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Original Article

Determinants of the functional state of sportsmen using heart rate variability measurements in tests with controlled respiration

GUZII O. V.[1], ROMANCHUK A. P.[2]
[1]Lviv State University of Physical Culture, UKRAINE
[2] Odesa Medical Institute of International Humanitarian University, UKRAINE

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Abstract:

According to the results of the study of the cardiopulmonary resuscitation system of 104 qualified athletes aged 20.6±0.9 using spiroarteriocardiorhythmograph (SACR), which included short-term registrations at spontaneous respiration (SR) and controlled respiration 6 (CR_6) and 15 times per minute (CR_{15}), an evaluation system of heart rate variability indicators and its reactivity were developed. The elaborated system includes the determination of the individual ranges of HRV indicators, taking into account the criteria of the percentile distribution at spontaneous and controlled respiration, and allows to define HRV indicators as norm, moderate and expressed decrease and increase. Based on received individual ranges, "ranges of changes" in controlled respiration tests are determined. The "ranges of changes" that have some physiological determinants and allow characterizing the reactivity of heart rate regulation. On the example of a survey of qualified athletes with different levels of functional state of the organism, the characteristic features of distribution of ranges and "ranges of changes" of individual indices of HRV for the high, average and low functional state of an athlete's body are determined. It is shown that for athletes with a low level of functional state of the FS the following is characteristic: at SR, there is a tendency for "moderate decrease" in the ranges of indicators of TP, VLF, "moderate" and "expressive" increase of the ranks of LF indicator, the normative values of HF; at CR_6, the "ranges of changes" of TP, LF are mainly "expected" by reactivity, VLF is mostly "reduced", and HF significantly varies with the predominance of "expected" reactivity; at CR_{15}, the TP "range of changes" tends to "increased" reactivity, the VLF is mostly "expected" with a slight tendency to "decreased" reactivity, LF significantly varies with the predominance of "expected" reactivity, HF is of "increased" reactivity.

Key words: percentile method, "ranges of changes", heart rate variability , functional state.

Introduction

The problem of express assessment of the functional state (FS) of an athlete's body in order to prevent the development of negative effects associated with the tension of adaptation mechanisms and its disruption prompts researchers to seek informative methods of medical control that could be applied in "field" conditions to determine the functional reserves of the body of athletes, early diagnosis of *donozological* and pre-morbid conditions [1, 2].

The problem of evaluating and preserving the functional reserves of the athlete's body is closely linked to the FS evaluation, which refers to the optimal activity of various physiological systems. FS has a basic level of activity of the main physiological systems and variable components that are formed for the implementation of certain activities when necessary. FS outside the activity is considered as background. One common method for evaluating the body's FS is the analysis of heart rate variability (HRV), which has been widely used in clinical practice, applied physiology, and sports medicine [3,4]. It allows to characterize the body's FS as a result of the work of regulatory systems to preserve homeostasis and maintain a balance between the organism and the environment. At the same time, individual HRV indicators reflect the activity of various links of regulatory mechanisms, and their integrated assessment gives the possibility of a holistic view of the FS of the body of athletes [5]. Existing integrated criteria for evaluating FS according to HRV data are not always suitable for the characterization and evaluation of subtle changes in FS of practically healthy people, which is especially important when examining the athletes' FS in "field" conditions [6]. And using simple breath-controlled tests will allow the method to be used in all conditions of the training process [7], which prompted research in this direction.

In our previous multifunctional studies, it has been shown that the characteristic feature of persons with high oxygen consumption rate (VO_2max) in resting state is lower HR in the background of more rapid viability of the ventricular myocardium (at values of QR, QRS, QTs); higher values of the total capacity of the HRV [8,9]. The high level of VO_2max in comparison with the low one is characterized by lower values of tidal volume (TV) and the ratio of the duration of inspiration to the duration of exhalation; greater baroreflex sensitivity

Corresponding Author: GUZII O. V, E-mail: o.guzij@gmail.com

(BRS), as well as hemodynamic economization at lower cardiac output (CO) and cardiac index (CI) rates and greater specific peripheral vascular resistivity (SPVR) in resting state [10,11]. However, a number of issues related to the evaluation of FS in an organism with a low (6 to 10) respiratory rate (RR) in rest are still relevant [12,13]. Our use of controlled respiration (CR) tests for athletes who trained endurance made it possible to establish that the latter increase was reflected in the response of HRV indices to controlled respiration 15 times per minute (CR_{15}), characterized by a pronounced increase in HF (ms^2) and a decrease in LF / HF. Significant are also the differences between VLF (ms^2), which indicate a decrease in neurohumoral effects on HR in CR_{15}. With controlled respiration 6 times per minute (CR_6), the features of changes in HRV indices with increasing endurance were not recorded [14].

HRV varies significantly with RR change. At CR_6, the contribution of the low frequency component of HRV increases essentially, which is accompanied by a significant growth in the total HRV power, while in the CR_{15}, the high frequency component of HRV, which does not particularly affect the overall HRV power, predominates[10]. It is incorrect to analyze and evaluate HRV at different RRs according to absolute values of the HRV indices even for the same individuals. It is well known that respiration with a given frequency causes a synchronization of the heart rate; therefore, it is advisable to carry out an individual assessment of HRV values in different respiratory frequency ranges and compare it with the evaluation of HRV values obtained with spontaneous respiration (SR). This will alleviate the effect of the respiratory rate on the HRV and individualize and objectify the assessment of the FS of the body according to the HRV.

The latter led to the development of HRV assessment criteria separately for SR and CR_6 and CR_{15} (Table 1) by conducting a survey of more than 3,000 young people with randomized and controlled breathing tests [13,7].

