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Research Article

The Role of Power and Frequency Characteristics of the Cardiorespiratory System in Conditions of Minimal Physical Exercise

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Abstract: It is our point of view that it is necessary to study in more detail and consistently the dynamics of joint reactions of respiration and blood circulation during physical load. The study aims to determine which component of the cardiorespiratory system is a more labile parameter in forming the body's adaptive reactions in minimal physical loads. The objectives of the study are to reveal the role of respiratory and cardiovascular components of the cardiorespiratory system in achieving the overall useful result during bicycle ergometry exercises of minimal power and to make a comparison of expressiveness changes in respiratory amplitude and its rate as well as to carry out comparing human cardiorespiratory system activity and the one in animals. Healthy young people of both sexes were examined. They were provided with standard stages of short-term physical exercise load ranging from negligible to moderate. A bicycle ergometer with a pedaling rhythm of 40 per minute was used to ensure this. Before loading, at its peak, and after it, spirography, pulsometry, and tonometry were performed. These parameters were obtained for each subject simultaneously. The principles of forming cardiorespiratory interaction, revealed in the given study in humans, corresponded with the parameters of baro - and chemoreflex obtained by us earlier in acute experiments on cats. The statistical analysis was carried out using Statistica ® 7.0 package (StatSoft Inc., USA). The results' significance was assessed using Student's t-test and sign test. At minimal physical exercises, pulmonary ventilation is performed through more pronounced changes in respiratory amplitude and less markedly through respiratory rate variations. Under given conditions, domination of the respiratory system, activity was proved to be most effective. Arterial pressure and pulse react least of all. First, the systemic blood pressure increases, and the changes in cardiac frequency activity are realized last. In such cases, this parameter even can remain unchanged. The principles that define the different intensities of cardiorespiratory system components' activity for human organisms and animals turn out to be similar.

Keywords: cardiorespiratory system, minimal exercise, acid-base status, acid-base balance, acidosis, alkalosis.

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1. INTRODUCTION

Scientists established a close interaction between the cardiovascular and respiratory systems. Specialists use modern techniques to study interaction principles between the cardiovascular and respiratory systems. In their articles, several scientists describe the parameters of hemodynamics and external respiration in the norm and various pathological processes.[1-5] Experts study functional indicators under experimental influences. Scientists have studied the reactions of the cardiovascular system[6-8] and described the pattern of the changes in pulmonary ventilation.[9-12] In the literature, there are few studies on the regularities of forming general reactions of hemodynamics and respiration. Academician P.K. Anokhin substantiated the concept of functional systems. Physiologists and some clinicians use the term "functional systems".[13] Later, scientists singled out the concepts of the cardiorespiratory system or the functional cardiorespiratory system. This term indicates the combined activity of external respiration and hemodynamics. The cardiorespiratory system can change critical homeostatic parameters such as the pH of the blood and other liquid body media, the concentration of carbon dioxide and oxygen, and other constants.[14] Experts found that regulating the values of these vital homeostatic constants is possible by a voluntary change in breathing. The role of the respiratory component is vital and, undoubtedly, requires closer examination. Aghajanyan notes that the functional cardiorespiratory system is "…a universal indicator of functional reserves and adaptive functions of the organism..." [15] This currently makes it significantly important to develop clinically relevant criteria for assessing cardiorespiratory system condition in the norm and different pathological states. The receptive fields of regulation centers for external respiration and blood circulation are common. The cardiovascular and respiratory systems centers are located nearby, in the same parts of the central nervous system. Such a morphological feature should ensure close joint activity of respiration and blood circulation centers. There are several peculiarities and shortcomings in studying this problem in recent scientific articles.[16] First, there is very little experimental data obtained on laboratory animals. An experimenter can achieve maximum standardization only in conditions of acute or chronic experiments. They can be carried out only on animals. Secondly, in Russian and foreign literature, a few studies registered simultaneous reactions of the respiratory and cardiovascular systems. Thus, Vanushin and Vanushin noted various indicators of external respiration, hemodynamics, and heart activity [2]. But in such works, even if the load conditions are standardized, many significant factors are almost impossible to be considered t. For example, the endocrine status constantly changes throughout the day. Central and peripheral nerve structures change their excitability. The digestive system affects gross and basic metabolism when eating. Everyone knows well that these changes take place every second and inevitably affect the activity of the respiratory and cardiovascular systems. The experimenter cannot take them all into account in his research. It is possible to avoid this disadvantage if the intensity of breathing and blood circulation on one object is fixed simultaneously. Third, most works focus only on respiration and hemodynamics frequency characteristics.[17,18] In our view, this is incorrect. To correctly assess the reactions of the cardiorespiratory system, it is necessary to consider the power characteristics: respiratory capacity and stroke volume output. Unfortunately, the number of works devoid of these shortcomings is critically small, and most relate to early studies. It is our point of view that it is necessary to study in more detail and consistently the dynamics of joint reactions of respiration and blood circulation during physical load. Such studies should begin with minimal loads. Is it possible to reduce the frequency of external respiration during physical exertion? Another critical issue is determining the shared participation of four components of cardiorespiratory activity (cardiac rate, arterial pressure level, respiratory amplitude, and its rate) in ensuring the final adaptive result. And one more relevant question. Are there fundamental differences between humans and animals in the regulatory principles of their cardiorespiratory interaction? We failed to find this important data in the available literatureThis important data is lacking in the available literature. The study aims to determine which component of the cardiorespiratory system - external respiration or the activity of the cardiovascular system - is a more labile parameter in forming the body's adaptive reactions in minimal physical loads. The following objectives make it possible to achieve the aim:

