**UDC: 616.2**
**DOI:**

# THE RESPIRATION MUSCLES RECOVERY TANGENT AFTER THE BREATH HOLDING – THE STUDY OF AFFIRMATION OF METHODS OF KNOWLEDGE

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**Abstract**

The subject of this research is the individual respiration constant calculated based on the respiratory musculature breathing equation. This non-experimental observation conducted on a sample of students from the Faculty of Sports and Physical Education in Belgrade (N=30). The measurement aimed at the acquisition and analysis of the average power of the surface electromyography signal (sEMG) in the protocols before and after prolonged respiratory retention. The results of the research showed that the individual coefficient of control break (Cp) represents a unique characteristic of the respiratory muscles of the subjects. In a relatively trained sample of young people of both sexes, it determined that after holding their breath, until the moment of the so-called "stroke" (progression of respiration to adapt to a stressful situation), recovery time has a linear course and is directly related to the engagement of the monitored respiratory muscles of the subjects, i.e., indirectly the capacity of the individual to assimilate $O_2$ from the inhaled air. In the practical meaning of this research, we emphasize that individual results can be correlated with the equation of respiration of respiratory muscles, to find out and approach the original method for the presented personal respirational constant.

**Keywords:** RESPIRATION / MUSCLE ACTIVITY / TIREDNESS / BREATH HOLDING / RECOVERY TIME

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## INTRODUCTION

The specificity of respiration, as a vital vegetative function, is reflected in the possibility of voluntary control to a certain extent, during an individually determined time. In this way, it is possible to hold the own breath for a while, and in that way indirectly affect the respiratory tissues, but also all other systems of the human body. There are several models of different complexity levels that describe these changes. The simplest is the one that follows the changes in the essential gases of the respiratory process: oxygen and carbon dioxide. Oxygen is the essence of the process of respiration, embodied in the need for every human cell to be supplied with it. In parallel, carbon dioxide eliminates as a final product. The $CO_2$ must not be overlooked here only as a final product, but also a catalyst in over 250 chemical reactions in all tissues. More directly, the successful uptake of $O_2$ molecules in each cell is disabled if the $CO_2$ level is below the critical level, which medical physiology describes by the suppressed Bohr effect (Guyton, 2005). Guyton further states that the sensitivity of the respiratory centers is proportional to the rate of conduction of $O_2$ and $CO_2$ through the bloodstream. Carbon dioxide diffuses through the cell membrane 20.2 times faster than the oxygen.

The main respiratory center locates in the *medulla oblongata* (Guyton, 2005). There are four functional spaces within this center. For this respiratory protocol, the activity of two is indirectly essential: (1) the pneumotaxic center (PTC), which controls the depth and frequency of respiration, and (2) the ventral respiratory center, which controls the inspiration. The characteristic feature of both centers reflects in the fact that they have a diachronic approach of sensitivity to the increase of $pCO_2$ (Henderson, 1940), which with its increase induces an increase in the minute tidal volume (MV). This effect extends to both enlarged breathing depth as well as the increased inhalation frequency per unit time.

The innervation of muscle groups is electrical. Bearing in mind that the nature of myofibrils is of a contractile character (Raković, 2008), this means that every muscle movement is induced only by contraction.

In response to the increased level of $pCO_2$ in working muscles, the pneumotaxic center sends a growing number of electrical impulses over a certain period, thereby inducing the augmented contractility of the actual muscle (Ostojić et al., 2020), what leads to a sequence of the following events (Barret et al., 2010):

- air retention causes a linear increase in $pCO_2$;
- the pneumotaxic center responds to the rise in $pCO_2$, with a larger frequency of triggering of efferent neurons;
- in the new condition, the respiratory muscle groups are being excited to incite the deliberate breathing– it is possible to delay this process by using their willpower.

Breath-holding requires appropriate training. After some period, the triggering of neurons reaches a frequency level that appears as a feeling of the so-called stroke in the region of the solar plexus, or a sense of uncomfortable swallowing. To be recognized appropriately, this requires practical training, that is, to be able to control and prolong the holding of the breath by its willpower.

At a specific moment, the threshold of the series of impulses is so dense that further retention of the breath is impossible, leading to the breath-holding interruption and the forced inspiration. Ganong marks this moment as a breakpoint (Barret et al., 2010). The function between the breaking point and holding the breath until the "stroke" is nonlinear (Rakimov, 2014), and the only connection is the individual ability of the person to catch his breath according to his feelings.

