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Original Article

Heart rate variability during controlled respiration after endurance training

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Abstract:
Heart rate variability (HRV) during spontaneous respiration (SR) and controlled respiration 6 (CR_6) and 15(CR_{15}) times per minute of 28 highly qualified athletes before and after 7-week endurance training was studied. There were no considerable changes in HR (min.$^{-1}$) at the beginning of CR_6, however, the reaction of HR during CR_{15} was characterized by noticeable rise: from 71.4(63.9;77.5) to 82.0 (72.2;89.3), $p < 0.01$; and after endurance training HR (min.$^{-1}$) it sharply fell to 64.3 (60.8;68.3), $p < 0.01$ during SR; its reaction to CR_6 and CR_{15} turned to be rather lower, yet, the reaction to CR_{15} with insignificant degree of probability still exceeded the one during SR та CR_6. The latter may indicate a more adequate HR response to hyperventilation, which occurs when the tests are performed. HRV indices before and after training during CR_6 do not differ between one another. The increase in endurance was reflected in response of HF (ms^2) of HRV that was not practically influenced by controlled respiration. That differed them from the data at the beginning of the training where there was significant decrease in HF (ms^2) to 967.2(479.6;2540.2) during CR_{15} in comparison with SR (2035.7(756.3;6037.3)) and CR_6 (2560.9(1361.6; 5098.0)) ($p<0.05$). There was significant decrease in LF/HF ($p<0.01$) during CB_{15} in response to increase in endurance. VLF (ms^2) indices during SR at the beginning and in the end of tests do not differ; and the reaction to CR_6 does not lead to changes in VLF (ms^2). The reaction to CR_{15} at the beginning does not differ from SR and CR_6 indices. At the end of the training there was a significant decrease in VLF (ms^2) during CR_{15} 348.0(196.0;590.5) comparing to both SR 765.2(299.3;1108.9) and CR_6 637.6(470.9;930.3), $p<0.01$.
Key words: heart rate variability, controlled respiration, athletes, endurance.

Introduction

Physical activity has great influence on autonomic regulation of the heart [1]. To determine the vegetative effects on the body heart rate variability (HRV) is investigated, the use of indices of which during stepping, current and operational inspections should significantly improve medical control of athletes for objectification of states of fatigue, overstrain, prevention of overtraining and other clinical conditions that may arise under the influence of excessive physical activity [2,3]. In most sports general physical endurance is important in the preparation of athlete. It causes corresponding changes in functional systems of the body that are associated with economization of cardiorespiratory system activity at rest and maximum mobilization of the system that is responsible for oxygen transport when performing intense exercise [4,5].

The HRV studies of recent years have revealed the correlation of changes in the ratio of the low frequency and high frequency component of HRV with the intensity of loads [6], certain connections with the low frequency and high frequency components of HRV were obtained depending on the intensity and direction of training loads [7,8]. Informative data on changes in HRV were obtained in the analysis of recovery processes in the body after performing physical activity of varying intensity [9, 10, 11]. A number of studies in which the intensity of physical activity was selected based on the changes in the HRV indices allowed to prove the effectiveness of this approach from the point of view of the development of the level of training [12,13]. Other studies [14] have shown that HRV changes in accordance with maximum absorption of oxygen and lactic acid levels. Some authors [15,16,17,18,19,20] observed the development of vegetative imbalance in the onset of overtraining. In our earlier studies, we showed the relationship between HRV indicators and athletes' health [21], their differentiation during recovery [22], differences at the stages of the training process [23,24], and others.

At the same time, the informativeness of the HRV indices is limited especially in conditions of rest, therefore, various stress tests are often used to specify the state and reactivity of the autonomic nervous system: dosage of physical activity, a change in body position, medication, controlled respiration (CR) [6]. The latter showed significant informativity in determining the high level of physical performance, the characteristics of hemodynamic support of the athlete, the baroreflector activity after training load and during the recovery [22]. Today, methods of correction of functional state of the body are widely used in the practice of sports medicine.

