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Differences in the levels of physiological-biochemical responses during physical exercise involving the lower and upper extremities in judo competitors

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Summary

Introduction. In the available literature, the information about the differences in the level of physiological-biochemical responses on physical exercise performed using lower and upper limbs in judo competitors is rather sparse. Therefore, the basic goal of the study was to complete knowledge on the topic.

Material and methods. The sample comprised judo 12 competitors who were tested for changes in the level of biochemical indicators using a graded test for the upper and lower limbs.

Results. The mean age of the subjects was 20.8±1.56 years. Their body height and body mass were 177.8±6.31 cm and 70.9±6.21 kg respectively. The mean time of test exercise was 14.4±1.99 minutes for the upper limbs while the mean time of performing the test on the ergometer, requiring workout of the lower limbs was 16.08±2.56 min. The mean maximal minute oxygen uptake (vo2max) was x=2840±430 ml for upper limb workout and 3814±656 ml for lower limb workout. The threshold of aerobic transformations which was determined based on the analysis of respiratory gas kinetics was noted during the upper limb workout, on average during the 7.80±2.10 minute of the test while for the lower limb workout it was noted during the 8.83±2.17 minute.

Conclusions. During the test exercise performed with the upper limbs, significant differences were noted in VO_{2max} values as well as the occurrence of anaerobic transformation threshold compared with the changes in these indicators during the test performed with the lower limbs. The results of this study can be of great value from the applicative and cognitive point of view, which would be helpful in developing training programs. The results also indicate that a special caution should be exercised when determining training loads for the upper limbs, based on the tests performed with the lower limbs.

Introduction

Scientific discoveries, the development of research techniques as well as long term observations allowed selection and hierarchization of the groups of factors determining the level of physical capacity. The great success of the past years was the development of the methods of blood lactate concentration assay, reflecting the anaerobic metabolic processes that occur during intensive physical work. The unquestioned success of these years was the measurement of maximal oxygen uptake (VO_{2max}). This is an integrated indicator determining physical capacity. The amount of oxygen that can be consumed by the human body during maximal effort is an aggregate indicator of the oxygen supply function and oxygen consumption in the tissues. The respiratory system, the cardiovascular system, blood morphotic elements (red blood cells) with their main component – haemoglobin, are engaged in oxygen transport. Generally, it is accepted that the higher the competitor's VO_{2max} value is, the more they are capable of intensive and sustained exercise performance and the better they tolerate changes in systemic homeostasis. With time, it turned out that the factors determining the ability of oxygen consumption under extreme conditions include: age, gender and genetic predispositions. Especially high VO_{2max} levels are noted in individuals involved in typical endurance sports. Some authors, however, indicate that also in speed-strength disciplines including combat sports (Littre 1991, Franchini 2011) high values of maximal oxygen uptake are noted. Interestingly, it was found (Lech et al. 2007) that high VO_{2max} values corresponded with activity increase in judo competitors during the second part of the fight and overtime.

Various tests are applied to determine physical capacity. The devices most often used for this purpose include arm and leg cycle ergometers, a mechanical treadmill and a water treadmill. It is important to apply physical exercise similar in nature to movement structure used in a given sport discipline while using these devices. The main physical exercise engages upper or lower muscle groups and often requires participation of both (Bobbert 1960, Bergh et al. 1976, Davis et al. 1976, Nagle et al. 1984, Pococco 2012, 2013).

