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Physiological aspects of post-training adaptation in martial arts

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Abstract

Background and Study Aim. Dependent on the character and intensity, sports training results in specific adaptive changes in the organism that can occur at different pace. In order to study the post-training adaptation of the organism, a group of martial arts athletes and a group of untrained students were tested. The aim of the study was morphofunctional characteristic of the person practicing martial arts and untrained youths.

Material and Methods. 8 Brazilian jiu jitsu athletes, 4 taekwondo athletes (SG) and 10 students (CG) performed an anaerobic Wingate test (WT) and then a cycle ergometer aerobic test (ET) during which the circulatory and pulmonary variables were recorded.

Results. The study has shown that the SG group in comparison to the CG group achieved higher anaerobic work (Wt) and average power during WT, whereas during ET they achieved higher values of power at anaerobic threshold (APAT), higher values of aerobic power at maximal load (APML), with a simultaneous higher energy expenditure (EE) and significantly higher values of VO_2max, maximum pulmonary ventilation (VE) and oxygen debt (OD), without the occurrence of other significant changes in the pulmonary and circulatory systems.

Conclusions. The obtained results suggest that the applied training loads lead to gradual adaptive changes in the organism that started with the increase of aerobic and anaerobic power, and with initial increase in exercise metabolism.

Key words: Brazilian jiu jitsu • taekwondo • aerobic power • anaerobic power • training adaptation

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Introduction

Martial arts represent an individual form of physical activity where taekwondo (TKD) and Brazilian jiu jitsu (BJJ) may be included among many other styles. The functional profile of TKD athletes that can be described by physiological changes taking place during training, simulated and real competition include: heart rate (HR) during simulated combat that ranged from 148±2 bpm [1] to 197±2 bmp [2], blood lactate concentration after combat simulation ranged from 2.9±2.1 mmol x L^{-1} [1] to 10.2±1.2 mmol x L^{-1} [2], whereas during the real competition the concentration ranged from 7.0±2.6 mmol x L^{-1} [3] to 11.9±2.1 mmol x L^{-1} [4]. On the basis of this data Campos et al. [5] suggest, that TKD is a sport that is largely based on the development of anaerobic capacity, because during the competition 2-3 rounds lasting 2 minutes each are played and during that time the athlete performs as fast as possible mostly punches and kicks [6].

BJJ is a martial art in which the goal is to project or take your opponent down and continue fight in this position. This form of combat is similar to the kind of fight performed in judo, where the round lasts for 5 minutes, mainly in upright position. BJJ is a form of combat that is performed mainly in recumbency, during which different techniques are used to affect the opponent. Once on the ground, the athletes must seek to control their adversaries using different techniques, including immobilizations, chokes and joint locks. During almost the entire combat that lasts for 5-10 minutes the BJJ athletes remain in direct contact with the opponent, maintaining a firm grip and trying to engage in active combat [7]. As a consequence of participation in competitive or training activities adaptive changes occur, which lead in BJJ and judo to the enhancement of the aerobic capacity, strength and physical endurance of the athletes [8, 9]. The maximum oxygen consumption (VO_2max) in judo reaches 50-60 ml×kg^1× min^{-1} [10] and this value is higher than the value reached in TKD [11]. It is only during short periods of time that determine the score of the combat, where explosive muscle power is developed [12].

The physical loads during training and competition in both TKD and BJJ modify the body composition in a similar fashion [13]. Comparison study of TKD and judo athletes performed by Tabben et al. [11] has shown that the TKD athletes achieved better results in speed tests, similar results in the developed power of legs and significantly lower results in the ranges of VO_2max compared to the judo athletes. This kind of post-training adaptation is similar to the changes that occur during endurance training and this adaptation should lead to better adaptive changes in the circulatory and pulmonary systems of the BJJ athletes in comparison to the TKD athletes, where these changes are visible to a lesser extent [14].

Taking into consideration the difference in adaptation of TKD and BJJ athletes, it was decided to join these athletes into one group (SG) in this paper and present their post-training changes compared to a group of untrained males (CG). The aim of the study was morphofunctional characteristic of the person practicing martial arts and untrained youths.

Material and methods

The study was approved by the Bioethics Research Committee of Jan Dlugosz University in Czestochowa, Poland.

