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# Volumetric respiratory variability as a criterion of body recovery after physical load

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## Abstract

**Purpose.** The aim of this study was to determine changes in volumetric respiratory variability in physically fit individuals during recovery after physical exercise.

**Material & Methods.** To achieve the goal with the spiroarteriocardiorhythmograph (SACR) device, 101 male athletes aged 22.3±2.4 years were examined. The procedure for studying the respiratory system included conducting measurements in a sitting position using the SACR device for 2 minutes. The initial measurement was carried out immediately before the start of training (c1), 5-7 min. After the training session, a second registration (C2) was carried out the following morning on an empty stomach. A third registration (C3) was carried out the next morning after training.

**Results.** Considering the received data, the changes in the TPR $(L\times min^{-1})^2$ and HFR $(L\times min^{-1})^2$ indicators, which characterize the effect of physical load, are worth noting. For TPR $(L\times min^{-1})^2$, at c1 – 327.6 (210.3; 538.2), at c2 – 497.3 (309.8; 1036.8) and at c3 – 302.8 (179.6; 458.0), f=18.1 and p=0.000. It is noteworthy that there were no significant changes in the LFR $(L\times min^{-1})^2$ indicator, which characterizes low-frequency effects on breathing, which, in our opinion, is associated with reflex stimulation of sympatho-adrenal mechanisms during physical load at the level of hemodynamic support, when the role of central mechanisms is significantly reduced. The VLFR $(L\times min^{-1})^2$ indicator, which is associated with central effects on breathing, has a certain informative value. 5-7 minutes after physical load, its values are significantly different from the initial VLFR $(L\times min^{-1})^2$, at c1 – 2.0 (1.0; 3.6) vs. c2 – 3.2 (2.0; 6.8), f=4.7, p=0.007. However, the next morning (c3) it has intermediate values that do not significantly differ from the previous ones (c1 and c2).

**Conclusions.** The results of the volumetric respiratory variability study suggest that TPR $(L\times min^{-1})^2$ and HFR $(L\times min^{-1})^2$ are clearly related to physical load and recovery after it, which complements information on the impact of physical activity on the respiratory system and its recovery after it.

**Keywords:** breathing regulation, physical load,recovery.

## Introduction

The main function of the body in various motor modes is to maintain an oxygen regime adequate to physical load (Benítez-Muñoz et al., 2025). The cardiorespiratory system performs this function. The effect of long-term adaptation of the human body to significant physical load can also be assessed by the dynamics of the cardiovascular system indicators, which are recorded at rest (Abreu et al., 2022; Pelliccia et al., 2018; Caselli et al., 2015).

Currently, modern non-invasive methods of studying indicators are being searched and tested, which would allow obtaining the most important information about the functional state of the athlete's body and his functional readiness to perform training and competitive loads, as well as recovery after previous physical load, which is the key to preventing the development of negative conditions associated with overstrain of various functional systems (Hoffmann et al., 2020; Guzii et al., 2023; Guzii & Romanchuk, 2021; Koval et al., 2025; Lazovic et al., 2015).

An important component of the study of the functional state of the human body is the determination of the function of systems that provide available and reserve (adaptive) capabilities that characterize and predict the state of health, the course of sanogenetic and pathological processes, taking into account individual morphometric, metabolic changes, the nature of activity, age and gender (Birdee et al., 2023; Castro et al., 2017; Chernozub et al., 2025; Dominelli & Molgat-Seon, 2022; Guzii et al., 2019).

One method of assessing the body's functional state is to perform a spectral analysis of cardiorespiratory system indicator variability. (Akselrod et al., 1985, Eckberg, 2000). There is a significant number of publications on the analysis of heart rate variability (HRV), which is widely used in various fields of medicine, physiology and sports, but somewhat less – publications on the analysis of blood pressure variability at each heartbeat (Parati et al., 2021; Guzii & Romanchuk, 2021). However, there are few publications on the volumetric variability of breathing (Anderson & Ramirez, 2017; Castro et al., 2010; LoMauro & Aliverti, 2021; Lopes et al., 2025; Romanchuk, O., 2023; Romanchuk, O., 2024; Romanchuk & Guzii, 2020a; Romanchuk & Guzii, 2020c; Shams et al., 2021; van den Aardweg & Karemaker, 1991). Moreover, the development of technologies, express devices for research and monitoring of the functional state of the body in the practice of sports medicine, public health and rehabilitation requires the definition and refinement of physiological parameters of the body's activity to create appropriate databases for objectification and unification of the assessment of functional changes in the human body (Kaverinskiy et al., 2025; Malakhov, 2024) both at rest and under the influence of various types of activity (Romanchuk et al., 2024a; 2024b). Physical activity is a natural factor in activating the activity of various body systems, primarily cardiovascular and respiratory, which determine the course of adaptive and subsequently restorative processes in the body. This allows us to study tolerance to physical load and recovery after them in natural conditions, as components of the functional state of the body, which is important in the practice of medicine, rehabilitation, and sports (Sikora et al., 2024; Tipton et al., 2017; van den Bosch, 2021). The role of the cardiovascular system in ensuring adaptive processes has been studied quite well, while data on the mechanisms that occur in the regulation of the respiratory system have certain gaps (Berton et al., 2023; Brændholt et al., 2023; Bruce et al., 2019; de Oliveira et al., 2023; Gujic et al., 2007; Krohn et al., 2023; Ryan et al., 2020; Tipton et al., 2017). This is due to the technical capabilities of field measurements, which have been somewhat limited for the respiratory system until recent years. In addition, most studies of respiratory function have focused on static measures or average respiratory parameters over time (van den Bosch et al., 2021).

At rest, breathing occurs naturally through active inhalation and passive exhalation. The mechanism for initiating inspiration is known to be due to several oscillators, particularly the pre-Botzinger complex, which is located in the medulla oblongata. (Moore et al., 2013). Regulation of breathing has significant individual and situational variability (Kandimalla et al., 2025). It is the latter that stops attempts to study spontaneous breathing, and also shifts scientific research to the study of the perfusion-ventilation capabilities of the respiratory system (Del Negro et al., 2018). In the respiratory system, changes in the partial pressure of oxygen ($pO_2$) and carbon dioxide ($pCO_2$) are detected by central and peripheral chemoreceptors and compensated for by changes in ventilation to maintain arterial blood gases within tightly regulated limits (Lin & Lin, 2012). Of course, this is important from the standpoint of understanding oxygen supply and gas exchange, but it does not always allow us to fully characterize regulatory influences, limited to chemo- and mechanoreceptor mechanisms (de Oliveira et al., 2023; del Rio et al., 2013; Forster et al., 2012; Harris et al., 2017). In recent years, the results of several studies conducted in laboratory conditions have appeared which analyze the central modulatory influences on breathing (Eckberg, 2000, Heck et al.; 2017, Yackle et al., 2017; Brændholt et al., 2023).

It is known that the process of regulating respiratory function is mediated by a complex neural network (Kluger et al., 2023), which takes into account numerous internal and external influences on the regulation of air flow and respiratory rate in a way that ensures blood gas homeostasis while minimizing the work of the respiratory system (Migliaccio et al., 2023). Studies on cardiorespiratory synchronisation and controlled breathing have shown that, during strength endurance development, respiratory volumes are used more economically (Romanchuk et al., 2024). Some studies conducted at rest have shown that experimentally induced increases in elasticity (Brack et al. 1997) or resistive loading (Brack et al. 1998) in healthy adults determine the variability of pulmonary ventilation and tidal volume, which is reflected in the ability to use respiratory reserve (Berton et al., 2023) not only during physical exertion but also at rest. Several authors have shown that with cyclic gradually increasing physical exertion, volumetric variability of breathing initially increases, but with increasing intensity, when the possibilities of respiratory reserve are exhausted, it begins to decrease (Lopes et al., 2025), which probably characterizes the development of fatigue (Berton et al., 2023). In general, however, it should be emphasized that the mechanisms involved in respiratory variability during physical exertion and the subsequent recovery period are still unknown.

