

Investigation of mutual aerobic and lower limb muscular activity during cycling

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The evaluation of physical activity is a complex task that requires performing an analysis of muscular activity and aerobic/anaerobic threshold and it is often difficult to observe and propose a single method. The purpose of the article is to evaluate a relation between aerobic capacity and activity of lower limb muscles via changes of muscle's EMG signal during physical, sub-maximal veloergometric loading. The activity parameters of 5 lower limb muscles such as semitendinosus, rectus femoris, biceps femoris, gastrocnemius medialis, and tibialis anterior were measured and analyzed during the veloergometric exercise tests and the heart rate and the aerobic capacity were estimated from registered data. The obtained aerobic parameters allow setting an individual and overall voluntary physical capacity. The regression oxygen function presented allows analyzing and predicting the ability of subjects to generate energy while maintaining muscle activity during the exercise. The correlation between the consumption of oxygen and constant physical loading time is determined. It was found that comparing VO_{2max} capabilities the physical effort in the male group was 16% higher than in women. Oxygen consumption and maximum muscle effort dependency on the load time was established. It was observed that the maximal muscular effort appeared before VO_{2max} reached maximal limit in both groups. The maximal oxygen consumption is achieved in the middle or sometimes at the beginning (depending on load) of exercise while maximal muscular effort was found in several phases of cycling: at the beginning and at the end of loading time.

Key words: iEMG, aerobic capability, physical activity, veloergometry, muscular effort, lower limbs, muscular fatigue

1. Introduction

The main function of the muscle is contraction which is realized by chemical energy transformed into mechanical energy. In this way, human skeletal muscle performs static and dynamic work. Dynamic work is done moving the body or its parts, static – maintaining the posture [1]. For the statics and dynamics of the human body very important are muscles of lower limbs, which are actively involved in the daily movements of walking, standing up from a sitting position, climbing stairs, maintaining balance in an upright position. Also the lower limb muscle condition and its improvement are very important object for profes-

sional sports (running, jumping, cycling, etc.), rehabilitation (especially physical therapy), and medical diagnosis. The most widely applied method for the analysis of muscle activity is electromyography, which allows determining the treatment and sports modes directly, analysis of muscle responses to external factors, to improve medical diagnosis and treatment of diseases [10]. Many scientists study lower limb muscle activity depending on age [2], [14], temperature [16]–[19], the pathology [17], the sport mode [1], and other factors. Paradoxically acting muscles are immobilizing fixed points of consciously controlled muscles and forces can be transmitted only to moving points [20]. However, with age a continually decline of muscle mass leads to a decrease in muscle

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strength [8], [13]. For this reason, the normal human daily activity is disrupted as well as the ability to look after oneself, and the risk of falling is increased. Studies have shown that physical activity helps to maintain and increase muscle strength and power, and this ensures the independence of elder people and the ability to move freely. Even completely simple exercises to improve muscle function and training program not only increases muscle strength, but also enhances the activity of internal organs [2]. An important feature is the ability of the organism to adapt to changing environmental conditions. Most of the physiological and other body processes are closely related to changes in body temperature. Elevated temperature accelerates the body's internal oxygen separation from hemoglobin and myoglobin, metabolic reactions, activates the blood flow in the muscles, reduces muscle viscosity, and increases the action potential propagation velocity, oxygen consumption [2]. Meanwhile, the fall in muscle temperature significantly reduces the force of muscle contraction and relaxation speed and intramuscular coordination [19]. Veloergometry is one of the most frequently used methods for lower limb muscle endurance and cardiopulmonary testing. There are many different ergometer tests for muscular endurance, heart and lung evaluation: the Astrand 6 minute cycle test, the Wingate test, the YMCA sub-maximal cycle test ERGOMETER, and others [7], [11], [12]. Veloergometry exercise test may determine the individual's physical capacity level that is indicated by two parameters: VO_{2max} and VO_2 . Most of the energy produced in the body aerobically, and the amount of oxygen consumption can be used to determine energy consumption. Oxygen consumption of the heart depends on several factors: the system's ability to pump blood; the tissue's ability to absorb oxygen; the lung volume and alveolar ability to produce oxygen from the air [24]. Human physical strength can be seen in the maximum amount of oxygen consumed during exercise. The maximum amount of oxygen consumption (VO_{2max}) is expressed in milliliters of oxygen content used in one minute per kilogram of body weight. Physical fit individuals can perform exercises with higher intensity [13]. Physical activity assessment in the field of research has shown that the indicators are improving in regular physical exercise training while maintaining the heart rate 65–85% of the maximum bpm and training for 20 minutes, 3–5 times per week [4]. By the veloergometry test estimated VO_{2max} values can be assessed for each test based on the physical capacity of the specified reference Heyward maximum oxygen consumption values for different age and sex of subjects [7]. How-

ever, the physical capacity tests are often measured in terms of physical activity regardless of aerobic oxygen consumption parameters which can influence the different outcome of the investigation. There are also often analyzed only major lower limb muscles, isolated from other muscle groups involved in the motion. As explained before, VO_{2max} reflects aerobic physical condition of an individual and is important to determine capacity of their endurance during sub-maximal exercises. Tests measuring VO_2 max can be dangerous for the individuals who are not considered normal healthy subjects, as any problems with the respiratory and cardiovascular systems will be greatly exacerbated in clinically ill patients. On the other hand, physical evaluation by using EMG reflects electrical activity of skeletal muscles and shows muscle activation characteristics, fatigue threshold, cadence, and muscular capability. By evaluating VO_{2max} and EMG parameters the quantitative evaluation of individual physical capability could facilitate the monitoring of cycling test process and with greater accuracy. The basic task of this article is to find the relationship between the aerobic capacity and muscular activity parameters, and also to find the methodology for physical effort evaluation as well as any possibilities of its prediction.

