Differences in the morphological and physiological characteristics of senior and junior elite Czech judo athletes

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B Data Collection
C Statistical Analysis
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Abstract

Background & Study Aim: The judo is combat sport in which the division into weight categories and age groups are applicable. Thus, both of these criteria even at the same period of training are determining the diversity of athletes especially in terms of the build. The aim of the study was the differences between the morphological and physiological characteristics of individual junior and senior judo athletes.

Material & Methods: Nineteen judo athletes (10 from the junior and 9 from the senior categories, participated in the study. Body composition was measured using bioelectrical impedance. The multi-sensorial platform was used for posturographic examination. Cardio-respiratory and functional indicators were set using the Cortex Metalyzer ®3B device, a laboratory test consisting of a submaximal and maximal component. Anaerobic variables were detected using the Wingate test-Monark 824E mechanical ergometer.

Results: The morphological variables between the groups showed significant differences in body height, body mass and fat free mass. Statistically insignificant changes were found in the indicators of aerobic load up to vita maximum. However, the effect size indicated a large difference between the groups (W_{170}, V, HR_{max}, and $\%VO_{2max}$). The greatest significant differences, as well as effect sizes, were detected in the anaerobic indicators. Moreover, significant differences were detected in postural stability in favour of the seniors. Decreases in blood lactate after an anaerobic load showed a significant effect of time and an insignificant effect of age.

Conclusions: In all of the monitored areas, we revealed better predispositions for performance in senior athletes. In further research, it will be necessary to eliminate the limits of the study (the small sample, objectification of recovery processes after anaerobic load, and greater specificity in relation to judo performance).

Keywords: aerobic indicators • anaerobic indicators • blood lactate • body composition • body postural stability • combat sports • randori

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Body composition – athlete's predisposition in terms of the proportion of active mass and inactive mass in the body.

Body postural stability – ability to maintain balance and compensate deviations from external factors, important in judo basic training, *randori* and tournament competitions.

Anaerobic variables – variables determining a judo athlete's anaerobic capacity (peak power, mean power, and fatigue index).

Randori – a training match basic on judo rules.

Introduction

Judo is a dynamic, high-intensity intermittent sport that requires complex skills and tactical excellence for success [1]. To be successful in international competitions, judo athletes must achieve an excellent level of physical fitness and physical conditioning during training. Judo is a complex sport that demands the combination of a number of specific characteristics to achieve a high level of competition [2].

The duration of a match, according to the rules, is 5 minutes in the male category; in the case of a draw, a match can, thanks to the "golden score", last for a full 8 minutes of intensive load. However, a typical high-level judo match lasts for 3 minutes, with 20–30 second periods of activity and 5–10 seconds of interruption [3]. From the physiological point of view, the short-term energy load of a judo athlete, in terms of 20–30 second periods of activity, is supplied anaerobically. Because there is no time for full recovery, the speed and efficiency of recovery processes play a very important role. Aerobic metabolism is especially important for effective recovery between matches [4]. Aerobic fitness seems to be important in high-intensity intermittent exercise, which is the case with judo, as it permits better recovery during the short rest periods between effort [5].

To optimize performance, in terms of winning in the shortest amount of time, it is inevitable to engage all of the factors affecting judo performance, the technical component and the fitness component (strength, endurance, speed, coordination, and stability), to choose the appropriate tactics and timing during the match and to be optimally mentally tuned and prepared for the match.

Concerning physiological predispositions, the available literary sources mention the assessment of somatotype and the quality of body composition in terms of the proportion of fat mass and active mass [2, 6–8], anaerobic profile based on peak power, mean power and fatigue index [2, 9–11], aerobic capacity assessed via maximal oxygen uptake, peak oxygen uptake, so called anaerobic threshold [2], and maximal, static and dynamic muscle strength [7, 12]. High levels of all of the mentioned morphological and physiological indicators provide the judo athletes with the necessary fitness preparedness for the load in a match (*randori*).

The aim of the study was the differences between the morphological and physiological characteristics of individual junior and senior judo athletes.

Material and methods

Subjects

Nineteen judo athletes (10 from the junior and 9 from the seniors categories), all of whom are members of the Czech national team, participated in the study. All participants practise judo at the elite level and they participate in international A category tournaments, and some of them have even won medals. The screened sample consisted of a junior world champion, the winner of the Judo Grand Slam Paris and the 2013 Kano Cup, the 2014 junior world champion, the 2014 senior world champion, the 2013 and 2014 European champion and other medallists who placed in the range from 1st – 5th place in European and World tournaments.