This study aimed to determine changes in volumetric respiratory variability in physically fit individuals during recovery after physical exercise.

## Material and methods

*Participants*

This study was conducted within the scientific programmes of the Exercise and Sports Medicine departments at South Ukrainian National Pedagogical University (September 2012 – July 2016) and Lviv State University of Physical Culture (January 2021), at various sports facilities in Odesa and Lviv, and with Team Ukraine. To achieve the goal, 101 male athletes aged 22.3±2.4 years were examined, who were engaged in various acyclic sports with the predominant development of strength abilities (boxing – 35 people, weightlifting – 10 people, powerlifting – 15 people, freestyle wrestling – 26 people, judo – 15 people). The experience of practicing sports was 10.3±3.1 years. On the eve of the study, the trainers instructed all participants to avoid consuming stimulant beverages (such as coffee, green tea and energy drinks) prior to the examination. Taking into account that the examination was carried out in different periods of the annual training cycle the training load was carried out in different modes. However, this usually occurs at the submaximal level.

Before the main study, morphometric parameters were measured using standard methods (Romanchuk, 2010). Table 1 presents the morphometric indicators of the examined group, which indicate optimal physique against the background of high values of the functional capabilities of the respiratory system (according to VCL and VI indicators) and great strength development (according to SI indicator).

**Table 1.** **Characteristics of morphometric indicators of the studied group (M±SD)**

| Indicator | M±SD |
|---|---|
| Weight, kg | 74.8±16.1 |
| Height, cm | 178.4±9.4 |
| BMI, kg×m$^{-2}$ | 23.3±3.3 |
| Body square, m$^2$ | 1.92±0.24 |
| Chest circumference (rest), cm | 97.2±9.8 |
| Chest excursion, cm | 7.2±2.5 |
| Stomach circumference, cm | 80.5±9.2 |
| Hip circumference, cm | 52.6±5.4 |
| SI, D×kg$^{-1}$×100 | 64.4±10.6 |
| VCL, ml | 4995.0±922.5 |
| VI, ml×kg$^{-1}$ | 67.4±8.2 |
| Fat, % | 13.3±6.3 |

Abbreviations: VCL (ml) – volume capacity of lungs, VI (ml×kg$^{-1}$) – vital index, SI (D×kg$^{-1}$×100) – strength index

*Methods*

The spiroarteriocardiorhythmograph (SACR) device (Panenko et al., 2006; Romanchuk & Guzii, 2020b) in the combined registration mode allows recording parameters of heart rate, blood pressure according to the Penaz method (Penáz, 1992) and flows of inspired and expired air (Noskin et al., 2018) (Fig. 1).

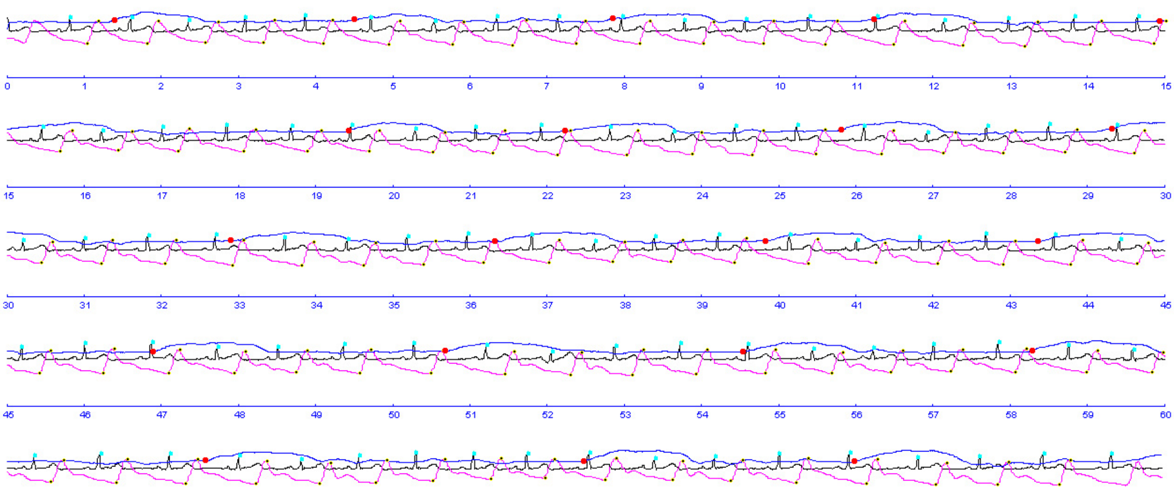


**Figure 1.** **A segment of recording of cardiorespiratory system activity curves (ECG, pulse wave, air flow wave) using SACR.**

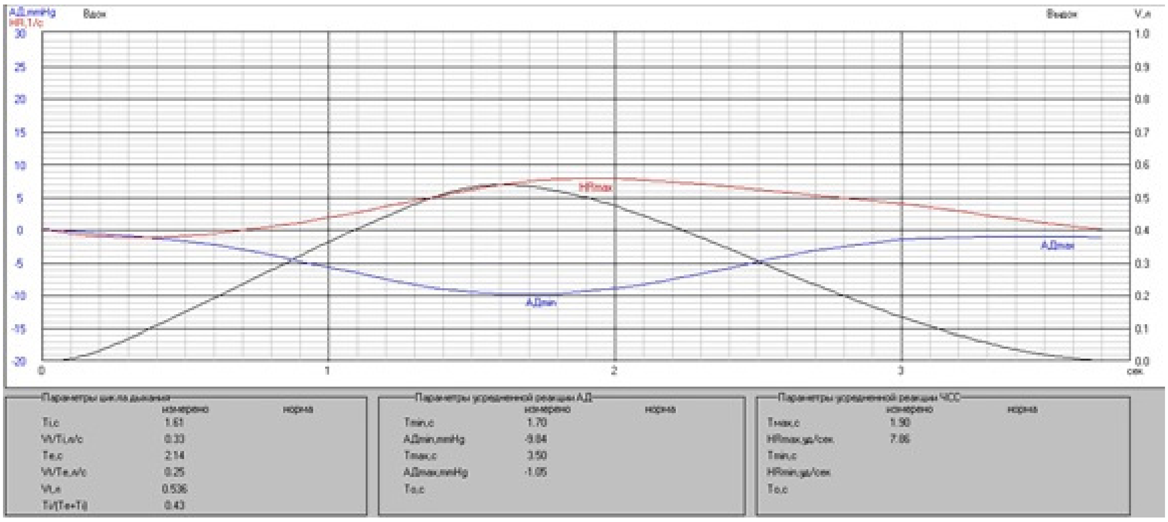

**Figure 2.** **Image of the curve of the average respiratory cycle with changes in heart rate and blood pressure in it with calculation of respiratory pattern indicators.**

