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Cardiorespiratory synchronization under the influence of strength endurance training

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Abstract

Purpose: to determine changes in the parameters of cardiorespiratory relationships during the maneuver with a change in breathing rate after a 4-month cycle of training aimed at the development of strength endurance.

Material & Methods: the results of the spiroarteriocardiorhythmographic study of 22 healthy men aged 20.7±2.3 years, who for 4 months 2 times a week for 90 minutes, were analyzed (a total of 30 classes were held) engaged in training for the development of strength endurance. The indicators of heart rate (min^{-1}), respiratory rate (min^{-1}), cardiac output ($dm^3 \times min^{-1}$), minute lung ventilation ($L \times min^{-1}$) and their derivatives – the Hildebrandt index (HR/RR) and volume synchronization index (CO/V), which were obtained during spontaneous respiration and controlled breathing at 0.1 Hz and 0.25 Hz.

Results: it was shown that strength endurance training led to a probable decrease in heart rate from 71.4 (63.9; 77.5) to 64.3 (60.8; 68.3), p=0.002, respiratory rate from 14.1 (12, 7; 16.8) to 13.8 (10.7; 15.3), p= 0.020 and minute lung ventilation from 8.19 (6.24; 8.86) to 6.40 (3.73; 7.74)), p=0.004 during spontaneous breathing, as well as a significant increase in the volumetric synchronization index. ($dm^3 \times L^{-1}$) during spontaneous respiration from 0.597 (0.490; 0.832) to 0.725 (0.564; 1.148), p=0.008, during controlled respiration at 0.1 Hz from 0.327 (0.382; 0.529) to 0.532 (0.441; 0.723), p=0.012 and during controlled respiration at 0.25 Hz from 0,245 (0,339; 0,455) to 0,481 (0,373; 0,616), p=0,003 against the background of a decrease in the Hildebrandt index during controlled respiration 0,1 Hz from 11.14 (10.43; 12.49) to 10.18 (9.54; 11.00), p=0.001, as well as with controlled respiration at 0.25 Hz from 5.33 (4.68; 5.85) to 4.46 (4.13; 4, 78), p=0.000.

Conclusions: endurance training for 4 months led to an economization of the cardiovascular and respiratory systems function and a decrease in the response to sympathoadrenal activation and hyperventilation.

Keywords: Strength endurance, cardiorespiratory synchronization, controlled respiration, Hildebrandt index, volumetric synchronization index.

Introduction

The search for subtle criteria of the state of the body in athletes, which would have prognostic value for determining the positive effects and prevention of negative consequences of training loads, as well as testifying to the development of training and the course of mechanisms to counteract the development of overstrain, is one of the modern directions of diagnostics in sports medicine. (Hoffmann et al., 2020;

Bellinger 2020; Kellmann et al., 2018). The difficulty of solving this task in many cases is due to the expediency of identifying minimal changes, which by themselves are often not clinically significant, but in combination with others can determine the mechanisms of certain shifts in homeostasis (Armstrong et al., 2022; Baumert et al, 2006). Considering the adaptive processes that occur in the athlete's body during the training process, this occurs at the level of certain, sometimes multidirectional, functional overstrains in various systems and organs of the body (Nicolò et al., 2020; Guzii & Romanchuk, 2021b; Guzii et al., 2023).

Strength endurance training is associated with the combined development of physical abilities (Gäbler et al., 2018), and is an integral part of recommendations for sports, physical activity for health maintenance and for the treatment of chronic diseases or disabilities (Garber et al., 2011). Many issues related to muscle changes, reactions of the cardiovascular system, hormonal status have been studied (Lamotte et al., 2010; Ignjatovic et al., 2011; Megahed et al, 2023; Schneider et al, 2019). However, has not been fully elucidated, and in contrast to training of general endurance, acute hemodynamic adaptation (stroke volume and cardiac output) to prolonged strength exercises is described very rarely (Spence et al, 2011; Chovanec & Gröpel, 2020). The issue of adaptive changes in the body related to cardiorespiratory interaction is not resolved (Hackett & Chow, 2013), although a number of publications on this issue have appeared (Matos-Santos et al, 2017). The study carried out to determine the reaction of the cardiorespiratory system to power loads of different duration and intensity, which is important for predicting the risk in healthy and sick people (Lässing et al, 2023) was sufficiently significant.