2. Methods

2.1. Subject characteristic

Ten healthy subjects (4 women and 6 men) participated in the study. None of the participants had any other injuries or disease affecting movement or coordination and all of them provided informed consent prior to participating in the study. The mean age was 21.5 ± 1.36 ($\bar{X} \pm SD$) years, weight 76.5 ± 10.84 kg for men and 54 ± 3.08 ($\bar{X} \pm SD$) kg for women.

2.2. Measurement protocol

A 16-channel BTS PocketEMG (BTS S.p.A., Italy) electromyographic system was used for the measurement of muscle biosignals. The activity of five lower limb muscles was recorded using surface electrodes (Ag/AgCl): rectus femoris, biceps femoris and semitendinosus, tibialis anterior and dual, gastrocnemius medialis. Surface electrodes on the muscles were approved and arranged according to European

Union Biomedical and Health Research Programme *Biomed II* the recommendations of non-invasive surface electromyographic leg muscle testing and evaluation – SENIAM [14] (Fig. 1).

A mechanical ergometer Monark 868 (Sweden) has been used for physical loading. According to Astrand’s 6 minute cycle test methodology the following exercise parameters have been chosen: cadence 60 rpm, 120 W loading for men, 90 W loading for women, and constant heart rate during exercise 130–

60 bpm. During exercise cardiac activity was observed by Kinetec wireless heart monitoring device. Study data were processed using MATLAB (MathWorks Inc., USA) software.

The study (Fig. 2) consisted of four phases: gait test, veloergometry loading exercise, gait test after physical exercise, and gait test 3 minutes after the veloergometric exercise.

During the cycling in constant loading mode for 6 minutes the heart rate of subjects was recorded