Table 1. Percentaneous distribution of HRV parameters of young people at randomized and controlled breathing

Parameters HRV	Respiration	<5	5-25	25-75	75-95	>95
TP, ms^2	SR	<1017.6	1017.6-2450.3	2450.4-7225.0	7226.1-15700.1	>15700.1
	CR_6	<3733.2	3733.2-9564.8	9564.9-20398.1	20398.2-31293.6	>31293.6
	CR_{15}	<795.2	795.2-1874.9	1875.0-5852.3	5852.4-11406.2	>11406.2
VLF, ms^2	SR	<77.4	77.4-207.4	207.5-812.3	812.4-2152.9	>2152.9
	CR_6	<193.2	193.2-424.4	424.5-1108.9	1109.0-2631.7	>2631.7
	CR_{15}	<130.0	130.0-316.8	316.9-961.0	961.1-3283.3	>3283.3
LF, ms^2	SR	<201.6	201.6-552.3	552.4-2116.0	2116.1-7885.4	>7885.4
	CR_6	<2631.7	2631.7-7259.0	7259.1-17004.2	17004.3-24617.6	>24617.6
	CR_{15}	<118.8	118.8-282.2	282.3-876.2	876.3-1764.0	>1764.0
HF, ms^2	SR	<265.7	265.7-835.2	835.3-3481.0	3481.1-7551.6	>7551.6
	CR_6	<278.9	278.9-691.7	691.8-3036.0	3036.1-6178.0	>6178.0
	CR_{15}	<201.6	201.6-655.4	655.5-3469.2	3469.3-9643.2	>9643.2
LFHF, ms^2/ ms^2	SR	<0.13	0.13-0.37	0.38-1.47	1.48-5.53	>5.53
	CR_6	<2.28	2.28 – 4.20	4.21 – 12.60	12.61 – 26.53	>26.53
	CR_{15}	<0.13	0.13 – 0.20	0.21 – 0.73	0.74 – 1.45	>1.45

That is, when entering the range of 25-75%, it is necessary to note the normative values of the corresponding indices, when they fall into the ranges of 5-25% and 75-95%: moderate decrease and moderate increase, respectively, and when they fall into the ranges of 0-5% and 95 -100% – expressed decrease and increase, respectively [12].

Materials and methods

The purpose of this study was to determine the peculiarities of changes in the cardiac rhythm variability of skilled athletes when performing tests with controlled breathing, taking into account the functional state of the athlete's body.

104 male athletes aged 20.6 ± 0.9 were examined and had no acute and chronic pathology. The examinations were carried out in the early hours of the onset and included the recording of the performance of the cardiopulmonary resuscitation system using Spiroarteriocardiorhythmograph (SACR) according to the protocol we developed, which included three consecutive two-minute registrations: SR, CR_6 and CR_{15}. Additionally, the registration of physical development indices and tests was carried out. Definition of body mass (BM) and body length (BL), vital lung capacity (VLC), dynamometry of wrists (DW), Martinet functional tests were performed to determine the response of heart rate (HR) and blood pressure (BP) to exercise and HR recovery time to the baseline.

The HRV study was conducted using SACR [15] and included the determination of the total HRV – TP (ms^2) power, the HRV in the ultra-low frequency range – VLF (ms^2), the HRV in the low-frequency range: LF (ms^2), the HRV in the high-frequency range: HF (ms^2), LF / HF (ms^2 / ms^2). The central heart rate index was also calculated: IC_{HR} (ms^2 / ms^2).

To determine the FS of the body of athletes, we used the system of assessment of the level of somatic health (LSH) by G. L. Apanasenko, which has a close connection with VO_2max of the body. Thus, the low level of LSH corresponds to VO_2max: 16 ± 7 ml / min. × kg, below the average: 23 ± 8 ml / min × kg, an average: 29 ± 4 ml / min × kg, above the average: 41 ± 3 ml / min.qkg, and high: 62 ± 6 ml / min × kg. In determining the level of FS of the organism, high and higher LSH levels were characterized as high FS, average LS as the average FS, low and lower than average LSH as low FS [1]. Non-parametric methods of statistical analysis with determination of Mann-Whitney criterion were used to evaluate the obtained results of the study.

Research results

In FS analysis, the examined group of athletes was divided as follows: 1st group with "high" FS consisted of 39 (group "high" – GH), 2d group with an average of FS were 46 (group "average" – GA), 3d groups with low FS included 19 people (group "low" – GL).

Table 2. Characteristics of physical development parameters of studied groups (Median (25%; 75%)

Parameters	GH	GA	GL
weight, kg	71.0 (69.0; 78.0)*	75.5 (70.0; 80.0)	77.0 (72.0; 80.0)
length, cm	178.0 (175.0; 181.0)	179.0 (174.0; 182.0)	180.0 (175.0; 182.0)
BMI, kg /m^2	22.7 (21.6; 23.7)	23.7 (22.0; 24.9)	23.5 (22.5; 24.2)
dynamometry of wrists r., kg	50.0 (46.0; 54.0)	48.0 (44.0; 52.0)	48.0 (42.0; 52.0)
dynamometry of wrists l.,kg	46.0 (42.0; 50.0)	47.0 (42.0; 52.0)	48.0 (42.0;49.0)
FI, %	70.4 (65.6; 77.9) *#	65.7 (61.1; 67,7)	60.5 (57.6; 67.5)
VC, ml	4900 (4550; 5500)	4850 (4500; 5150)	4900 (4300; 5500)
VI ml/kg	68.5 (64.3; 72.8) *	65.1 (61.0; 72.5)	63.3 (56.9; 71.8)

* - p<0.05 in comparison with GL; # - p<0.05 in comparison with GA

Table 2 shows the average data of the analysis of measurements of the parameters of the body structure of athletes of the studied groups. We emphasize the probable differences that characterize the "high" FS.

