %), relative power of very low frequency range (PVLF, %), LF/HF ratio, VLF/HF, centralization index (VLF+LF)/HF [2, 13, 14].

The results of this work are based on the methods of statistical processing of HRV indices taking into account the initial background, psycho-emotional and physical loads, as well as indices of clinical blood analysis and the ratio of stress hormones (cortisol/dehydroepiandrosterone) in saliva. The results of the study were processed using Excel for Windows 2016, for data systematization we used specialized package of applied programs of statistical analysis “Statistica 7” [10]. Significance ($p<0,05$) of differences between groups for nonparametric and dependent samples was determined using Mann-Whitney U-test. Correlation analysis of the measured indices and FS was performed using Spearman's rank correlation method. The method of discriminant analysis [10] was used to build a prognostic diagnostic model of FS level determination.

Results and discussion. Analysis of HRV in athletes participating in extreme sports showed that depending on the psycho-emotional tension and intensity of physical exertion significant differences in the indices characterizing the levels of FS are registered.

In critical FS in athletes there were registered the signs of disturbance in mechanisms of regulation of cardiac activity and depletion of neurohormonal systems, due to prolonged stress, which is confirmed by low levels of cortisol and dehydroepiandrosterone (DHEA). In these athletes, the development of acute, persistent infectious diseases and exacerbation of chronic diseases were registered more often [8].

In the premorbid FS in athletes there was registered a state of relative depletion of hypothalamic-pituitary-adrenal system, characterized by low levels of DHEA and normal or elevated levels of cortisol in saliva. In this group of athletes, according to the classification of P.M. Baevskij, a low level of the body's adaptive reserves was noted [1, 6, 9], carrying out stress testing showed a decrease in the functional capacity of the body in 1,5 times as compared to the optimal state of health.

In an acceptable FS, the athletes tolerate the adaptation to the new environmental factors well.

In the optimal FS the activity of regulatory systems in athletes participating in extreme sports is registered within the physiological norm and is characterized by a high level of adaptive reserves, which contributes to easy adaptation to new conditions of sports work [9].

Using Statistica 7 program we analyzed the obtained data in order to identify the most significant predicative signs for further inclusion in the model of differential diagnosis of FS level of athletes participating in extreme sports.

The method of linear discriminant analysis made it possible for us to develop a model for predicting the FS of athletes based on four levels: LDF4 corresponds to the optimal level; LDF3 to an acceptable level; LDF2 to a premorbid level and LDF1 to a critical level.

Based on the results of linear-discriminant function computing we determined significant predictors and their coefficients, which influence the assignment of a particular athlete to one of the FS levels, for this purpose we must take into account such significant ($p<0,05$) parameters as: SI, SDNN, HR, CV, pNN50, Xmax, Mean RR, Xmin, AMo50, Mo, MxRMn, HFmx, RMSSD, LF/HF, CC1.

In order to solve the problem of developing a final discriminant model, we used a stepwise selection of the most significant ($p<0,05$) characteristics with a reliability level of at least 95%. The first table shows the values included in the model with the gradation levels of the features, their significance and coefficients according to each function.

To determine the level of FS, as well as to predict possible changes in the state of health, we solved the problem using LDF formulas, substituting the HRV values included in the model, obtained during the examination of a particular athlete (Table 1). According to the results of solving the equations of the discriminant function, the highest value of LDF corresponds to FS. For example, if LDF2 is the highest, then this athlete most likely has premorbid FS.

Table 1

HRV parameters included in the model of differential diagnosis of FSO and their degree of severity

Parameters	Abbreviation	Coefficients				p-level
		LDF1	LDF2	LDF3	LDF4	
SI	X1	0,23	-0,26	-0,26	-0,25	0,000
SDNN	X2	5,70	5,45	5,46	5,63	0,000
HR	X3	52,21	50,38	49,59	49,48	0,000
CV	X4	-38,49	-35,56	-34,83	-35,84	0,000
pNN50	X5	-0,42	-0,46	-0,49	-0,46	0,000
Xmax	X6	-0,31	-0,31	-0,30	-0,29	0,000
Mean RR	X7	2,70	2,64	2,63	2,62	0,000
Xmin	X8	0,85	0,85	0,84	0,82	0,000
AMo50	X9	0,88	0,87	0,77	0,70	0,000
Mo	X10	-0,07	-0,07	-0,07	-0,06	0,000
MxRMn	X11	177,37	176,29	175,46	172,96	0,007
HFmx	X12	0,05	0,04	0,04	0,04	0,002
RMSSD	X13	-0,13	-0,11	-0,10	-0,10	0,000
LF/HF	X14	0,25	0,39	0,72	0,94	0,020
CC1	X15	50,46	50,95	47,93	48,72	0,039
Constant		-3438,35	-3244,45	-3177,27	-3172,73	

If LDF1>LDF2, LDF3 and LDF4, athletes in extreme sports are most likely to have a critical level of FS; if LDF2>LDF1, LDF3 and LDF4, athletes in extreme sports have the highest probability of premorbid FS; at LDF3>LDF1, LDF2 and LDF4, athletes of extreme sports have the highest probability of an acceptable FSO level; if LDF4>LDF1, LDF2 and LDF3, athletes of extreme sports have the highest probability of an optimal FS level.