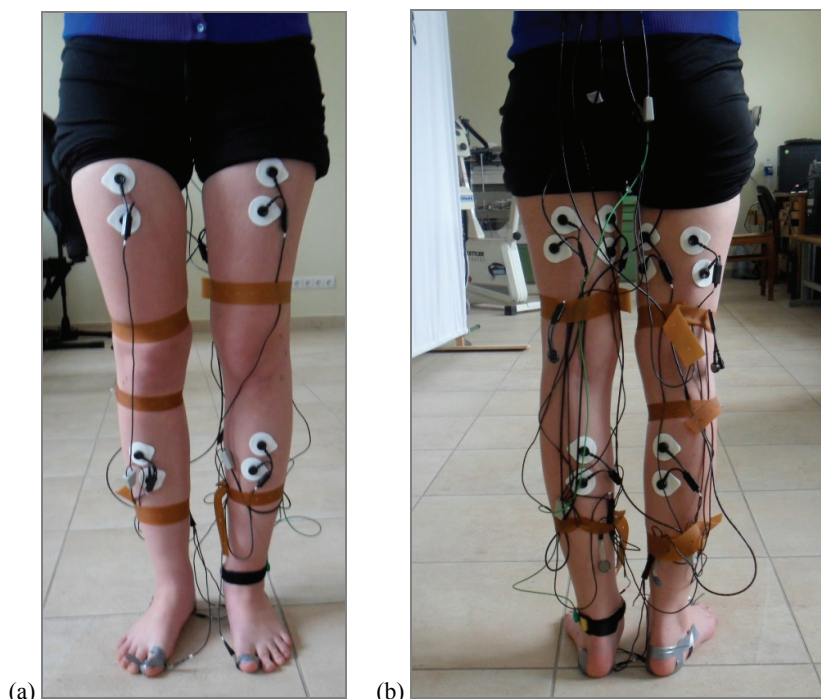


Fig. 1. Electrode placement: (a) frontal side, (b) back side

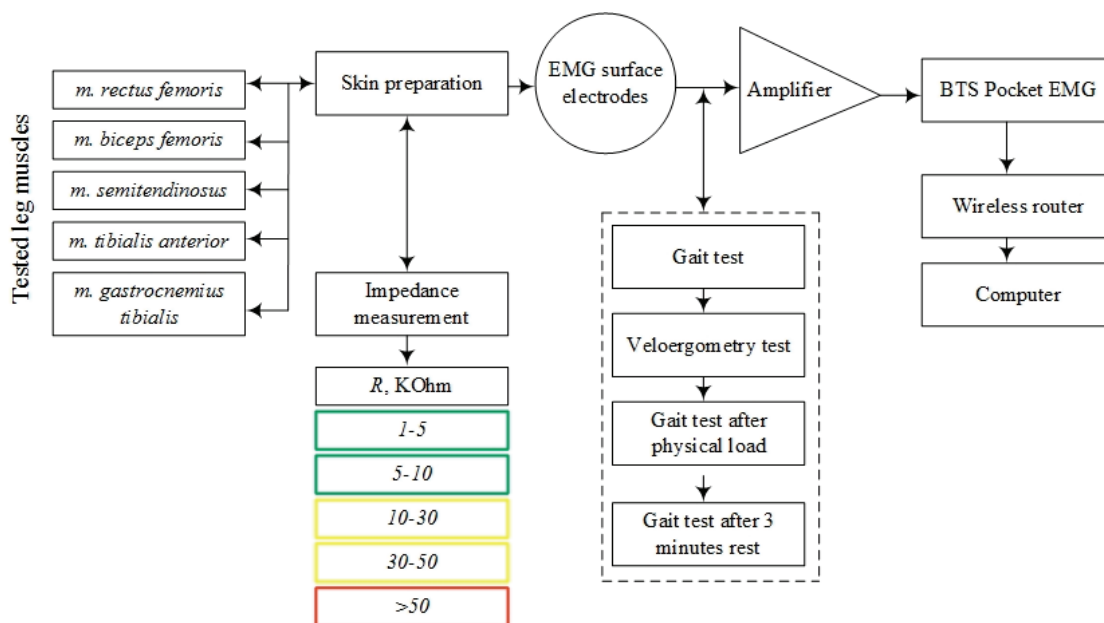


Fig. 2. Scheme of research process

(Table 1). Pedaling time was started to count when subjects' heart rate had reached approximately 130 beats per minute. The further study continued with the heart rate between 130–160 beats per minute, while maintaining steady pedaling rate – 60 rpm.

VO₂ values for men and women were estimated from measured heart rates and by using a modified *Astrand* nomogram [7]. This method has been used instead of others, for example, direct oxygen consumption, because of its simplicity, accuracy and reliability. This method is often used for physical testing during cycle-ergometry and it also helps to monitor heart rates during exercises.

For the analysis of oxygen consumption changes in men the regression analysis of oxygen consumption by the time function was made (1), which allows oxygen consumption to be predicted at any time, under specified loading conditions.

During the test pedaling time started to run as a volunteer heart rate reached 130 bpm. Therefore, the maximum amount of oxygen consumption (VO_{2max}) was reached already in the first minute. Using mathematical dependencies of oxygen consumption in men and women on pedaling time (1, 3) maximum oxygen consumption was found in the experimental groups. In order to better reflect the results of test of maximum oxygen consumption values, the results are converted to the amount of oxygen in milliliters per one kilogram of body weight per loading minute. For men oxygen consumption rate (VO_{2max}) is 43 ml·kg⁻¹·min⁻¹ and for women it is 51.2 ml·kg⁻¹·min⁻¹.

In order to evaluate muscular activity changes in six-minute steady veloergometric test the integrated EMG (iEMG) signal curve was analyzed. The curves were obtained by integrating the raw recorded signal, at one second muscle contraction section (1). This section corresponds to one pedaling cycle of volunteer pedaling at 60 rpm.

$$S_{iEMG} = \int_{t_2}^{t_1} S_{EMG}(t) dt, \quad (1)$$

where S_{iEMG} is the integrated EMG signal, S_{EMG} stands for the raw EMG signal and t is the time in seconds.

Integrated EMG signal is the rate that corresponds to the area under the curve. This value is expressed in mV/s, and represents the maximum muscle effort to do the work. The physical sense of the mechanical work is the module of forces acting on the body and the body displacement multiplication, and in the present case the muscular effort to do the work is regarded as the muscle's ability to main-

tain a constant load pedaling veloergometer at a constant speed. Averages of maximal subjects' muscle iEMG

$$\bar{X}_{iEMG} = \frac{1}{n} \sum_{i=1}^n iEMG_i, \quad (2)$$

where t is the loading time from 1 to 6 seconds, i is the corresponding muscle's iEMG maximal value, n stands for the quantity of values – values of 6 for the right leg muscles, and 6 – for the left), for a volunteer pedaling veloergometer for 6 minutes under a defined constant load are presented in Fig. 4.

When subject was pedaling veloergometer the lower leg muscle's electromyogram was recorded for 20 sec every minute. Recorded muscular contractions in every section were considered to be a muscle contraction in one minute of constant veloergometric loading. These every minute recorded muscular contraction rates were integrated and resulting maximal values averaged. iEMG_{max} averages and standard deviations of men and women presented in Tables 2 and 3.

2.3. Statistical analysis

For data analysis the statistical and mathematical methods have been used. Means and standard deviations were calculated for the total subject sample using computer software Statistica 10 (StatSoft, Tulsa, OK, USA). Ordinary least squares method has been used for regression analysis of VO_{2max} and muscle activity relations.