Analyzing the data of the structure of the body of GH athletes, first of all, it is necessary to stress on the differences associated with VM, which is here significantly smaller (p <0.05) than in GL, however, not differing from GA. At the same time, according to the body mass index (BMI), which is an integral characteristic of BM, the probable differences in the groups of athletes are not registered. Significant differences were observed in the strength index (SI) in GH compared to GA and GL (p <0.05), as well as vital index (VI) compared to GL (p <0.05). With regard to the latter, it should be noted that the absolute values of the VLC are not likely to differentiate the groups.

Table 3 reveals the results of measurements of cardiovascular activity indices recorded during the Martinet functional tests. HR calculation during this test is carried out by a palpation method on the radial artery during 10 seconds, and BP is recorded using a sphygmomanometer with the auscultatory method by Korotkov.

Table 3. Characteristics of the results of the measurement of cardiovascular system performance of the studied groups by routine methods (Median (25%; 75%))

Parameters	GH	GA	GL
HR (rest), min^{-1}	60 (60; 72) *	66 (60; 72)	66 (60; 78)
SBP, mmHg	110 (110; 120)	120 (110; 130)	120 (110; 130)
DBP, mmHg	60 (60; 70) *#	70 (60; 80)	70 (70; 80)
PBP, mmHg	50 (40; 50)	50 (40; 50)	50 (40; 54)
MBP, mmHg	85.2 (81.0; 91.0) *	91.0 (81.0; 96.8)	92.6 (86.8; 96.8)
Δ HRload, %	58.3 (44.4; 75.0)	68.3 (54.5; 72.7)	63.6 (42.9; 80.0)
Δ SBPload, %	18.2 (9.1; 23.1) *	12.7 (9.1; 22.2)*	23.1 (16.7; 27.3)
Δ DBPload, %	-14.3 (-16.7; 0)	-14.3 (-16.7; -12.5)	-14.3 (-25.0; -12.5)
QRI	0.83 (0.48; 1.11)	0.59 (0.48; 0.83)*	0.93 (0.63; 1.25)

* - p<0.05 in comparison with GL; # - p<0.05 in comparison with GA

Measurement of HR and BP by routine methods during the Martinet functional tests showed that GH athletes are probably (p <0.05) different from GA and GL in view of DBP indices, as well as in HR (rest) and MBP from GL. According to other indices, probable differences are not recorded. At the same time, there are probable differences in SBP growth rates in response to standard loading (Δ SBPload) and QRI (p <0.05) between GA and GL data. The values of the last GH indices, although they are the closest to the optimal ones, are considered to be in the range of 0.5 – 1.0, but unlike GA and GL, they are not significant.

That is, based on data of routine cardiovascular research in performing Martinet test, GH athletes are probably to differ from others according to HR and DBP, whose measurement results are taken into account by Robinson index (RI). The analysis of the latter and other integral indexes are presented in Table 4.

Table 4. Results of the calculation of the main integral indexes used to evaluate the functional state of the organism in the studied groups (Median (25%; 75%))

Parameters	GH	GA	GL
Baevsky's AP	1.86 (1.71; 2.01)*#	2.02 (1.89; 2.26)	2.06 (1.90; 2.30)
Pirogova's LPS	0.785 (0.736; 0.852) *#	0.718 (0.639; 0.786)	0.688 (0.592; 0.786)
Skibinska's index	6578 (4958; 8546)	5931 (4813; 7500)	6655 (4809; 7840)
Robinson's index	72 (62.4; 79.2)*#	79.2 (70.2; 86.4)	79.2 (72.0; 92.4)
Kerdo index	0.00 (-0.17; 0.09)*	-0.03 (-0.17; 0.09)*	-0.17 (-0.21; 0.09)

* - $p<0.05$ in comparison with GL; # - $p<0.05$ in comparison with GA

As can be seen from Table 4, for all indices, in the formula for calculating of which either HR or SBP parameters in a resting state are included, there are probable differences in individuals with high FS. This applies to Baevsky's adaptive capacity (Baevsky's AP), Pirogova's level of physical condition (LPS), and IR, the differences between the group with high FS are probable compared to GA and GL. However, there were no probable differences between GA and GL according to these indices. In view of this, special attention deserves the lack of differentiation of Skibinska's index indices, which in the studied groups do not differ at all. It is worth mentioning that its calculation includes the VLC and inhibition time, analyzing which earlier (Table 1, 2) we did not establish the probable differences in the studied groups. The results of calculating the Kerdo index proved to be informative enough to show that in GH and GA they are significantly different from the results in GL. In addition, in GL (with low FS), there was a fairly distinct propensity to moderate parasympathetic content, in contrast to GH and GA, in which variants of the eutonium with a certain tendency to parasympathetic content were superior.

Table 5 presents the results of testing the hypercapnic and hypoxic resistance of the body according to the performance of breath test: to the inspiration (Stange) and exhalation (Genchi). According to the results of the latter, the groups do not differ. According to the Stange test, although differences in median values are noted they, however, are not probable. These data confirm the low informativeness of such tests in healthy individuals.