Subjects

Twelve martial arts athletes (SG) (4 TKD athletes and 8 BJJ athletes) and ten untrained students (CG) with comparable age were studied. The martial arts athletes had an average training experience of 3.65±2.44 years and the frequency of training sessions was 3-5 times per week each of 1.5 h duration.

Procedures and calculations

The study began with the recording of age, body height (BH), and other somatic variables, i.e. body mass (BM), body fat (BF), total content of water (TBW), fat-free mass (FFM), and body mass index (BMI), which was obtained by using a body composition analyzer, the Tanita BS 418 - MA. In the next stage of the research, an anaerobic Wingate test (WT) was performed using legs. During the test the following parameters were obtained: total work performed during 30s (Wt), maximal power (Pmax), mean power (Pmean), minimal power (Pmin), total power slope (Ts) and rate of fatigue (Rf). After 4 hours of rest and 10 minutes in a sitting position, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured on the arm. Heart rate (HR) was also measured in rest position (R). Based on these values the mean arterial pressure (MAP), pulse pressure (PP) and the rate pressure product of systolic pressure x heart rate (RPP=SPB × HR ×1000^{-1}) were calculated. Then while a face mask was tightly secured in place and connected with quick breath analyzer (Ergo Card), the following pulmonary variables were recorded: maximum pulmonary ventilation per minute (VE), oxygen consumption per minute (VO_2), carbon dioxide output per minute (VCO_2), respiratory exchange ratio (RER), cardiac output (CO). Based on these values, the ventilatory equivalent for oxygen (EQO_2), the ventilatory equivalent for carbon dioxide ($EQCO_2$), the factor of oxygen consumption and heart rate ($VO_2 \times HR^{-1}$) and stroke volume (SV) were calculated. Cardiac output (CO) was calculated by Ergo Card from the Fick formula, based on a non-invasive method for determining the size of the absorbed oxygen by the body [15].

Afterwards the participants have performed a cycle ergometer aerobic test (ET), which consisted of pedaling at a rate of 60 rpm with an initial load of 60W. Thereafter every 3 minutes the load has been increased by 30W, until the individual maximum load was reached (ML). At each load all the previously mentioned physiological parameters were recorded and calculations were performed and at AT and ML aerobic power (AP) was recorded. Using the changes of VE during test, the anaerobic threshold (AT) was calculated by the method proposed by Beaver et al.[16] and expressed it in watts [W]. Energy expenditure per minute (EE) during ET was calculated according to the modified Weir equation [17]: EE = (3.94 x VO_2) + (1.1 x VCO_2); where EE is energy expenditure (kcal/min), VO_2 is the volume of the oxygen uptake (l/min), VCO_2 (l/min) is the volume of carbon dioxide excretion. In the statistical analysis, apart from the R values, only the values obtained at AT and during the maximum individual load (ML) were taken into consideration. After the test was terminated, the oxygen debt (OD) was measured during a period of 5 minutes.

Statistical analysis

Data is presented as the mean ± standard deviation for each variable. “t” Student test was applied to determine the statistical differences of the intra-group and the two-factor analysis of variance was used to simultaneously determine the inter and intra-group differences of the applied variables (SPSS software, version Statistics 20). The level of significance was set at 0.05.

Results

There was no difference in the age and somatic parameters of the both groups (Table 1).

The study of the anaerobic power performed with WT has shown that the trained athletes reached higher values in the ranges of: Wt and Pmean (W) ($p<0.01$) as well as Pmean ($W \times kg^{-1}$), ($p<0.001$) in comparison to the CG (Table 2).