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They are based on the use of feedback from the HRV associated with the frequency and rhythm of respiration, which also has a clear practical value [25, 26].

Materials and Methods

The purpose of this study was to determine the changes in HRV indices for arbitrary and controlled respiration in qualified athletes who, for a long time, were engaged in endurance physical activity.

To achieve the goal, 28 qualified male athletes aged 20.2 ± 0.7 years were examined, who were usually engaged in various sports. Within 7 weeks they were acclimated to workout general endurance. The bulk of the training sessions included the running load at a distance of 5 km. In total, 30 training sessions were conducted during 7 weeks.

A survey of athletes was held in the morning hours, fasting, and included registration of cardiorespiratory system indicators using spiroarteriocardiorhythmograph (SACK) [27] under developed by us protocol provided for the three consecutive two-minute registrations: spontaneous respiration (SR) with controlled respiration 6 times per minute (CR_6) and with controlled respiration 15 times per minute (CR_{15}). In addition, the registration of physical development indicators and tests were carried out. Body mass (BM, kg) and body length (BL, cm) were determined, as well as area of the body was calculated. The routine methods of systolic (SBP), diastolic (DBP) and pulse (PBP) blood pressure tests were also used, as well as calculation of a number of indices that characterize the functional state of the cardiorespiratory system and the body as a whole: the index Robinson (IR), Baevsky's adaptive capacity (Baevsky's AP), Skibinska's index, Pirogova's level of physical condition (LPS).

The HRV study included the determination of the following indices: 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 and n.o.), HRV in the high-frequency range, HF (ms^2 and n.u.), LF / HF and the heart rate centering index (ICHR). Non-parametric methods of statistical analysis with determination of Wilcoxon criterion were used to evaluate the obtained results of the study.

Results

Table 1 shows the average data of anthropometric measurements and estimated indexes of the functional state of athletes at the beginning and end of the experimental study.

Table 1.Morphofunctional characteristics of athletes at the beginning and end of the experimental study

Parameter	Before	After
BL, cm	178.0 (175.5; 181.0)	178.5 (174.5; 180.5)
BM, kg	73.0 (71.0; 78.5)	75.0 (69.5; 78.5)
SBP, mmHg	120.0 (115.0; 135.0)	112.0 (110.0; 120.0)*
DBP, mmHg	70.0 (65.0; 75.0)	70.0 (65.0; 75.0)
PBP, mmHg	50.0 (45.0; 65.0)	40.0 (37.5; 52.0)*
Robinson's index	79.2 (72.3; 93.0)	74.4 (67.5; 82.5)*
Skibinska's index	5863.6 (4452.8; 7711.1)	6488.0 (5194.4; 8742.4)*
Baevsky's AP	2.00 (1.89; 2.25)	1.87 (1.73; 2.00)*
Pirogova's LPS	0.740 (0.654; 0.816)	0.786 (0.737; 0.865)*

* - $p < 0.05$

The routine performance indicators of the cardiovascular system after exercise training in resting conditions revealed a probable decrease in SBP (mmHg) from 120.0 (115.0; 135.0) to 112.0 (110.0; 120.0), (P <0.05) and PBP (mmHg) from 50.0 (45.0; 65.0) to 40.0 (37.5; 52.0), (p <0.05). It was significant that according to all calculated indexes a pronounced improvement of the functional state was observed (Table 1).

Analyzing the results of the ECG indices of athletes at the beginning and end of the experiment during SR and CR (Table 2), the following should be noted: at the beginning of CR_6, no significant HR ($min.^{-1}$) changes were noted, but the HR response to CR_{15} was characterized by a significant increase from 71.4 (63.9; 77.5) to 82.0 (72.2; 89.3), p <0.01, and at the end the HR ($min.^{-1}$) during SR decreased significantly from 71.4 (63.9; 77.5) to 64.3 (60.8; 68.3), p <0.01, and its reaction to CR_6 and CR_{15} was significantly lower, but the reaction to CR_{15} with negligible degree of probability nevertheless exceeded the one during SR and CR_6. It is noteworthy that during CR_6, differences between QTc (c) and ST (n.u.) were not observed in comparison with SR at the beginning and at the end of the experiment. At the same time, CR_{15} caused significant changes in these indices at the beginning compared to SR (QTc) and CR_6 (QTc and ST), p <0.05. At the end of the study, this difference was retained only by QTc compared to SR.