The evidence-based focus of modern medicine on the search for certain signs of conditions and diseases significantly increases the requirements for taking into account a whole complex of functional parameters of the organism (Meeusen, et al., 2013), however, as a rule, it does not pay attention to intersystem parameters. Therefore, the standardization of modern diagnostic and therapeutic methods, which significantly increase the efficiency of diagnosis, treatment and rehabilitation (Pinna et al., 2017), still has certain problems in predicting the condition of a specific person (Guzii & Romanchuk, 2021a).

The existing arsenal of modern functional diagnostics in the vast majority of cases is based on the identification of markers of pathology, that is, it is reduced to the identification of signs characterizing the formation of a pathological trace in the body (Illigens & Gibbons, 2019). On the other hand, the available experience of prognostic medicine proves that even with reliable identification of pathological markers, the final result of an individual prognosis of the course of the body's pathology and its recovery is quite problematic (Dupuy et al., 2018).

These difficulties can be overcome by implementing into the practice of functional diagnostics in sports medicine methods of combined instrumental research of various functions, which allow establishing individual variants of intersystem interactions at rest and in the dynamics of certain influences (Dick et al., 2014; Abreu et al., 2023).

In polyfunctional studies, the degree of correlation of individual functions at the intra- and intersystem levels is of great importance. In this regard, only objective data can be a condition for reliable prediction of certain dysregulations, which means risks of susceptibility to the development of diseases, pathological processes during sports or recovery of work capacity after injuries and diseases (Angelova et al., 2021; Da Silva et al., 2023).

Cardiorespiratory interaction, which occurs at multiple levels of the nervous system and includes the coordinated regulation of respiratory, cardiovagal, and sympathetic inputs, is central to understanding the mechanisms of dysregulation (Incognito et al., 2019). Many neurons in each of the two ventrolateral medullary networks (respiratory and autonomic) are differentiated and directly regulated by oligosynaptic input signals from chemoreceptors, baroreceptors, pulmonary mechanoreceptors, and their control is carried out through the formation of patterns of cardiovascular and respiratory interaction in the cerebral cortex, hypothalamus, pons (Garcia et al., 2013; Fisher et al, 2022; Fuller et al, 2022; Sampaio et al., 2012).

It is well known that deep breathing with a frequency of 0.1 Hz is characterized by an increase in respiratory volume and can increase the excursion of the diaphragm (Vostatek et al., 2013; Stromberg et al., 2015), promotes more effective ventilation and oxygenation of the blood by attracting more alveoli and also reduces alveolar dead space (Bilo et al., 2012). A decrease in chemoreflex sensitivity was shown (Bernardi et al., 2001; Dempsey & Smith, 2019). Involvement of this extracardiac circulatory factor contributes to increased venous return, right heart filling and, accordingly, increased stroke volume and cardiac output (Byeon et al., 2012; Paprika et al, 2014). The effect of synchronizing pulse oscillations of systolic and diastolic blood pressure with heart rhythm was noted (Sin et al., 2010). An improvement in capillary blood flow is likely (Ovadia-Blechman et al., 2017; Russo et al, 2017). Resonantly, 0.1 Hz breathing increases RSA activity (Bernardi et al., 2001; Javorka et al., 2020). The efficiency of pulmonary gas exchange is improved (Hayano et al., 1996), heart work is saved (Baumert et al., 2015), and blood pressure fluctuations are buffering (Gibbons et al., 2019; Li et al, 2018). On the part of the autonomic nervous system, the effects of increasing the activity and tone of the parasympathetic link are observed (Eckberg & Karemaker, 2009; Guzii & Romanchuk, 2017). The optimization of the release and hydrolysis of acetylcholine in the SA node (Bernardi et al., 2001) and the strengthening of the phase modulation of sympathetic activity (Limberg et al., 2013) were noted, which contributes to the improvement of orthostatic reactions (Vidigal et al., 2016). Our previous studies have shown that effect of a CR of 0.1 Hz is in an increase in end-systolic volume, cardiac output, cardiac index on the background of a decrease in systolic volume, total peripheral vascular resistance and systolic index (Romanchuk, 2023). That is, deep breathing with a frequency of 0.1 Hz allows you to determine the structure of body systems under the imposed parasympathetic influence.