In literature describing physiological responses to physical exercise, the papers by Asmusen (1958), Åstrand (1961) and Pococco [2013] are of note. Based on their observations, the authors found that a typical workout requiring an isolate engagement of arms and legs or simultaneous activities of both upper and lower limbs evokes differentiated physiological responses of the body. Asmusen (1958) made an attempt to seek the factors responsible for limiting upper limb workouts in children, considering the factors connected with body constitution and the development of cardiovascular system capacity, which is lower in children due to their underdeveloped cardiovascular system. Åstrand (1968) in turn, measuring physiological indices during simple activities performed with arms and legs (in isolate body positions), found that the heart rate, systolic blood pressure and lung ventilation were higher during arm workout. Earlier information on the differences in circulatory system responses to exercise performed with the upper limbs, in comparison with the exercise performed with the lower limbs was provided by Collet and Liljestrand (cited after Kubica 1995). Pococco (2013) showed differences in the levels of responses to anaerobic upper and lower limb exercise, both in male and female judo competitors. Despite these interesting findings concerning the discussed physiological problem, before the seventies of the twentieth century there were not enough studies on the above mentioned differences in body responses to the activity of activated muscle groups. At the beginning of the eighties there was a breakthrough in the research on this issue. The studies indicated that training of the upper limbs results in favorable changes in the cardiovascular system, which may be important in competitions involving upper limb workout or in rehabilitation of patients with medullary paralysis, confined to their wheelchairs, amputees or patients with vascular conditions of the upper limbs (Wahren et al. 1971, Shaw et al. 1974, Fardy et al. 1977, Schwade et al. 1977, Pococco 2013). Training of the upper and lower limbs in competitive sports, such as canoeing, rowing or combat sports), the disciplines requiring high volume and high intensity athletic performance, results in maximal oxygen consumption during upper limb workout, similar to the values obtained during lower limb workout and may amount to 70-85% of these values. A similar phenomenon is observed in the case of the values corresponding to minute respiratory volume and heart rate which are usually lower during upper limb workout (Åstrand et al. 1986, Tesch 1984, Pałka 2013a). One should remember, however, that during upper limb workout with submaximal load or specific percentage of VO_{2max} the activation of the circulatory and respiratory systems may result in higher values than these obtained during leg workout (higher values of HR, ventilation or higher scores in Borg scale and higher values of systolic pressure), (Żuchowicz 1990, 1999). Conversely, in non-training individuals, maximal exercise of the upper limbs on an arm ergometer can result in: lower oxygen consumption, lower post-exercise blood lactate concentration, lower cardiac output and stroke volume or higher blood pressure as compared with the values obtained after maximal exercise during lower limb workout (Åstrand et al. 1961, Åstrand et al. 1965, Bevegard et al. 1966, Åstrand et al. 1968, Karlson et al. 1975, Bouchard et al. 1979, Nagle et al. 1984, Żuchowicz et al. 1990, 1999).

During submaximal upper limb exercise oxygen consumption is higher as compared with the corresponding lower limb exercise (Żuchowicz 1990). Energy expenditure during upper limb workout is significantly higher due to a higher vascular resistance while cardiac minute output does not significantly differ between the types of exercise reported in this paper (Åstrand et al.1965). Significantly bigger differences between body response to arm and leg workout can be observed in the respiratory system. It was shown that during the initial phase of upper limb workout, the increase in lung ventilation is bigger as compared with the ventilation stimulated by leg workout (Bergh et al. 1976, Żuchowicz 1990). It is of note that using the same relative loads results in compensation of the differences between exercises engaging different muscle masses. In such cases, the differences in arterial blood pressure, heart rate, catecholamine concentration, changes in plasma volume or subjective fatigue no longer exist. However, even with identical submaximal relative loads ($\%VO_{2max}$), activities of the upper limbs are associated with higher lung ventilation, higher respiratory rate and lower respiratory volume as compared with the values obtained during lower limb workout. This is probably due to a significant decrease in blood pH levels, which is the consequence of a higher lactate accumulation during leg workout. It is also documented that oxygen consumption during upper limb workout is lower than during lower limb workout (Stenberg et al. 1967, Eston et al. 1986). Moreover, it was found that oxygen content in arterial blood does not significantly differ between the two types of exercise reported in this paper, but the peripheral arteriovenous difference in oxygen content is significantly lower during lower limb workout, performed with the same load as that applied during lower limb workout (Tesch et al. 1984). In conclusion, the facts cited above indicate that there are three basic factors responsible for the differences in the level of physiological body responses to upper or lower limb exercise. These usually are: a small volume of the upper limb muscles restricting the blood flow in the lower limbs during exercise, a large mass of inactive muscles of the lower limbs, limiting venous return and decreasing stroke volume and a decreased oxygen extraction by upper limb muscles, indicating the domination of anaerobic metabolism leading to an increased accumulation of lactate during submaximal exercise performance, resulting in a delayed lactate elimination and the occurrence of anaerobic transformation threshold with a much lower oxygen uptake (Davis et al. 1976, Dolgener 1983, Żuchowicz et al. 1999).