- Reveal the role of respiratory and cardiovascular components of the cardiorespiratory system in achieving the overall useful result during bicycle ergometry exercises of minimal power.
- Make a comparison of expressiveness changes in respiratory amplitude and its rate. Carry out comparing human cardiorespiratory system activity and the one in animals.

2. MATERIAL AND METHODS

The study was carried out in two sets of studies on 47 healthy humans aged 19 – 26 of both sexes. They had different body types, which were defined by height and weight. Women had a height of 166,1±12,5 cm and a body weight of 61,6±1,0 kg. Men – 176,81±1,9 cm and 66,19±1,84 kg,g, respectively. These parameters corresponded on average to the normothermic body type. The study used a bicycle ergometer Oxygen Satori U (China). Young men and girls were subjected to physical exercise with a pedaling rhythm of 40 per minute. To determine the loading intensity, Borg method [19-20] was used. The physical load was measured from an extremely negligible level to an exceptionally light tone. Each subject performed a dynamic bicycle load of I-II levels (25 and 50 W) for 60 seconds each. The subjects were provided with short-term loads, which are used in cyclo ergometric studies to determine the initial reactions of the body.[21] Pulso-, tonometries, and spirography were performed. These indicators were measured at three-time points: before the exercise, at its height, and 3 minutes after it. The pulse oximeter MD300W (China) and the multifunctional spirograph – «SMP-21/01» (Russia) were used. Systolic and diastolic pressure were also measured by tonometry (OMRON M2 Basic Automatic Blood Pressure Monitor, Japan). Spirography was performed using the device «SMP-21/01» according to the technique used to assess the activity of the respiratory system by measuring pulmonary volumes.[22-23] The tidal volume and respiratory rate were registered. Based on these data, respiratory minute volume was calculated by the formula: Respiratory minute volume = Tidal volume × Respiratory rate. After the level I load (25 W), the subjects rested for 3 to 5 minutes until the measured parameters returned to the resting level. Then, the examinees were subjected to a level II load (50 W). Their pulse, pressure, and shallow breathing were measured again. It is necessary to emphasize that an important fact of the methodology of these studies was the following. We performed pulso-, tonometries, and spirography on each patient simultaneously (at the same time). Statistical processing was performed with MS ® Excel ® 2016 ™ and Statistica ® 7.0 (StatSoft Inc., USA) programs software. Differences in continuous variables between cases and controls were analyzed using the unpaired Student's t-test and by sign test.[24-25] The mean values of the parameters, the deviations of the mean value, and the mean square deviation were calculated as well. The differences were sometimes considered significant at $p<0.01$ or $p<0.05$.

3. RESULTS

The obtained results are given in table 1. In the first set of tidal volume was observed to increase by about 0.14 l (nearly 29% compared with rest; $p<0.0001$), and its frequency was observed to decrease by 2.26 movements/minute ($p<0.0001$). Minute respiratory volume increased by 0.93 l (near 10%; $p<0.0001$). An increase in blood pressure (systolic – $p<0.01$; diastolic – $p<0.01$ or in the second set – $p<0.05$) took place as well. But it realizes to a much lesser extent (by about 5%). Moreover, diastolic pressure and heart rate often didn't change, increasing the mean value dispersion ($p<0.05$ in individual cases of the second set). Increased physical exercise in the second set results in greater expressiveness of most cardiorespiratory parameter changes. It is noteworthy that against the backdrop of tidal volumes and minute respiratory volumes increasing both in the first and the second sets, the respiratory rate decreased. Such data is lacking in the available scientific literature.