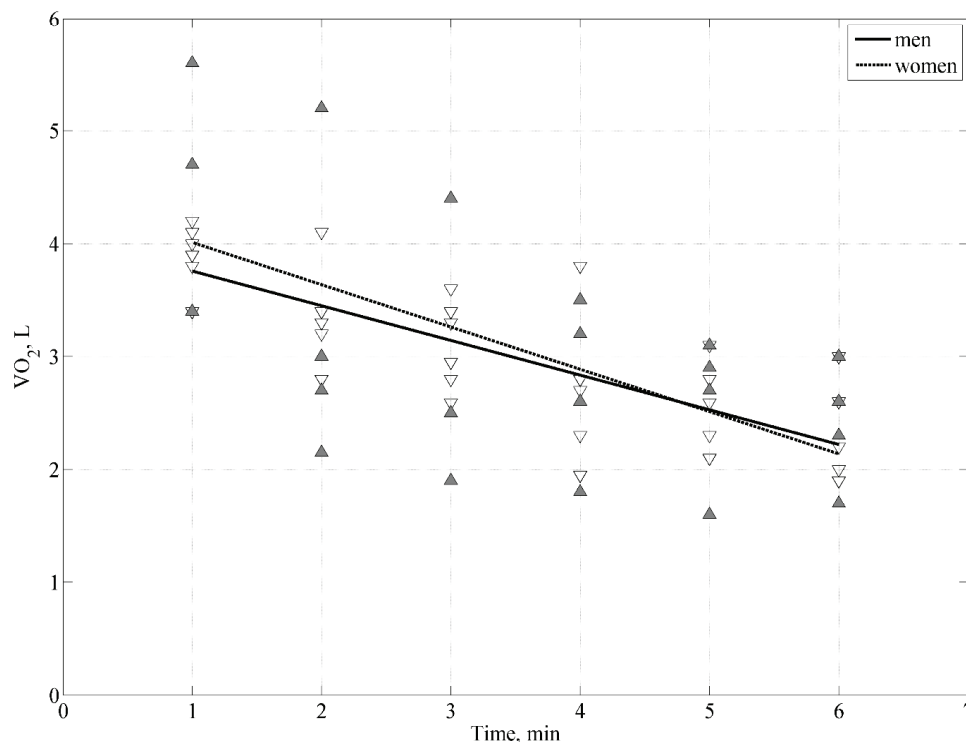
3. Results

Variations of oxygen consumption rates in the six-minute pedaling test are presented in Fig. 3 and the heart rates in Table 1. As seen from Fig. 3, oxygen consumption values in men have low spread over time. The study showed that it was not difficult for men to maintain the pedaling rate at the 120 W magnitude load and heart rate for a six-minute period gradually increased.

As mentioned before, VO_{2max} shows the body's ability to absorb oxygen and use it for energy generation in muscle [14]. The obtained VO_{2max} results for men and women could be evaluated by the Heyward maximum oxygen consumption values for different age and sex of subjects [7], [14]. By supporting this assessment, the oxygen content consumed by the women can be seen as very good, men – as satisfac-

Table 1. The heart rates of volunteers during veloergometrical loading

Time, min	Heart rates, bmp									
	Men, (n = 6)						Women, (n = 4)			
	A	B	C	D	E	F	G	H	I	J
0–1	134	133	138	130	131	132	130	136	136	145
1–2	138	146	131	139	140	134	133	153	166	161
2–3	144	149	136	146	141	138	138	160	172	165
3–4	146	160	138	153	146	145	147	151	173	159
4–5	151	153	141	147	153	146	155	150	177	157
5–6	159	160	144	156	155	148	159	154	174	163

Fig. 3. The variation of oxygen consumption rates (VO_2) in men and women during veloergometry

tory. Such results are influenced by the difference between the relatively high levels of the weight difference and the difference between the fixed pedaling loadings. The obtained aerobic capacity results suggest that the muscle fatigue resulting after physical exercise and power loss will be higher among women. The regression analysis of men's oxygen consumption (3) allows predicting oxygen consumption at any time, on specified loading conditions. The resulting coefficient of determination $R_{men}^2 = 0.665$ indicates that the mathematical model is good for the trial data characterization. By removing the root of the coefficient of determination, the correlation coefficient (4) was obtained, which shows a strong, linear, negative relationship between experimental data in this case.

$$f(y) = -0.1813 \cdot x + 3.5219, \quad (3)$$

$$R_{men} = \sqrt{R_{men}^2} = \sqrt{0.665} = 0.815. \quad (4)$$

Women's oxygen consumption values vary over a range of values because the distribution of time has a higher spread (Fig. 3). The reason behind this is that the heart rate of volunteers during veloergometry loading reached 160 bpm limit. In this case, the load was reduced from 90 W to 60 W in order to stabilize the heart rate to study an acceptable range of 130–160 bpm. The rise in heart rate decreases the amount of oxygen consumed. For women's oxygen consumption the regression analysis of oxygen consumption by the time function was made (5). It is assumed statistically that the coefficient of determination values less than 0.25 indicates that a mathematical model poorly describes the research model. The estimated coefficient of determination $R_{fem}^2 = 0.378$

satisfies the condition $R_{fem}^2 \geq 0.25$, suggesting that the function correctly describes the experimental data (6). The calculated correlation coefficient indicates a moderate, linear, negative relationship between women's test loading time and consumption of oxygen.

$$g(y) = -0.2155 \cdot x + 2.9522, \quad (5)$$

$$R_{wom} = \sqrt{R_{wom}^2} = \sqrt{0.378} = 0.614. \quad (6)$$

The functions $f(y)$ and $g(y)$ explain that the amount of oxygen consumed by men during veloergometry in appropriate test conditions changes slowly and thus in the end of the test retains higher values. This indicates a greater ability for men muscles to absorb oxygen to

generate energy on six minutes submaximal veloergometric loading.