Deep breathing 15 times per minute (0.25 Hz) in a set rhythm for 2 minutes can cause initial signs of hyperventilation and affect various systems and tissues of the body, modifying manifestations of sympathoadrenal activation (Hornsveld et al., 1995; Macefield & Henderson, 2019; Krohn et al., 2023). The latter was shown when testing with hyperventilation for 100 s with a rhythm of 0.33 Hz (Kox et al., 2014). However, hyperventilation with a frequency of 0.25 Hz for 2 minutes is quite mild, although it can also cause the development of certain symptoms. Among the signs that we obtained in previous studies: an increase in HR (min^{-1}), a decrease in BR_{LF} ($ms \times mmHg^{-1}$), BR_{HF} ($ms \times mmHg^{-1}$) at rest and during the recovery period after physical load, changes of system hemodynamics (Guzii & Romanchuk, 2016; Guzii & Romanchuk, 2017, 2018, Romanchuk et al., 2023). At CR 0.25 Hz, compared to SR, a stable end-systolic volume, an increase in cardiac output, cardiac index against the background of a decrease in end-diastolic volume, systolic volume, total peripheral vascular resistance and systolic index were revealed. That is, performing a breathing maneuver increases the preload on the heart, which is compensated by an increase in HR (min^{-1}) on the background of a decrease in SBP (mmHg) (Romanchuk, 2023). If we talk about hyperventilation tests in general, then their classical performance lasting up to 3 minutes can stimulate the appearance of symptoms (King, 1988), which can cause deterioration of well-being or even contribute to the development of conditions that require emergency care (Gardner, 1996). In view of the above, we proposed a reaction-friendly procedure for performing a breathing maneuver, but it allows us to detect the body's reactivity to influences that stimulate, at least, the activation of the sympathetic and parasympathetic links of the autonomic nervous system (Zoccal et al., 2022).

In our opinion, the study of cardiorespiratory relationships is important in determining the functional state of the human body and will contribute to the development of new approaches to the diagnosis of changes in the body of athletes under the influence of training of various orientations.

The main hypothesis of this study was to show that streigth endurance training leads to changes in cardiorespiratory interaction associated with hemodynamic support of the body, which can be of diagnostic value for determining the current functional state of the body.

The goal of this study was to determine changes in the parameters of cardiorespiratory relationships during a maneuver with a change in breathing rate after a 4-month cycle of training aimed at developing strength endurance.

Material and methods of research

Study subjects

This research was carried out within the scientific program of the Department of Medical Rehabilitation of the Ukrainian Research Institute of Medical Rehabilitation and Resort therapy of the Ministry of Health of Ukraine (Odesa, Ukraine). We analyzed the results of the study of 22 healthy men aged 20.7±2.3 years, which were regularly engaged in physical culture, did not complain of disorders in the body's condition, and did not have acute diseases. The first study was conducted before the start of training for the development of strength endurance, the second - after completing the training cycle, which lasted 4 months and included regular (2 times a week for 90 min.) physical exercises for the development of strength endurance (30 sessions were conducted). All procedures described in this study have been performed in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the principles of the Declaration of Helsinki of 1964 and its latest version. Written informed consent or its equivalent has been obtained from all patients. This study was approved by the Ethics Committee of the Ukrainian Research Institute of Medical Rehabilitation and Resort therapy of the Ministry of Health of Ukraine (No. 5 dated October 20, 2023).

Research procedure

The method of the cardiorespiratory system research included carrying out combined measurements of the respiratory and cardiovascular systems activity indicators in a sitting position using a spiroarteriocardiograph (SACR) device. The duration of the study was 6 minutes and involved the sequential registration of three measurements (2 minutes each) with a change in breathing rate. During the first 2 minutes, SACR indicators were recorded during normal spontaneous breathing (SR), in the second 2 minutes – during controlled breathing 6 times per minute (5 s inhalation, 5 s exhalation) (CR_6), in the third 2 minutes – during controlled breathing 15 times per minute (2 s inhalation, 2 s exhalation) (CR_{15}). All examinations were performed in the morning, 2-3 hours after a light breakfast. On the eve of the study, all participants were instructed to avoid consumption of stimulant beverages (coffee, green tea, energy drinks) before the examination. The main condition for admission to the study was the absence of intense and prolonged physical load the day before.

Method

The device "Spiroarteriocardiorhythmograph"

(SACR; "Intox" company, St. Petersburg) was used to determine the cardiorespiratory condition. The device combines three specific methods of physiological research into a single hardware complex, which allows achieving a fundamentally new quality of measurements, i.e., simultaneous registration of HR and blood pressure at different stages of the respiratory act (Panenko et al., 2006; Romanchuk & Guziy, 2020a).

ECG registration in lead 1 makes it possible to determine the indicators of cardiointervalometry – the frequency of heart rate (HR, min^{-1}), indicators of systemic hemodynamics (Kim et al., 2005) – stroke volume (SV, cm^3), cardiac output (CO, $dm^3 \times min^{-1}$).