All participants have practised judo at least for 10 calendar years and attained a level of competency between 1st and 3rd dan. Concerning the sport training periodization, the research was carried out at the beginning of the competition period. The volume of the load in the preparatory period in the monitored groups is 720–1200 min in men and 600 min in the junior category, i.e. 60–80 tournaments for the men and 40-50 tournaments for the junior category in the preparatory period. Basic anthropometric characteristics (average age, average body weight and average body height) are listed in the results section (Table 1).

The research was approved by the Ethical committee of Faculty of Physical Education and Sport, Charles University in Prague (Czech Republic).

Procedures

Anthropometric assessment: body composition

Data identifying body composition were recorded under the same conditions: in the morning, the participants did not use any medication, and they neither radically, nor over the long-term, reduced their body weight. Body height was measured using a digital stadiometer (SECA 242, Hamburg, Germany), and body weight was measured using a digital scale (SECA 769, Hamburg, Germany). To determine the whole-body bioimpedance, we used a BIA 2000M multifrequency bioimpedance analyser (Data Input GmbH, Germany). Standardized conditions of the bioimpedance measurement were met [13]. We observed the absolute and relative amount of fat free mass (FFM and FFM/kg), the ratio of extracellular and intracellular mass (ECM/BCM), the percentage of fat mass (FM) and the phase angle. When indirectly calculating the measured parameters indicating the quality of body composition, we used software with the appropriate prediction equations (Data Input GmbH, Germany).

Postural stability

The multi-sensorial Footscan platform (RS scan; Belgium; 0.5 m x 0.4 m; approximately 4100 sensors; sensitivity from 0.1 of $N.cm^{-2}$; sampling frequency 500 Hz) was used for the posturographic examination. Pressure on individual sensors was measured, and the centre of pressure (COP) was calculated at the contact area. The test of stability consisted of 3 partial sub-tests (wide stance with sight control for 30 s, and the flamingo test on the dominant and non-dominant leg for 60 s). Stability was recorded before the load in the above-mentioned order. During the test, the participants stood 3 metres from a wall with a mark at eye level (a black circle with a diameter of 3 cm). The standard standing posture with a wide base was measured according to standard practice [14], and transparent sheeting for tracing foot position was used during the examination. The following indicators were assessed: medio-lateral directional deviation (delta X), anterio-posterior directional deviation (delta Y) and the whole course of total travelled way (TTW) of COP.

Aerobic performance test

To assess the level of aerobic capacity, a laboratory test consisting of a submaximal and maximal component [15] was chosen. Standardized warm-up was performed at an intensity of 1.5 and 2.5 $W.kg^{-1}$, each lasting for 4 minutes. During the warm-up phase, attention was paid to the steady response of the organism to the load. The device used was the Lode Excalibur Sport ergometer, which allows for the load to be set between 8 W and 1500 W and which is designed for a maximal long-term load. The own load was performed in the frequency independent mode, in the range of 85 to 95 rpm, with an accuracy of ±5 W. Based on the response of the organism at these levels of intensity, the size of the initial load for the graded maximal test was calculated. This initial intensity, which corresponded with a performance heart rate of 170 bpm, was set to examine the maximal functional parameters. During the maximal part of the test, the load was increased by 20 W each minute. The test was finished upon exhaustion of the organism or a stagnation or reduction of the functional indicators.

The cardio-respiratory and functional indicators were set using an open system of Cortex Metalyzer® 3B device (MetaLyzer® 3B, Cortex, Leipzig, Germany), a breath-by-breath variant with a module for measuring the heart frequency. The percentage of O_2 was measured using a paramagnetic sensor, concentration of CO_2 in the exhaled breath was measured using an infrared analyser and lung ventilation was measured using a turbine [16]. Output indicators also included the VO_{2max} ($ml.kg.min^{-1}$) values to completely characterize the aerobic predispositions of the participants. Prior to the measurement of each participant, the device was recalibrated.