The results of analysis of the averages of iEMG maximal values and standard deviations for each pedaling minute for men and women are presented in Tables 2 and 3. The obtained data show that the highest values of maximum effort during exercise load and pedaling speed were kept by the muscles of the men: rectus femoris, gastrocnemius medialis, and semitendinosus muscles, and of the women: gastrocnemius medialis, anterior tibialis, semitendinosus muscles. As the tibialis anterior muscle is functionally adapted to foot movements, a relatively high maximum effort values and their standard deviations can be explained by the different pedaling strategies.

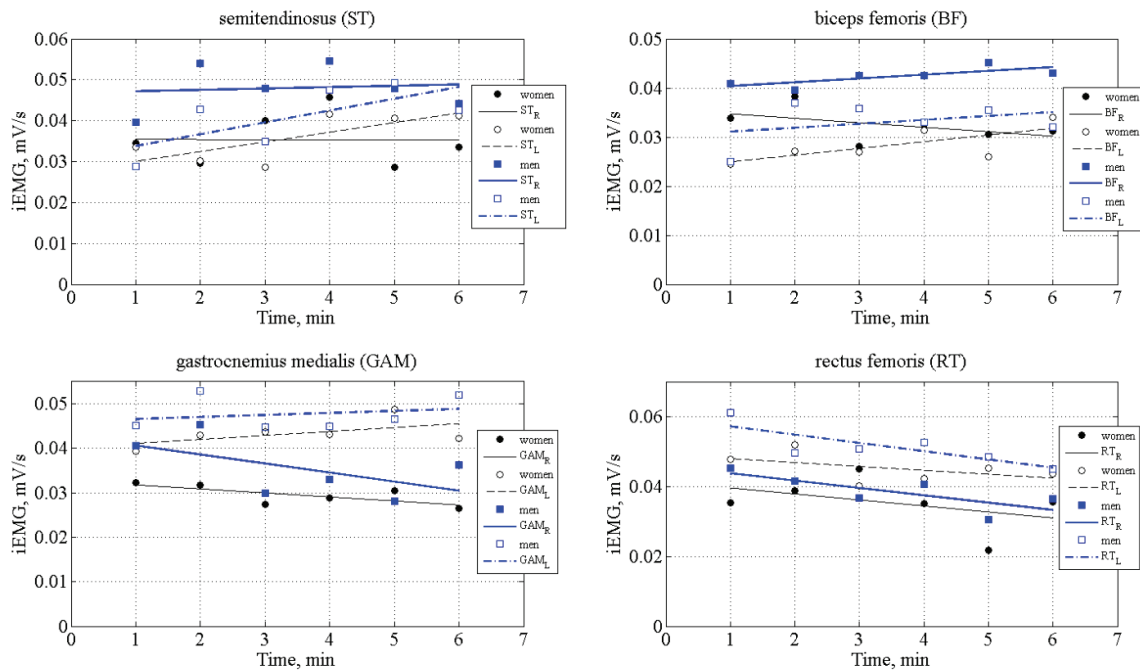


Fig. 4. Variation of the peak average in the leg muscle's iEMG during veloergometric stress: R – right lower limb, L – left lower limb

Table 2. Rates of averages of iEMG peaks and standard deviations ($\bar{X} \pm SD$), V/s ($\cdot 10^{-3}$ mV/s) of women's leg muscular activity during veloergometry test

t, min	Women (n = 4)									
	ST	ST	BF	BF	GAM	BAM	RF	RF	TA	TA
	R	L	R	L	R	L	R	L	R	L
Pedaling load 90 W (550,64 Kg-m/min)										
1	34.48 ± 18.33	33.61 ± 5.78	33.89 ± 11.7	24.59 ± 5.27	32.33 ± 8.37	39.4 ± 2.35	35.46 ± 26.44	47.8 ± 6.3	41.54 ± 13.8	48.4 ± 26.2
2	29.55 ± 9.93	30.21 ± 8.91	38.3 ± 9	27.16 ± 4.37	31.68 ± 4.5	42.96 ± 12.9	38.73 ± 17.51	52.01 ± 17.23	48.31 ± 18.62	42.2 ± 17.29
3	40.06 ± 7.4	28.64 ± 9.4	28.13 ± 1.6	27.01 ± 5.5	27.5 ± 8.6	43.66 ± 0.9	45.1 ± 14.56	40.27 ± 19.13	43.3 ± 5.22	38.88 ± 12.4
4	45.73 ± 24.7	41.61 ± 26.26	32.69 ± 11.93	31.44 ± 15.5	28.77 ± 9.93	43.08 ± 0.006	35.15 ± 28.57	42.22 ± 22.76	33.29 ± 8.89	42.99 ± 16.95
5	28.67 ± 3.87	40.6 ± 20.1	30.59 ± 2.128	26.06 ± 10.07	30.4 ± 16.47	48.81 ± 0.91	21.85 ± 8.53	45.28 ± 22.77	42.13 ± 14.91	49.82 ± 23.55
6	33.59 ± 9.7	41.31 ± 16.44	31.2 ± 8.7	33.95 ± 11.94	26.52 ± 9.13	42.23 ± 1.56	35.54 ± 18.95	43.62 ± 25.62	42.75 ± 17.56	41.57 ± 8.55

*R – right lower limb, L – left lower limb.