The ultrasonic sensor of the SACR device allows you to measure air flow during inhalation and exhalation and to determine the average parameters of pattern breathing: duration of inhalation, duration of exhalation, respiratory rate (RR, min^{-1}), tidal volume (V_T, L), as well as minute respiration volume (V, $L \times min^{-1}$) (Romanchuk & Guzii, 2020b).

For all measurements, indicators of frequency and volume synchronization of the cardiorespiratory system were calculated – the Hildebrandt index (HI) and volume synchronization index (VSI) (Hildebrandt, 1953; Romanchuk, 2023).

$$HI = HR(min^{-1})/RR(min^{-1})$$

$$VSI = CO(dm^3 \cdot min^{-1})/V(L \cdot min^{-1})$$

Statistical analysis

Processing of the obtained results was carried out using the STATISTICA program for Windows (version 10.0), Microsoft Excel 2012. The obtained data are presented in the form of a median with 25-75% (Q_1; Q_3) percentiles. Differences between baseline and follow-up measurements were obtained using the Wilcoxon matched-pairs test.

Results of the study

Table 1 shows the changes in the morphofunctional indicators of the group of men over 30 sessions of the strength endurance training cycle. The presented changes indicate a rather characteristic effect of training on the development of strength endurance. First of all, you should pay attention to a significant ($p<0.05$) decrease in height, chest circumference, as well as a tendency to decrease sitting height ($p=0.055$), abdominal circumference ($p=0.053$), increase in neck circumference ($p=0.084$), forearm circumference ($p=0.088$), leg circumference ($p=0.084$). These changes can characterize the peculiarities of the training process aimed at the development of strength endurance, which are characterized by the development of muscle mass and some decrease in body length indicators. This is probably due to the negative impact of classes that are characterized by dynamic long-term physical exercises with weights.

On the other hand, there was a significant decrease in HR (min^{-1}) at rest from 71.4 (63.9; 77.5)

Table 1. Morphofunctional indicators of individuals at the beginning and at the end of the training cycle, Medium (Q_1; Q_3), n=22

Indicator	Initial	Final	z	p-value
Body weight, kg	76.5 (69.0; 81.0)	73.0 (68.0; 80.0)	1.57	0.117
Body length, cm	179.0 (173.0; 182.0)	178.0 (174.0; 181.0)	3.20	**0.001**
BMI, $kg \times m^{-2}$	22.9 (21.5; 25.3)	22.9 (21.7; 24.7)	0.49	0.627
Body area, m^2	1.91 (1.86; 2.01)	1.89 (1.84; 2.02)	2.16	**0.031**
Body length (sitting), cm	92.5 (90.5; 95.0)	92.0 (90.0; 94.0)	1.92	0.055
Fat, %	14.8 (11.3; 16.7)	13.3 (11.2; 16.8)	0.96	0.338
Neck circumference, cm	38.0 (37.0; 40.0)	38.5 (37.0; 40.0)	1.73	0.084
Abdominal circumference, cm	79.0 (77.0; 85.0)	78.0 (77.0; 84.0)	1.93	0.053
Circumference of the chest (pause), cm	98.0 (95.0; 102.0)	97.0 (91.0; 100.0)	2.57	**0.010**
Excursion of the chest, cm	7.8 (6.0; 8.0)	8.0 (7.0; 9.0)	1.58	0.115
Shoulder circumference (rl), cm	30.0 (28.5; 33.0)	30.8 (28.0; 33.0)	1.10	0.272
Shoulder circumference (tg), cm	33.0 (32.0; 35.0)	32.5 (31.0; 35.0)	0.78	0.433
Forearm circumference, cm	27.0 (26.0; 28.5)	28.0 (27.0; 29.0)	1.71	0.088
Hip circumference, cm	54.0 (51.0; 58.0)	54.0 (51.0; 56.0)	0.44	0.659
Leg circumference, cm	37.0 (35.0; 38.0)	37.5 (35.0; 39.0)	1.73	0.084
VC, ml	4850 (4500; 5400)	4975 (4500; 5550)	0.78	0.433
δVC, %	10.8 (-0.4; 19.7)	12.5 (1.0; 20.6)	1.28	0.200
VI, $ml \times kg^{-1}$	67.6 (61.0; 72.5)	70.6 (65.7; 74.2)	1.16	0.244
Stange's test, s	77 (66; 97)	80 (64; 90)	0.17	0.867
Genchee test, s	46 (38; 52)	46 (35; 52)	0.36	0.717
SBP, mmHg	120 (110; 120)	110 (110; 120)	1.28	0.201
DBP, mm Hg	70 (60; 80)	60 (60; 70)	0.85	0.394
PBP, mm Hg	50 (40; 50)	50 (40; 50)	0.45	0.650
Heart rate, min^{-1}	71.4 (63.9; 77.5)	64.3 (60.8; 68.3)	3.15	**0.002**
RR, min^{-1}	14.1 (12.7; 16.8)	13.8 (10.7; 15.3)	2.32	**0.020**
V, $L \times min^{-1}$	8.19 (6.24; 8.86)	6.40 (3.73; 7.74)	2.84	**0.004**
CO, dm^3	4.45 (4.20; 5.10)	4.35 (4.00; 4.80)	1.36	0.175