Anaerobic performance test

The Anaerobic Wingate test was carried out on a modified Monark 824E (Monark, Stockhlom, Sweden) mechanical ergometer. After a standardized warm-up [17], the load was applied, i.e. braking torque of 6 $W.kg^{-1}$ (frequency of 60 rpm), which, using the Monark mechanical ergometer, is equivalent to a load of 0.106 $kg.kg^{-1}$ of the participant's body weight. This braking torque corresponds with the optimized requirements for conditions to achieve the highest possible mechanical performance from the perspective of speed and strength according to the level of fitness of the examined population [18]. Performance for individual levels of speed was assessed on-line, and subsequently, a computer set the basic indicators of the test: maximum aerobic performance, i.e. the best test performance with 5 second intervals (in Watts as well as in Watts per kilogram of body weight); anaerobic capacity as total work, i.e., multiplying the average performance and time (in kilojoules and $J.kg^{-1}$); and the index of fatigue, i.e. the decrease in performance between the highest five-second performance and the lowest five-second performance (usually at the end of the test), which is expressed relatively as the percentage of the maximal performance [17].

Blood lactate concentration

In the fifth minute of recovery, after cessation of the anaerobic test, capillary blood samples from the fingertips were taken (20 µl), and the blood lactate concentration was determined electrochemically using a Biovendor Super GL apparatus (BioVendor, Candler, NC, USA). The samples of the capillary blood (20 µl) were immediately diluted with a system solution (1 ml), which ensured their haemolysis and stabilization. The samples were further analysed with a biosensor using amperometric principles [19]. Prior to each measurement, the analyser was calibrated with a standard concentration of 12 $mmol.l^{-1}$. Monitoring of lactate during the anaerobic test was carried out prior to the test and after 5, 10 and 15 minutes of recovery after the cessation of the exercise (Wingate test).

Statistical analysis

Data are presented as the mean ± standard deviation. The normality of the distributions was checked using the Shapiro-Wilks test. Descriptive statistics were calculated for the junior and senior judo athletes. Differences between groups were evaluated using Student's t-test for independent variables. The probability of a type I error (alpha) was set at 0.05 in all statistical analyses. The probability of a type II error (beta) was controlled using posthoc (retrospective) analysis and was set at 0.2 (conventional value). Moreover, the effect size between the means of the screened groups was assessed using Cohen's coefficient of effect size "d". It was calculated as the difference of the means of the compared variables and divided by a "pooled" standard deviation [20]. The coefficient was assessed as follows: d = 0.20: small effect, d = 0.50: medium effect and d = 0.80: large effect [21].

Correlations between the postural stability measurements were determined using Pearson's correlation. Significant differences in blood lactate levels after the anaerobic Wingate test were evaluated using a mixed model of analysis of variance for repeated measurements (RM ANOVA 2x3), which compares the variance of within-group effects (time) and the between group effects (age).

When the criterion of sphericity as one of the conditions of ANOVA, which was assessed using Mauchly's test (χ^2), was not met, the degrees of freedom were adjusted by means of Greenhous-Geisser's (GG) sphericity correction, and then, the statistical significance was assessed according to particular degrees of freedom. Rejection of the null hypothesis was assessed at the level of $p<0.05$. The effect size was evaluated using the "Eta square" coefficient (η^2), which explains the proportion of the variance of the monitored factor.

Statistical analyses were performed using IBM® SPSS® v21 (Statistical Package for Social Science, Inc., Chicago, IL, USA).

Results

The comparison of the morphological variables between groups showed significant differences in body height, body mass and fat free mass. In these variables, a high effect size was also detected (>0.8). Statistically insignificant changes ($p>0.05$) were found in the indicators of the aerobic load up to vita maximum. However, the effect size indicated a high difference between the groups in 4 out of 8 variables (W_{170}, V, HR_{max}, and $\%VO_{2max}$). The greatest differences between the groups were detected in the anaerobic variables, when, apart from $P_{max/kg}$ and LA, the groups significantly differed (statistically as well as in effect size) in all of the other indicators. Moreover, significant differences were detected in postural stability in which senior athletes achieved lower values in comparison to junior judo athletes at all three tests (Table 1).

The decrease in blood lactate after an anaerobic load showed a significant effect of time $F_{2,34} = 25.19$, $p<0.01$, $\eta^2 = 0.60$ and an insignificant effect of gender $F_{1,17} = 0.06$, $p>0.05$, $\eta^2 = 0.01$. The interaction effect between gender and time in lactate reduction was not significant ($F_{2,34} = 1.85$, $p>0.05$, $\eta^2 = 0.03$) (Figure 1).