Table 2. Indicators of electrocardiographic examination of athletes in the 1st withdrawal at the beginning and end of the study

Parameters		SR	CR_6	CR_{15}
HR, min^{-1}	Before	71.4 (63.9; 77.5)	72.4 (67.8; 81.2)	82.0 (72.2; 89.3)$^{**\#}$
	After	64.3 (60.8; 68.3)	66.2 (62.0; 71.5)$^{\#}$	69.2 (64.9; 74.2)$^{*\#}$
QTc, s	Before	0.412 (0.398; 0.424)	0.413 (0.399; 0.422)	0.420 (0.417; 0.433)$^{*\#}$
	After	0.409 (0.401; 0.425)	0.413 (0.402; 0.429)	0.420 (0.408; 0.432)*
ST, n.u.	Before	0.089 (0.034; 0.126)	0.096 (0.039; 0.147)	0.113 (0.034; 0.157)*
	After	0.100 (0.068; 0.122)	0.103 (0.065; 0.127)	0.104 (0.071; 0.152)

* - $p < 0.05$, ** - $p < 0.01$ – comparing CR_{15} and SR;
$^{\#}$ - $p < 0.05$ – comparing CR_{15} and CR_6

Table 3 shows changes in HRV and their CR responses. At the beginning and at end of the study, the TP (ms^2) index was the same during SR. During CR_6 and CR_{15}, changes reflected the effect of rhythm and respiratory rate, which was characterized by a significant increase in TP (ms^2) in response to CR_6 – to 22316.0 (13248.0; 26699.6), $p < 0.001$ and a significant decrease in TP (ms^2) in response to CR_{15} – to 2842.1 (1310.4; 4382.4), $p < 0.01$ at the beginning, and, similarly, at the end of the study. The VLF (ms^2) parameter of SR at the beginning and at end of the study did not show any differences, and the reaction to CR_6 did not cause VLF changes (ms^2). The reaction to CR_{15} at the beginning did not differ from the SR and CR_6 parameters. At the end of the training, there was a significant decrease in VLF (ms^2) during CR_{15} 348.0 (196.0; 590.5) compared with SR 765.2 (299.3; 1108.9), and during CR_6 637.6 (470.9; 930.3), $p < 0.01$.

The LF (ms^2) index during SR at the beginning and at end of the study slightly varied: 1884.6 (823.7; 3329.3) versus 1870.6 (697.0; 8854.8), ($p < 0.05$). During CR_6 (ms^2) there was a pronounced increase in LF (ms^2) at the beginning and at the end ($p < 0.001$), which described the effect of respiration. Similar changes were detected during CR_{15}, which was characterized by a significant decrease in LF (ms^2) compared with SR ($p < 0.01$) and CR_6 ($p < 0.001$) both at the beginning and at end of the study, which did not differ between themselves.

According to the parameter HF (ms^2) at the beginning and at the end of the SR study, there was a decrease from 2035.7 (756.3; 6037.3) to 1693.4 (761.8; 2992.1), ($p < 0.05$).