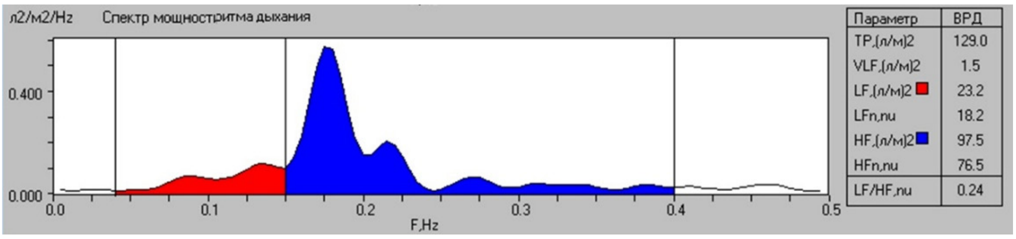

**Figure 3.** **Power spectrum of spontaneous breathing.**

Before each VRV study, blood pressure (systolic – SBP in mmHg; diastolic – DBP in mmHg; pulse – PBP in mmHg) was measured using the Korotkoff method, in accordance with the standard procedure, while the participant was sitting. (Parati et al., 2021). During SACR registration, parameters of HRV, blood pressure variability, pattern, and respiratory variability were determined. This report presents an analysis of statistical indicators of HRV – SI (stress index, c.u.), SDANN (standard deviation of the values of cardio intervals, ms), RMSSD (square root of the sum of squares of the differences in the values of consecutive pairs of normal intervals, ms), pNN50 (the percentage of NN50 from the total number of consecutive pairs of intervals that differ by more than 50 milliseconds, obtained over the entire time recording, %) (Malik et al., 1996).

Airflows in the SACR device are recorded using an ultrasonic sensor. This allows the indicators of the breathing pattern and volumetric respiratory variability (VRV) to be determined and calculated using the spectral method (according to Fourier's law of distribution). Among the indicators of the breathing pattern, the following were determined: breathing frequency – *f*R ($min^{-1}$), tidal volume – Vt (L), inhalation time – Ti (s), exhalation time – Te (s), inhalation fraction – Ti/TOT (c.u.), inspiratory volume rate – Vt/Ti ($L\times s^{-1}$), expiratory volume rate – Vt/Te ($L\times s^{-1}$), minute ventilation of the lungs – Ve ($L\times min^{-1}$) (Fig. 2). VRV indicators were determined in ranges characteristic of HRV (Fig. 3). These include the total power of the respiratory variability spectrum ($TP_R$, $(L\times min^{-1})^2$), the power of the respiratory variability spectrum in the ultra-low frequency range ($VLF_R$, $(L\times min^{-1})^2$), the power of the respiratory variability spectrum in the low frequency range ($LF_R$, $(L\times min^{-1})^2$), the power of the respiratory variability spectrum in the high frequency range ($HF_R$, $(L\times min^{-1})^2$), and the ratio of the variability spectra in the low and high frequency ranges ($LF/HF_R$, (c.u.)).

*Procedure*

The procedure for studying the respiratory system included conducting measurements in a sitting position using the SACR device for 2 minutes. VRV indicators were registered under the conditions of the training process. The initial measurement was taken immediately before training (c1). Five to seven minutes after the end of the training session, a second measurement was taken (c2). The third measurement of the VRV indicators was taken on an empty stomach the morning after training (c3). In other words, this protocol enabled the assessment of changes indicating immediate and long-term recovery following the load.

The protocols and procedures were approved by the Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association Declaration of Helsinki (1964) and subsequent amendments. This study was approved by the Human Research Ethics Committee of the University where the experiments were carried out. All athletes were informed about the study and signed an informed consent form before the trial.

*Statistical analysis*

The processing of the received results was carried out with the help of STATISTICA program for Windows (version 10.0), Microsoft Excel 2012. One-way ANOVA was used for VRV. The accepted significance level was 5%. The Tukey's honestly significant difference test (Tukey's HSD) was used to test differences among sample means for the significance. The data are presented as the mean (M) and standard deviation (SD) for parameters with normal distribution and the median (Me) and the upper and lower quartiles (Q1-Q3) for parameters with non-normal distribution.

## Results

To understand the processes that occur in the body, we present an analysis of changes in the cardiovascular and autonomic nervous systems indicators, which are most often used to assess changes in the body under the influence of physical load (Table 2). As can be seen from Table 2, all the applied indicators of the cardiovascular and autonomic nervous systems indicate changes that occur in the body during physical load. They all reflect the effect of the load. In this case, 5-7 minutes after the end of the load, those transient processes occur in the body during recovery. After all, knowing the features of their changes at the peak of the load, we can say about a certain tension due to the activation of the sympatho-adrenal system. The most significant of these items is an increase in HR ($min^{-1}$) from 61.9±7.9 to 84.7±12.6, *f*=124.5, p=0.000, SI (c.u.) from 76.9±63.9 to 344.1±380.7, *f*=46.9, p=0.000, SBP (mmHg) from 118.9±12.9 to 136.7±14.5, *f*=12.3, p= 0.000, and a decrease in SDANN (ms) from 87.7±34.9 to 50.5±30.0, *f*=28.8, p=0.000. However, the next morning all these indicators return to the initial values and almost do not differ from them. Among the indicators used, there are several that not only recover to the initial values, but also show a significant deviation in the opposite direction - the pNN50 indicator (%) at c1 – 16.9±7.2, at c2 – 11.5±4.4, at c3 – 20.4±10.1, *f*=56.3, p=0.000 ($p_{c1-c3}$=0.000), or a tendency towards it – the RMSSD (ms) indicator at c1 – 69.0±37.3, at c2 – 41.6±36.3, at c3 – 75.5±37.9 ($p_{c1-c3}$=0.179). According to the changes in these indicators, it can be stated about the pronounced activation of parasympathetic influences in the morning after physical exertion. This can characterize the complete recovery of the body and the formation of conditions for improving the functional state of the body, which is important in the training process.

Table 3 presents changes in respiratory pattern indicators, which indicate the recovery process after physical load. As can be seen from the presented data, 5-7 minutes after load, moderate differences are noted in *f*R ($min^{-1}$) - at c1 – 14.5±4.5 versus at c2 – 16.3±6.3, *f*=4.8, p= 0.008 ($p_{c1-c2}$=0.040) against the background of a similar initial state, Vt (L) – at c1 – 0.615±0.293 versus at c2 – 0.654±0.276, *f*=3.4, p=0.036 ($p_{c1-c2}$=0.545). It is significant that against the background of unchanged indicators Ti (s), Te (s) and Ti/TOT (c.u.), *f*=0.5, p=0.629, *f*=0.5, p=0.617 and *f*=0.8, p=0.468, respectively, significant differences are noted in the indicators Vt/Ti (L×$s^{-1}$), Vt/Te (L×$s^{-1}$) and Ve (L), *f*=10.8, p=0.000, *f*=7.5, p=0.001 and *f*=10.3, p=0.000,