to 64.3 (60.8; 68.3), p=0.002, RR (min^{-1}) from 14.1 (12.7; 16.8) to 13.8 (10.7; 15.3), p=0.020 and V ($L\times min^{-1}$) from 8.19 (6.24; 8.86) to 6.40 (3.73; 7.74), p=0.004, which indicates the economy of the activity of the cardiovascular system and the respiratory system, which characterizes the training process with the aim of developing general endurance. CO (dm^3) also decreased at rest from 4.45 (4.20; 5.10) to 4.35 (4.00; 4.80), but did not reach a significant level (p=0.175). That is, without taking into account the results of strength endurance testing, according to the data of the morphofunctional study; it is possible to assert the achievement of certain effects related to their impact on the athlete's body.

Our task was to monitor the effect of strength endurance training on the indicators of cardiorespiratory system synchronization – HI (c.u.) and VSI ($dm^3\times L^{-1}$) when performing a breathing maneuver with a change in breathing frequency. In fig. 1 shows the changes in HR (min^{-1}), V ($L\times min^{-1}$) and CO (dm^3) that occur during the breathing maneuver.

From fig. 1 shows that at the end of the cycle of training for the development of strength endurance, less pronounced changes in indicators are observed for all the presented parameters when performing a breathing maneuver with a change in RR. This especially applies to HR (min^{-1}) and V ($L\times min^{-1}$), although changes in CO (dm^3) also demonstrate an economization of the response to controlled breathing at the end of the training cycle compared to the initial state. This applies both to indicators during spontaneous breathing and to indicators during controlled breathing.

In fig. 2 and in table. 2 shows the changes in HI (c.u.) and VSI ($dm^3\times L^{-1}$) indicators when performing breathing maneuver with a change in breathing frequency. Analyzing the presented changes in HI (cu), it can be asserted that the response of cardiorespiratory interaction according to frequency indicators (HI, c.u.) for CR_6 and CR_{15} after the training cycle is associated with the smaller changes compared its initial state, for CR_6 and CR_{15}. This probably reflects a less pronounced response of the cardiovascular system to the modulation of sympathetic and parasympathetic influences at the end of training cycle, which may reflect a certain level of adaptive changes under the influence of strength endurance training.

With spontaneous respiration (SR) at the end of strength endurance training cycle, a significant increase in the VSI index ($dm^3\times L^{-1}$) was noted from 0.597 (0.490; 0.832) to 0.725 (0.564; 1.148),