Table 5. Characterization of the results of hypoxic tests of the studied groups

Parameters	GH	GA	GL
Stange test, s	81.0 (70.0; 103.0)	85.0 (70.0; 98.0)	90 (72.0; 97.0)
Genchi test, s	48.0 (38.0; 60.0)	45.0 (36.0; 60.0)	47.0 (39.0; 53.0)

Table 6 reveals the results of the analysis of HRV indices for SR, which characterize regulatory influences on the sinus node, which are associated with different levels of autonomic cardiac activity [16, 17]. The indices of total power (TP, ms^2) of the HRV spectrum indicates the general adaptive capacity of cardiac regulation, which determines the functional reserve of adaptive reactions of the heart muscle and the body as a whole [18,19]. For GH, this value is significantly higher than for GA and GL. However, these differences are probable only between GH and GL ($p <0.05$). In this case, GA and GL indices do not differ between themselves and are within the population regulatory limits [13]. On the other hand, the probable larger margins of GH individuals indicate that they fall into the range of excessive regulatory activity, which is considered to be the case when the values of 8000-10000 ms^2 are exceeded, which can characterize overstrain and overtraining of athletes with "high" FS. This assumption is further proved by the VLF index associated with thermoregulation, the effect of endocrine factors such as thyroxin, sex hormones, renin-angiotensin system, steroids, and others [20, 21], and psycho-emotional factors [19]. As can be seen from Table 3, the VLF indices is significantly higher for GH and GA ($p <0.05$) than for GL, which may indicate a greater influence of implemented through humoral and metabolic factors super-segmental structures on the cardiac rhythm at the "high" FS. On the other hand, its reduction in GL can characterize the energy deficit of athletes with "low" FS. The probable differences ($p <0.05$) between GH and GL were also observed in the LF (ms^2), which characterizes mainly the activity of the sympathetic department of the VNS.

Table 6. Results of registration of HRV indices using SACR in the studied groups (Median (25%; 75%))

Parameters	GH	GA	GL
HR, min^{-1}	66.2 (60.8; 73.3)*	69.8 (63.6; 77.1)*	77.8 (65.9; 82.9)
TP, ms^2	6021.8 (3080.3;11406.2)*	4409.1 (2450.3; 6872.4)	3294.8 (2275.3; 5083.7)
VLF, ms^2	761.8 (368.6; 1149.2)*	545.3 (275.6; 1062.8)*	299.3 (204.5; 524.4)
LF, ms^2	1892.3 (1204.1; 5852.3)*	1580.1 (576.0; 2611.2)	1036.8 (823.7; 3352.4)
HF, ms^2	1980.3 (1024.0; 3271.8)	1870.9 (835.2; 3540.3)	1267.4 (734.4; 3364.0)
LF/HF, ms^2/ms^2	1.21 (0.64; 2.89) #	0.73 (0.49; 1.21) *	1.00 (0.49; 3.24)
IC_{HR}, ms^2/ms^2	1.50 (0.71; 4.51)	1.22 (0.58; 2.82)	1.64 (0.55; 4.16)

* - $p<0.05$ in comparison with GL; # - $p<0.05$ in comparison with GA

That is, the "high" FS is characterized by the most significant activity of the stress-relieving system associated with sympathetic adrenal mechanisms. At the same time, the high frequency component of HRV (HF, ms^2), which shows the activity of autonomous (parasympathetic) regulation mechanisms [22, 23] is also the largest in GH, but negligible. The latter is displayed in the index of the ratio of LF / HF, which is significantly larger in GH ($p < 0.05$) than in GA, but does not differ from GL. Hence, it can be concluded that "high" FS is characterized by a significant increase in regulatory influences on SR due to all components of regulation, of which most likely are humoral, metabolic and stress-relieving systems [20, 22]. At the same time, the increase in the activity of the autonomous regulatory circuit is significant, but not so essential in comparison with other groups.

In order to achieve the goal and determine the changes in the HRV indices in controlled respiration tests, athletes with different levels of FS were examined individually for HRV indices at random, CR_6 and CR_{15} with range definition based on the data presented in Table 1. For each of the obtained values the corresponding range was assigned (Table 7).

Table 7. Characteristics of the HRV indices ranges

Characteristics of the indices ranges	Value ranges	Centile range
pronounced decrease	-2	<5
moderate decrease	-1	5-25
norm	0	25-75
moderate increase	+1	75-95
pronounced increase	+2	>95

Table 8 shows the distribution of ranges of HRV indices recorded in randomized breathing resting state, which according to the chosen approach to analysis should be as close as possible to the expected distribution: 5%: 20%: 50%: 20%: 5%. The features were identified (presented in the distinguished font in Table 5), which allowed to supplement the data presented in Table 3. Namely, 41% of athletes with high FS have a moderate and pronounced increase in TP (ms^2), whereas at the average and especially low levels of the FS there is a well-established tendency to moderate decrease in the total power of regulating effects on the heart rate.

The activity of over-segmental influences (VLF, ms^2) at moderate and especially high levels is moderately elevated by 30.4% and 38.5%, respectively, while 36.8% of athletes have a moderate decline at low FS.