Table 3. HRV indicators at the beginning and end of the study

Parameters	Before	After
	Spontaneous respiration (SR)	
TP, ms^2	4975.5 (2480.0; 11406.2)	4874.6 (2611.2; 13409.6)
VLF, ms^2	564.8 (334.9; 1310.4)	765.2 (299.3; 1108.9)
LF, ms^2	1884.6 (823.7; 3329.3)	1870.6 (697.0; 8854.8)*
LFn, n.u.	48.9 (29.9; 74.1)	49.0 (35.0; 69.1)
HF, ms^2	2035.7 (756.3; 6037.3)	1693.4 (761.8; 2992.1)*
HF, n.u.	49.4 (24.4; 68.1)	46.7 (30.2; 64.2)
LFHF, ms^2/ ms^2	1.00 (0.49; 3.24)	1.11 (0.49; 2.25)
ICHR, ms^2/ ms^2	1.44 (0.63; 3.18)	1.73 (0.91; 5.04)
	Controlled respiration (CR_6)	
TP, ms^2	22316. (13248.0; 26699.6)$^{\#\#\#}$	19168.7 (16926.0; 25504.1)$^{\#\#\#}$
VLF, ms^2	676.4 (445.2; 806.6)	637.6 (470.9; 930.3)
LF, ms^2	18351.3 (9370.2; 21170.3)$^{\#\#\#}$	17056.4 (13642.2; 19126.9)$^{\#\#\#}$
LFn, n.u.	83.2 (76.2; 89.0)$^{\#\#\#}$	83.9 (78.4; 89.6)$^{\#\#\#}$
HF, ms^2	2560.9 (1361.6; 5098.0)	2218.7 (1383.8; 3931.3)$^{\#}$
HF, n.u.	15.6 (10.2; 22.2)$^{\#\#\#}$	14.5 (9.8; 18.2)$^{\#\#\#}$
LFHF, ms^2/ ms^2	5.53 (3.61; 9.00)$^{\#\#\#}$	5.77 (4.41; 9.00)$^{\#\#\#}$
ICHR, ms^2/ ms^2	5.56 (3.52; 9.12)$^{\#\#\#}$	6.23 (4.42; 9.59)$^{\#\#}$
	Controlled respiration (CR_{15})	
TP, ms^2	2842.1 (1310.4; 4382.4)$^{\$\$\&\&\&}$	2726.1 (1552.4; 4816.4)$^{\$\$\&\&\&}$
VLF, ms^2	499.7 (225.0; 967.2)	348.0 (196.0; 590.5)$^{*\$\$\&\&}$
LF, ms^2	583.2 (285.6; 1274.5)$^{\$\$\&\&\&}$	600.5 (285.6; 1043.3)$^{\$\$\&\&\&}$
LFn, n.u.	41.9 (22.6; 51.5)$^{\$\&\&\&}$	34.7 (21.7; 43.3)$^{\$\$\&\&\&}$
HF, ms^2	967.2 (479.6; 2540.2)$^{\$\&\&}$	1728.8 (829.4; 2683.2)*
HF, n.u.	54.9 (44.1; 76.1)$^{\$\&\&\&}$	63.7 (53.2; 76.8)$^{\$\$\&\&\&}$
LFHF, ms^2/ ms^2	0.81 (0.25; 1.21)$^{\$\&\&\&}$	0.57 (0.25; 0.81)$^{**\$\$\&\&\&}$
ICHR, ms^2/ ms^2	1.51 (0.60; 2.32)$^{\&\&\&}$	0.79 (0.67; 1.23)$^{**\$\$\&\&\&}$

* - $p < 0.05$, ** - $p < 0.01$ – between at the beginning and end;
$^{\#}$ - $p < 0.05$, $^{\#\#}$ - $p < 0.01$, $^{\#\#\#}$ - $p < 0.001$ – between controlled respiration 6 $min.^{-1}$ and spontaneous respiration;
$^{\$}$ - $p < 0.05$, $^{\$\$}$ - $p < 0.01$ – between controlled respiration 15 $min.^{-1}$ and spontaneous respiration;
$^{\&}$ - $p < 0.05$, $^{\&\&}$ - $p < 0.01$, $^{\&\&\&}$ - $p < 0.001$ - between controlled respiration 6 $min.^{-1}$ and controlled respiration 15 $min.^{-1}$.