Aims of the study

The arguments cited above indicate the still existing problem connected with the physiological mechanisms underlying the differences between upper and lower limb activity. Given this fact, the authors decided to analyze selected circulatory and respiratory indices during workout with progressively increased load until refusal or subjective fatigue is met.

Material and methods

Study program

The sample comprised 12 judo competitors, participating in regional and national competitions. Their physical activity was limited to participation in training sessions three times a week with the training unit lasting 120 minutes.

Before starting exercise tests, each participant was informed about the aim of the study and was allowed to withdraw from participation in the experiment at any stage.

During the first stage of observation, basic somatic indices were measured. These included BMI, body height (BH) and the thickness of skin fat folds. The measurements of BH and body mass enabled calculation of body surface and Quetelet II (BMI) index according to Dubois (Dubois 1916).

The thickness of skin fat folds was measured under the lower scapular angle with the fold held obliquely and on the rear surface of the loosely dropped arm with the skin fat fold held vertically. The measurement of the subcutaneous adipose tissue allowed calculation according to the formula proposed by Slaughter et al. (1986) of the lean body mass (LBM), fat mass (FM) and percentage of fat in comparison with the total mass (PF).

During the subsequent stage of the study exercise intensity was gradually increased with two types of load applied. The first one required involvement of the upper limbs while the second one activated the lower limbs.

The exercise was preceded by the measurements of resting circulatory-respiratory indices, the parameters of acid-base balance (pH, BE) and blood lactate (La) concentration. Blood samples were taken from the participants' ear lobes.

Exercise tests on the arm cycle ergometer (AA) and leg cycle ergometer (LL) began with a 2-minute long warm up with the 60 Watt load applied on the upper limbs and 110 Watt load applied on the lower limbs (Figure 1). Next, the load was increased every two minutes in 15 Watt increments for the upper limbs (arm test) and in Watt increments for the lower limbs (leg test). In both kinds of the applied load, exercise was continued to refusal. The frequency of rotations was dictated using a metronome and amounted to 60 rotations per minute. During this observation session, aimed at the assessment of aerobic capacity with different muscle groups engaged, the minute values were recorded from the first minute of test per-

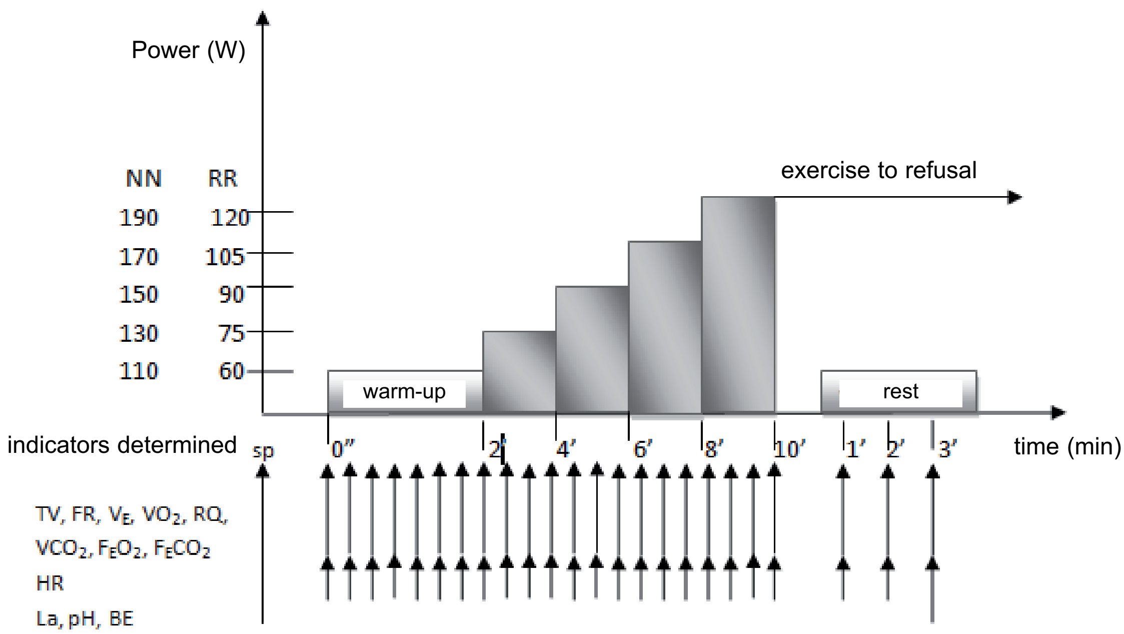

Figure 1. The graph of the graded test on the arm and leg cycle ergometer with the measurement points

formance until it was completed. These were: heart rate (HR), minute respiratory volume (VE), maximal oxygen uptake (VO_2) and carbon dioxide excretion in one minute (VCO_2). In order to determine the effect of the load applied on biochemical parameters, blood samples were taken from the participants' ear lobes during the third minute after completion of test exercise.