Discussion

Body composition

For optimal body composition, generally, inactive fat mass is undesirable and active muscle mass is desired for movement. Excessive adipose tissue acts as dead weight in activities where the body mass must be repeatedly lifted against gravity during locomotion and jumping [22]. Based on the weight categories for judo, athletes attempt to maximize the amount of lean tissue, minimize the amount of body fat and minimize total body weight [2]. The required body weight can be attained though continuous monitoring of the body composition and proportion of fat mass or, on the contrary, the intentional rapid reduction of body weight before a tournament. Rapid reduction of body weight before competitions is related to negative effects on an individual's health and performance, especially if the reduction is carried to the extreme, and increases the risk of injuries and disease [23–25]. However, the critical limit is difficult to define, as it varies by individual and can negatively influence performance if exceeded. A low proportion of fat mass in judo athletes was indicated in our data (Table 1), and both tested groups had low proportions of fat mass in accordance with the available literature [2, 8, 26]. According to Franchini et al. study [7], world and Olympic level male judo athletes usually have <10% body fat. Koury et al. [8] consider fat masses with the range of 7–10 % to be the optimal fat mass for judo athletes. When comparing available sources, the measurement method used and often the representation of subcutaneous adipose tissue should be taken into consideration.

The mean values of our variables suggest a better predispositions of the senior team; on the other hand,

Table 1 The physiological and morphological indicators of elite Czech judo athletes.

Variable	Senior (n = 9)		Junior (n = 10)		t	Sig	d	Effect Size
	x	SD	x	SD				
Age (years)	21.78	2.59	16.80	1.66	24.58	p<.01	2.28	high
Body height (cm)	184.34	7.73	176.22	7.60	5.04	p<.05	1.06	high
Body mass (kg)	84.72	10.82	71.53	13.72	4.97	p<.05	1.07	high
FM (%)	12.92	2.83	13.29	3.37	0.06	N.S.	0.12	small
FFM (kg)	73.31	7.59	61.56	9.37	8.31	p<.01	1.38	high
FFM/kg	0.87	0.03	0.87	0.03	0.02	N.S.	0.00	small
ECM/BCM	0.71	0.09	0.75	0.10	0.67	N.S.	0.42	medium
α (°)	7.52	0.76	7.48	0.72	0.02	N.S.	0.05	small
W_{170} ($W.kg^{-1}$)	3.68	0.76	3.12	0.77	2.36	N.S.	0.80	high
W_{max} ($W.kg^{-1}$)	4.63	0.43	4.32	0.48	1.15	N.S.	0.68	medium
VO_{2max} ($ml.kg.min^{-1}$)	55.00	3.54	53.58	4.74	0.50	N.S.	0.34	small
V (l)	135.22	9.54	124.20	13.86	3.69	N.S.	0.93	high
HR_{max} ($beat.min^{-1}$)	187.67	5.61	192.40	6.56	2.64	N.S.	0.81	high
LA ($mmol.l^{-1}$)	12.48	2.68	11.04	1.71	1.91	N.S.	0.65	medium
ANP_{HR} ($bet.min^{-1}$)	171.22	4.44	174.3	5.31	1.74	N.S.	0.63	medium
P_{max} (W)	1116.78	142.95	889.87	130.12	12.46	p<.01	1.66	high
$P_{max/kg}$ ($W.kg^{-1}$)	13.21	1.03	12.61	1.32	1.12	N.S.	0.51	medium
$P_{average}$ (W)	909.38	116.78	638.94	189.15	12.62	p<.01	1.72	high
$P_{average/kg}$ ($W.kg^{-1}$)	10.73	0.52	9.89	0.93	5.26	p<.05	1.12	high
AnC (J)	322.29	15.91	296.83	28.12	17.50	p<.01	1.12	high
AnC/kg ($J.kg^{-1}$)	27.29	3.51	20.97	2.92	5.26	p<.05	1.96	high
Fatique Index (%)	35.5	5.62	41.02	5.25	4.65	p<.05	1.02	high
LA ($mmol.l^{-1}$)	11.25	1.69	11.51	2	0.09	N.S.	0.14	small
TTW_{WSEO} (mm)	106.01	12.79	167.79	67.72	6.52	p<.05	1.26	high
X_{WSEO} (mm)	3.46	1.58	7.23	3.41	8.41	p<.01	1.42	high
Y_{WSEO} (mm)	6	1.42	7.37	2.82	1.59	N.S.	0.61	medium
TTW_{FD} (mm)	925.63	220.29	1174.61	499.32	1.73	N.S.	0.65	medium
X_{FLD}(mm)	16.17	2.84	22.81	5.23	10.48	p<.01	1.58	high
Y_{FLD}(mm)	26.03	6.17	32.97	8.54	3.75	N.S.	0.93	high
TTW_{FN} (mm)	1019.95	282.43	1366.16	402.74	4.75	p<.05	1.00	high
X_{FN} (mm)	20.42	5.7	27.68	4.71	8.81	p<.01	1.39	high
Y_{FN} (mm)	30.7	18.48	38.86	10.71	1.38	N.S.	0.54	medium