In the practical example of sports, holding the breath until the "stroke" is much more comfortable and safer than maximum holding until the breakpoint.

There are several summary publications on the topic of breath-holding and the flow of reactions of organic systems. Probably the most comprehensive is that of professor Dos Reis et al. (Dos Reis et al., 2019). In addition to this, for the cognitive design of this study, papers that include the measurement of various respiratory parameters were analyzed by clinical devices during acute and chronic conditions caused by physiological and pathological agents. However, for this study, the most interesting are those facts and scientific records found among different populations of top athletes. Thus, Vigotsky deals with the method of monitoring EMG signals of respiratory muscles during the rehabilitation of athletes (Vigotsky et al., 2017). The St. Petersburg group deals with respiratory muscle fatigue during anaerobic activities (Segizbaeva et al., 2015), and the latest research by Lejun et al. (Lejun et al., 2020) based on the sEMG activity of the respiratory muscles of top cyclists during a high level of physical exhaustion.

## THE SUBJECT, PROBLEMS, AND METHODS OF WORK

This research deals with the phenomenon of the effects of breath-holding, which, as a voluntary respiratory maneuver, causes a relatively less stressful situation and a chain of physiological reactions of the organism of young and healthy subjects (**the paper subject**). By electromyographic imaging, the physiological response of the respiratory muscles monitored to a condition believed to have induced an increased partial concentration of carbon dioxide ($pCO_2$) and read through biochemical reactions in the respiratory muscles themselves. Through the analysis of surface electromyography (sEMG) records, this paper aims to gain insight into various respiratory phenomena that have been very popular in sports and training in recent years.

Based on the insight into the theoretical context, methodological, and empirical facts about the subject of this observation, the following **research hypotheses** were**:**

**General hypothesis:**

Hg - the relaxation time of the mean strength of sEMG is variable.

**Auxiliary hypotheses:**

H1 - relaxation time is proportional to the breath-holding time of the subjects (BHT);

H2 - relaxation time is equivalent to the maximum mean power of the sEMG signal of the relevant region;

H3 - relaxation time is more uniform, depending on the relaxation angle of the average power of the sEMG signal.

### Sample of volunteers

Measurement of respiratory muscle activity performed on a sample of students of the Faculty of Sports and Physical Education in Belgrade, middle-aged persons, random sample (N = 30), male and female (4 females and 26 males), aged 21 (± 1) years. The measurement conducted on the premises of the Institute for Experimental Phonetics and Speech Pathology in Belgrade in the afternoon. Before measuring, the volunteers had a theoretical explanation and practical training related to the procedure and course of the measurement. Namely, they learned the technique of breath-holding after spontaneous exhalation, with the gradual successful recognition of the physiological response to prolonged (as long as possible) breath-holding, which occurred before the theoretical (longest) holding (Rakimov, 2014). Therefore, the volunteers of this study asked to concentrate on their breath-holding until the "stroke," or until the so-called physiological response to breath-holding, to realize the research problem, which was reflected in the indirect determination of individual respiration constant through the muscular equation of respiration (Ostojić, 2018), based on EMG signals during a prolonged respiratory arrest. The goal in the training of the subjects was a functional response so that after the cessation of breath-holding should not be the breathing rhythm disturbance, but the continuation of normal, previous calm breathing. One of the indicators of a wrongly performed exercise would be the appearance of shortness of breath.

**Sample variables**

- Breath Holding Time (BHT);
- the maximum average power level achieved in the relevant region (cervical SCM, and diaphragmatic DIA);
- the relaxation time of the average mean power after impact and
- signal relaxation angle (*arcus tangent* of the average power and relaxation time).

**Order of measurement**

The course and method of performing the measurements consisted of the following steps:

- the subject sat on a chair, with his back straight, at rest for 5 minutes, in order to relax all the muscles, especially the respiratory one, in which the stated relaxation led to a spontaneous exhalation of air, breathing exclusively through the nose (mouth constantly closed);
- according to his own will, after one spontaneous inhalation, the subject closed his nose with his right thumb and forefinger, with simultaneous pressure of the switch with his left hand (first pressure of the switch);
- испитаник је задржавао нос затвореним све док није осетио први нагон за удахом (пракса је показала да се ова прва жеља појављује као невољно гурање дијафрагме нагоре или покрет гутања у пределу грла), и
- притисак прекидача левом руком и након 1 s извођење удаха.