Table 1. Somatic characteristic of subjects

Variables	Groups	X	SD	T	p<
Age [years]	SG	24.08	4.72	1.973	0.071
	CG	21.30	1.16		
Body height [cm]	SG	173.59	7.66	–0.761	0.456
	CG	175.72	4.62		
Body mass [kg]	SG	72.87	8.75	0.759	0.457
	CG	69.83	10.09		
BMI [$kg \times m^{-2}$]	SG	24.18	2.56	1.326	0.200
	CG	22.60	3.04		
BF [%]	SG	15.15	3.80	0.569	0.576
	CG	14.05	5.25		
BF [kg]	SG	11.26	3.82	0.521	0.608
	CG	10.27	5.14		
FFM [%]	SG	84.82	3.82	–0.571	0.575
	CG	85.93	5.24		
FFM [kg]	SG	61.61	5.90	0.846	0.408
	CG	59.56	5.33		
TBW [%]	SG	62.08	2.80	–0.578	0.570
	CG	62.90	3.82		
TBW [kg]	SG	45.09	4.33	0.840	0.411
	CG	43.60	3.92		

Table 2. Results of anaerobic power reached during Wingate test

Variables	Groups	x	SD	t	p<
Wt [kJ×30sec^{-1}]	SG	16.95	2.53	2.973	**0.008**
	CG	13.99	2.05		
Pmax [W]	SG	930.22	166.89	1.599	0.125
	CG	160.76	319.49		
Pmax [W×kg^{-1}]	SG	12.72	1.40	0.836	0.413
	CG	12.07	2.21		
Pmean[W]	SG	569.36	85.70	2.945	**0.008**
	CG	470.27	68.91		
Pmean [W×kg^{-1}]	SG	7.79	0.46	3.687	**0.001**
	CG	6.77	0.82		
Pmin[W]	SG	368.77	61.09	1.892	0.073
	CG	325.78	41.20		
Ts [W×s^{-1}]	SG	19.54	8.21	0.188	0.853
	CG	18.94	6.33		
Rf [%]	SG	55.26	18.43	–0.785	0.442
	CG	60.14	7.34		

APAT in both groups were significantly lower than APML. The subjects from SG reached higher values of APAT ($p<0.01$) and APML ($p<0.05$) in comparison with the subjects from CG (Table 3). During ET VE was significantly higher ($p<0.05$) in SG than in CG both at AT and ML. The parameter VO_2 ($l \times min^{-1}$) was also significantly higher in SG in comparison to CG at AT and ML ($p<0.01$) and the same difference was observed in EE only at ML (Table 3).

The range of differences of each physiological variable measured at R, AT and ML was lowest at R for both studied groups, significantly higher at AT and the highest at ML. The statistically significant differences ($p<0.001$) between R, AT and ML were found in the following parameters: VE, VO_2 ($l \times min^{-1}$), VCO_2, HR, VO_2 ($ml \times min^{-1} \times kg^{-1}$), EE and CO (Table 3 and 4). SV in both groups differed between R and AT as well as R and ML ($p<0.001$). SBP, MAP, PP and RPP were lower at R compared to values obtained at AT and ML in both groups ($p<0.001$) and in CG at AT lower values of SBP ($p<0.05$), PP ($p<0.05$) and RPP ($p<0.001$) were observed with relation to values obtained at ML. In SG at AT, MAP and RPP, were significantly lower ($p<0.05$; $p<0.01$) than at ML. However TPR was significantly higher at R than at AT and ML in both studied groups ($p<0.001$), at the same time it was also lower at ML than at AT in SG (Table 3).

The changes in the RER coefficient (Table 4) showed significant differences in SG between R and AT as well as at R and ML ($p<0.01$), and additionally between R and AT, R and ML, AT and ML in CG ($p<0.001$). EQO_2 was higher at ML than at AT in SG group, whereas in CG group significantly lower values of this variable were observed at AT in comparison to the values at R and ML ($p<0.001$). Also $EQCO_2$ in SG was significantly lower at AT with regard to R and ML, whilst in CG the differences at R, AT and ML were shown to be statistically significant. The significant differences were found in case of the $VO_2 \times HR^{-1}$ coefficient; they were present in the comparison of R and AT as well as R and ML ($p<0.001$) and at AT and ML ($p<0.01$) in both groups. SaO_2 was higher in SG at R conditions in comparison to AT and ML ($p<0.001$) and in CG it was also higher at R than at ML ($p<0.01$).

It was also observed that the value of the oxygen debt recorded in the 5 minute post-exercise recovery, was significantly higher ($p<0.05$) in SG (4.68 ± 1.02 l × 5min^{-1}) than in CG (3.75 ± 0.86 l × 5min^{-1}).