Legend: FM – fat mass, FFM – absolute value of fat free mass, FFM/kg – relative value of fat free mass, ECM/BCM – ratio of extracellular and intracellular mass, α – phase angle, W_{170} – performance at heart rate of 170 bpm, W_{max} – the best achieved performance at the graded load, VO_{2max} – maximum oxygen consumption, V – ventilation, HR_{max} – maximum heart rate, LA – maximal value of lactate, ANP_{HR} – heart rate on the anaerobic threshold, P_{max} – maximum peak power, $P_{max/kg}$ – maximum peak power per kg of body mass, $P_{average}$ – mean power, $P_{average/kg}$ – mean power per kg of body mass, AnC – anaerobic capacity, AnC/kg – anaerobic capacity per kg of body mass, La – concentration of lactate in the 5th minute after the anaerobic test, TTW_{WSEO} – total travelled way in the wide stance test with sight control, X_{WSEO} – medio-lateral directional deviation in the wide stance test with sight control, Y_{WSEO} – antero-posterior directional deviation in the wide stance test with sight control, TTW_{FD} – total travelled distance in stance on the dominant leg, X_{FD} – medio-lateral directional deviation in stance on the dominant leg, Y_{FD} – antero-posterior directional deviation in stance on the dominant leg, TTW_{FN} – total travelled distance in stance on the non-dominant leg, X_{FN} – medio-lateral directional deviation distance in stance on the non-dominant leg, Y_{FN} – antero-posterior directional deviation distance in stance on the non-dominant leg.