**Table 2.** **Comparative characteristics of the cardiovascular and autonomic nervous systems in the studied group of athletes**

| Indicator | M±SD | | | f Statistic | P-value | p-value | | |
|---|---|---|---|---|---|---|---|---|
| | c1 | c2 | c3 | | | c1-c2 | c1-c3 | c2-c3 |
| HR, $min^{-1}$ | 61.9±7.9 | 84.7±12.6 | 61.2±7.2 | 124.5 | **0.000** | **0.000** | 0.875 | **0.000** |
| SBP, mmHg | 118.9±12.9 | 136.7±14.5 | 116.8±13.7 | 12.3 | **0.000** | **0.000** | 0.843 | **0.000** |
| DBP, mmHg | 72.8±8.2 | 74.6±9.4 | 70.1±7.4 | 1.1 | **0.049** | **0.046** | 0.086 | **0.039** |
| PBP, mmHg | 46.2±13.2 | 62.0±15.2 | 46.5±13.0 | 4.5 | **0.000** | **0.000** | 0.848 | **0.000** |
| SI, c.u. | 76.9±63.9 | 344.1±380.7 | 68.9±52.9 | 46.9 | **0.000** | **0.000** | 0.943 | **0.000** |
| SDANN, ms | 87.7±34.9 | 50.5±30.0 | 88.2±33.1 | 28.8 | **0.000** | **0.000** | 1.000 | **0.000** |
| RMSSD, ms | 69.0±37.3 | 41.6±36.3 | 75.5±37.9 | 34.0 | **0.000** | **0.000** | 0.179 | **0.000** |
| pNN50, % | 16.9±7.2 | 11.5±4.4 | 20.4±10.1 | 56.3 | **0.000** | **0.002** | **0.000** | **0.000** |

Abbreviations: HR ($min^{-1}$) – heart rate, SBP (mmHg) – systolic blood pressure (by Korotkoff), DBP (mmHg) – diastolic blood pressure (by Korotkoff), PBP (mmHg) – pulse blood pressure (by Korotkoff), SI (c.u.) – stress index, SDANN (ms) – standard deviation of the values of cardio intervals, RMSSD (ms) – square root of the sum of squares of the differences in the values of consecutive pairs of normal intervals, pNN50 (%) – the percentage of NN50 from the total number of consecutive pairs of intervals that differ by more than 50 milliseconds, obtained over the entire time recording.

**Table 3.** Changes in respiratory pattern indicators in the studied group of athletes

| Indicator | M±SD | | | f Statistic | P-value | p-value | | |
|---|---|---|---|---|---|---|---|---|
| | c1 | c2 | c3 | | | c1-c2 | c1-c3 | c2-c3 |
| *f*R, min$^{-1}$ | 14.5±4.5 | 16.3±6.3 | 14.1±4.8 | 4.8 | **0.008** | **0.040** | 0.885 | **0.011** |
| Vt, L | 0.615±0.293 | 0.654±0.276 | 0.557±0.217 | 3.4 | **0.036** | 0.545 | 0.276 | **0.028** |
| Ti, s | 1.9±1.2 | 1.8±1.0 | 1.9±1.1 | 0.5 | 0.629 | 0.644 | 0.990 | 0.730 |
| Te, s | 2.7±1.3 | 2.9±1.5 | 2.8±1.2 | 0.5 | 0.617 | 0.717 | 0.990 | 0.635 |
| Ti/TOT, c.u. | 0.41±0.05 | 0.42±0.04 | 0.41±0.05 | 0.8 | 0.468 | 0.819 | 0.801 | 0.435 |
| Vt/Ti, L×s$^{-1}$ | 0.31±0.11 | 0.37±0.15 | 0.29±0.11 | 10.8 | **0.000** | **0.006** | 0.316 | **0.000** |
| Vt/Te, L×s$^{-1}$ | 0.27±0.13 | 0.33±0.18 | 0.25±0.12 | 7.5 | **0.001** | **0.017** | 0.589 | **0.001** |
| Ve, L | 8.281±3.283 | 9.918±4.747 | 7.547±3.133 | 10.3 | **0.000** | **0.007** | 0.359 | **0.000** |

Abbreviations: fR (min$^{-1}$) – frequency of respiration, Vt (L) – tidal volume, Ti (s) – mean inspiratory time, Te (s) – mean expiratory time, Ti/TOT (c.u.) – mean inspiratory duty cycle, Vt/Ti (L×s$^{-1}$) – mean inspiratory flow, Vt/Te (L×s$^{-1}$) – mean expiratory flow, Ve (L) – minute ventilation.

**Table 4.** Changes in volumetric respiratory variability in a group of athletes over the course of the study

| Indicator | Me ($Q_1$; $Q_3$) | | | f Statistic | P-value | p-value | | |
|---|---|---|---|---|---|---|---|---|
| | c1 | c2 | c3 | | | c1-c2 | c1-c3 | c2-c3 |
| $TP_R$, (L×min$^{-1}$)$^2$ | 327.6 (210.3; 538.2) | 497.3 (309.8; 1036.8) | 302.8 (179.6; 458.0) | 18.1 | **0.000** | **0.000** | 0.768 | **0.000** |
| $VLF_R$, (L×min$^{-1}$)$^2$ | 2.0 (1.0; 3.6) | 3.2 (2.0; 6.8) | 2.6 (1.7; 4.0) | 4.7 | **0.010** | **0.007** | 0.303 | 0.253 |
| $LF_R$, (L×min$^{-1}$)$^2$ | 13.0 (7.8; 53.3) | 17.6 (9.6; 82.8) | 13.7 (6.6; 70.6) | 0.7 | 0.515 | 0.619 | 0.992 | 0.545 |
| $HF_R$, (L×min$^{-1}$)$^2$ | 243.4 (148.8; 441.0) | 412.1 (161.3; 835.2) | 208.9 (115.6; 346.0) | 16.4 | **0.000** | **0.000** | 0.620 | **0.000** |
| $LF/HF_R$, c.u. | 0.040 (0.026; 0.260) | 0.044 (0.020; 0.123) | 0.078 (0.028; 0.456) | 0.4 | 0.678 | 0.737 | 0.714 | 0.999 |

Abbreviations: $TP_R$, dispersion of $V_T/T_E$ in a given time interval (total power) <0.4 Hz; $VLF_R$, power spectrum of $V_T/T_E$ in the very-low frequency range ≤0.04 Hz, $LF_R$, power spectrum of $V_T/T_E$ in the low frequency range 0.04-0.15 Hz; $HF_R$, power spectrum of $V_T/T_E$ in the low frequency range 0.15-0.4 Hz, $LFHF_R$, $LF_R$[(L×min$^{-1}$)$^2$]/$HF_R$[(L×min$^{-1}$)$^2$]=c.u.

respectively. Their changes resemble those for the RMSSD (ms) indicator: 5–7 minutes after the load, they are significantly higher than the initial values, and the next morning after training, there is a tendency for them to decrease below these values. This suggests that such dynamics also reflect the recovery of the respiratory system and its readiness for further loads.