The analysis of the course of basic indices of respiratory transformation and additionally, the percentage of CO_2 content in the expired air (%$FECO_2$) were measured; the value is a respiratory equivalent for carbon dioxide ($VE \cdot VCO_2^{-1}$) and in doubtful cases, it is also an equivalent of the respiratory rate (RER). During subsequent minutes of the test "to refusal" the Threshold of Decompensated Metabolic Acidosis (TDMA) was determined for both types of exercise applied during the study.

The amount of load and the recorded at the same time level of circulatory-respiratory indices, above which a nonlinear increase of VE, VCO_2 and RER level was noted, were accepted as the physiological measure and the criteria for gas assay after determining TDMA and when the percentage of carbon dioxide content in the expired air reached its maximal level and the respiratory equivalent for CO_2 reached its minimal value (Reinhard et al. 1979, Kozłowski et al. 1983, Bhambhani et al. 1985, Chwlbińska-Moneta 1993).

Measurement techniques

Body height (BH) was measured in males using Martin antropometer (USA) with the accuracy 0.5cm while the body mass (BM) was measured using electronic F type scales (Sartorius 1505 – DZA, Germany) with the accuracy of 1 gram. BH and BM measurements were used to calculate Quetelet II (BMI) index. The thickness of skin fat folds was assessed using Harpenden caliper with the accuracy of 0.1 mm.

The measurements of basic parameters of the respiratory system (VE, VO_2,VCO_2,VE x VCO_2^{-1}) and the percentage of oxygen and carbon dioxide resilience in the expired air were measured using Medikro type 202 computer gas analyzer (Finland). Arterial blood pressure (BP) at the level of the brachial artery was measured in seated subjects using routinely the Korotkoff's method. Heart rate was recorded telemetrically every 15 seconds using Polar-Electro 610S- type Sport-Tester (Finland). The main part of the test was conducted on Monark 875 E ergometer for the lower limbs and 891 E ergometer for the upper limbs (Sweden). Lactate concentration was determined by means of the enzymatic method using BioMerieux test (France). Indices of acid-base balance (pH; BE) were determined using Rapid Lab 348 apparatus, Siemens (Germany).

Statistical methods

The obtained results were statistically analyzed by calculating the arithmetic mean (x), standard deviation (SD) and variability range (Ex).

Significance of the differences in the arithmetic means of the measured physiological-biochemical indices between the applied tests was calculated using student's-t test for dependent samples.

Significance level was set at 5% of confidence level with degrees of freedom equal to n-1 [Stanisz 2001].

Results

Morphological characteristics of the studied sample

It should be emphasized that although the analysis of somatic features of study participants is not the main goal of this study, it is obvious that the values corresponding to such features have a significant impact on functional indices, especially during workout of the activated muscle groups, differing in mass.

The values of the indices of somatic body constitution are presented in Table 1. The mean age of the participants was 20.8±1.56 years, which, when considering the low values of variation coefficients (SD) and variability range (Ex), indicates slight between-group differences. The length of training in the studied competitors was 8,36±1,5 years. Their body height and body mass were 177,8±6,31 cm and 70,9±6,21 kg respectively. The mean body surface which was calculated based on body height and body mass (BSA) values was x=1.80±0.21m^2 (Ex=1.61-1.99m^2). Different body height and body mass values affected variability range of body surface. The mean BMI value was 22.43±1.91.

After subtracting fat mass (x=8,1±2,66 kg) from the global body mass (x=70.9±6.21 kg), the mean value of lean body mass (LBM) was x=62.8±6,21 kg. The mean fat content in the total mass (PF) was x=11.4±2.7% .