Table 8. Distribution of HRV indices by rank depending on the FS level of athletes

Parameter	Level FS	Value ranges, %				
		-2	-1	0	+1	+2
	high	0.0	12.8	46.2	**25.6**	**15.4**
TP, ms^2	average	0.0	**26.1**	52.2	17.4	4.3
	low	0.0	**37.5**	**56.3**	0.0	6.3
	high	0.0	7.7	48.7	**38.5**	5.1
VLF, ms^2	average	2.2	10.9	52.2	**30.4**	4.3
	low	0.0	**36.8**	52.6	10.5	0.0
	high	0.0	7.7	46.2	**25.6**	**20.5**
LF, ms^2	average	2.2	17.4	50.0	**26.1**	4.3
	low	0.0	5.3	**57.9**	**26.3**	**10.5**
	high	2.6	0.0	**74.4**	15.4	7.7
HF, ms^2	average	8.7	0.0	**63.0**	23.9	4.3
	low	5.3	0.0	**73.7**	5.3	**15.8**
	high	0.0	15.4	43.6	23.1	**17.9**
LFHF, ms^2/ms^2	average	4.3	19.6	54.3	15.2	6.5
	low	0.0	21.1	42.1	**26.3**	**10.5**

An informative enough is an increase in the variants of moderate and significant growth of low-frequency (sympathetic) influences (LF, ms^2) on the cardiac rhythm, which are noted at high and low FS, and at a high one they are happening significantly more often (20,5% vs. 10,5%). The activity of high-frequency influences (HF, ms^2) is maximally balanced at all levels of the FS (from 63% to 74.4%), except for the growth of variants of expressed increase in 15.8% of cases at low FS.

To determine the peculiarities of the FS levels of the athlete's body using a CR_6 and CR_{15} test, an evaluation system was developed that included the determination of the "ranges of changes" of individual parameters, taking into account the criteria of the percentile distribution presented in Table 1. Namely, the difference between the starting grade of the indices (when tested with randomized breathing) and the range assigned in tests CR_6 and CR_{15} was taken into account. Table 9 shows the criteria for evaluating test results of CR_6 and CR_{15}.

Table 9. "Ranges of changes" of indices at controlled respiration testing

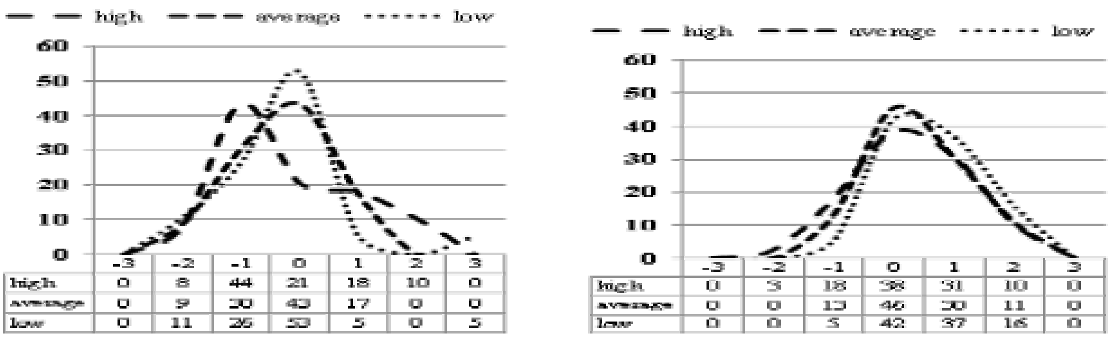
Ranges of changes	Characteristic
-3	too low reactivity
-2	markedly reduced reactivity
-1	reduced reactivity
0	expected reaction
+1	increased reactivity
+2	markedly increased reactivity
+3	extraordinary reactivity

Here is an example of applying the approach to the definition and assessment of HRV. When examining an athlete K., 21 years of age, who had a high FS level, using the SACR at random, the following HRV parameters were obtained: TP - 11406.2 ms^2 (range - +1), VLF - 1317.7 ms^2 (range - +1), LF - 3025.0 ms^2 (range - +1), HF - 6872.4 ms^2 (range - +1), LF / HF - 0.49 ms^2 / ms^2 (range - 0). At CR_6: TP - 31826.6 ms^2 (range - +2), VLF - 961.0 ms^2 (range - 0), LF - 25154.0 ms^2 (range - +2), HF - 5098.0 ms^2 (range - +1), LF / HF - 4.84 ms^2 / ms^2 (range - 0). At CR_{15}: TP - 4382.4 ms^2 (range - 0), VLF - 967.2 ms^2 (range - +1), LF - 1274.5 ms^2 (range - +1), HF - 2088.5 ms^2 (range - 0), LF / HF - 0.64 ms^2 / ms^2 (range - 0). After determining the ranges of the indices, the "ranges of changes" are calculated. For the TR indices the "ranges of changes" at CR_6 are (CR_6 range +2) - (SR range +1) = +1; at CR_{15}: (CR_6 range 0) - (SR range +1) = -1 and so on for other indices.

Figure 1 reflects the distribution of the "ranges of changes" in the TP indices, which implies that the response to CR_6 (Figure 1a) is predominantly expected in 43% and 53% of cases for athletes with low and average FS levels respectively. For athletes with high FS levels, the response to CR_6 is substantially lower than expected and in 44% of cases it is noted at the level of "reduced reactivity". On the other hand, 10% of athletes with high level of FS are characteristic for "markedly increased reactivity". 5% of athletes with a low level of FS are noted for an "extraordinary reactivity" in terms of TP. These cases require a separate study. At the same time, the reaction to CR_{15} in the identified groups (Figure 1b) is not clearly differentiated, although one can see a tendency to increase reactivity in comparison with "expected" results for athletes with a decrease in FS level.