Table 4 presents changes in VRV parameters, which reflect the total respiratory power ($TP_R$, (L×min$^{-1}$)$^2$) and its power in different frequency ranges (VLF, LF and HF). Considering the presented data, it is worth noting the changes in the $TP_R$ (L×min$^{-1}$)$^2$ and $HF_R$, (L×min$^{-1}$)$^2$ indicators, which characterize the effect of physical load and resemble changes in the Ve (L) indicator, when the values of spectral power the morning after training change in the opposite direction with a tendency to a greater decrease than the initial values. For $TP_R$ (L×min$^{-1}$)$^2$, at c1 – 327.6 (210.3; 538.2) vs. at c2 – 497.3 (309.8; 1036.8) vs. at c3 – 302.8 (179.6; 458.0), *f*=18.1, p=0.000. For $HF_R$ (L×min$^{-1}$)$^2$, at c1 – 243.4 (148.8; 441.0) vs. c2 – 412.1 (161.3; 835.2) and vs. at c3 – 208.9 (115.6; 346.0), *f*=16.4, p=0.000. It is noteworthy that there were no significant changes in the LFR (L×min$^{-1}$)² indicator, which characterises the effects of low frequencies on breathing. In our opinion, this is associated with the reflex stimulation of the sympatho-adrenal mechanisms during physical exertion that supports haemodynamics, when the role of central mechanisms is significantly reduced. The $VLF_R$ (L×min$^{-1}$)$^2$ indicator, which is associated with central effects on breathing, has a certain informative value. 5-7 minutes after physical load, its values are significantly different from the initial $VLF_R$ (L×min$^{-1}$)$^2$, at c1 – 2.0 (1.0; 3.6) vs. at c2 – 3.2 (2.0; 6.8), *f*=4.7, p= 0.007. However, the next morning (c3) it has intermediate values that do not significantly differ from the previous ones (c1 and c2). That is, the $TP_R$ (L×min$^{-1}$)$^2$ and $HF_R$, (L×min$^{-1}$)$^2$ indicators can be considered as sensitive to the influence of physical load and recovery after them, the role of the $VLF_R$, (L×min$^{-1}$)$^2$ and $LF_R$, (L×min$^{-1}$)$^2$ indicators are currently unclear and, given the results obtained, requires further research.

## Discussion

The mechanisms that provide VRV are an important component of the body's optimal functional state (Heck et al., 2017). VRV indicators,

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calculated using spectral analysis, enable us to distinguish between different frequency influences and can significantly supplement information on regulatory influences on the respiratory system (Harbour et al., 2022). On the other hand, these influences are transmitted to the functions of the cardiovascular system, gas exchange, and metabolism (Shams et al, 2021). Previously, we conducted studies of VRV in athletes at different stages of the training process and during competitions. The study of VRV in 1930 practically healthy young male subjects at rest during spontaneous breathing allowed us to determine the normative ($Q_1$-$Q_3$) limits of the VRV indicators distribution in different frequency ranges (similar to HRV): $TP_R$ $(L\times min^{-1})^2$ – 290.0-635.0; $VLF_R$ $(L\times min^{-1})^2$ – 1.3-4.8; $LF_R$ $(L\times min^{-1})^2$ – 7.9-33.6; $HF_R$ $(L\times min^{-1})^2$ – 207.4-547.5; $LF/HF_R$ (c.u.) – 0.025-0.150 (Guzii et al, 2019). VRV parameters were also studied in 58 qualified athletes with high and low $VO_2max$ levels (Romanchuk & Guzii, 2017), which showed significant differences in $TP_R$ $(L\times min^{-1})^2$ – 231.0 (158.8; 342.3) vs. 349.7 (210.3; 524.4) and $HF_R$ $(L\times min^{-1})^2$ – 174.2 (62.4; 285.6) vs. 237.2 (90.3; 404.0), respectively. At the same time, the values Q3 of the $LF_R$ $(L\times min^{-1})^2$ were significantly higher in both groups compared to the normative distribution (84.6 and 64.0, respectively, versus 33.6). The differences in VRV of 202 highly qualified athletes at rest were analysed, taking into account the type of cardiac rhythm regulation, which indicates the development of fatigue. It was found that, with centralisation of regulatory influences on the cardiac rhythm, was significantly greater than with the predominance of autonomic influences 416.0 (331.0; 888.0) vs. 277.0 (213.0; 339.0), which was determined by significantly higher values of $HF_R$ $(L\times min^{-1})^2$ – 357.0 (286.0; 807.0) vs. 180.0 (107.0; 260.0). It was interesting that when autonomic influences prevailed, the relative contribution of $LF_R$ $(L\times min^{-1})^2$ tended to be higher than when the cardiac rhythm regulation was centralized. Analysis of the dynamics of VRV indicators in this athlete's group under the influence of the workload showed that they differed for the development of sympathetic overstrain (Romanchuk & Guzii, 2020a, Guzii et al., 2023). The dynamics of these indicators were separately studied in 9 athletes during competitive load (Romanchuk & Guzii, 2020c). The latter showed that the $TP_R$ $(L\times min^{-1})^2$ in the morning after the competitive load returned to the pre-competitive values 420.3 (163.8; 600.3) vs. 400.0 (338.6; 479.6), and a day later significantly decreased to 231.0 (213.2; 278.9), which indicated a significant economization and restitution of respiratory function. Moreover, the dynamics of $LF_R$ $(L\times min^{-1})^2$ were characterized by a significant decrease the day after the competition, dropping from 13.7 (9.0; 22.1) before the competition to 6.8 (2.9; 9.6).4) the morning after the competition. The dynamics of $HF_R$ $(L\times min^{-1})^2$ were characterized by a significant decrease the day after the competition, dropping to 210.3 (204.5; 225.0) from 302.8 (216.1; 400.0) before the competition, and from 269.0 (125.4; 376.4) the morning after the competition. In this case, the highest values of $HF_R$ $(L\times min^{-1})^2$ in the morning after the competition deserve attention, which may indicate the activation of high-frequency influences on breathing during recovery.

The results of a study in the clinic of internal medicine in patients with bronchial asthma turned out to be quite informative regarding VRV. The differences in VRV indicators in a study of 86 patients with controlled and uncontrolled bronchial asthma were found to be quite significant (Romanchuk et al., 2019, Romanchuk & Bazhora, 2018), which showed a significant increase in $TP_R$ $(L\times min^{-1})^2$ in both groups of patients to 1373.4 (721.0; 3378.1) and 1162.8 (625.0; 1814.8), respectively. The latter occurred due to an increase in all frequency components. The greatest contribution to the increase was made by $HF_R$ $(L\times min^{-1})^2$ – 1217.0 (622.5; 2987.9) and 818.0 (453.7; 1267.4), respectively. The groups were differentiated due to the predominance of $LF_R$ $(L\times min^{-1})^2$ in persons with a controlled course – 44.2 (29.7; 61.6) vs. 26.0 (11.6; 64.0). This indicated a more pronounced influence of low-frequency regulation, which could characterize the intermittent course. Separately (Bazhora & Romanchuk, 2018). It was also shown that the presence of overweight and obesity plays an important role in the regulation of respiratory function.

Lopes et al. (2025) conducted an informative study of VRV in men and women, which enabled gender differences in athletes during running exercise to be identified. To achieve this, RMSSD indicators for $V_T$, $V_E$ and fR were used. For this, RMSSD indicators for $V_T$, $V_E$, *f*R were used. The authors demonstrated that increased exercise intensity reduces $V_T$ variability. In men, unlike in women, $V_T$ variability is associated with $V_T$ reserve. It was also demonstrated that, when running, women with a gradual increase in physical activity had lower $V_E$ variability than men. This may lead to an ineffective response to future challenges, such as increased metabolic demand (Nery et al., 1982). On the contrary, excessive VRV can cause instability of homeostasis (Jubran & Tobin, 2000). On the other hand, the use of the RMSSD indicator, while providing a general characteristic of VRV, does not allow analyzing the frequency characteristics of VRV, which are behind regulatory influences, the role of which is associated with the activation of carotid artery chemoreceptors (Del Rio et al., 2013; Marcus et al., 2014; Forster et al., 2012), muscle afferents (type III and IV fibers) in the conditions of the formation of metabolic needs at rest and during physical load (Bruce et al., 2019; de Oliveira et al., 2023; Silva et al., 2018). In general, the conducted studies reveal new mechanisms of respiratory control and its participation in ensuring the optimal functional state of the body.