Discussion

The studied athletes in SG were characterized by higher values of Wt performed during the 30s WT and higher Pmean (expressed in W and W×kg^{-1}) compared to CG. The increase of anaerobic power of the legs after TKD training sessions was confirmed by Bridge et al. [18] and Moreira et al. [19]. In BJJ an increased explosive power of legs muscles is also required [8, 12]. This motoric conditioning in BJJ is formed with the simultaneous development of strength endurance

Table 3. Variables characteristic of cardiovascular function and applied workloads

Variables	Groups	R		AT		ML		Group		Intensity of exercise		Interaction (group vs intensity)	
		x	SD	x	SD	x	SD	F	p<	F	p<	F	p<
HR [bpm]	SG	80.10^{aaa}	14.75	158.80^{ccc}	11.52	180.70^{bbb}	6.55	2.829	0.127	692.766	**0.001**	1.377	0.306
	CG	80.30^{ddd}	6.11	169.00^{fff}	11.71	188.20^{eee}	7.24						
CO [l×min^{-1}]	SG	5.00^{aaa}	1.15	17.90^{ccc}	2.38	19.90^{bbb}	2.02	0.001	1.000	894.702	**0.001**	0.390	0.689
	CG	5.40^{ddd}	0.70	17.80^{fff}	1.62	19.60^{eee}	1.71						
SV [ml]	SG	68.00^{aaa}	21.85	113.50	14.37	110.00^{bbb}	12.86	0.830	0.386	384.360	**0.001**	0.651	0.547
	CG	68.60^{ddd}	12.01	105.10	9.21	104.36^{eee}	10.07						
SaO_2 [%]	SG	96.80^{aaa}	0.92	92.70	0.95	93.10^{bbb}	1.10	0.175	0.686	71.355	**0.001**	1.667	0.248
	CG	96.00	2.71	93.40	2.76	92.30^{ee}	2.26						
SBP [mmHg]	SG	124.50^{aaa}	13.01	185.50	7.24	195.00^{bbb}	17.79	0.148	0.710	81.808	**0.001**	0.074	0.929
	CG	128.00^{ddd}	8.56	186.50^{f}	22.37	196.50^{eee}	21.48						
DBP [mmHg]	SG	80.50	4.97	82.50	4.25	84.00	4.59	0.022	0.885	5.456	**0.032**	0.655	0.545
	CG	79.50	3.69	83.50	4.74	83.50	4.74						
MAP [mmHg]	SG	95.17^{aaa}	6.21	116.83^{c}	3.46	121.00^{bbb}	6.67	0.074	0.792	58.356	**0.001**	0.167	0.849
	CG	95.67^{ddd}	3.35	117.83	9.03	121.17^{eee}	8.05						
PP [mmHg]	SG	44.00^{aaa}	12.43	103.00	8.88	111.00^{bbb}	18.38	0.184	0.678	95.054	**0.001**	0.302	0.747
	CG	48.50^{ddd}	10.01	103.00^{f}	21.24	113.00^{eee}	21.63						
RPP [mmHg×min^{-1}]	SG	10.08^{aaa}	2.63	29.44^{cc}	2.23	35.22^{bbb}	3.34	1.260	0.291	242.372	**0.001**	0.735	0.509
	CG	10.27^{ddd}	0.99	31.64^{fff}	5.29	37.05^{eee}	4.98						
TPR [mmHg×L^{-1}×min^{-1}]	SG	19.32^{aaa}	4.08	6.63^{cc}	0.90	6.14^{bbb}	0.67	0.286	0.606	279.816	**0.001**	0.500	0.624
	CG	18.01^{ddd}	2.66	6.64	0.49	6.42^{eee}	0.99						
AP [W]	SG			186.00^{ccc,hh}	23.66	240.00^{i}	28.28	17.190	**0.002**	245.000	**0.001**	0.060	0.811
	CG			159.00^{fff}	20.25	210.00	20.00						