Table 1. The values of body somatic constitution indices

Wskaźnik Index	BH (cm)	BM (kg)	PF (%)	LBM (kg)	FM (kg)	BSA (m^2)	BMI
$\bar{X}$ SD	177,8±6,31	70,9±6,21	11,4±2,7	62,8±6,21	8,1±2,66	1,8±0,21	22,43±1,91

Table 2. The values of the physiological indices recorded in the graded test

Wskaźnik Index	DE (min)	MWL (W)	VO_{2max}		
			$ml \cdot min^{-1}$	$ml \cdot min \cdot kg^{-1}$	$ml \cdot min \cdot LBM^{-1}$
AA	14,4±1,99	151±10,56	2840±430	40,1±5,95	45,28±6,61
LL	16,8±2,56	256±13,21	3814±656	53,88±7,36	60,92±8,27

The values of the studied indices determined during exercise of maximal intensity with upper and lower limb involvement

The mean duration of test exercise (DE) was 14.4±1.99 minutes for upper limb workout and 16.08±2.56 minutes on the ergometer requiring leg workout. Although these values are not comparable since the dynamics of load increase was different in each test applied in the study, the similar exercise duration confirms that selection of load in both types of tests and the accepted construction of exercise tests were adequate. Exercise intensity during the last minutes of arm and leg workout, expressed as the amount of load (mean workout load – MWL) significantly differed between the subjects (t°= 2.95; $p<0.001$). In the test involving upper limb workout, this parameter value was =151±10.56 Watt and in the test involving lower limb workout it was =256±13,21 Watt. The variability measures of the parameters under study, calculated for each of the two types of exercise, indicate rather significant differences in the values obtained from the same type of test and between the tests. Relative load values (load.$\cdot$kg^{-1}; load.$\cdot$ kg LBM^{-1}), were: 2.13±0.21 and 2.41±0.24 W$\cdot$kg^{-1} respectively for the test involving upper limb workout and 3.63±0.61 and 4.10±0.74 W$\cdot$kg^{-1} for the test involving lower limb workout. The absolute load corresponding to arm workout (x=151 Watt) constituted 59% of the lower limb workout (256 Watt). After considering the total and lean body mass, these relations were almost identical and amounted to 58.7%.

The level of circulatory – respiratory indices

Maximal oxygen consumption (VO_{2max}) which is the measure of aerobic capacity, reached the average level x=2840± 430 ml for upper limb workout and 3814±656 ml in the test involving lower limb workout. Similarly, as in the case of dosed load, the comparison between the absolute VO_{2max} values and the individual body mass values did not eliminate, but rather enhanced the differences in the results obtained from the two types of exercise – hence the relative mean VO_{2max} values amounted to 40.1±5,95 mlxkg^{-1} in the set of exercises activating the lower limbs and 53.88±7.36 mlxkg^{-1} when the lower limbs were engaged. The VO_{2max} value, converted into kg of lean body mass (LBM), reached the values of 45,28±6,61 ml and 60,92±8,27 ml$\cdot$ kg$\cdot$LBM^{-1} for upper and lower limb workout respectively.

The mean values reflecting the minute respiratory volume (VE) were: 108,1$\cdot$min^{-1} and x=127,8±11,21 L$\cdot$min^{-1} for the upper and lower limb workout respectively. The differences in all the indices reflecting respiratory transformation, noted in the tests involving a different group of muscles, were statistically significant at a high confidence level ($p<0.001$). Individual values reflecting oxygen uptake from the ventilated air (VE$\cdot$$VO_2^{-1}$) were differentiated in both applied types of tests and the differences between them were statistically significant ($p<0,005$). The obtained index value was 37.72 L$\cdot$L^{-1} for upper limb involvement and 33.981 L$\cdot$L^{-1} for lower limb involvement. The difference between the applied tests in the oxygen-pulse rate value which was 15.64 ml$\cdot$beats^{-1} for upper limb involvement and 20.2 ml$\cdot$beats^{-1} for lower limb involvement was also statistically significant ($p<0.001$). The mean values of the respiratory rate (RER) were 1.08±0.21 and x=1.120.22 for arm and leg workout respectively. The observed difference between the arithmetic means was statistically significant ($p< 0.005$). The maximal heart rate (HRmax) was x=182±7.89 beats.$\cdot$min^{-1} for the workout on the arm ergometer and x= 192±8.11 in the second type of exercise involving arm workout.