However, it is clear that further research is needed to answer a number of questions regarding the possibility of using VRV indicators in sports medicine, respiratory function monitoring in internal medicine clinics, and rehabilitation.

## Conclusion

The results of the VRV study suggest that $TP_R$ $(L\times min^{-1})^2$ and $HF_R$ $(L\times min^{-1})^2$ are clearly related to physical load and recovery after it, which complements information on the impact of physical activity on the respiratory system and its recovery after it.

## References

Abreu, R. M. de, Porta, A., Rehder-Santos, P., Cairo, B., Sakaguchi, C. A., da Silva, C. D., Signini, É. D. F., Milan-Mattos, J. C., & Catai, A. M. (2022). Cardiorespiratory coupling strength in athletes and non-athletes. *Respiratory Physiology & Neurobiology*, 305, 103943. https://doi.org/10.1016/j.resp.2022.103943

Akselrod, S., Gordon, D., Madwed, J. B., Snidman, N. C., Shannon, D. C., & Cohen, R. J. (1985). Hemodynamic regulation: investigation by spectral analysis. *American Journal of Physiology-Heart and Circulatory Physiology*, 249(4), H867–H875. https://doi.org/10.1152/ajpheart.1985.249.4.H867

Anderson, T. M., & Ramirez, J.-M. (2017). Respiratory rhythm generation: triple oscillator hypothesis. *F1000Research*, *6*, 139. https://doi.org/10.12688/f1000research.10193.1

Bazhora, Ya. I., & Romanchuk, O. P. (2018). Variability and Respiration Pattern of Patients with Persistent Asthma and Obesity. *Ukraïns'kij Žurnal Medicini, Bìologìï Ta Sportu*, 3(7), 74–83. https://doi.org/10.26693/jmbs03.07.074

Benítez-Muñoz, J. A., Alcocer-Ayuga, M., Cupeiro, R., Guisado-Cuadrado, I., Rojo-Tirado, M. Á., Alfaro-Magallanes, V. M., Romero-Parra, N., Aparecida-Castro, E., Ramos-Campo, D. J., Armero-Sotillo, A., Peinado, A. B., & Benito, P. J. (2025). Ventilatory Thresholds Differences According to Aerobic Fitness Level in 1450 Males and 241 Females on Cycle-Ergometer: A Cross-Sectional Study. *European Journal of Sport Science*, 25(7). https://doi.org/10.1002/ejsc.12323

Berton, D. C., Plachi, F., James, M. D., Vincent, S. G., Smyth, R. M., Domnik, N. J., Phillips, D. B., de-Torres, J. P., Nery, L. E., O'Donnell, D. E., & Neder, J. A. (2023). Dynamic Ventilatory Reserve During Incremental Exercise: Reference Values and Clinical Validation in Chronic Obstructive Pulmonary Disease. A*nnals of the American Thoracic Society*, 20(10), 1425–1434. https://doi.org/10.1513/AnnalsATS.202304-303OC

Birdee, G., Nelson, K., Wallston, K., Nian, H., Diedrich, A., Paranjape, S., Abraham, R., & Gamboa, A. (2023). Slow breathing for reducing stress: The effect of extending exhale. *Complementary Therapies in Medicine*, *73*, 102937. https://doi.org/10.1016/j.ctim.2023.102937

Brack, T., Jubran, A., & Tobin, M. J. (1997). Effect of elastic loading on variational activity of breathing. *American Journal of Respiratory and Critical Care Medicine*, 155(4), 1341–1348. https://doi.org/10.1164/ajrccm.155.4.9105077

Brack, T., Jubran, A., & Tobin, M. J. (1998). Effect of Resistive Loading on Variational Activity of Breathing. *American Journal of Respiratory and Critical Care Medicine*, 157(6), 1756–1763. https://doi.org/10.1164/ajrccm.157.6.9704114

Brændholt, M., Kluger, D. S., Varga, S., Heck, D. H., Gross, J., & Allen, M. G. (2023). Breathing in waves: Understanding respiratory-brain coupling as a gradient of predictive oscillations. *Neuroscience & Biobehavioral Reviews*, 152, 105262. https://doi.org/10.1016/j.neubiorev.2023.105262

Bruce, R. M., Jolley, C., & White, M. J. (2019). Control of exercise hyperpnoea: Contributions from thin-fibre skeletal muscle afferents. *Experimental Physiology*, 104(11), 1605–1621. https://doi.org/10.1113/EP087649

Caselli, S., di Paolo, F. M., Pisicchio, C., Pandian, N. G., & Pelliccia, A. (2015). Patterns of left ventricular diastolic function in olympic athletes. *Journal of the American Society of Echocardiography*, 28(2), 236–244. https://doi.org/10.1016/j.echo.2014.09.013

Castro, R. R. T. de, Lima, S. P., Sales, A. R. K., & Nóbrega, A. C. L. da. (2017). Minute-Ventilation Variability during Cardiopulmonary Exercise Test is Higher in Sedentary Men Than in Athletes. Arquivos Brasileiros de Cardiologia. https://doi.org/10.5935/abc.20170104

Castro, R. R. T., Antunes-Correa, L. M., Ueno, L. M., Rondon, M. U. P. B., Negrão, C. E., & Nobrega, A. C. L. (2010). Ventilation variability inversely correlates to ejection fraction in heart failure: Table 1–. *European Respiratory Journal*, *36*(6), 1482–1483. https://doi.org/10.1183/09031936.00044910

Chernozub, A., Tsos, A., Olkhovyi, O., Hlukhov, I., Koval, V., & Zavizion, O. (2025). Readaptation of functional capabilities of special unit servicemen with long-term hypodynamia caused by peripheral neuromuscular system damage. *Physical Rehabilitation and Recreational Health Technologies*, 10(1), 9–19. https://doi.org/10.15391/prrht.2025-10(1).02

de Oliveira, D. M., Lopes, T. R., Gomes, F. S., Rashid, A., & Silva, B. M. (2023). Ventilatory response to peripheral chemoreflex and muscle metaboreflex during static handgrip in healthy humans: evidence of hyperadditive integration. *Experimental Physiology*, 108(7), 932–939. https://doi.org/10.1113/EP091094

del Rio, R., Marcus, N. J., & Schultz, H. D. (2013). Carotid Chemoreceptor Ablation Improves Survival in Heart Failure. Journal of the American College of Cardiology, 62(25), 2422–2430. https://doi.org/10.1016/j.jacc.2013.07.079

del Negro, C. A., Funk, G. D., & Feldman, J. L. (2018). Breathing matters. *Nature Reviews Neuroscience*, 19(6), 351–367. https://doi.org/10.1038/s41583-018-0003-6

Dominelli, P. B., & Molgat-Seon, Y. (2022). Sex, gender and the pulmonary physiology of exercise. *European Respiratory Review*, 31(163), 210074. https://doi.org/10.1183/16000617.0074-2021

Eckberg, D. L. (2000). Physiological basis for human autonomic rhythms. *Annals of Medicine*, 32(5), 341–349. https://doi.org/10.3109/07853890008995937

Forster, H. V., Haouzi, P., & Dempsey, J. A. (2012). Control of Breathing During Exercise. In *Comprehensive Physiology* (pp. 743–777). Wiley. https://doi.org/10.1002/cphy.c100045