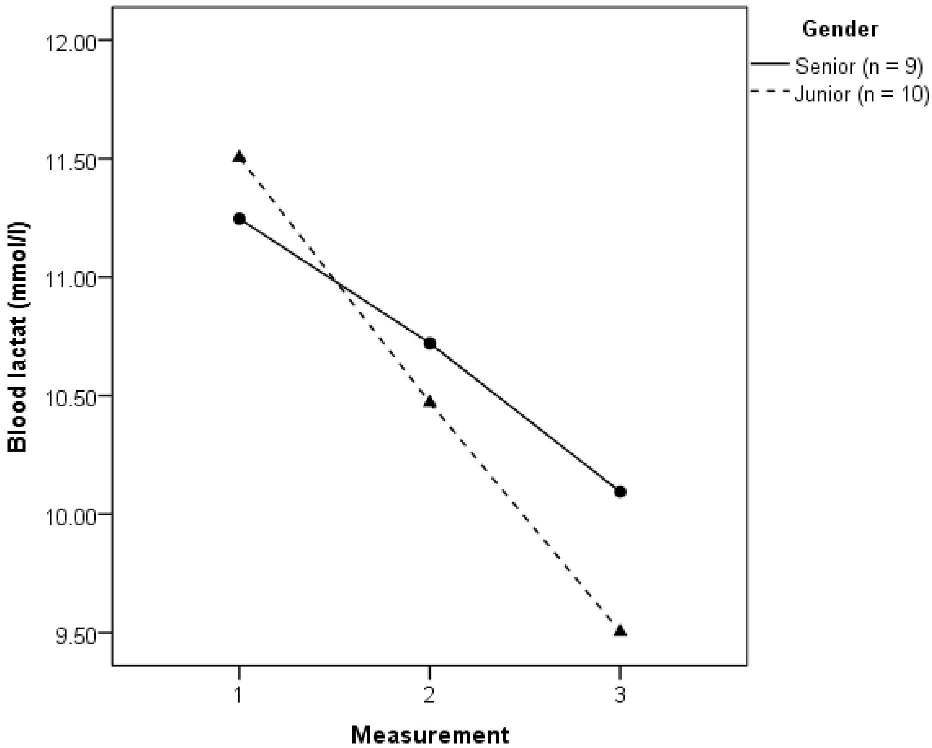

Figure 1. The course of the lactate curve Czech judo athletes

the only significant difference was in the absolute value of fat free mass (Table 1). The highest absolute value of FFM was recorded in an athlete from the 100+ kg weight category in men (83.9 kg) and in an athlete in the up to 100 kg category in juniors (76.3 kg), while the lowest FFM value was detected in the athletes from the category up to 60 kg in men (61.3 kg) and up to 60 kg in juniors (52.1 kg). The reason for the significance is probably due to a significant difference between the average body weight in men and junior athletes, in accordance with the insignificant difference between the relative FFM values. In other variables identifying the quality of body composition (phase angle, fat mass, and ECM/BCM), a significant difference between senior and junior athletes was not found and the effect size was only small or medium (Table 1). The highest value of fat mass was measured in the athletes from the senior 100 kg+ category (18.6 %) and in athletes from the juniors up to 100 kg category (18.9 %). Concerning the lowest value of fat mass, in the men's category it was found in an athlete from the weight category of up to 71 kg (7.8 %) and in the juniors an athlete from the category of up to 60 kg (8.7 %). Low ECM/BCM values and high phase angle values (Table 1) confirmed the predispositions for elite performance in all judo athletes.

Aerobic variables

Although decisive components in judo are mainly dependent on anaerobic metabolism, aerobic fitness seems to be important in high-intensity intermittent exercise, which is the case with judo, as it permits better recovery during short rest periods [5]. High levels of aerobic capacity should allow judo athletes to maintain higher intensity levels during matches, delay the accumulation of metabolites associated with fatigue processes and improve the recovery process between two consecutive matches [27]. Tomlin and Wenger [28] associate a faster recovery after high intensity intermittent exercise with aerobic fitness. Study by Gariod et al. [29] confirm that judo athletes who normally obtain their scores in the final moments of a match have higher VO_{2max} values and are able to resynthesise gastrocnemius creatine phosphate faster compared to others who score earlier in matches.

Our recorded mean $VO_{2max/kg}$ body weight, V and HR_{max} are at the level of elite athletes [1, 9, 10, 29–32]. The difference between the monitored groups appeared to be insignificant (Table 1). The results are consistent with studies, which compared the aerobic capacity of elite and non-elite male judo athletes and national teams and found that the differences were not significant [11, 31].

The difference between the observed groups was not significant; however, the effect size indicated high differences between the groups for some variables, which confirms the importance, although not the necessity, of high levels of aerobic capacity among judo athletes. When the weight categories are compared, it is possible to note a decrease in relative aerobic power parallel to an increase in body mass [32]. Only one study presents a significant difference; male heavyweights had lower values compared to athletes from all other weight classes [31]. In our screened sample, the highest value of $VO_{2max/kg}$ body weight was recorded in an athlete from the 100 kg weight class+ in the men's category (50.5 $ml.kg^{-1}$) and in an athlete from the up to 100 kg weight class in the junior category (46.4 $ml.kg^{-1}$). In individual variables, it is not possible to determine the trend among weight classes.

Anaerobic variables

The Wingate test evaluates variables (peak power, mean power and fatigue index) that are reportedly used in the upper and lower body actions of judo athletes [9–11]. The relationship between these variables and judo performance was indicated by moderate and strong correlations between anaerobic abilities and the percentage of wins among female judo athletes in the European World Cup (peak power, r = 0.66, mean power, r = 0.68). Concerning the men's category, a moderate correlation (r = 0.76) between the relative total work performed in two consecutive upper body Wingate tests and the number of attacks performed during a match simulation was found [11]. A limit to the compared studies is that based on these studies it can be concluded that judo athletes of both sexes show great power and anaerobic capacity when exercise involves the upper body, and this aspect is a potential discriminating factor in performance. Moreover, the power and anaerobic capacity values from the lower body are not prominently higher than that observed in other athletic groups or even in active individuals. Additionally, these variables do not appear to be predictors of performance or success in judo [2].