Table 1: Reactions intensity of respiratory and cardiovascular systems parameters at physical exercises of I-II levels (25-50 W)

Parameters (M±m)/state	Tidal volume, l	Respiratory rate, movements per minute	Respiratory minute volume, l	Heart rate, beats/minute	Systolic pressure, mm Hg	Diastolic pressure, mm Hg
Baseline at rest. I set (II sets)	0.49±0.07 (0.48±0.06)	18.4±1.9 (18.46±1.14)	8.99±0.77 (8.84±1.02)	72.6±6.25 (72.05±6.55)	116.14±8.1 (117.96±6.1)	73.86±5.96 (75.43±4.83)
At the height of exercise in I set	0.63±0.1	16.14±1.6	9.92±1.02	82.6±5.81	122.3±4.81	77.5±5.06
At the height of exercise in II set	0.62±0.07	16.46±0.91	10.4±1.2	78.77±5.67*	124.55±4.6	78.63±5.38*

Note: * – $p<0.05$; in other cases – $p<0.01$.

Thus, in minimal physical exertion, the stimulation of external respiration is achieved by an increase in the amplitude of respiratory movements while the frequency of respiration decreases (fig. 1, 2). To a much lesser extent, adaptation under given conditions is carried out due to the reactions of the cardiovascular system.

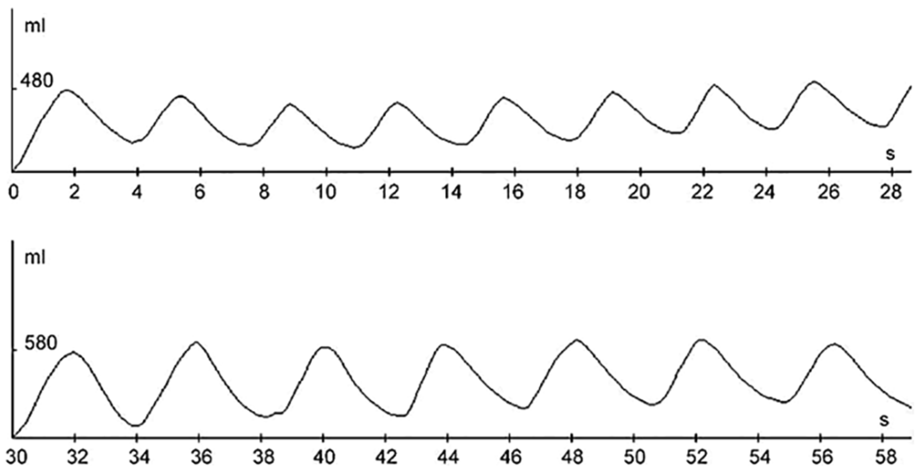

Fig 1: Spirogram.

From top downward: I – at rest; II – for 60 seconds 25 W bicycle ergometry.

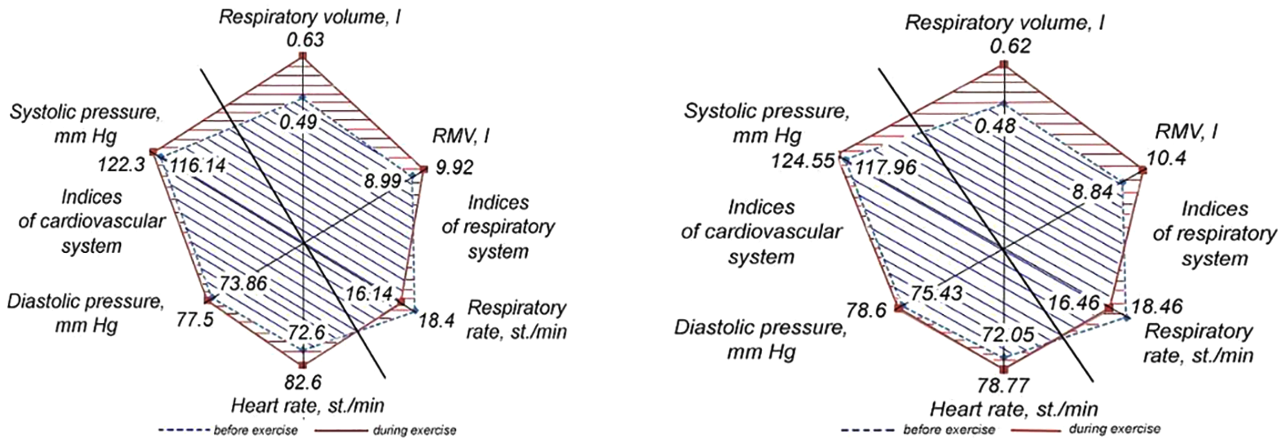

Fig. 2. Comparison intensity reaction of respiratory and cardiovascular systems at the physical exercise of 25 W (I set; left side) and 50 W (II sets; at right).