A statistically significant ($p<0,05$) model of early differential diagnosis of FS is based on four levels:

– Critical level of functional state (LDF1)

$$LDF1= -3438,35 + (-0,23 \times X1) + 5,70 \times X2 + 52,21 \times X3 + (-38,49 \times X4) + (-0,42 \times X5) + (-0,31 \times X6) + 2,7 \times X7 + 0,85 \times X8 + 0,88 \times X9 + (-0,07 \times X10) + 177,37 \times X11 + 0,05 \times X12 + (-0,13 \times X13) + 0,25 \times X14 + 50,46 \times X15;$$

– Premorbid level of functional state (LDF2)

$$LDF2= -3244,45 + (-0,26 \times X1) + 5,45 \times X2 + 50,38 \times X3 + (-35,56 \times X4) + (-0,46 \times X5) + (-0,31 \times X6) + 2,64 \times X7 + 0,85 \times X8 + 0,87 \times X9 + (-0,07 \times X10) + 176,29 \times X11 + 0,04 \times X12 + (-0,11 \times X13) + 0,39 \times X14 + 50,95 \times X15;$$

– Acceptable level of functional state (LDF3)

LDF 3= -3177,27 + (-0,26 × X1) + 5,46 × X2 + 49,59 × X3 + (-34,83 × X4) + (-0,49 × X5) + (-0,30 × X6) + 2,63 × X7 + 0,84 × X8 + 0,77 × X9 + (-0,07 × X10) + 175,46 × X11 + 0,04 × X12 + (-0,1 × X13) + 0,72 × X14 + 47,93 × X15;

– Optimal level of functional state (LDF4)

LDF 4= -3172,73 + (-0,25 × X1) + 5,63 × X2 + 49,48 × X3 + (-35,84 × X4) + (-0,46 × X5) + (-0,29 × X6) + 2,62 × X7 + 0,82 × X8 + 0,7 × X9 + (-0,06 × X10) + 172,96 × X11 + 0,04 × X12 + (-0,1 × X13) + 0,94 × X14 + 48,72 × X15.

The results of the linear-discriminant function have a sufficiently high information capacity (90,7%), which is confirmed by the results of stress testing, according to the results of which there is a significant 1,5 and 1,9 times decrease in functional performance of athletes in premorbid and critical state of the body, and the correlation relationship is in a strong positive relationship ($r>0,70$; $p<0,05$). Rank correlation of the results of general clinical blood analysis according to L.H. Garkavi classification (determination of types of adaptive reactions) with FS levels shows an average negative correlation ($-0,69<r<-0,30$; $p<0,05$) with only two types of adaptation – overactivation and stress, they coincide in 61,8% of cases with premorbid and critical state of the body of athletes participating in extreme sports. Additionally, as objectivizing diagnostic indicators of the early period of tension of mechanisms of regulation of hypothalamic-pituitary-adrenal system, we analyzed the concentration of hormones in the saliva of athletes by high performance liquid chromatography-mass spectrometry (HPLC-MS). The calculated ratios of cortisol to dehydroepiandrosterone had a strong positive correlation ($r>0,70$; $p<0,05$) with LDF prediction and stress state severity in athletes.

According to the data presented in the classification matrix of FS prediction in an athlete participating in extreme sports (Table 2), we see that in the fourth group of optimal condition the proposed model provides coincidence of the predicted level, with the real result in 80,3% of cases. In the third and second FS groups, the coincidence of the predicted diagnosis with the real results was 97,1% and 84,1%, respectively. In the first critical FS group, the estimated model provided a predictive match in 77,1% of cases. The classification ability to determine the level of FS of athletes participating in extreme sports provides a predicted match in 90,1% of cases with real results.

Table 2

Classification matrix of prognosis of functional state of the athlete participating in extreme sports

Diagnosis	%	LDF1	LDF2	LDF3	LDF4	Total
Critical functional state	77,08	4	22	0	0	96
Premorbid functional status	84,05	5	195	32	0	232
Acceptable functional state	97,08	0	10	898	17	925
Optimal functional state	80,27	0	0	59	240	299
Overall	90,66	9	227	989	275	1552

Note: by rows - classification according to the database; by columns - classification according to the forecast

The developed discriminant model of differential diagnosis of FS level according to HRV analysis is based on 15 statistically significant ($p<0,05$) simple indices (SI, SDNN, HR, CV, pNN50, Xmax, Mean RR, Xmin, AMo50, Mo, MxRMn, HFmx, RMSSD, LF/HF, CC1) and has rather high (90,1 %) information capacity.

Calculations using the developed formula can be performed with the help of a calculator or to simplify the calculation build an algorithm in the program Excel. We have developed a free application for a personal computer.

This model can be used at any stage of athlete support. An important point is its simplicity, availability and scalability, because a portable HRV headset and a personal computer are sufficient to perform measurements.

It should be emphasized that screening by HRV parameters is a primary diagnostic procedure aimed to identify athletes with a high probability of critical and premorbid functional state of the body. Additional clinical and laboratory examinations are required to make a final decision. This model is only a primary diagnostic tool, which in the aggregate allows to assess FS in athletes at the earliest stage and initiate metabolic correction at the point of its maximum effectiveness.

Conclusion.

1. The change in the FS is caused by the processes of its adaptation to the environmental conditions and the intensity of physical and psycho-emotional loads associated with readjustment of the regulation mechanisms, which is confirmed by recording the HRV.

2. Significant ($p<0,05$) predictive HRV parameters (SI, SDNN, HR, CV, pNN50, Xmax, Mean RR, Xmin, AMo50, Mo, MxRMn, HFmx, RMSSD, LF/HF, CC1) were determined, whose values should be substituted into the developed formulae of linear discriminant function.

3. The developed prediction model is characterized by high information capacity (90,1%), which allows timely and reliable ($p<0,05$) prediction of FS level in athletes participating in extreme sports.

4. For the developed model a strong correlation ($r>0,70$; $p<0,05$) of FS level in extreme sports athletes, in the onset of a pronounced stress reaction in premorbid and critical condition with the results of the ratio of hormone concentration in saliva was revealed.

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