^{a}-difference between R and AT in SG; ^{b}-difference between R and ML in SG; ^{c}-difference between AT and ML in SG; ^{d}-difference between R and AT in CG; ^{e}-difference between R and ML in CG; ^{f}-difference between AT and ML in CG; ^{h}-difference between SG and CG at AT; ^{i}-difference between SG and CG at ML; $^{a\,a\,a,\ bbb,\ ccc,\ ddd,\ eee,\ fff}$ – $p < 0.001$. $^{cc,\ hh,\ ee,\ hh,}$– $p < 0.01$. $^{,c,\ ,f,\ i}$– $p < 0.05$;

[8]. The development explosive power ability reached only average level because it requires simultaneous enhancement of an aerobic power [12]. It has been suggested that in BJJ an elevated level of explosive power of arms is also required and it should also be characterized by an enhanced hand grip strength. This would make possible to maintain constant level of strength for an extended period of time, so that it is viable to overcome the resistances of the opponent [20]. However the development of the explosive power and strength of the arms in BJJ must be treated with caution because the values reached in this case are only moderately elevated in comparison to other sport disciplines or compared to untrained people [21]. The combined adaptable changes in TKD and BJJ were the reason of the higher value of anaerobic power in SG than in CG.

It was also shown that in SG significantly higher values of aerobic power reached at AT and ML during ET than in CG. The more significant development of aerobic power in SG is confirmed by a higher absolute value of VO_2max ($p<0.001$), higher VO_2 at AT ($p<0.01$), higher VE reached at AT as well as at ML ($p<0.05$) in comparison to CG. Although in the presented results the reached VO_2max values in SG were higher than in CG, they belong to the lower ranges in relation to trained individuals. In the research Tabben et al. [11] highly trained judo athletes reached high values of VO_2max = 60.6 ml× kg^{-1} ×min^{-1} and for highly trained TKD athletes these values were significantly lower and reached the level of 57.8 ml× kg^{-1} ×min^{-1}. In our study the relative values of VO_2max did not differ between both groups and were significantly lower than those determined by Tabben et al.

Table 4. Variables characteristic of respiratory function and metabolism

Variables	Groups	R		AT		ML		Group		Intensity of exercise		Interaction (group vs intensity)	
		x	SD	x	SD	x	SD	F	P<	F	P<	F	P<
VE [l×min⁻¹]	SG	10.61[aaa.]	3.19	68.81[ccc.h]	17.62	122.08[bbb.i]	28.86	9.323	**0.014**	153.742	**0.001**	7.162	**0.016**
	CG	10.70[ddd]	1.64	55.77[fff]	9.06	96.70[eee]	13.34						
VO_2 [l×min⁻¹]	SG	0.36[aaa]	0.09	2.62[ccc.hh]	0.54	3.35[bbb.ii]	0.34	8.978	**0.015**	512.770	**0.001**	8.121	**0.012**
	CG	0.38[ddd]	0.05	2.39[fff]	0.37	3.00[eee]	0.39						
VO_2 [ml×min⁻¹×kg⁻¹]	SG	5.10[aaa]	0.99	36.90[ccc]	6.30	47.40[bbb]	3.66	2.228	0.170	1210.326	**0.001**	2.462	0.147
	CG	5.40[ddd]	1.17	34.60[fff]	6.20	43.40[eee]	5.62						
VCO_2 [l×min⁻¹]	SG	0.31[aaa]	0.08	2.58[ccc]	0.41	3.58[bbb]	0.40	3.701	0.087	578.065	**0.001**	1.745	0.235
	CG	0.32[ddd]	0.05	2.36[fff]	0.38	3.35[eee]	0.44						
RER	SG	0.85[aa]	0.08	0.99	0.06	1.08[bb]	0.15	0.104	0.755	49.885	**0.001**	1.023	0.402
	CG	0.84[ddd]	0.09	0.99[fff]	0.03	1.12[eee]	0.09						
EQO_2	SG	29.48	4.64	26.08[ccc]	1.56	36.08	6.19	0.286	0.606	108.066	**0.001**	15.296	**0.002**
	CG	33.70[ddd]	1.36	23.35[fff]	0.86	32.55	5.05						
$EQCO_2$	SG	34.67[aaa]	4.11	26.37[c]	3.02	34.57	10.21	3.647	0.088	160.329	**0.001**	0.972	0.419
	CG	33.70[ddd]	1.36	23.66[fff]	0.65	28.96[ee]	2.88						
VO_2×HR⁻¹ [ml×beat⁻¹]	SG	4.67[aaa]	1.58	16.44[cc]	3.04	18.59[bbb]	2.08	9.991	0.012	355.683	**0.001**	3.467	0.082
	CG	4.72[ddd]	0.90	14.11[ff]	1.80	15.87[eee]	2.04						
SaO_2 [%]	SG	96.80[aaa]	0.92	92.70[cc]	0.95	93.10[bbb]	1.10	0,175	0.686	71.355	**0.001**	1.667	0.248
	CG	96.00	2.71	93.40	2.76	92.30[ee]	2.26						
EE [kcal×min⁻¹]	SG	1.75[aaa]	0.44	13.15[ccc]	2.55	17.15[bbb, ii]	1.45	9.883	**0.012**	616.399	**0.001**	4.793	**0.043**
	CG	1.83[ddd]	0.24	12.00[fff]	1.87	15.47[eee]	1.99						