Table 3. Rates of averages of iEMG peaks and standard deviations ($\bar{X} \pm SD$), V/s ($\cdot 10^{-3}$ mV/s) of men's leg muscular activity during veloergometry test

t, min	Men (n = 6)									
	ST	ST	BF	BF	GAM	BAM	RF	RF	TA	TA
	R	L	R	L	R	L	R	L	R	L
	Pedaling load 120 W (734,19 Kg-m/min)									
1	39.56 ± 7.74	28.76 ± 10.36	40.91 ± 2.161	25.08 ± 5.06	40.7 ± 21	45.08 ± 11.49	45.23 ± 14.8	61.16 ± 35.35	38.67 ± 23.11	55.73 ± 23.79
2	53.95 ± 15.13	42.81 ± 14.33	39.57 ± 6.52	36.94 ± 12.9	45.36 ± 5.86	52.94 ± 6.92	41.56 ± 18.3	49.54 ± 25.7	47.52 ± 7.51	47.65 ± 6.525
3	47.86 ± 20.23	35.01 ± 17.98	42.62 ± 17.11	35.88 ± 15.34	29.88 ± 14.23	44.71 ± 8.72	36.69 ± 18.56	50.87 ± 29.29	39.37 ± 9.25	39.42 ± 9.723
4	54.67 ± 24.69	47.6 ± 21.52	42.62 ± 12.72	32.97 ± 10.72	33.07 ± 15.47	44.87 ± 14.85	40.69 ± 22.51	52.58 ± 42.22	42.17 ± 4.23	40.3 ± 17.03
5	47.89 ± 22.27	49.29 ± 29.53	45.1 ± 18.17	35.51 ± 14.98	28.07 ± 14.7	46.64 ± 11.32	30.42 ± 10.3	48.46 ± 39.38	36.62 ± 8.82	44.81 ± 20.89
6	44.16 ± 16.3	42.59 ± 11.93	42.98 ± 17.624	32.09 ± 4.47	36.21 ± 4.359	52.04 ± 2.98	36.39 ± 21.93	44.91 ± 25.45	46.49 ± 12.05	42.79 ± 7.05

*R – right lower limb, L – left lower limb.

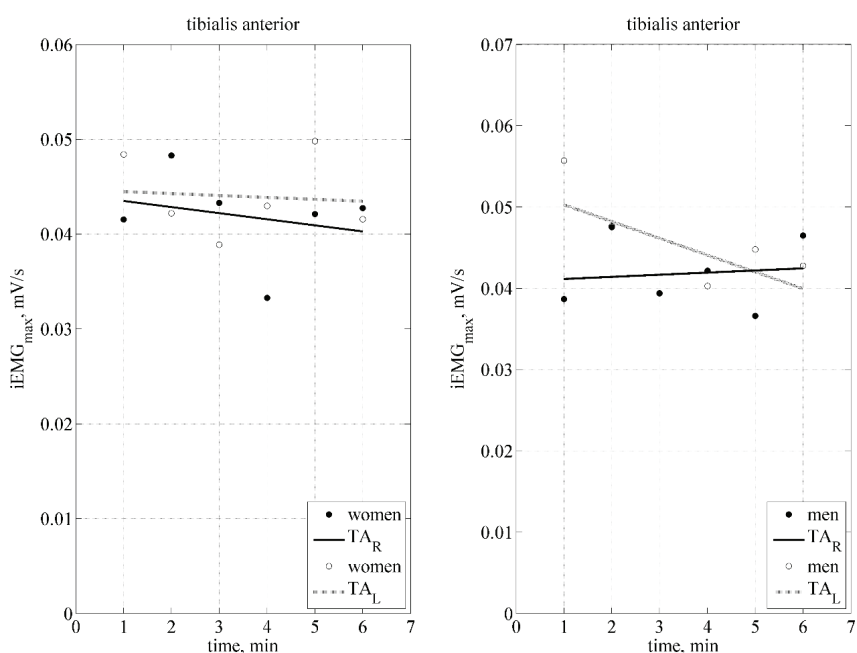


Fig. 5. Variation of the peak averages in leg muscle's tibialis anterior iEMG during veloergometric stress for women (on the right) and men (on the left)