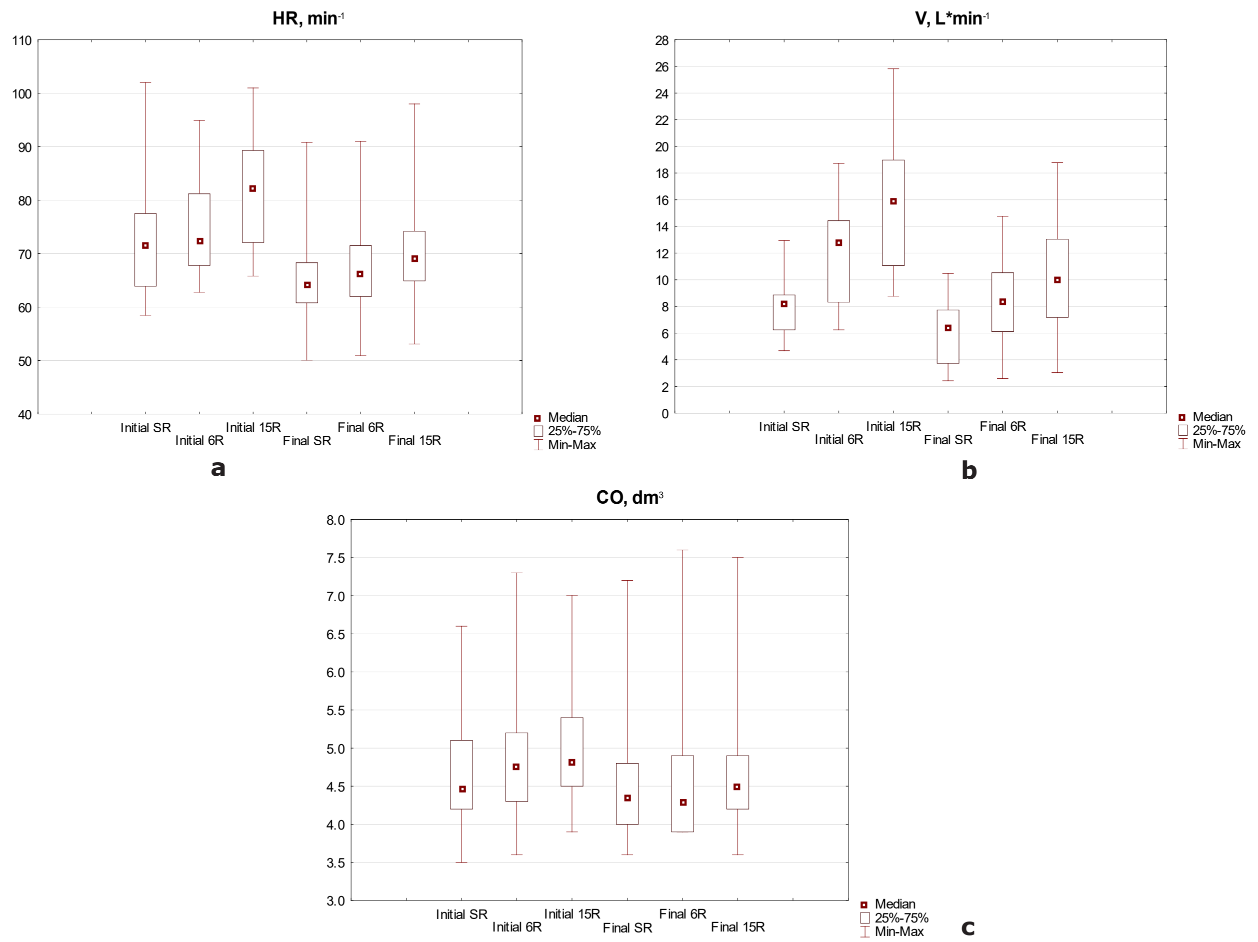

Figure 1. **Dynamics of changes in HR, min^{-1} (a), V, $L\times min^{-1}$ (b) and CO, dm^3 (c) during the performance of a breathing maneuver at the beginning and at the end of the study.**

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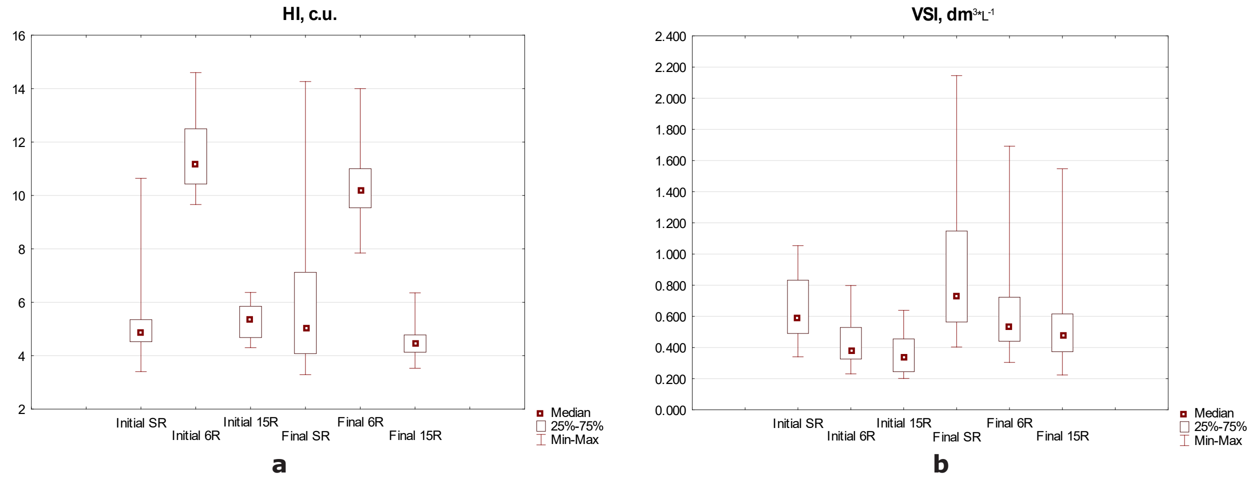

Figure 2. Changes in HI (c.u.) and VSI ($dm^3 \times L^{-1}$) indicators during the respiratory maneuver at the beginning and at the end of the study.