[a]-difference between R and AT in SG; [b]-difference between R and ML in SG; [c]-difference between AT and ML in SG;[d]-difference between R and AT in CG; [e]-difference between R and ML in CG; [f]-difference between AT and ML in CG; [h]-difference between SG and CG at AT; [i]-difference between SG and CG at ML; [a a a, bbb, ccc, ddd, eee, fff] – $p < 0.001$. [aa, bb, cc, ee, ff, hh ,ii,] – $p < 0.01$. [.c, i] – $p < 0.05$;

[11]. That is why the aerobic capacity of the athletes from SG must be considered as low.

Taking into account the fact that the TKD training leads to insignificant increase in VO_2max while BJJ training has the stronger influence; this paper shows a significant increase of the absolute value of this variable, whereas relation variable (to body mass) does not show any difference between both groups. Despite the average increase of VO_2max, the increase of aerobic power reached at AT and at ML in SG was more pronounced, which suggests that in the studied martial arts group the increasing rate of both variables is different. This can be a result of a definite improvement of the aerobic and anaerobic metabolism and their mutual interactions in trained individuals [9]. The credibility of this hypothesis is reinforced by the fact that a higher anaerobic power was reached in SG in relation to CG. Such discrepancy of reaching higher values of aerobic and anaerobic power, with a simultaneous limited rise of VO_2max, is also supported by the observation that during training an increase of the exercise capacity precedes other functional changes in the organism [22]. Sale [23] had shown earlier that during the first stage of strength and power development training, nervous improvement is more pronounced than metabolic effects. The necessity of obtaining high values of VO_2max in judo athletes is also negated by Franchini et al. [9]. On the other hand it has been shown that individuals with higher VO_2max are capable to resynthesize faster phosphocreatine resources [24], remove faster lactates and they maintain appropriate pH level during 5 minutes of combat [25].

The EE per minute reached during ET was higher in SG only at ML compared to CG ($p<0.01$), which should be linked with the higher power level at maximum loads in the first group. The reached values of EE in both groups was very high already at AT and at ML because it exceeded 15 kcal × min^{-1}. Such values can be seen only during exertions in extreme sports or extremely intensive professional work [26]. In the presented study only the “global” EE was calculated during ET, without specifying the energetic components of the expended energy. Campos et al. [5] described that during a 2 minute round of simulated combat in TKD 66±6%, 30±6%, 4±2% of the energy is generated by the aerobic, non-lactate anaerobic and lactate anaerobic system, respectively. Also in Matsushigue et al. study [27] point out the significant importance of anaerobic, non-lactate metabolism to safeguard energy levels during TKD combat (and due to this fact, the importance of a diet high in carbohydrates). In the presented paper the energetic components of EE were not determined, however the OD was measured and it corresponds in a stated degree to anaerobic potential of the organism [28]. The OD expressed in l × $5min^{-1}$ was higher in the SG than in the CG, which confirms differences observed between both groups in the range of anaerobic power.