With regard to the specific speed-power and power-endurance demands of judo, mainly anaerobic tests, such as the Wingate test of the upper and lower limbs, are used in diagnostics. In the Wingate test of lower limbs in elite judo athletes with so called endurance profiles. Gariod et al. [29] described top anaerobic performance at 14.6±0.9 $W.kg^{-1}$ and average performance at 12.0±1.0 $W.kg^{-1}$; in judo athletes with so called explosive profiles, they set the top performance at 16.2±1.1 $W.kg^{-1}$ and average performance at 12.0±0.9 $W.kg^{-1}$. Wojczuk et al. [37] reported top performance to be 11.3±1.0 $W.kg^{-1}$ and average performance at 8.7±1.0 $W.kg^{-1}$ in elite Polish junior judo athletes; similarly, study by Mickiewiczová et al. [38] described the average performance of junior judo athletes to be 11.4 $W.kg^{-1}$; in male senior judo athletes. the average performance was 11.5 $W.kg^{-1}$, and in female senior judo athletes, the average performance was 9.6 $W.kg^{-1}$. Borkowski et al.[31] measured the top performance of the Polish national female team in the anaerobic Wingate test of the lower limbs at a value of 10.6±0.9 $W.kg^{-1}$, and the average performance was 7.9±0.7 $W.kg^{-1}$. In another study authors compared the results of the anaerobic Wingate tests in judo athletes according to weight classes [39]. The absolute values of the top and average performance increased with body weight; however, the relative values of the top and average anaerobic performance were highest (approximately 10–11 $W.kg^{-1}$ and 8.5-9.0 $W.kg^{-1}$) in middle weight classes (to 73 kg, to 81 and to 90 kg), while the relative values of the achieved results observed in the lightweight classes (to 60 and to 66 kg) or heavyweights (to 100 kg and over 100 kg) were significantly lower, and the index of fatigue (37–41 %) did not differ in respective weight classes. Overall, the achieved values of the maximum and average anaerobic performance in our study are lower in comparison to French male national team [29] assessed by an anaerobic Wingate test of the lower limbs, the maximum anaerobic performance of which was at the level of 14.6 to 16.2 $W.kg^{-1}$ and the average performance of which was approximately 12.0 $W.kg^{-1}$; on the other hand, our results are higher than those reported in elite judo athletes [31, 37–39], which can be attributed to the different measurement methods used; for example, the Polish authors used a lower braking torque in the Wingate test, namely, 0.075 $kg.kg^{-1}$ of body weight, which is primarily defined for the inactive population.

The highest absolute values of peak power (1336 W) and mean power (1083.40 W) were recorded in athletes from the 100 kg+ weight class in the men's category; analogically, 1108 W and 874 W were recorded in athletes from the up to 100 kg weight class in the junior category. The highest relative values of peak power (14.4 $W.kg^{-1}$) and mean power (11.4 $W.kg^{-1}$) were observed in the athletes from the up to 60 kg and to 81 kg weight classes; similarly, the highest relative values of peak power (15.3 $W.kg^{-1}$) and mean power (11.2 $W.kg^{-1}$) were observed in a junior athlete from the up to 100 kg weight class. In case of the fatigue index, we cannot determine a clear trend in relation to the weight class, as the lowest value

(24.2 %) was detected in athletes from the up to 81 kg weight class in the men's category and up to 66 kg in the junior category (50.7 %) and the highest value (42.2 %) was found in athletes from the up to 60 kg weight class in the men's category and in junior athletes from the up to 71 kg weight class (33.4 %). The obtained data are in accordance with the statement of the study Franchini et al. [2], that athletes from heavyweight categories have higher absolute values of both peak and mean power than lighter athletes. On the contrary, in relative values, lighter athletes present higher power levels than heavyweight athletes. Concerning the values of anaerobic capacity, similarly, we cannot express any trend in relation to weight categories in intra-individual comparison.

A significant difference between men and junior judo athletes in the absolute value of peak power, the absolute and relative value of mean power and the absolute and relative value of anaerobic capacity (Table 1) indicates better predispositions for performance in the men's team. Additionally, a difference was observed in the fatigue index values, i.e. incoming fatigue was significantly slower in men in comparison to junior judo athletes. The cadet judo athletes have lower absolute peak and mean power compared to both junior and senior athletes and lower relative peak power compared to senior judo athletes [2]. Men appeared to be more able to resist incoming fatigue as well as to achieve better anaerobic performance, even repeatedly, during individual successive matches. The differences between the observed variables of anaerobic capacity in men and junior athletes are probably related to growth.

Differences between the lactate levels after the Wingate test were not significant (Table 1). Additionally, the decrease in values during regeneration after the Wingate test is comparable between men and junior athletes and did not indicate any better predisposition for faster regeneration after load in men or in junior judo athletes (Figure 1).

Eventually, monitoring of anthropometric and physiological characteristics can be used to identify talent, select judo athletes and predict judo performance. In the study Franchini et al. [9] were compared the results of a wide spectrum of tests (body composition, anthropometric parameters, Wingate tests of the upper body, changes in heart rate during specific judo tests, VO_{2max} on treadmill, speed of running at the anaerobic threshold, blood lactate concentration response to load in a simulated match and maximum isometric strength) in a large sample of successful elite judo athletes (n = 43) but also in judo athletes of lower performance level (n = 93).