When performing CR_6, HF (ms^2) compared with SR slightly increases – more significantly at the end of the study ($p < 0.05$). At CR_{15}; a significant reduction in HF (ms^2) was observed – to 967.2 (479.6; 2540.2) in comparison with SR (2035.7 (756.3; 6037.3)) and CR_6 (2560.9 (1361, 6; 5098.0)), $p < 0.05$ and $p < 0.01$, respectively, whereas at the end of the experiment no noticeable differences from HF (ms^2) were recorded during SR and CR_6. At the same time, HF (ms^2) effect on HR at CR_{15} at the end of the study was significantly higher than at the beginning – 1728.8 (829.4; 2683.2) versus 967.2 (479.6; 2540.2), p <0, 05.

Significant differences in the LF / HF parameter at the beginning and end of the experiment were not observed during SR and CR_6. The probable changes in this indicator were characterized by HRV taking into account the frequency of respiration. However, during CR_{15}, the decrease in LF / HF at the end of the study was more significant than at the beginning ($p < 0.01$). These data were completed by the heart rate centralization index (ICHR): its changes revealed a significant decrease at the end of the experiment when performing the CR_{15} test – to 0.79 (0.67; 1.23) versus 1.51 (0.60; 2.32) at the beginning ($p < 0.01$), in the absence of significant changes during SR and CR_6.

Discussion

7 weeks cycle endurance training according to standard methods of research led to the expected changes in the cardiovascular system, which are related to decrease in heart rate, SP and PP at rest. These integral indexes characterizing the economization of the heart (IR), the functional state of the respiratory system (Skibinska's index), Pirogov's LPS associated with physical ability and Baevsky's, characterizing the course of adaptation processes revealed a significant improvement. Against this backdrop, there were changes in the reaction of the ECG and HRV indices in response to CR.

Given ECG, it can be argued that with increased CR_6 and CR_{15} endurance compared to SR, HR responsiveness is significantly reduced, which may indicate a more adequate HR response to hyperventilation, which occurs when tests are performed [28]. However, the QTc, which is a predictor of sudden blood disorders, shows some deterioration during CR_{15}, although it does not reach dangerous levels[29]. Also, during CR_{15}, the decrease in the left ventricular repolarization disorders is sufficiently characteristic at the end of the experiment.

Changes in HRV values during CR are due to the frequency and rhythm of breathing, but the response of the HRV indices is significantly different and indicates, as a rule, the possibility of including the appropriate regulatory mechanisms. During CR_6, the low-frequency (LF) parameters of the heart rate regulator significantly increase, while during CR_{15} this is characteristic for high-frequency (HF) parameters. Given the HRV characteristics, they are most often connected with the activity of the sympathetic and parasympathetic regulatory circuits, respectively. These changes, first of all, manifest themselves in the analysis of TP (ms^2), LF (ms^2, n.u.), HF (ms^2, n.u.), LF/HF and ICHR, but their expressiveness changes with the growth of the endurance of athletes.

First of all, it should be noted that HRV indices at the beginning and end of training do not differ between themselves during CR_6, which suggests that in general, the response to low-frequency effects does not change with increasing endurance.

At the same time, during CR_{15} an increase in endurance does not lead to differences in the overall regulation of cardiac rhythm, does not affect low-frequency effects, but causes significantly greater activation of the high-frequency component of the regulation of the cardiac rhythm. The latter is reflected in a significant reduction in LF / HF, as compared with the vegetative tone at the beginning of the study, and as well as with SR. Similar changes reflect the ICHR changes in the VLF components of the HRV during CR_{15} were sufficiently informative: they showed a decrease in neurohumoral effects on the heart rate compared to SR and the data at the beginning of the study [30].

Conclusions

The use of CR tests of athletes training endurance allowed us to establish that the increase in the latter is reflected in the response of HRV to CR_{15}, which is characterized by a pronounced increase in HF and a decrease in LF / HF. Significant are also the differences in VLF, which, in case of CR_{15}, indicate a decrease in neurohumoral effects on HR after endurance training.

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