In the present study training did not lead to any somatic differences between SG and CG**,** despite the adaptive changes in the capacity of physical exertion. In our opinion this is either an effect of too short period of training (or/and its low intensity) experience of the studied athletes (3.65 ± 2.44 years) or a specificity of somatic adaptation to applied workloads in martial arts. The later assumption has been confirmed by Diaz-Lara et al. [29], who did not record any changes in fat content in experienced (9.5±4.6 years of training), and much less experienced (3.0±1.1 years of training) BJJ athletes. It has been observed in our study that the body fat content (measured also using the bioelectrical impedance method) in both groups was similar and ranged averagely between 14 and 15 %, but these values were significantly higher than presented by Diaz-Lara et al. [29] in BJJ group. To complement the above mentioned arguments, it is important to underline, that Moreira et al. [19] has listed low body mass, low body fat content, high relative non-fat body mass as predictive factors in development sports level in TKD.

Many of the variables presented in Table 3 and Table 4 that characterize the functioning of the circulatory and pulmonary systems were similar in both groups and did not differ statistically between them. Some of them (HR, SV, EQO_2, $EQCO_2$, VO2×HR^{-1}, RPP) have shown only a tendency to a post-training increase [30-34]. Such changes suggest that: 1) in martial arts only a small enhancement of circulatory and pulmonary functions can be observed, 2) the training loads either were too low (may be period of training was too short) and did not lead to specific adaptive changes, typical for trained individuals or 3) applied workloads were optimal and did not lead to the improvement of these systems but also did not lead to their overtrained failure. Only intergroup differences were registered in the range of the circulatory and pulmonary variables between R, AT and ML, which is well documented in literature and does not shed any new light on the research aspects of the presented paper.

Conclusion

In conclusion, it has to be stated, that the applied martial arts training caused an increase in aerobic and anaerobic power, combined with the occurrence of higher OD. In consequence of these changes, an average increase of VO_2 occurred at different applied loads, without the incidence of somatic, circulatory and pulmonary changes. The range of these changes seems to be dictated by the specificity of post training adaptation in TKD and BJJ.

References

1. Butios S, Tasika N. Changes in heart rate and blood lactate concentration as intensity parameters during simulated taekwondo competition. J Sports Med Phys Fit 2007; 47: 179-185
2. Bouhlel E, Jounini A, Gmada N, Nefzi A et al. Heart rate and blood lactate responses during taekwondo training and competition. Sci Sports 2006; 21: 285-290
3. Chiodo S, Tessitore A, Cortis C, Lupoc et al. Effects of official taekwondo competitions on all-out performance elite athletes. J Strength Con Res 2011a; 25: 334-339
4. Bridge CA, Jones MA, Drust B. Physiological responses and perceived exertion during international taekwondo competition. Int J Sports Physiol Perfor 2009; 4: 485-493
5. Campos FAD, Bertuzzi R, Dourado AC, Santos VGF et al. Energy demands in taekwondo athletes during combat situation. Eur J Appl Physiol 2012; 112:1221-1228; DOI 10.1007/s00421-011-2071-4
6. Wąsik J. Kinematic analysis of the side kick in Taekwon-do. Asta Bioen Biom 2011;13(2):71-75
7. Oliveria M, Moreira D, Godoy JRP, Cambraia AN. Avaljação da força de preensão palmar em atletas de jiu-jitsu de nível competitivo. R bras Ci e Mov 2006;14(3):63-70
8. Jones NB, Ledford E. Strength and conditioning for Brazilian jiu-jitsu. Strength Con J 2012;34(2):60-68
9. Franchini E, Nunes AV, Moraes JM and Vecchio FB. Physical Fitness and anthropometrical profile of the Brazilian male judo team. J Physiol Anthropol 2007;26:59-67