Concerning skinfold thickness, the groups did not significantly differ, although more successful judo athletes had higher circumference values of the arm, forearm, wrist and calf than lower performance judo athletes; furthermore, they had wider humorous and femur epicondyle; in 30 second upper body Wingate tests, they achieved a higher maximum anaerobic performance (7.63 ±0.98 $W.kg^{-1}$ vs. 7.00±1.30 $W.kg^{-1}$) as well as higher a mean performance (5.73±0.77 $W.kg^{-1}$ vs. 5.36±0.75 $W.kg^{-1}$) than less successful judo athletes; moreover, in specific judo tests, they achieved a higher number of throws (with the help of sparing partners at a distance of 6 meters) at lower heart rates in addition to a more rapid heart rate decrease in the recovery phase.

Body postural stability

Ability to maintain body balance during a tournament match or randori is one of the most important traits in judo [33]. Our recorded values show stability at the level of elite combat athletes [33], where a significant improvement appears thanks to regular repeated controlled physical activity. This is consistent with the fact that athletic training, whatever the discipline, tends to improve balance control, particularly when the training conditions are difficult [34]. Smaller deviations in the medio-lateral direction in comparison to deviations in the antero-posterior direction in both observed groups are in accordance with the available literature. A significant difference between the monitored groups in favour of men was revealed in basic stabilometric measurements as well as in the stance on the dominant and non-dominant leg, as assessed by the total travelled distance and the medio-lateral distances from the centre. Because the highest level of static balance occurred in the 16–17 boys' age group, we assume that a higher level in men is the result of regular and organized judo training. Combat sports stimulate the mechanisms responsible for the stability of human body posture [35].

Study by Witkowski et al. [33] confirmed the stimulating influence of judo training on these coordination abilities. The detected correlation in our screened sample of judo athletes (n = 19) was significant (r = 0.649, p<0.01) and is consistent with a study by Witkowsi et al. [33], in which the values of stability in the flamingo left-right leg test were correlated 0.706 (n = 26, Junior High School judokas, 14–15 years old).

The results of Kalina's et al. [40] provide empirical evidence that long-term judo training disturbation stimulates the body balance disturbation tolerance skills. Among the 16 groups compared athletes have a higher level only: performers on horse-back, sports gymnasts, sport dancers and basketball players.

Judo thus appears to be a sport discipline that symmetrically develops both sides of the human body; when practising leg techniques (*ashi waza*) or hip techniques (*goshi waza*) on both sides, no differences occur in the level of stability of the respective extremities. In-depth analysis of the level of stability related to specific judo techniques, randori or eventual muscle imbalances connected with preferring one-sided repetitive judo techniques, possible deficits, such as flat foot, lateral shoulder asymmetry, forward head posture, winged scapula [36] and injury consequences, should be identified and assessed using other diagnostic methods (dynamic posturography, kinesiology, isokinetic strength testing, kinematic analysis, and measuring the segmental distribution of fluids) with the aim of eliminating possible deficiencies and to optimize the level of individual performance characteristics in judo [26].

Conclusion

The identified physiological and morphological parameters are at the level of elite athletes and can serve as the desired values of individual characteristics for judo athletes from lower performance levels. In all of the monitored areas, we revealed better predispositions for performance in senior athletes. The most significant differences were found in anaerobic variables where the statistical significance as well as effect size was in favour of senior judo athletes. In contrast, the decrease in blood lactate levels after anaerobic load was not significant in the monitored groups. Similarly, significant differences in favour of senior athletes were detected in somatometric characteristics and body composition variables. Statistically insignificant differences, confirmed by the effect size, in favour of senior judo athletes were recorded in tests of the aerobic variables. Concerning postural stability, a significant difference appeared in select indicators of each test.

In the future, it is necessary to focus on several indicators of fitness preparedness in judo athletes taking into consideration the specific characteristics of judo. Therefore, the inclusion of terrain tests is inevitable, as they are more specific to judo and allow us to monitor cognitive and decisive processes. An example of this assessment method is the Judo Fitness test [41] and the objectification of recovery processes after an anaerobic intermittent load. Concerning postural stability, it will be necessary to analyse the dynamic components that are specifically related to judo technique, especially balancing processes when stability is disturbed by an opponent, as occurs in randori; furthermore, the effect of fatigue on changes in postural stability should also be examined. Such detailed analyses would allow us to compare individual predictors and to specify their role in judo performance.

COMPETING INTEREST

The authors declare that they have no competing interests.

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