Notes: RMV – respiratory minute volume in each coordinate axis having its division value, the reaction proportionality is preserved. On exercise termination, the studied indices quickly returned to initial or close to their values within 1-3 minutes.

4. DISCUSSION

Using special devices, the amplitude of external respiration, frequency, heart rate, and blood pressure were studied as parameters of cardiorespiratory system activity. Other specialists also investigated these parameters. The peculiarity of our work lies in the fact that we substantiated the proportional participation of the cardiorespiratory system parameters in forming the body's adaptive reactions in conditions of minimal physical exercise loads. Eskov et al., Yoon et al., and other authors showed that all these parameters are the main ones in achieving the final adaptive result of regulating gas exchange and acidity at the level of tissues. Many researchers proved that these parameters in different situations could respond independently. And it may provide a certain adaptive effect to a varying degree.[1,5] Our previous research demonstrated that the activity of the cardiorespiratory system is an integrative result of interaction between all the above-said components.[26] The relevance of our study lies in the fact that in all of the works, as mentioned earlier, there are no answers to the following questions. What is the participation interest of the studied parameters in ensuring the organism's adjustment to the first moments of physical exercise? And what within the prescribed conditions is the use of greater reactions of respiration depth compared to its rhythm changes? It is necessary to emphasize that in minimal physical activity, despite the decrease in the frequency of respiratory movements, there was an increase in the respiration minute volume. The respiratory rate measured at rest showed 18.4±1.9 movements per minute. The tidal volume at rest was 0.49±0.07 l. At the level I load on the bicycle ergometer in the subjects, the tidal volume increased to 0.63±0.1 l. At this, the respiratory rate was established to decrease to 16.14±1.6 movements per minute. Such data on a decreased respiratory rate during physical exercise load are not available in the literature. It is exactly the reaction first observed in our studies. From the standpoint of the body's energy exchange, external respiration is more effectively regulated. Namely, it increases due to the depth of respiration rather than its frequency changes. The parameters of the cardiovascular system are also shown to be more rigid. The systolic pressure level increased from 116.14±8.1 Hg (at rest) to 122.3±4.81 Hg (I level load). Hence, the adaptive reactions of external respiration are more pronounced. Such data on numerical indicators of the cardiorespiratory system reactions in minimal physical exertion was not found in the available literature. Other scientists proved that more pronounced changes in blood pressure and heart rate would be manifested in more intensive physical exertion.[27-28] Whereas, according to our findings, the respiratory system plays the leading role in the first moments of exercise load. More profound reactions of external respiration are reasonably assumed to be realized in the conditions of expressed loads. But this is the subject of our future research. Results obtained in the present work correspond with other authors' data.[29-31] In addition, earlier in experiments on cats in the laboratory of ChuvSU, the normal physiology department obtained data described in detail in one of our previous articles.[32] In acute experiments in cats when implementing baro- and chemoreflex under physiological conditions, the dominance of the respiratory component over the cardiovascular system reactions was also recorded.[33-34] In these experiments reflexive increase in the respiratory minute volume against the background of a decrease in the frequency of respiratory movements was observed (fig. 3).

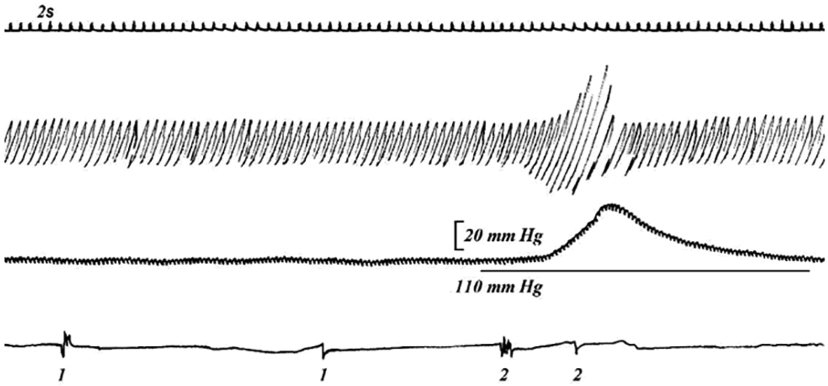

Fig. 3. Chemoreflexes from the vertebral artery (upon injection of 3.0 mmol/l lactic acid in a physiological solution) on external respiration (marked increase in the amplitude and decrease in its rate) and on the cardiovascular system (heart rate not changed, increase in blood pressure by about a third).