10. Borkowsky L, Faff J, Starczewska-Czapowska J. Evaluation of the aerobic and anaerobie fitness in judoists from the Polish national team. Biol Sport 2001;18:107-111
11. Tabben M, Chaouachi A, Mahfoudhi H, Aloui A et al. Physical and physiological characteristics of high-level combat sport athletes. 2014;1(2):1-5
12. Andreato LV, Franchini E, de Moraes SMF, Pastório JJ. Physiologocal and technical-tactical analysis in Brazilian jiu-jitsu competition. Asian J Sports Med 2013;4(2):137-143
13. Andreato LV, Franchini E, de Moraes SMF, Esteves JVCE. Morphological profile of Brazilian jiu-jitsu elite athletes. Rev Bras Med Esporte 2012;18(1):46-50
14. Cornelissen VA, Vagard RH. Effects of endurance training on blood pressure, blood pressure regulating mechanism, and cardiovascular risk factors. Hypertension 2005; 46: 667-675
15. Stringer WW, Hansen JE, Wasserman K. Cardiac output estimated noninvasively from oxygen uptake during exercise. J Appl Physiol 1997;82(3):908-912
16. Beaver WL, Wassermann K, Whipp BJ. A new method for detecing the anaerobic threshold by gas exchange. J Appl Physiol 1986;60(6):2020-2027
17. Fujii TK, Phillips BJ. Quick Review: The Metabolic Cart. Int J Internal Med 2003; 3(2)
18. Bridge CA, McNaughton LR, Close GR, Drust B et al. Taekwondo exercise protocols do not recreate the physiological responses of championship combat. Int J Sports Med 2013; 34(7):573-581
19. Moreira PVS, Crozara LF, Gpethel MF, Vinhas de Paula L. Talent detection in taekwondo: which factors are associated with the longitudinal competitive success? Arch Budo 2014;10:295-306
20. Andreato LV, Franzói de Moraes SM, Lopez de Moraez Gomez T, Del Conti Esteves JV et al. Estimated aerobic power, muscular strength and flexibility in elite Brazilian jiu-jitsu athletes. Sci Sport 2011;26:329-337
21. Fernandes Monteiro L, Massuça ML, García García JM et al. Plyometric muscular action tests in judo and non-judo athletes. Isokinet Exerc Sci 2011;19:287-293
22. Triki M, Rebai H, Shamssain M, Masmoudi K et al. Comparative study of aerobic performance between football and judo groups in prepubertal boys. Asian J Sports Med 2013;4(3):165-174
23. Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc 1988 Oct; 20 (5 suppl): S135-145
24. Gariod L, Favre-Juvin A, Novel V, Reutenauer H et al. Evaluation du profit energetique des judokas par spectroscopie RMN duP31. Sci Sports 1995 ; 10 :201-207
25. Tomlin DL, Wenger HA. The relationship between aerobic fitness and recovery form high intensity intermittent exercise. Sports Med 2001;31:1-11
26. Karvonen M.J. Work and activity classification, in L.A. Larsen (ed): "Fitness, health and work capacity" p. 38. Macmillan Publishing Company., Inc, New York, 1974
27. Matsushigue K, Hartmann K, Franchini E. Taekwondo: physiological responses and natch analysis. J Strength Cond Res 2009;23(4):1112-1117
28. Bangsbo J, Gollnick PD, Graham TE, Juel C et al. Anaerobic energy production and O_2 deficit-debt relationship during exhaustive exercise in humans. J Physiol 1990 Mar; 422: 539-559
29. Diaz-Lara FJ, García García JM, Monteiro LF, Ablan-Vicen J. Body composition, isometric hand grip and explosive strength leg – similarities and differences between novices and experts in an international competition of Brazilian jiu jitsu. Arch Budo 2014;10:211-217
30. Fontana P, Betschon K, Boutellier U, Toigo M. Cardiac output but not stroke volume is similar in a Wingate and VO_2 peak test. Eur J Appl Physiol 2011 Jan; 111 (1): 155-158. doi: 10.1007/s00421-010-1645-x
31. Cornelissen VA, and Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. J Am Heart Assoc 2003 Feb; 1; 2 (1): 1-9, e004473. doi:10.1161/JAHA.112.004473
32. Hagins M, Moore W, and Rundle A. Does practicing hatha yoga satisfy recommendations for intensity of physical activity which improves and maintains health and cardiovascular fitness? BMC Com Alter Med 2007; 7, 40:1-9. doi:10.1186/1472-6882-7-40
33. Hermida RC, Fernández JR, Ayala DE, Mojón A, et al. Circadian rhythm of double (rate-pressure) product in healthy normotensive young subjects. Chronobiol. Int. 2001, May; 18 (3):475-489
34. . Sinha B, Ray US, Pathak and Selvamurthy W. Energy cost and Cardiorespiratory changes during the practice of Surya Namaskar. Indian J Physiol Pharmacol 2004; 48 (2): 184-190