The electrodes placed on *m. sternocleidomastoideus* (Fig. 1) and at the level of the diaphragm on the right. The method of electrode placement follows the internationally agreed topographic lines of the *thorax*, which include the current lines for this work: *linea mediana anterior* (extends from *incisura jugularis* to *siphysis pubica*) and *linea sternalis* (extends parallel along the lateral edge of the sternum). The procedure of determining the place (marking the point at the level of the diaphragm) where the upper electrode placed as follows: first, a small extension at the end of the sternum (*prosessus xyphoideus*) was located by palpation, which was in the direction of the *linea mediananterior, to* perform the marking of the first point. The direction of the *linea sternalis* was then determined. The last step was to draw a line perpendicularly from that point towards the *linea sternalis*, to obtain the marking point where the upper electrode was on the abdomen. The lower abdomen electrode places in the direction of the *linea sternalis*, below the top electrode, at a distance of 10 cm.

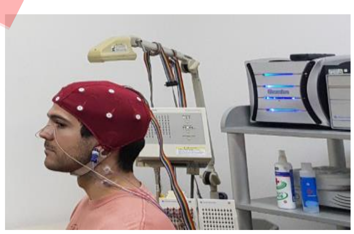

**Figure 1** EEG cap and electrode on m. *Sternocleidomastoideus*

The recruitment of volunteers, their previous training, and consent to participate in the protocol, as well as measurements, performed by the ethical standards of the Serbian Medical Association. The recordings carried out on a Japanese-made device *Neurofax EEG* (*Nihon Kohden*), which, thanks to technical performance, enabled the multichannel recording of a wide range of electropolygraphic signals, via:

- *EEG cap with sixteen channels and two pairs of ground electrodes*,
- *ECG - heart recordings according to Einthoven*,
- a respiratory signal from the tip of the nose – it had the task to record the moment of inhalation.

In parallel with the acquisition of direct measurement data, HD camera recording performed as an inherent part of this study.

The standard clinical method for measuring EMG is moderately invasive, consisting of inserting the needle electrodes to both ends of skeletal muscle (De Luca, 1997). It shows spectral characteristics up to about 450 Hz (Boxtel, 2001), which is almost ten times higher than standard EEG signals, and up to a hundred times in its intensity. Furthermore, if these types of measurements include activation of the desired muscle groups, this cognitive process becomes even more complicated, with broader scope and powers of the registered variables. Thus, the researchers used the method of surface electromyography (sEMG), which is a non-invasive, comfortable method (Merletti, Muceli, 2019). Intensities are of the order of magnitude above the EEG signal, and the frequency range is up to 40 Hz (Milosavljević, 2017).

The muscular equation of respiration gives in the form (Ostojić, 2018):

$$P_{CO_2} \sim e^{\frac{A-A_p}{A_p}} - 1 = e^{(C_p-1)} - 1$$

where $C_p$ depicts as the quotient of the total muscular work of the whole organism and the work of the pleural muscles given by the label $A_p$.

### Statistical data processing

The following standard statistical methods had used: minimum and maximum value, the average mean value, standard deviation, as well as signal deviation coefficient, as the ratio of the standard deviation to the mean signal value (van Leuteren et al., 2019). Also, a two-way Kolmogorov-Smirnov test applied between all these signals, which showed a significant deviation of the distribution for all pairs, clearly indicating a low degree of correlation.

## RESULTS

The described protocols obtained 30 raw multichannel signals - recordings, and after removing the artifacts, the four groups of signals (without EEG signals used) labeled according to the appropriate time intervals:

- normal condition, without activity, before holding the breath;
- phase at the beginning of breath-holding;
- the state of the physiological response to the prolonged holding of breath, which we will further call "stroke";
- the last phase immediately after the stroke with a relaxation period at the end (Ostojić, Milosavljević, 2019).нормално стање, без активности, пре задржавања даха;

For this paper, the records of EEG signals were neither analyzed nor presented, but the possibility of parallel measurement of all these polygraph signals was determined. Each subject examined for an EEG signal, which showed that there was a completely healthy state, pronounced alpha activity, indicating that these were healthy, young people.