The range of changes in the acid-base balance and lactate concentration assessed after maximal exercise with arm and leg involvement

The resting level of blood pH (pH; H^+) was similar in both tests and its mean value amounted to x=7.38±0.97 (42 nmol$\cdot$ L^{-1}) units before the upper limb test and 7.39±1.01 units (40,7 nmol$\cdot$L^{-1}) immediately prior to the exercise activating the lower limbs. The maximal exercise during arm workout resulted in pH decrease to 7.24±0.91 (57.8 nmol$\cdot$L^{-1}) level and during the leg workout it decreased to x=7.21 (62,2 nmol$\cdot$L^{-1}). The differences noted between the resting and post-exercise values reflecting blood reaction (ΔpH; ΔH) were statistically significant.

Table 3. The values of physiological indices recorded during the graded test

Wskaźnik Index	RER	HRmax (sk$\cdot$min^{-1})	VE (L$\cdot$min^{-1})	VE$\cdot$$VO_2$	$VO_2\cdot HR^{-1}$
AA	1,08±0,21	182±7,89	108,1±11,21	37,7±3,74	15,64±,1,99
LL	1,12±0,22	192±8,11	127,8±13,33	33,98±3,01	20,2±2,25

Table 4. Changes in the biochemical parameters recorded in the graded test

Wskaźnik Index	La (mmol$\cdot$L^{-1})		pH (nmol$\cdot$L^{-1})		BE (mmol$\cdot$L^{-1})
	Przed before	Po after	Przed before	Po after	
AA	1,9±0,31	10,80±1,1	7,38±0,97	7,24±0,91	-11,30±2,88
LL	2,01±0,33	13,90±1,21	7,39±1,01	7,21±0,89	-17,20±3,91

The average post-exercise loss of blood buffer bases (BE) for the upper and lower limbs during the ergometer tests amounted to -11.30 mmol·L⁻ and 17.20 mmol·L^{-1} respectively and was statistically significant at t°=18.25; p<0.001. The mean resting value of blood lactate level (LA) was similar and fell within the limits of the physiological norm in both sets of exercises while lactate accumulation in the test involving lower limb workout was significantly higher (p<0.005), reaching the mean values of =13.90±1.21 mmol·L^{-1}, compared with the mean value obtained for arm workout which was x= 10.80±1.1mmol·L^{-1}. Generally, the disturbances of the acid-base balance and blood lactate concentration were always bigger during leg workout as compared with the values obtained for arm workout.

The values of selected mechanical and circulatory-respiratory indices recorded while the threshold of anaerobic transformations (TDMA) was reached

The threshold of anaerobic transformations (t_{TDMA}), determined on the basis of the analysis of respiratory gas kinetics was noted for arm workout, on average during the 7.80±2.10 minute of the test while in the case of leg workout it was 8.83±2.17 minute. The cited time values corresponded to the load (WL_{TDMA}) of x=96.3±15.11Watt in the first test involving arm workout 175 Watt in the second test. The relative values of this parameter converted into body mass unit were 1.36 and 2.49 Wat·kg^{-1} in relation to the total body mass and 1.54 and 2.82 Wat·kg^{-1} in relation to lean body mass. The directly proportional relationship with the load, exercise oxygen consumption on TDMA threshold (VO_{2TDMA}) was 1722±195ml and 2615±231ml for arm and leg workout respectively. After considering the body mass, the above mentioned values amounted to 24.39±5.21ml·kg^{-1} and 36.84±6.36ml·kg^{-1} for arm and leg workout respectively. After conversion into lean body mass units, the threshold values of oxygen uptake amounted to x=27.47±5.37ml·kg LBM^{-1} and 41.68±6.61ml·kg LBM^{-1} for the first (arm workout) and second (leg workout) type of tests. The consumption of oxygen amount, determined at the level of anaerobic threshold during arm workout, constituted approximately 66% of O_2 consumption with O_2 level determined during the ergometer test involving leg workout. The minute excretion of carbon dioxide during the test exercise involving leg workout was on average 810 ml lower than during the arm workout. During the exercise on the arm cycle ergometer, the value of minute respiratory volume amounted to 53.3±6.31 while for leg workout, this value amounted to x=66.1±7.28 l. The differences in all the so far analyzed post-exercise parameters turned out statistically significant at a high confidence level (p<0.001). The mean heart rate values noted at the moment of exceeding the Threshold of Decompensated Metabolic Acidosis (HR_{TDMA}) were x=148±6.55 beats·min^{-1} and x=159±7.01 beats·min^{-1} for arm and leg workout respectively. The differences in heart rate were statistically significant (p< 0.005). The oxygen uptake rate for the oxygen consumed from the ventilated air on TDMA threshold reached the values of 31.05±5.01 and 25.36±5.22 L·L^{-1} for the workout on the arm and leg ergometer respectively. Also the differences between the arithmetic means showed statistical significance at confidence level p<0.001. The amount of oxygen per one heartbeat or the so called oxygen-pulse rate, with threshold load amounted to 11,62 ml·$beat_{-1}$) for arm workout. This value was lower than that obtained for leg workout (16.53 ml O_2 per heartbeat).