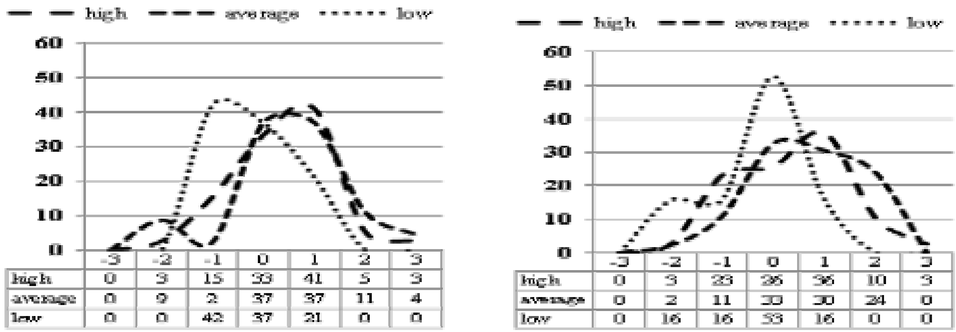
Figure 2 shows the distribution of the "ranges of changes" of the supra-elemental component of the HRV-VLF, which testifies that athletes with low FS levels have a predominantly "reduced reactivity" to CR_6 (Figure 2a), which is significant (42% of cases), and is differentiated from persons with average and low level of FS. According to the reaction to CR_6 the latter do not differ much and the reaction of the majority of them is characterized as "expected" and "high reactivity". 9% of cases of athletes with average level of FS are noted by a "markedly reduced" reactivity of neurohumoral regulatory influences of VLF, which also requires separate consideration.

The VLF reactivity range of CR_{15} (Figure 2b) is clearly visualized in athletes with low FS, preferably at the "expected" level (53% of cases). At the same time, athletes with average and high FS have a pronounced tendency to the growth of the "increased" (30% and 36%, respectively) and "markedly increased" (24% and 10%, respectively) reactivity of variants. The latter may indicate a better mobilization of neurohumoral and ergotrophic regulation mechanisms when activating the parasympathetic ANS at CR_{15}.



a b

Fig. 1 Distributions of TP "ranges of changes" for tests CR_6 (a) and CR_{15}



a b

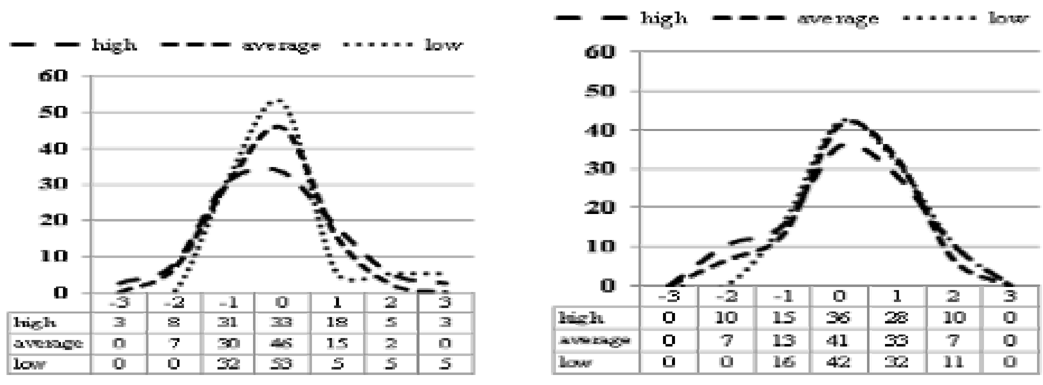
Fig. 2 Distributions of VLF “ranges of changes” for tests CR_6 (a) and CR_{15}

Figure 3a depicts the distribution of “ranges of changes” of LF in CR_6, from which it is clear that in all groups there is a tendency to “moderate” decrease in reactivity, but in a group with a high level of FS, it is accompanied by a significant dispersion of “ranges of changes” at all levels, with the “expected” variant to be observed only in 33% of cases. Less significant dispersion of “ranges of changes” is noted among athletes with an average level of FS, while the “expected” variant is found in 46% of cases.

The smallest variance of “ranges of changes” is noted at low FS, and “expected” variants are found in 53% of cases. That is, the variation of “ranges of changes” at high FS is the largest, which, considering the chosen approach to the analysis and evaluation of HRV parameters, may serve as the basis for more careful consideration of these options of “ranges of changes” in the future. At CR_{15} there is a tendency for “moderate increase” in reactivity in all groups of athletes; the variability of “changes in ranks” is the highest in the group with a high level of FS. At the same time, it is in this group that 25% of athletes are marked with variants of “lowered” and “markedly reduced” reactivity, which may be due to the “pronounced increase” of LF at randomized breathing.

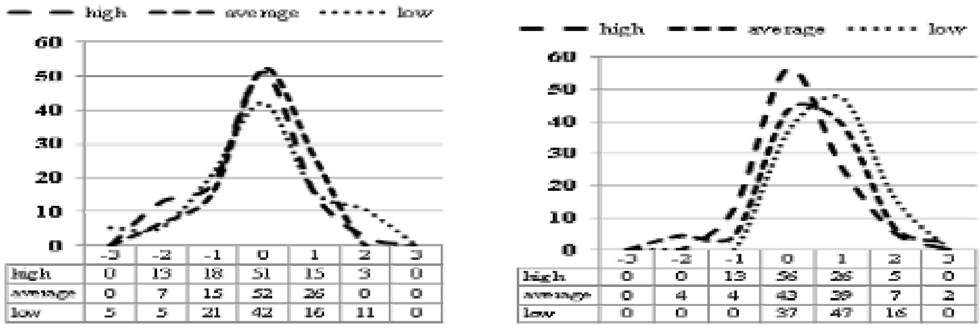
No less significant are the results presented in Figure 4, which shows the “ranges of changes” of the HF index for tests CR_6 (Figure 4a) and CR_{15} (Figure 4b). When performing the CR_6 test, no significant differences were observed in the examined groups except for the minor tendency of athletes with high FS to “expressed” reduced reactivity in 13% of cases, as well as a slight tendency for athletes with low FS to “markedly increased” reactivity in 11% of cases. At the same time, at CR_{15}, the “ranges of changes” in athletes with high and low FS are clearly differentiated: in the group with high FS, the distribution is as close as possible to the “expected”, while in the group with low FS the “ranges of changes” in 63% of athletes is noted for an increase in the options of “increased” and “markedly increased” reactivity. Athletes with average FS have an intermediate version of the distribution of “ranges of changes”.