Gujic, M., Laude, D., Houssière, A., Beloka, S., Argacha, J., Adamopoulos, D., Xhaët, O., Elghozi, J., & van de Borne, P. (2007). Differential effects of metaboreceptor and chemoreceptor activation on sympathetic and cardiac baroreflex control following exercise in hypoxia in human. *The Journal of Physiology*, 585(1), 165–174. https://doi.org/10.1113/jphysiol.2007.141002

Guzii, O., Mahlovanyi, A., & Romanchuk, O. (2023). Multifunctional changes in the athletes' body during the formation of autonomic regulations' overstrain under the influence of training load. *Fizicna Reabilitacia Ta Rekreacijno-Ozdorovci Tehnologii*, 8(2), 91–104. https://doi.org/10.15391/prrht.2023-8(2).03

Guzii, O., Romanchuk, A., Mahlovanyi, A., & Trach, V. (2019). Polyfunctional express-evaluation criteria of the sportsman organism state. *Journal of Physical Education and Sport*, 19(4), 2352–2358. https://doi.org/10.7752/jpes.2019.04356

Guzii, O., & Romanchuk, A. (2021). Post-Loading Dynamics of Beat-To-Beat Blood Pressure Variability in Highly Qualified Athletes. *Fizicna Reabilitacia Ta Rekreacijno-Ozdorovci Tehnologii*, *6*(1), 5–14. https://doi.org/10.15391/prrht.2021-6(1).01

Harbour, E., Stöggl, T., Schwameder, H., & Finkenzeller, T. (2022). Breath Tools: A Synthesis of Evidence-Based Breathing Strategies to Enhance Human Running. *Frontiers in Physiology*, 13. https://doi.org/10.3389/fphys.2022.813243

Harris, K. D., Dashevskiy, T., Mendoza, J., Garcia, A. J., Ramirez, J.-M., & Shea-Brown, E. (2017). Different roles for inhibition in the rhythm-generating respiratory network. *Journal of Neurophysiology*, 118(4), 2070–2088. https://doi.org/10.1152/jn.00174.2017

Heck, D., McAfee, S., Liu, Y., Babajani-Feremi, A., Rezaie, R., Freeman, W., Wheless, J., Papanicolaou, A., Ruszinkó, M., Sokolov, Y., & Kozma, R. (2017). Breathing as a Fundamental Rhythm of Brain Function. *Front. Neural Circuits*, 10(115). https://doi.org/10.3389/fncir.2016.00115

Hoffmann, B., Flatt, A. A., Silva, L. E. V., Młyńczak, M., Baranowski, R., Dziedzic, E., Werner, B., & Gąsior, J. S. (2020). A Pilot Study of the Reliability and Agreement of Heart Rate, Respiratory Rate and Short-Term Heart Rate Variability in Elite Modern Pentathlon Athletes. *Diagnostics* (Basel, Switzerland), 10(10). https://doi.org/10.3390/diagnostics10100833

Jubran, A., & Tobin, M. J. (2000). Effect of Isocapnic Hypoxia on Variational Activity of Breathing. *American Journal of Respiratory and Critical Care Medicine*, *162*(4), 1202–1209. https://doi.org/10.1164/ajrccm.162.4.9907003

Kandimalla, M., Lim, S., Thakkar, J., Dewan, S., Kang, D., In, M.-H., Jo, H. J., Jang, D. P., Nedelska, Z., Lapid, M. I., Shu, Y., Cheon-Pyung, Cogswell, P. M., Lowe, V. J., Lee, J., & Min, H.-K. (2025). Cardiorespiratory dynamics in the brain: Review on the significance of cardiovascular and respiratory correlates in functional MRI signal. *NeuroImage*, 306, 121000. https://doi.org/10.1016/j.neuroimage.2024.121000

Kaverinskiy, V., Chaikovsky, I., Mnevets, A., Ryzhenko, T., Bocharov, M., & Malakhov, K. (2025). Scalable Clustering of Complex ECG Health Data: Big Data Clustering Analysis with UMAP and HDBSCAN. *Computation*, *13*(6), 144. https://doi.org/10.3390/computation13060144

Kluger, D. S., Forster, C., Abbasi, O., Chalas, N., Villringer, A., & Gross, J. (2023). Modulatory dynamics of periodic and aperiodic activity in respiration-brain coupling. *Nature Communications*, 14(1), 4699. https://doi.org/10.1038/s41467-023-40250-9

Koval, V., Tsos, A., Olkhovyi, O., Drobot, K., Chernozub, A., & Potop, V. (2025). Overtraining syndrome in bodybuilding and the difficulty of searching for informative biomarkers for disadaptation diagnostics. Physical Rehabilitation and Recreational Health Technologies, 10(2), 108–119. https://doi.org/10.15391/prrht.2025-10(2).06

Krohn, F., Novello, M., van der Giessen, R. S., de Zeeuw, C. I., Pel, J. J., & Bosman, L. W. (2023). The integrated brain network that controls respiration. *ELife*, 12. https://doi.org/10.7554/eLife.83654

Lazovic, B., Mazic, S., Suzic-Lazic, J., Djelic, M., Djordjevic-Saranovic, S., Durmic, T., Zikic, D., & Zugic, V. (2015). Respiratory adaptations in different types of sport. *European Review for Medical and Pharmacological Sciences*, 19(12), 2269–2274. http://www.ncbi.nlm.nih.gov/pubmed/26166653

Lin, C., & Lin, C. (2012). Work of breathing and respiratory drive in obesity. *Respirology*, 17(3), 402–411. https://doi.org/10.1111/j.1440-1843.2011.02124.x

LoMauro, A., & Aliverti, A. (2021). Sex and gender in respiratory physiology. European Respiratory Review, 30(162), 210038. https://doi.org/10.1183/16000617.0038-2021

Lopes, T. R., de Oliveira, D. M., Amoroso de Lima, L. A., & Silva, B. M. (2025). Breathing variability during running in athletes: The role of sex, exercise intensity and breathing reserve. *Respiratory Physiology & Neurobiology*, 331, 104350. https://doi.org/10.1016/j.resp.2024.104350

Malakhov, K. S. (2024). Innovative Hybrid Cloud Solutions for Physical Medicine and Telerehabilitation Research. International Journal of Telerehabilitation, 16(1). https://doi.org/10.5195/ijt.2024.6635

Malik, M., Camm, A. J., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., Coumel, P., Fallen, E. L., Kennedy, H. L., Kleiger, R. E., Lombardi, F., Malliani, A., Moss, A. J., Rottman, J. N., Schmidt, G., Schwartz, P. J., & Singer, D. H. (1996). Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. European Heart Journal, 17(3), 354–381. https://doi.org/10.1093/oxfordjournals.eurheartj.a014868

Marcus, N. J., del Rio, R., Schultz, E. P., Xia, X.-H., & Schultz, H. D. (2014). Carotid body denervation improves autonomic and cardiac function and attenuates disordered breathing in congestive heart failure. The Journal of Physiology, 592(2), 391–408. https://doi.org/10.1113/jphysiol.2013.266221

Migliaccio, G. M., Russo, L., Maric, M., & Padulo, J. (2023). Sports Performance and Breathing Rate: What Is the Connection? A Narrative Review on Breathing Strategies. Sports, 11(5), 103. https://doi.org/10.3390/sports11050103

Nery, L. E., Wasserman, K., Andrews, J. D., Huntsman, D. J., Hansen, J. E., & Whipp, B. J. (1982). Ventilatory and gas exchange kinetics during exercise in chronic airways obstruction. Journal of Applied Physiology, 53(6), 1594–

1602. https://doi.org/10.1152/jappl.1982.53.6.1594

Noskin, L., Rubinskiy, A., & Romanchuk A. (2018). Indications of the Level Individual Cardiovascular and Respiratory Homeostasis Using Continuous Spiroarteriocardiorhythmography. *Biomedical Journal of Scientific & Technical Research*, 6(1). https://doi.org/10.26717/bjstr.2018.06.001309

Panenko, A., Babov, K., Noskin, L., Romanchuk, O., & Pivovarov, V. (2006). *Spiroarteriocardiorhythmography as a multifunctional method of research of the cardiorespiratory system in rehabilitation institutions*. Kyiv; Methodological recommendations of the MHU.