The respiratory quotient on the anaerobic threshold amounted to x=0.98±0.19 and x=0.96±0.17 for arm workout and the second type of test. The application of a pair test for significance of the differences between the applied types of exercise turned out significant (p<0.001). The percentage values of selected indices, reflecting the use of maximal potential during exercise performed with the intensity corresponding to the threshold of anaerobic transformations, reached significantly different values with the graded load involving different groups of muscles.

The mean threshold load constituted 65.2% and x=70.20% of maximal load for arm and leg workout respectively. The oxygen uptake measured at that moment amounted to 61.80± 3.56% for arm workout and 68.40±4.01% for the active involvement of the lower limbs. Minute respiratory volume (VE_{TDMA}), as compared with the maximal values, was similar in the two types of tests and statistically insignificant (51.40% VE_{max} and 52.50% for arm and leg workout respectively). The percent-

Table 5. The values of physiological indices recorded on TDMA threshold

Wskaźnik index	t_{TDMA} (min)	HR_{TDMA} (sk·min^{-1})	WL_{TDMA} (W)	VO_{2TDMA}			VE_{TDMA} (l·min^{-1})
				(ml·min·kg^{-1})	(ml·min^{-1})	(ml·min·LBM^{-1})	
AA	7,80±2,10	148±6,55	96,3±15,11	24,39±5,21	1722±195	27,47±5,37	53,3±6,31
LL	8,83±2,17	159±7,01	8,83±5,21	36,84±6,36	2615±231	41,68±6,61	61,1±7,28

Table 6. The values of physiological indices recorded on TDMA threshold

Wskaźnik Index	RER	%HRmax	%VO_2max	VE·VO_2	VO_2·HR^{-1}
AA	0,98±0,19	61,80±3,56	81,80±9,01	31,05±4,06	11,62±1,91
LL	0,96±0,17	68,40±4,01	82,70±8,89	25,36±4,89	16,53±2,11

age threshold values of heart rate were similar and amounted to 81.80±9.01% HR max in test exercise involving arm workout and 82.70±8.89% HR max in test exercise involving leg workout.

Discussion

Generally, involvement in any motor activity is connected with the mobilization of systemic energy sources and switching of the organs and systems to exercise level, enabling effective performance of physical work through their synchronized activities. The so far reported abundant data obtained from the papers presented by many researchers indicate that metabolic and circulatory-respiratory transformations depend on the type, intensity and duration of the activity performed (Lech 2007, 2010, Pałka 2011, 2013, Pocecco 2013). The size of muscle groups engaged in the activity performed is equally important. In sports, assessment of adaptive changes determined during extreme exercise performance with gradually increasing intensity is essential. Still, before the beginning the seventies of the twentieth century, the maximal minute oxygen uptake (VO_{2max}) was regarded as the determinant of aerobic capacity. Its values accurately reflected the degree of changes in systemic homeostasis. The participants of this study underwent a progressive exercise test during which numerous of physiological-biochemical indices were recorded. The applied tests comprised two types of exercise involving upper and lower limb workout respectively.