Table 2. Pairwise differences in indicators of frequency and volume synchronization of the cardiorespiratory system when performing a breathing maneuver, Med (Q_1; Q_3), n=22

Indicator		Initial		Final		Initial-Final	
						Z	p
HI, c.u.	SR	4.91 (4.53; 5.35)		5.06 (4.08; 7.12)		0.83	0.408
	CR_6	11.14 (10.43; 12.49)		10.18 (9.54; 11.00)		**3.33**	**0.001**
	CR_{15}	5.33 (4.68; 5.85)		4.46 (4.13; 4.78)		**3.62**	**0.000**
		Z	p	Z	p		
	$SR\text{-}CR_6$	**4.11**	**0.000**	**3.88**	**0.000**		
	$SR\text{-}CR_{15}$	1.02	0.306	1.74	0.082		
	$CR_6\text{-}CR_{15}$	**4.11**	**0.000**	**4.11**	**0.000**		
VSI, $dm^3 \times L^{-1}$	SR	0.597 (0.490; 0.832)		0.725 (0.564; 1.148)		**2.65**	**0.008**
	CR_6	0.327 (0.382; 0.529)		0.532 (0.441; 0.723)		**2.52**	**0.012**
	CR_{15}	0.245 (0.339; 0.455)		0.481 (0.373; 0.616)		**2.97**	**0.003**
		Z	p	Z	p		
	$SR\text{-}CR_6$	**3.94**	**0.000**	**2.52**	**0.012**		
	$SR\text{-}CR_{15}$	**4.11**	**0.000**	**3.68**	**0.000**		
	$CR_6\text{-}CR_{15}$	**3.00**	**0.003**	1.83	0.067		

p=0.008 compared the initial state. This proves a higher level of economization of the function of external breathing and a greater efficiency of the cardiovascular system. At the same time, changes in this indicator both at CR_6 and at CR_{15} are significantly greater than at the beginning, which generally indicates a better adaptation of the cardiorespiratory system to suppression of postganglionic sympathoadrenal activity during CR_6 and activation of hyperventilation during CR_{15}. The most likely is adaptation to the conditions of hyperventilation, which, even with an imposed rhythm of breathing with accelerated exhalation, contributes to a fairly effective and economical oxygenation, preventing manifestations of sympathoadrenal activation.

Discussion

In this study, the analysis of the cardiorespiratory interaction indicators, obtained during the simultaneous registration of cardiac and respiratory activity data, was carried out. The specified changes confirm a number of known facts that allow to supplement the understanding of the physiological and pathophysiological aspects of the interaction of the cardiovascular and respiratory systems in the maintenance of hemodynamic homeostasis, as well as to identify diagnostically important features of cardiorespiratory relationships (Abreu et al., 2022; Brændholt et al., 2023; Pinsky et al., 2018; Parviainen et al., 2022; Matić et al., 2022). Taking into account the problem of diagnosing the state of athletes in the conditions of the training process, there is an expediency of using express valid non-invasive methods of instrumental diagnosis of the functional state of the body, which would allow directly during training and competitions to investigate the impact of psychophysical loads (Girin et al., 2021; Harford et al., 2019).

The device we used (SACR) has the ability to simultaneously register and process indicators of the activity of the cardiorespiratory system. It is mobile relative to the study site, so it is widely used in "field conditions" (Guzii et al, 2019). On the other hand, the continued development of devices or clothing for the body will allow recording indicators of body activity to assess the functional state of the body not only in athletes (Mühlen et al., 2021), but also in ordinary people, as well as patients with various pathologies, especially cardiac vascular and respiratory systems. Therefore, the simultaneous registration of indicators of the cardiovascular and respiratory systems is currently relevant, especially from the standpoint of determining adaptive changes under the influence of training of different orientations.