At the same time, no absolute values for the ranges for randomized respiration of the group were differentiated in terms of HF. Confirmation of the significance of HF “ranges of changes” for CR_{15} is the correlation with the indexes of hypercapnia resistance ($r = -0.20$, $p < 0.05$), Skibinskaya index ($r = -0.25$, $p < 0.05$), ICHR ($r = -0.26$, $p < 0.05$) and RI ($r = 0.22$, $p < 0.05$)..



a b

Fig. 3 Distributions of LF “ranges of changes” for tests CR_6 (a) and CR_{15} (b)



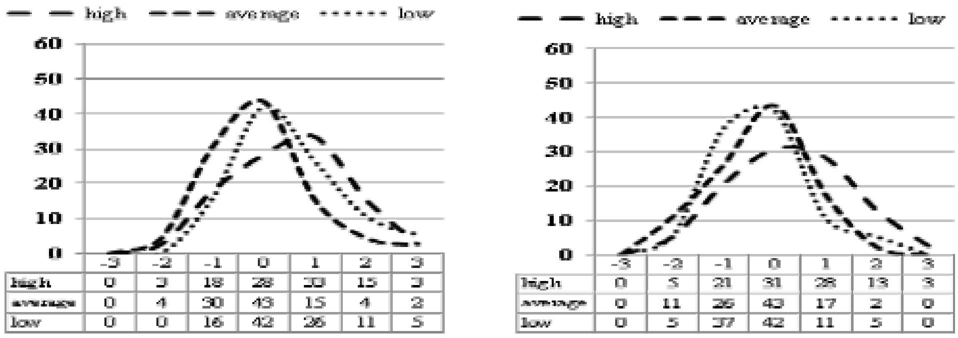
a b

Fig. 4 Distributions of HF “ranges of changes” for tests CR_6 (a) and CR_{15} (b)

The LF / HF range ratios (Figure 5) were sufficiently informative, which showed that CR_6 athletes with low and average FS differentiated slightly due to the tendency to growth in the number of “increase” and “decrease” variants for these indices. Athletes with high FS tendency to growing variants of “increase” and “pronounced increase” of reactivity significantly differentiate from athletes with average FS. According to this index, the differences from athletes with low FS are less significant and are determined at the level of the tendency. The distribution of “ranges of changes” of LF / HF at CR_{15} is almost repeated. However, athletes with low and average FS do not differ in general, and the distribution of “ranges of changes” for athletes with high FS tends to enlarge the variants of “increase” and “pronounced increase” reactivity in comparison with low and average FS..

An important aspect of the implementation of this approach to the analysis of HRV indices is the determination of the possible physiological determinants of the ranges used by us and the “ranges of changes” of HRV indices in CR. A correlation analysis was conducted considering the ranges of the HRV indices (Table 7) and their “ranges of changes” (Table 9) and the studied parameters of physical development, metrics for the response to metered physical activity (Martinet test), test indices and various indexes that characterize the FS of the body.

Analyzing the obtained data, it should be noted that the TP range is directly related to the percentage increase in HR ($r = 0.23$, $p < 0.05$) and SBP ($r = 0.23$, $p < 0.05$) in response to the standard load in the Martinet test. The range of TP is related to VI ($r = 0.21$, $p < 0.05$). The “ranges of changes” for CR_6 is determined by the initial values of SBP ($r = 0.33$, $p < 0.05$), PBP ($r = 0.33$, $p < 0.05$), MBP ($r = 0.20$, $p < 0.05$), RI ($r = 0.20$, $p < 0.05$), IC_{HR} ($r = 0.22$, $p < 0.05$) and adaptive potential ($r = 0.25$, $p < 0.05$). That is, the low values of these indexes, which characterize the economization of the activity of the cardiovascular system, predict a less significant TP response to CR_6. The “ranges of changes” for TP at CR15 are predicted by values of IC_{HR} ($r = 0.21$, $p < 0.05$) at SR.



a b

Fig. 5 Distributions of LF/HF “ranges of changes” for tests CR_6 (a) and CR_{15} (b)

Less significant relations were found between the ranges of the indicator and the “ranges of changes” of the VLF, the first of which was expectedly characterized by the IC_{HR} ($r = 0.20$, $p < 0.05$), which includes the VLF parameter. However, it was also related to VI ($r = 0.25$, $p < 0.05$), SI ($r = 0.25$, $p < 0.05$), and characterized the level of somatic health according to G. L. Apanasenko ($r = 0.31$, $p < 0.05$). The VLF “ranges of changes” for CR_6 were associated with PBP ($r = 0.21$, $p < 0.05$) at rest, and at CR_{15} no pronounced relations were established.