1-1 – duration of a «pure» physiological solution perfusion.
2-2 – length of lactic acid injection.

Similar data are contained in other authors' studies conducted on human beings.[35,36] Thus, during physical exercise or hypoxic hypoxia, "Respiratory minute volume increases due to excitation of arterial chemoreceptors, shifts reach their peak at pO_2 70-60 mm Hg". In addition, in creating hypoxia in anesthetized rats, the authors observed external respiration stimulation by increasing the tidal volume several times and the respiratory rate by a few percent. At the same time, the change in the respiratory rate was unstable. The authors also indicate that against the background of a significant increase in respiratory minute volume, «heartbeat rate, in general, was stable.» Yu. and. Vanushin showed that in teenagers and athletes aged 36 – 60 at the exercise of rising power working capacity, the leading role in ensuring the body with oxygen is played by the respiratory component of the cardiorespiratory system.[2] In studies on pupils of Suvorov Military College N.A. Agadganyan showed that the most adapted to new social and environmental conditions are young people with a vagotonic nervous system. Less adapted are those with a hyper sympathicotonia type.[37] Our group analyzed the indicators of the cardiorespiratory system activity listed in this article. It turned out that hyper sympathicotonia correlates with more stress on the cardiovascular system. In contrast, at vagotonia parameters of the cardiovascular system, functioning has a less tension value, and the activity of the respiratory system turns out to be greater. Thus, the most adapted type of the nervous system correlates to the cardiorespiratory activity by the respiratory type.[38] Conversely, the cardiovascular type is the least optimal type of the cardiorespiratory system adaptive reactions formed by the nervous system. It should be noted that despite the findings obtained by the authors of the studies mentioned above, they didn't pay any attention to the greater effectiveness of constructing cardiovascular reactions by the respiratory type. Our present research proves this. According to the Russian Scientific Electronic Library eLIBRARY.RU, it is possible to find not much more than 335 works in which spiro graphic studies were carried out over the past ten years. Such several works are not enough to fully understand the importance of external respiration in forming the reactions of the cardiorespiratory system. No data were found in the available literature on the role of external respiration in minimal physical exertion. As our current study shows, the respiratory rate turns out to be a more labile value than the heart rate. Even earlier, in minimal physical exertion, the tidal volume changes. Under given conditions, blood pressure (systolic and diastolic) remains virtually unchanged, or its minor changes are out of statistical control.

5. CONCLUSION

At minimal physiological exercise, pulmonary ventilation is implemented mainly through more pronounced changes in respiratory amplitude and less markedly through respiratory rate variations. Under given conditions, the respiratory component of cardiorespiratory system domination was proved to be most effective. Arterial pressure and pulse react least of all. The increase in systemic blood pressure occurs first, and the changes in cardiac frequency activity are the last to be realized. In such cases, this parameter even can remain unchanged. The principles that define the different intensities of cardiorespiratory system components' activity for human organisms and animals are similar. More pronounced reactions of changes in hemodynamic component activity may occur at greater physical exercises. In this case, heart functioning will be "the last frontier" in implementing cardiorespiratory system adaptation mechanisms. However, the role of increasing exercises in regulating cardiorespiratory activity has already been the subject of our research but has yet to be given in the present work.

6. AUTHORS CONTRIBUTION STATEMENT

Dr. Kupriyanov Sergey Vladilenovich, Dr. Bochkarev Sergey Viktorovich, and Dr. Semenova Ludmila Mikhaylovna conceptualized and designed the study, Dr. Kruglikov Nikolay Yurievich and Dr. Zhuravleva Nadezhda Vladimirovna gathered the data and prepared the original draft. Dr. Kupriyanov Sergey Vladilen and Dr. Ukhterova Nadezhda Dimitrievna discussed the methodology and analyzed the data. Dr. Myasnikova Irina Alexeyevna and Dr. Smirnova Tatiana Lvovna provided valuable inputs in designing the manuscript. All authors read and approved the final version of the manuscript.

7. CONFLICT OF INTEREST

Conflict of interest declared none.

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