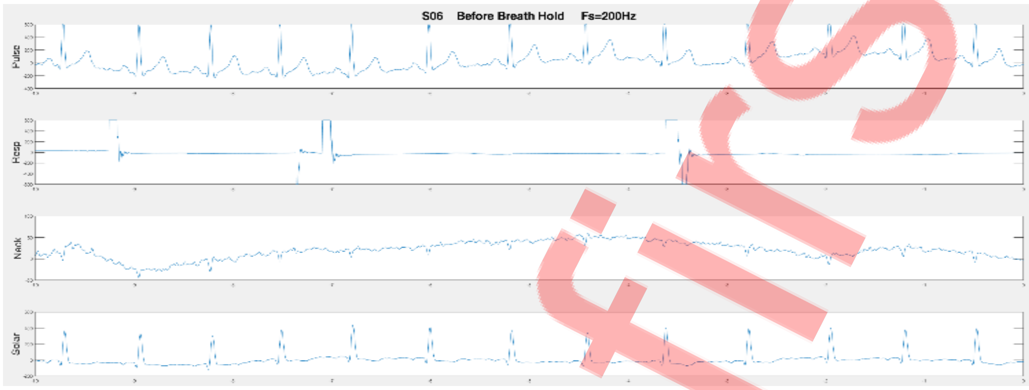


**Figure 2** The time domain of the recorded signals

Figure 2 shows the four signals obtained for a one-time interval. As a result of this, we have the measured signals at rest that refers to the sixth volunteer. Four top-down signals observed: ECG, respiratory signal, sEMG signal in the neck (SCM), and in the region of the solar plexus (DIA). The selection frequency was 200 Hz. A typical healthy ECG signal sees, while the RESP signal correctly indicates both *inspirium* and *expirium*.


**Figure 3** The time change of the average power signal

Figure 3 shows the time domain of the change in mean power, just before the "stroke" for the volunteer number 16. The first signal indicates a difference in the average power of the ECG signal; the following shows a change in the average power of the neck region, and the last "DIA" indicates a difference in the average power in the part of the solar plexus. A significant increase in the average power in the cervical region of the SCM sees, while the other sEMG area, as well as the ECG itself, does not show any significant changes. The average signal power in the time domain is of importance here. Neurofax equipment records signals in $\mu V$ at unit resistance (https://www.medwrench.com/equipment/4722/nihon-kohden-eeg-1200).

Figure 4 shows the next time zone for the ninth volunteer. The dominant bump is observed here exclusively in the DIA region, where the only significant change in the monotonicity of all signals can find. It lasts about only 3 s, after which all signals show the same previous patterns.


**Figure 4** The change in the square amplitude value after the bump

The figure shows the changes in ECG, SCM, and DIA signals. The slope of the red line is proportional to the speed of recovery of the mean square value of the amplitude. The closer the gradient is to a right angle, the slower the recovery. The angle of the red tangent line contains all the relevant variables of this study at this figure. It directly depends on the value of the y-axis, which represents the maximum value of the mean power in the observed event, and the x-axis is the relaxation time, i.e., the time for which the mean signal returns to the values from the beginning of the experiment. There is a very swift return of the average power in the DIA region after normalization of respiration. The red line is created by joining the maximums of the descending curve. (*downtrend line*). While observing the declination rate of the red trending line, one can spot that it decreases at different speeds, which is described by the angle, in Figure 4, at point 3 on the x-axis.

**Table 1** The results of the statistical analysis parameters of measured variables

| Statistical analysis parameters | BHT[ms] | $P_{SCM}$ [mW] | $P_{DIA}$ [mW] | $T_{RLX}$ [ms] | Signal relaxation angle [°] |
|---|---|---|---|---|---|
| MEAN VALUE | 28466.67 | 36.46 | 20.40 | 1288.33 | 15.87 |
| MIN | 11000.00 | 10.00 | 10.00 | 400.00 | 4.09 |
| MAX | 66200.00 | 80.00 | 40.00 | 2100.00 | 55.49 |
| ST. DEVIATION | 12471.66 | 22.93 | 11.07 | 432.18 | 10.90 |
| STD/ MEAN [%] | 43.81% | 62.88% | 54.29% | 33.55% | 68.67% |

Relaxation time values to the initial value $T_{rlh}$ vary for the population in the range from 400 – 2100 ms and shows in summary in Table 1. The mean value is 1288,33 ms, with a standard deviation of 432,18. The results of cross-correlation analysis (Kolmogorov-Smirnov bilateral test) showed a low rate below 5% (K-S=3,87298, p<0,001) and the absence of links between all relevant variables, which in this case means that the relaxation time is conditioned neither by the holding time of the breath nor by the values of the maximum mean power in the neck or diaphragmatic region. The relaxation time has the smallest ratio of 33.55% between the standard deviation and the mean value, so posses the most accurate description of the mentioned phenomenon of returning the maximum average power to the initial values.