Parati, G., Stergiou, G. S., Bilo, G., Kollias, A., Pengo, M., Ochoa, J. E., Agarwal, R., Asayama, K., Asmar, R., Burnier, M., de La Sierra, A., Giannattasio, C., Gosse, P., Head, G., Hoshide, S., Imai, Y., Kario, K., Li, Y., Manios, E., … Mancia, G. (2021). Home blood pressure monitoring: Methodology, clinical relevance and practical application: A 2021 position paper by the Working Group on Blood Pressure Monitoring and Cardiovascular Variability of the European Society of Hypertension. *Journal of Hypertension*, 39(9), 1742–1767. https://doi.org/10.1097/HJH.0000000000002922

Penáz, J. (1992). Criteria for set point estimation in the volume clamp method of blood pressure measurement. *Physiol Res*, 41(1), 5–10. PMID: 1610779

Pelliccia, A., Caselli, S., Sharma, S., Basso, C., Bax, J. J., Corrado, D., D'Andrea, A., D'Ascenzi, F., di Paolo, F. M., Edvardsen, T., Gati, S., Galderisi, M., Heidbuchel, H., Nchimi, A., Nieman, K., Papadakis, M., Pisicchio, C., Schmied, C., Popescu, B. A., … Lancellotti, P. (2018). European Association of Preventive Cardiology (EAPC) and European Association of Cardiovascular Imaging (EACVI) joint position statement: Recommendations for the indication and interpretation of cardiovascular imaging in the evaluation of the athlete's heart. *European Heart Journal*, 39(21), 1949–1969. https://doi.org/10.1093/eurheartj/ehx532

Ryan, L., Rahman, T., Strang, A., Heinle, R., & Shaffer, T. H. (2020). Diagnostic differences in respiratory breathing patterns and work of breathing indices in children with Duchenne muscular dystrophy. *PloS One*, 15(1), e0226980. https://doi.org/10.1371/journal.pone.0226980

Romanchuk, O. (2023). Cardiorespiratory dynamics during respiratory maneuver in athletes. *Frontiers in Network Physiology*, 3. https://doi.org/10.3389/fnetp.2023.1276899

Romanchuk, O. (2024). Peculiarities of cardio-respiratory relationships in qualified athletes with different types of heart rhythm regulation according to respiratory maneuver data. *Frontiers in Sports and Active Living*, *6*. https://doi.org/10.3389/fspor.2024.1451643

Romanchuk O. (2010). *Medical and pedagogical control in health physical culture.* Odesa, UA: Bukaev V.V.

Romanchuk, O., & Bazhora, Y. (2018). Regulatory peculiar features of uncontrolled bronchial asthma. *Journal of Education, Health and Sport*, 8(1), 330–346. https://apcz.umk.pl/JEHS/article/view/5883

Romanchuk, A., & Guzii, O. (2017). Multifunctional determinants of athletes' health. *Journal of Medicine and Health Research*, 2(1), 12–21. https://www.ikprress.org/index.php/JOMAHR/article/view/3314

Romanchuk, A., & Guzii, O. (2020a). Variability and pattern of spontaneous respiration in different types of cardiac rhythm regulation of highly trained athletes. *International Journal of Human Movement and Sports Sciences*, 8(6), 483–493. https://doi.org/10.13189/saj.2020.080622

Romanchuk, O. P., & Guziy, O. V. (2020b). Modern approaches to the objectification of the functional state of the athletes' body during current examinations. *Fizicna Reabilitacia Ta Rekreacijno-Ozdorovci Tehnologii*, 5(1), 8–18. https://doi.org/10.15391/prrht.2020-5(1).02

Romanchuk, O. P., & Guzii, O. V. (2020c). Peculiarities of Changes in Respiratory Variability under the Influence of Training Load in Athletes with Cardiovascular Overstrain by Sympathetic Type. *International Journal of Education and Science*, 3(2), 54. https://doi.org/10.26697/ijes.2020.2.38

Romanchuk, O., Guzii, O., Mahliovanyi, A., & Smirnov, I. (2024a). Cardiorespiratory synchronization under the influence of strength endurance training. *Fizicna Reabilitacia Ta Rekreacijno-Ozdorovci Tehnologii*, *9*(1), 25–35. https://doi.org/10.15391/prrht.2024-9(1).04

Romanchuk, O., Polianska, O., Polianskyi, I., & Yasinska, O. (2024b). Telerehabilitation. Current Opportunities and Problems of Remote Patient Monitoring. *Neonatology, Surgery and Perinatal Medicine*, 14(4–54), 183–190. https://doi.org/10.24061/2413-4260.XIV.4.54.2024.25

Romanchuk, O. P., Velychko, V. I., & Bazhora, Ya. I. (2019). Reactivity of cardiorespiratory system in bronchial asthma patients according to the tests with respiratory maneuvers performance. *Zaporozhye Medical Journal*, 0(4), 449–457. https://doi.org/10.14739/2310-1210.2019.4.173191

Shams, S., LeVan, P., & Chen, J. J. (2021). The neuronal associations of respiratory-volume variability in the resting state. NeuroImage, 230, 117783. https://doi.org/10.1016/j.neuroimage.2021.117783

Sikora, M., Mikołajczyk, R., Łakomy, O., Karpiński, J., Żebrowska, A., Kostorz-Nosal, S., & Jastrzębski, D. (2024). Influence of the breathing pattern on the pulmonary function of endurance-trained athletes. *Scientific Reports*, 14(1), 1113. https://doi.org/10.1038/s41598-024-51758-5

Silva, T. M., Aranda, L. C., Paula-Ribeiro, M., Oliveira, D. M., Medeiros, W. M., Vianna, L. C., Nery, L. E., & Silva, B. M. (2018). Hyperadditive ventilatory response arising from interaction between the carotid chemoreflex and the muscle mechanoreflex in healthy humans. *Journal of Applied Physiology*, 125(1), 215–225. https://doi.org/10.1152/japplphysiol.00009.2018

Tipton, M. J., Harper, A., Paton, J. F. R., & Costello, J. T. (2017). The human ventilatory response to stress: rate or depth? *The Journal of Physiology*, 595(17), 5729–5752. https://doi.org/10.1113/JP274596

van den Aardweg, J. G., & Karemaker, J. M. (1991). Respiratory variability and associated cardiovascular changes in adults at rest. *Clinical Physiology*, 11(2), 95–118. https://doi.org/10.1111/j.1475-097X.1991.tb00103.x

van den Bosch, O. F. C., Alvarez-Jimenez, R., de Grooth, H.-J., Girbes, A. R. J., & Loer, S. A. (2021). Breathing variability—implications for anaesthesiology and intensive care. *Critical Care*, *25*(1), 280. https://doi.org/10.1186/s13054-021-03716-0

## Supplementary Information

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