Sufficiently informative correlations were found between the range of the low frequency component of HRV (LF), which appeared to be related to HR growth in response to standard exercise ($r = 0.24$, $p < 0.05$) and IC_{HR} ($r = 0.23$, $p < 0.05$). In this case, the range of LF associated with the activity of the sympathetic ANS unit clearly determines the HR response to physical activity. The LF “ranges of changes” for CR_6 is determined by the initial SBP ($r = 0.32$, $p < 0.05$) and PBP ($r = 0.36$, $p < 0.05$), adaptive potential ($r = 0.21$, $p < 0.05$), RI ($r = 0.20$, $p < 0.05$), the larger (less favorable) values of which predict a more pronounced reaction of LF to CR_6. A similar reaction is determined by higher IC_{HR} values ($r = 0.26$, $p < 0.05$). The LF “ranges of changes” for CR_{15} is also related to the IC_{HR} ($r = 0.21$, $p < 0.05$). It was sufficiently informative that the LF “ranges of changes” in CR_6 and CR_{15} were inversely related to the hypoxic resistance of the organism, which is determined by the result of the Genchi test ($r = -0.24$, $p < 0.05$ and $r = -0.21$, $p < 0.05$), and shows a lower reactivity of the sympathetic component of HRV in CR with better resistance to hypoxia.

Significant were the relations obtained for the range of high-frequency component of HRV (HF), which indicated the feedback of the latter with resistance to hypercapnia ($r = -0.34$, $p < 0.05$), Skibinskaya index ($r = -0.21$, $p < 0.05$) and with a SBP increment in response to a standard physical load. Links with the HF “ranges of changes” proved to be important for CR. Namely, at CR_6, the increase in the HF response is determined by the strength of the right palm ($r = 0.20$, $p < 0.05$), (BMI) ($r = 0.26$, $p < 0.05$), resistance to hypercapnia ($r = -0.24$, $p < 0.05$), the Skibinskaya index ($r = -0.22$, $p < 0.05$), adaptive potential ($r = 0.22$, $p < 0.05$) and SBP at rest ($r = 0.21$, $p < 0.05$). At CR_{15}, the HF “ranges of changes” in addition to the specified hypercapnia resistance ($r = -0.20$, $p < 0.05$) and the Skibinskaya index ($r = -0.25$, $p < 0.05$) also depend on the initial level of integral parameters such as IC_{HR} ($r = -0.26$, $p < 0.05$) and RI ($r = 0.22$, $p < 0.05$). In addition, it can be pointed out that people with a higher level of somatic health have a more pronounced HF “ranges of changes” ($r = -0.21$, $p < 0.05$).

An important characteristic of HRV is the ratio of LF / HF, which indicates the predominance of the tone of the sympathetic or parasympathetic ANS branches. The range of this indices is directly related to BL ($r = 0.22$, $p < 0.05$), hyperkapnia resistance ($r = 0.25$, $p < 0.05$), the Skibinskaya index ($r = 0.24$, $p < 0.05$) and IC_{HR} ($r = 0.60$, $p < 0.05$). The LF / HF “ranges of changes” for CR_6 is determined by resistance to hypercapnia ($r = 0.21$, $p < 0.05$), and at CR_{15} by LSH ($r = 0.22$, $p < 0.05$).

That is, both the ranges of HRV parameters themselves and their “ranges of changes” have clear physiological determinants that indicate the FS of organism.

Discussion of the results

The developed approach to the estimation of indices of HRV has shown its informativeness in relation to determination of FS of an organism of athletes. Its informativeness is determined by the definition of 5 ranges of indexes that neglected the type of distribution of parameters, and due to the use of the percentile method of estimating distributions for all indices, it is possible to compare these in conditional notation (ranges) taking into account changes that occur when performing CR tests. Such an approach should facilitate the search for synchronization mechanisms that arise between the respiratory and cardiovascular systems, as well as algorithmize them. It is worth mentioning that the use of such method can be useful not only for practically healthy persons and athletes, but also for people with different diseases.

The development of the “ranges of changes” index for HRV indices when performing CR tests allows to determine the final number of reaction variants in response to a simple stimulus within the deviations of the individual range of a separate indicator from the expected one (taking into account developed criteria for the estimation of absolute values of the indicators). This article singles out 7 “ranges of changes” for each index. However, if necessary, they can be extracted, for example, in determining 7 or 9 ranges for randomized breathing, which can specify certain states and reactions.

The analysis of ranges and “ranges of changes” showed that they have physiological determinants associated with the performance of the cardiovascular and respiratory systems. First of all, it is necessary to dwell on the peculiarities of these indices in athletes taking into account the FS of the body.

For athletes with a high level of FS the following is typical: at SR – prevalence of “moderately high” and “expressed high” index of TR ranges, the prevalence of “moderately high” VLF range, the prevalence of “moderately high” and “expressed high” index ranges of LF; while for the CR_6 the “ranges of changes” indicate mostly “lower” TP reactivity, “higher” reactivity of VLF, considerable variation in LF response, “expected” HF reactivity with little tendency to “low”; CR_{15} is noted for “ranges of changes” proving “expected” TP reactivity with little tendency to “increase” of mainly “higher” VLF reactivity, considerable variation in LF reactivity, “expected” reactivity of HF.

For athletes with low FS the characteristic is as follows: at SR there is a tendency for “moderate decrease” in the range of indicators of TP and VLF, “moderate” and “expressed” increase of ranges of LF index, normative values of HF; at CR_6: the “ranges of changes” of TP and LF are mainly “expected” by reactivity, VLF is mostly “reduced”, HF significantly varies with the predominance of “expected” reactivity; at CR_{15}: the TP “ranges of changes” tend to “increased” reactivity, the VLF is mostly “expected” with a slight tendency to “decreased” reactivity, LF varies considerably with the predominance of “expected” reactivity, and HF has mainly “increased” reactivity.

Conclusions

In our opinion, the algorithmization of the results, taking into account other physiological and functional criteria of the athlete’s body to be researched in the future, will allow to determine the clear markers of the current state of the athlete’s body, which is important in the conduct of stage, current and operational surveys of highly skilled athletes.

Conflicts of interest
Authors have declared that no competing interests exist.

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