## DISCUSSION

The quotient of the total muscular work of the whole organism ($C_p$) is an individual characteristic of each person and depends on many factors. In the first place, those are the total organism muscle mass (includes the locomotor, smooth and transverse-striped musculature), as well as all the muscles that participate in the process of respiration. The very nature of myofibrils is genetically determined, defining the ranges of energy production and end products per unit time. The training of the organism also plays a critical role.

The main practical requirement of MRE is to permanently keep the $pCO_2$ concentration in the range between 2-6%. Practically, the only regulatory mechanism of an individual in this sense is the control of the portion of respiratory musculature in the function of the total muscular activity of the whole organism. Theoretical energy expenditure of the respiratory musculature ranges from 3-51% of the possible maximum (Guyton, 2005). During sleep and in complete peace, it is necessary to be at the level of 3%, and the maximum 51% is only justified to use during extreme physical effort (short time) and at extreme heights, due to the reduced concentration of oxygen in the air.

If increased efforts cannot accompany the portion of respiratory muscles, there is an excessive accumulation of carbonic acid in the blood, which would lead to terminal acidosis in a prolonged time interval. On the other hand, a disproportionate portion of respiratory muscles leads to another side effect, which is hyperventilation. Practice shows that this often happens in less than half an hour. There are very few similar results over the healthy population, while different health etiologies are described in the proceedings. The meaningful work of the Athens group considers different clinical outcomes of asthmatics of different disease progressions (Papyris, et al., 2002). The recovery from exertion caused by hypercapnia (an excessive amount of $CO_2$ in the blood) either by exercise or by holding one's breath went from half an hour for milder cases, to as much as 24 hours for seriously ill asthmatics. A similar result was recorded by the Egyptian group (Azabet et al., 2015), measuring total / forced lung capacity, respiratory rate, minute ventilation, inspiratory/expiratory time. Our subjects showed a recovery time of at most 2.1 s, which is a clear indicator of the excellent condition of their respiratory musculature.

On the other hand, the incomplete correlation between breath-holding time, BHT, indirectly indicates an insufficient degree of training. For this study and the affirmation of the method of cognition within FSFV students, as a group of volunteers, it is essential to note the importance of breath-holding maneuvers and accompanying physiological responses necessary for their participation in swimming activities (diving, swimming). In other words, the requirement to this group should not be only to recognize the course and importance of holding the breath, but also the exercise that would lead to the acquisition of a "diving reflex." Striving towards this goal requires learning and regular exercise, which would impose the necessity for self-training of this group of volunteers and access to the profession through a clear perspective continuous physical readiness for swimming and diving activities and occupations.

## CONCLUSION

This study aimed to determine the individual respiration constant of the muscular equation in moderately trained individuals, to determine the relaxation time of the average power of sEMG with prolonged retention of the act of breathing.

The obtained indicator of relaxation time from the moment of "shock" at the end of breath-holding to complete normalization of the average sEMG power, is a significant respiratory capacity prediction indicator of the functional abilities status to assimilate oxygen from inhaled air faster, which is proportional to air holding time (BHT), thus confirming the first hypothesis ($H_1$).

The results of the study showed that the relaxation time was not proportional to the maximum average value of the sEMG signal of the relevant region, which did not confirm the second hypothesis ($H_2$). It also found that the relaxation time became more uniform than the relaxation rate of the average power of the sEMG signal, thus confirming the third hypothesis ($H_3$). Based on the previous results, the general hypothesis (Hg) was confirmed - the relaxation time is variable.

From the muscular equation of respiration, it determined that the degree of cell saturation by $pO_2$ is proportional to the partial concentration of $pCO_2$, while Cp represents an individual characteristic. The slope of the curve shows the speed of the organism's recovery from hypoxia. It is directly related to the concentration $pCO_2$, which means that the coefficient Cp also has direct proportionality.

For now, it is not possible to answer if some another parameter affects the slope of the curve, i.e., the relaxation time $T_{rlh}$, and this means that additional parallel measurements of different biochemical, gaseous and ventilatory parameters can bring us closer to the goal of full affirmation of the cognitive method. On the other hand, the time of relaxation certainly has a direct relationship with the level of volunteer training skills, as well as that in the background, are his abilities to assimilate faster $O_2$ from inhaled air with the progression of effort. A small, portable electronic device to monitor the activity of respiratory muscles in sports practice might be quickly developed for the stated problems. The results would be instantaneous, and the input signals should be taken simultaneously from the neck and solar plexus region.