IH (cu), which characterizes the frequency synchronization of the cardiorespiratory system in normal, is 2.8-4.9. Most often, it is associated with the vegetative state. However, in our opinion, it is not able to adequately reflect changes both at rest and during exercise, since this coefficient does not take into account the volumetric characteristics of the cardiorespiratory system, which determine its energy capabilities both at rest and under exercise time It was previously shown that IH (cu) in a group of physically active men when performing tests with controlled breathing likely increases from 4.77 (3.98; 6.20) to 10.92 (9.97; 12.14), p=0.000 at CR_6 and remains unchanged in comparison with spontaneous breathing 5.00 (4.48, 5.84), p=0.209 at CR_{15} (Romanchuk, 2023). Other authors demonstrated its increase during physical load, which occurred due to a relative increase in heart rate (min⁻¹) compared to HR (min⁻¹). The latter, in their opinion, indicates its informativeness regarding the strengthening of sympathetic influences and the "physiological price" of the work performed and predicts the refusal of intense physical exertion (Gastinger, et al, 2010). From these positions, its less pronounced growth at the end of training for the development of strength endurance testifies to higher reserve capabilities of the cardiorespiratory system.

When studying VSI ($dm^3 \times L^{-1}$), which characterizes volumetric synchronization, it was previously shown that when performing a breathing maneuver with a change in respiratory rate, it reliably decreases from 0.586 (0.477; 0.745) in SR to 0.441 (0.327; 0.582) at CR_6 to 0.360 (0.247; 0.477), p=0.000 at CR_{15} (Romanchuk, 2023). In other studies, it was found that it increases with work capacity (Gastinger, et al, 2010). That is, with the help of this indicator, it is possible to characterize the adequacy of the reaction to physical exertion and energy expenditure. During the examination of 202 highly qualified athletes before, after the end and the next morning after training, quite stable indicators were obtained, which proves the possibility of using this indicator to characterize the individual ability of the body to tolerate the load and recover after it. – up to 0.566 (0.448; 0.765), after 0.574 (0.432; 0.790), the next morning 0.593 (0.482; 0.891) (Guziy and Romanchuk, 2021b). At the same time, the results obtained by us during the performance of the breathing maneuver testify to the peculiarities of its changes under the influence of training on the development of strength endurance, which indicates the adaptation of cardiorespiratory relationships under the influence of training, which is characterized by effective and economical oxygen supply, which prevents the development of excessive sympathoadrenal activation. Thus, strength endurance training leads to an increase in the VSI indicator ($dm^3 \times L^{-1}$) during spontaneous breathing at rest from 0.597 (0.490; 0.832) to 0.725 (0.564; 1.148), p=0.008, which reflects its increase during CR_6 from 0.327 (0.382; 0.529) to 0.532 (0.441; 0.723), p=0.012, and at CR_{15} from 0.245 (0.339; 0.455) to 0.481 (0.373; 0.616), p=0.003.

In any case, unlike IH (cu), VSI ($dm^3 \times L^{-1}$) is related to the perfusion capabilities of the respiratory system and reflects the participation of the cardiovascular system in supplying the body with oxygen. The latter may indicate its informativeness regarding the diagnosis of the ability of the cardiorespiratory system to respond more gently to the proposed breathing rhythm, which may cause signs of hyperventilation, and accordingly prevent excessive sympathoadrenal activation.

Exercises on the development of strength endurance for 4 months led to the economization of the function of the cardiovascular and respiratory systems, which was characterized by a probable decrease in HR, RR and V_T at rest, as well as a reliable increase in the volume synchronization index VSI. ($dm^3 \times L^{-1}$) at rest and with controlled breathing at a frequency of 0.1 Hz, when the functioning of body systems occurs under imposed parasympathetic influence, and with controlled breathing at a frequency of 0.25 Hz, when sympatho-adrenal activation occurs. At the same time, they did not differ significantly from each other. According to the HI (cu) indicator, its likely decrease was noted, both in response to controlled breathing with a frequency of 0.1 Hz and in response to controlled breathing with a frequency of 0.25 Hz. The latter testifies to the possibility of the cardiorespiratory system to respond more gently to the proposed breathing rhythm and to prevent excessive activation of the sympathoadrenal system.

Conclusion

The strength endurance training for 4 months led to the cardiovascular and respiratory systems functions economization and the decrease of response to sympathoadrenal activation and hyperventilation.

Author's contribution

Conceptualization, O.R.; methodology, O.R. and O.G.; investigation, O.G. and I.S.; writing – review and editing, O.R. and A.M.; visualization, O.R.; supervision, O.R. and A.M.; project administration, O.R. and I.S. All authors have read and agreed with the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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