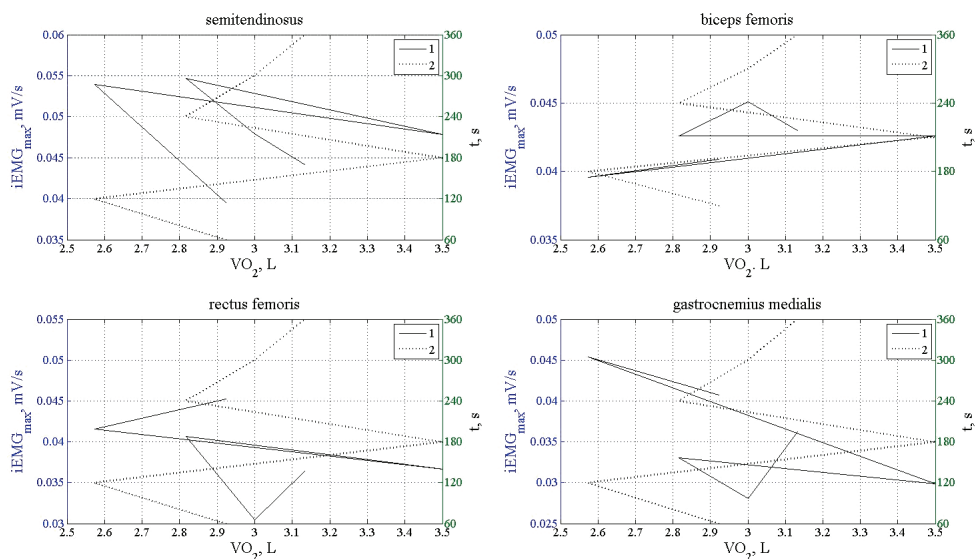


Fig. 6. The relation between aerobic parameter VO_2 and corresponding maximal muscle effort $iEMG_{max}$ in working time t : 1 – $iEMG_i$ dependence on VO_2 and 2 – variation of VO_2 consumption in time t during work

If during the cycling the toes are placed on the pedals the muscle should be loaded much more in comparison with another pedaling strategy when the arch of the foot is placed on pedals during cycling (Fig. 5).

In most cases, the left lower limb muscle performing work requires a higher maximum muscle effort. The relatively large standard deviations obtained indicate a different physical fitness level. The maximum muscle effort data obtained during investigation suggest that increased muscle fatigue will be seen in left leg muscles because these muscles need higher maximum effort while maintaining a constant load and pedaling speed.

In order to assess the relation between aerobic parameters and maximum muscle effort, the dependences (Fig. 6) were established which show the evolution of a person's maximal effort $iEMG_{max}$ in loading time t and how much oxygen was consumed (VO_2) at such a maximum exertion.

4. Discussion

The evaluation of physical activity is a very serious problem analyzed in many scientific researches. The main valuable parameters such as muscular activity, muscle strength, and aerobic/anaerobic threshold are often analyzed in different cases, so it is very difficult to observe and propose one method for evaluation of physical activity [23]. According to the pulse frequency response to the work of average intensity the test for evaluation of VO_{2max} with 10 percent error was proposed by Astrand, Rhyning in 1954 and maximal oxygen consumption rate scale was presented and used in practice. Therefore, for aerobic parameters were performed according to the proposed methodology as sufficient and accurate enough. The main factors that affect VO_{2max} : genetics, age, training level, the form of exercise, body mass and body composition and gender. Genetic make-up of every person has a very strong influence over his/her VO_{2max} and this is ultimately what defines their upper limit for VO_{2max} improvements. The capacity of the circulatory system to deliver oxygenated blood to muscles and also the specific physiology of them are both genetically predetermined to a certain extent. The average person's VO_{2max} peaks at the age of around 18 and remains fairly level (only a slight decline occurs) until the age of 25. Beyond 25 years of age VO_{2max} declines by roughly 1% per year. At the age of 55 the average person has a VO_{2max} that is approximately 27% less than that of a 20 year old. Although there is a negative

correlation between VO_{2max} and age, the available evidence indicates that the influence of a person's training level on VO_{2max} is stronger than the influence of their age [8].

VO_{2max} is heavily influenced by training level. Depending on the nature of the training program adopted, an untrained person can improve their VO_{2max} from 5% to 30%. For the recommended ACSM training guidelines for cardiorespiratory training (The American College of Sports Medicine (ACSM) divides aerobic (i.e., cardiorespiratory) exercise types into three groups, based on the skill demands of the activity) a 15% increase in VO_{2max} is common. The majority of improvements to VO_{2max} will occur during the first 2 months of training. After this point VO_{2max} will continue to improve, but at a slower pace [3], [5], [13].

Since oxygen is ultimately consumed in the muscles during exercise, it follows that a volume of VO_{2max} , when measured, will vary in accordance with the specific form of exercise one is performing.