**Conflicts of interest**

The authors declare that there is no conflict of interest regarding the publication of this paper

**REFERENCES**


1. Azab, N.Y., ElMahalawy, I.I., AbdElAal, G.A. &Taha, MH (2015). Breathing pattern in asthmatic patients during exercise. *Egyptian Journal of Chest Diseases and Tuberculosis*, 64(3): 521-527.
2. Barret, K.E., Barman, S.M., Boitano, S. & Heddwen, L.B. (2010). *Ganong's Review of Medical Physiology*, Twenty – third Edition; by the McGraw – Hill Companies.
3. Boxtel, VA (2001). Optimal signal bandwidth for the recording of surface EMG activity of facial, jaw, oral, and neck muscles. *Psychophysiology*, 38(1):22-24.
4. De Luca, C.J. (1997). The use of surface Electromyography in biomechanics. *Journal of applied biomechanics*, 13 (2): 135-163.
5. Dos Reis, I.M.M., Ohara, D.G., January, L.B., Basso-Vanelli, R.P., Oliveira, A.B.& Jamami, M. (2019). Surface electromyography in inspiratory muscles in adults and elderly individuals: A systematic review. *J Electromyogr Kinesiol*, 44:139-155.
6. Guyton, A.C. (2005). *Physiology of the human body*. Philadelphia: Sunder, College Publishing.
7. Henderson. (1940*). Carbon dioxide*, in *Cyclopaedia of medicine*. Philadelphia: FA Davis Co. p.
8. Lejun, W., Qineng, S., Guoqiang, M., Mingxin, G., Wenxin, N., & Jun, Q. (2020). Pedaling Performance Changing of Elite Cyclists Is Mainly Determined by the Fatigue of Hamstring and Vastus Muscles during Repeated Sprint Cycling Exercise. *BioMed Research International 2020(1):1-9.*
9. Merletti, R. & Muceli, S. Surface (2019). EMG detection in space and time: Best practices. *J. Electromyogr Kinesiol*, 49 (2019) 102363.
10. Milosavljević, M. (2017). *Robust Digital Processing of Speech Signals*. New York: Springer.

11. Nihon Kohden, Neurofax Brochure. https://www.medwrench.com/equipment/4722/nihon-kohden-eeg-1200..
12. Ostojić, M. (2018). *Umeće disanja*. Beograd: Pešić & Sinovi.
13. Ostojić M, & Milosavljević M. (2019). The Possibility of Electromyography Measuring as The Answer to Breath Holding. *Sinteza 2019, International scientific conference on information technology and data related research "Electrical Energy Markets and Engineering Education and Advanced Engineering". Novi* Sad, 20. April, Zbornik radova, pp. 307-312.
14. Ostojić, M., Milosavljević, M., Kovačević, A., Stokić, M. Stefanović, Đ., Mandić-Gajić, G. & Jeličić, J. (2020). Changes in the power of surface electromyogram during breath-holding. *Serbian archives of medicine*, DOI: https://doi.org/10.2298/SARH191118037O
15. Papyris, S., Kotanidou, A., Malagari, K. & Roussos, C. (2002). Clinical review: Severe asthma. *Critical Care* Feb;6(1):30-44.
16. Rakimov, A. (2014). *Normal Breathing*. Toronto: Amazon Digital Services.
17. Raković, D. (2008). *Biophysics*. Belgrade: IASC & IEFPG.
18. Segizbaeva, M, O., Timofeev, N.N., Donina, ZhA. & Kur'yanovich, E.N. (2015). Effects of inspiratory muscle training on resistance to fatigue of respiratory muscles during exhaustive exercise. *Adv Exp Med Biol*.; 840:35-43.
19. van Leuteren, R.W., Hutten, G.J., de Waal, C.G., Dixon, P., van Kaam, A.H. & de Jongh, FH (2019). Processing transcutaneous electromyography measurements of respiratory muscles, a review of analysis techniques. *J. Electromyogr Kinesiol*. 1 (48): 176-186.
20. Vigotsky, A.D., Halperin, I., Lehman, G.J., Trajano, GS & Vieira, T.M. (2018). Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences, *Front Physiol* 2018 (8): 985.
21. Vitasalo, J.H.T & Komi, PV (1977). Signal characteristics of EMG during fatigue. *European Journal of Applied Physiology and Occupational Physiology*, (37 )111-121.