Minute oxygen uptake, recorded during the final minutes on the leg cycle ergometer test reached a global mean value of 3814 $ml \cdot min^{-1}$ which, converted into body mass units corresponded to 53.88 $ml \cdot kg \cdot min^{-1}$. This value was significantly higher than that characterizing the studied sample during the alternatively performed exercise with upper limb involvement. The VO_{2max} in the test involving arm workout constituted only 74.4% of the value corresponding to the workout requiring active engagement of the lower limbs. The results noted and reported by Pałka (2013a) are similar to these obtained by Bobbert (1960), Åstrand et al. (1961, 1965), Bergh et al. (1976), and Bouchard et al. (1979), Eston et al. (1986) and Żuchowicz et al. (1990, 1999) in a somehow different sample. The different body reactivity to exercise requiring involvement of muscle groups having different mass, noted by many researchers (Åstrand 1968, Żuchowicz 1990, 1999, Pałka 2013a, Pocecco 2012, 2013) was also confirmed in this study. The dependence between the range of response from activated muscle parts comprised, inter alia, such parameters as: maximal heart rate (HRmax), minute respiratory volume (VE), oxygen consumption coefficient ($VE \cdot VO_2^{-1}$), oxygen-pulse rate ($VO_2 \cdot HR^{-1}$) as well as blood reaction (pH), loss of buffer bases (BE) and lactate concentration (LA). The difference between such values as eg. HRmax in comparable versions of tests amounted to 10 beats. This value is in conformity with those observed by Ånstrad et al. (1965, 1968, 1986), Fardy et al. (1977), Shaw et al. (1974), Stenberg et al. (1967), Żuchowicz et al. (1990, 1999), Pałka (2013a) and Pocecco (2013). Characteristics of most of the body responses to the preset maximal exercise with the involvement of muscle groups (test involving engagement of LL and AA) reveals that the range and level of the changes noted in the test involving lower muscle parts workout was each time more substantial. This finding is confirmed by the initial hypothesis. The phenomenon of metabolic thresholds, described almost 30 years ago by Wasserman and McIlroy (1964), initiated numerous studies on the structure of physical capacity. The fact that maximal minute oxygen uptake is strongly genetically determined and properly selected training components allow its increase by 20-25% of baseline values is essential. Determining the thresholds, in turn, enables an increase of exercise capacity – with a stabilized VO_2 max value – even by 40% of their initial level (Żuchowicz 1999). In the light of this information, many papers were written, proposing the applied procedure and the technique of threshold value assessment. Typically, there were relatively few reports on the differences in threshold formation during workout involving different muscle masses. Anaerobic threshold in this study was determined using a noninvasive method based on the analysis of respiratory gas kinetics and routine application of physiological criteria. The amount of load applied when anaerobic threshold (TDMA) is exceeded during arm workout, amounting on average to 96,3 Watt, constituted 55% of the value noted in the test with lower limb involvement. The mean value of threshold oxygen uptake during arm workout was 1722 $ml \cdot min^{-1}$. This value corresponded to 65% of O_2 used that time during workout on the leg cycle ergometer. The above values are almost identical as the results obtained by Davis et al. (1976), Dolgener et al. (1983) and Pałka (2013). At the moment of reaching TDMA threshold, the minute heart rate during arm workout was – analogically – as in the case of exercise of maximal intensity – lower by o 10 heartbeats as compared with the results obtained from the alternative test involving leg workout. The percentage of threshold heart rates obtained during both applied test series compared in this study, after being compared with the maximal pulse rate values were similar (81.80% for arm workout and 82.70% HRmax for leg workout).

In conclusion, it turned out that many circulatory and respiratory indices, determined during progressive exercise and on the anaerobic threshold show differences depending on the mass of the activated muscles.

Conclusions

1. Maximal oxygen uptake (VO_{2max}), determined in the graded test to refusal, is significantly higher during leg workout than during arm workout ($p<0.001$). The mean VO_{2max} value for arm workout constitutes 73.55% of the values determined in the test with lower limb involvement.
2. Maximal heart rate level (HRmax) and the threshold is on average lower by 10 $beats \cdot min^{-1}$ than during upper limb exercise.
3. The comparative analysis of the post-exercise (maximal) level of base balance parameters (pH, BE) and lactate

concentration (La), indicates a significantly wider range of changes during lower limb exercise.
4. The Threshold of Decompensated Metabolic Acidosis (TDMA), determined during upper limb exercise, occurs with lower absolute loads than these applied during lower limb workout.
5. The results of the comparison of responses to exercise, noted during upper and lower limb workout indicates high specificity of these responses.
6. Caution should be exercised when determining the load to be applied on the upper limbs based on the lower limb test exercise.

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