There is an inherent disparity in the VO_{2max} capabilities of men and women. Men have roughly 10% to 25% higher VO_{2max} capabilities than women, even when experimental adjustments are made to eliminate and/or minimize differences in total body mass, training level and so on. The available data suggest that the differences are biologically predetermined and largely due to size differences in contracting muscles [9]. The paper presents the VO_{2max} value dependences of time in men and women groups. For the analysis of women's and men's oxygen consumption changes a regression analysis of oxygen consumption by the time function was made. The correlation coefficient of men's data 0.815 shows a strong, linear, negative relationship between experimental data. For women group the calculated correlation coefficient 0.614 indicates a moderate, linear, negative relationship between test loading time and consumption of oxygen. The regression functions $f(y)$ and $g(y)$ explain that the amount of oxygen consumed by men during veloergometry in appropriate test conditions changes slowly and thus in the end of the test retain higher values. This indicates a greater ability for men muscles to absorb oxygen to generate energy for a six minute submaximal veloergometric loading test. These results are similar to those presented in literature [15]–[18]. In this study, during test pedaling time started to count as a volunteer heart rate reached 130 bpm. Therefore, the maximum amount of oxygen consumption (VO_{2max}) was reached already in the first minute. So men's oxygen consumption rate (VO_{2max}) is $43 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ as well as for women it is

51.2 ml·kg⁻¹·min⁻¹. This proved higher physical effort of men in this research having 16% higher VO_{2max} capabilities than women.

VO_{2max} is used to determine the fitness levels, not only in sportsmen, but also in patients with heart failure, and is therefore both a prognostic and diagnostic tool [11], [12], [15], [22]. A lot of clinicians and scientists use only aerobic parameters to assess overall physical form of a person. They use ergometer for workload fulfillments and monitors heart rates [11], [21]. However, a further analysis of physical activity in a single parameter is not enough. Integrated EMG signal (iEMG) is the rate that corresponds to the area under the curve, but it also represents the maximum muscle effort to do the work in appropriate loading conditions. The highest power output that can be maintained without an increase in the integrated electromyogram signal (iEMG) over time has been termed the electromyogram “fatigue threshold” EMG_{FT} [15]. It represents muscular activity during exercise, but EMG usually was measured only from one of the muscles, continually or partly, so it was very hard to find relation between aerobic parameters and muscular effort. Previous studies proposed that EMG_{FT} is more closely associated with the steady state of lactate metabolism in the active muscles than with ventilatory threshold [15]. However, the present study does not provide support for this hypothesis. The maximum studied muscles effort by a parameter iEMG showed the relation between oxygen consumption during exercise, but an increase or decrease of these parameter values depends on many factors, such as physiological function of the muscle and its activation order and range during work knowing the fact that single muscle activity depends on other muscles work at the same time. That is why the present study proposes to evaluate activity of a group of muscles involved in the exercise and to look at complex muscular effort or capability (iEMG_{max}) to do work in time. Overall response, expressed in percent of maximal voluntary contraction (% MVC), EMG in time (root mean square, RMS) and frequency (median power frequency MdPF) domain could show recruitment of appropriate type of motor units [18], which depend on fast (FR, 64 W min⁻¹) or slow ramp (SR, 8 W min⁻¹). Progressive decrease in MdPF was observed in FR and it remained relatively constant during SR suggesting that either there was no appreciable recruitment of less efficient type II muscle fibers, at least in addition to those recruited initially at the onset of exercise, or the decrease in MdPF associated with fatigue was offset by the addition a higher frequency of type II fibers to replace the fatigued motor units. Oxygen uptake during SR occurred in the

absence of coincident deviation in either the RMS or MdPF [18].

Analyzing the results of the investigations it was observed that the maximum values reached iEMG_{max} appeared before or VO₂ max limit. iEMG values in dependence on the oxygen consumption during exercise shows oxygen consumption of muscle activity periods of cycling. The maximum oxygen consumption is achieved in the middle or at the beginning of the work, i.e., about 3 minutes of work, while the maximum muscular effort to keep the load revealed several phases of work at the beginning and end of the cycle. On the other hand, muscular capacity depends on the size of the load, because the higher the load or load time, the greater the muscular effort visible. It can be said that the decrease in VO_{2max} is associated with muscular effort or iEMG increase, on the contrary, increased oxygen consumption results in lower muscle effort to do the work. So, VO₂ is not linearly proportional to the maximum muscle iEMG or ability to support a load that would provide the opportunity to predict the physical abilities.

5. Conclusions

The relation between aerobic parameters (VO_{2max}) and maximum muscle effort (iEMG) was found and shows the evolution of a person’s maximal effort iEMG_{max} in loading time *t* and oxygen consumption (VO₂) at the maximum exertion. Aerobic oxygen consumption in both groups is similar and varies depending on the parameters of the work, veloergometric loading, and heart rate. For men and women the maximum oxygen consumption is achieved in the middle or at the beginning of the work, i.e., about 3 minutes of work, while the maximum muscular effort to keep the load revealed several phases of work at the beginning and end of the cycle. On the other hand, muscular capacity depends on the size of the load, because the higher the load or load time, the greater the muscular effort is visible. The relation between VO_{2max} and iEMG parameters showed non-linear dependence. The maximal iEMG values were found only after VO_{2max} the highest results. The physical capability to work longer with decreased values of iEMG and VO_{2max} was found in the last measurements in both groups. The left leg muscle effort to maintain the maximum load was higher as compared with the right leg in both groups. Considering all the results, it could be said that VO_{2max} and iEMG parameters explore more information about

physical effort. So, not only aerobic parameters could be used for the precise prediction of physical development. The results proved the fact with if more effort used to do the work the physical fatigue in the end of exercises is greater. However, the present research has to be improved by greater amount of test individuals of different age and in different physical capability groups.

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