ORIGINAL ARTICLE

Gender differences in strength lateral asymmetries, limbs morphology and body composition in adolescent judo athletes

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Abstract

Background and Study Aim: Maladaptive changes and asymmetries represent a high risk of adolescent injury in judo practice. Another health risk in judo is the manipulation of body weight to compete in the tactically most advantageous weight category. The aim of the study was the gender differences in body composition, upper limb muscle strength, upper and lower limb morphology in adolescent judo athletes.

Material and Methods: Fifty-nine judo athletes participated in the study (39 boys and 20 girls); all were members of the Czech adolescent judo teams. Using multi-frequency bio-impedance analysis, we monitored body height, body mass, body mass index, lean body mass, relative lean body mass, percentage of fat mass, bone mass, protein mass, total body water, segmental proportion of muscle mass, fat mass, phase angle and percentage differences between the upper and lower extremities. Muscle strength was measured using a calibrated hand dynamometer.

Results: The difference in the percentage of fat mass between boys and girls was significant (boys: 17.27 ±5.02%, girls: 23.38 ±4.28%, F = 22.48, p = 0.00, d = 1.31). The boys had a significantly higher proportion of muscle mass in upper and lower limbs compared with the girls ($p<0.01$). Bilateral comparison of muscle mass proportion in the preferred and non-preferred limb in the group of boys showed a significant proportion of muscle mass in the preferred upper and lower limb ($p<0.01$). Gender did not have any significant effect on the size of the phase angle between the compared limbs ($p>0.05$). In the non-dominant limb, we detected a significant correlation between the phase angle and the level of muscle strength (boys: $r = 0.64$, $p<0.01$, girls: $r = 0.61$, $p<0.01$).

Conclusions: To reduce the risk of injury and negative impacts on the health of adolescent athletes, it is important to continuously monitor and correct optimal body composition concerning the targeted weight category of each athlete and the symmetrical proportion of active mass in particular segments.

Keywords: lean body mass • maladaptation • muscle mass • muscle strength

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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 during adolescence is recommended as an activity that encourages all-around physical development and as a suitable physical activity for children and youths to optimally develop strength and coordination abilities. Most parents already choose judo for their children at pre-school age due to its all-around gymnastics training and inclusion of combative exercises and floor gymnastic exercises. Combative exercises are also frequently used in sport training in other disciplines (e.g., soccer and hockey). Martial arts have a greater positive effect on muscular endurance and flexibility than team sports in adolescents compared to non-sports participation. Martial arts can be a valuable part of physical education and can be a physical leisure activity [2].

Adolescence is characterised by the period of rapid growth between childhood and adulthood, including physiological, psychological and social development [3]. The components of health-related physical fitness in adolescents are cardiovascular endurance, muscular strength and endurance, flexibility, and body composition. Judo influences the optimal level of body composition with a high proportion of muscle mass, lean body mass and body cell mass [4], low proportion of fat mass and a high value of phase angle as a predisposition for optimal muscle work [5]. Even short-term sport-specific training has shown to decrease body fat percentage in youth wrestlers [6].

Walowski and Poliszczuk [7] reported that, in judo athletes, no apparent asymmetry of torque was observed in the muscles responsible for trunk rotation and handgrip strength. Fukuda et al. Stout [8] support using judo training in the improvement of anthropometric measurements (body composition) and sport-specific measurements (flexibility, jumping power, force, velocity and improved judo-specific ability) in adolescent athletes. Results of other studies [9, 10] also emphasise the educational aspect of combative sports and its influence on adolescent self-control. Eventual risk in judo training is commonly found in unilateral physical load, which develops when an athlete has a preference for one side in training or personal technique (*Tokui waza*) and when compensation of this inclination is missing as a part of training; this uneven training increases the risk of morphological and strength asymmetries and the related risk of injury. Specific judo throwing techniques (*uchi-mata*, *haraigoshi*, *osoto-gari* and *o-uchi-gari*) [11] and sport-related development of movement patterns proved safe regarding the risk of marked functional asymmetry [12]. Possible asymmetries may lead to severe physical consequences, making it easier for the occurrence of injuries [13]. Asymmetrical loading in the long term may lead to differences between the dominant and non-dominant arm regarding bone mineral composition and density [14] as well as in morphological strength asymmetries [15]. Additionally, arm asymmetry attested to approximately 20% more bone mineral content and muscle mass in the dominant arm [16]. These maladaptive effects regarding different kinds of body asymmetries (morphological, physiological, neurophysiological) may influence some components of physical fitness in both the young and adult population, which can also be compounded by the negative trend of lifestyle or eventual unilateral uncompensated physical load. Socha et al. [17] reported significant differences between forearm circumferences and suprailiac skinfolds in adult female judo athletes. In the case of right-side-dominant judo throwing techniques, the authors also reported significant differences in isometric strength of the upper limbs. Sterkowicz et al. [11] reported a strong correlation between the preferred side of judo attack and motor dominance.

Another eventual health risk in judo is the manipulation of body weight to compete in the tactically most advantageous weight category. Even adolescents intentionally reduce body weight below their optimal level using dehydration and diuretics [18], which can lead to decreased performance in judo and subsequent health problems. It has been shown that even in adolescent athletes, inappropriate weight loss methods are used, resulting in a caloric deficiency, nutrient deficiency and dehydration [8, 18]. Moreover, dehydration does not lead to better performance, as the most affected indicators in dehydrated athletes are muscle strength, muscle power and average muscle strength production [19]. Therefore, it is necessary to continuously monitor optimal body composition concerning the targeted weight category of each athlete as well as the symmetrical proportion of active mass in

Bioelectrical impedance analysis – ***noun*** an accurate method of measuring body fat using an electrical current. Abbreviation **BIA** [40].

Adolescence – usually defined as the period of rapid growth between childhood and adulthood, including physiological, psychological and social development.

Body composition – the contribution of particular tissues (e.g., fat and muscle, called body components) to body mass, often shown in kilograms or percentages.

Lean body mass – ***noun*** same as **fat-free mass** [40].

Body cell mass – Body cell mass (BCM) is the metabolically active cell mass involved in O2 consumption, CO2 production and energy expenditure [41].

Resistance – ***noun*** **1.** the ability of a person not to get a disease the ability of a bacterium or virus to remain unaffected by a drug **3.** opposition to a force [40].

Reactance – Reactance – resistance in bioimpedance measurements. It is a measure of body cell mass [41].

Hand strength – force exerted when gripping or grasping.

Segmental muscle mass – the proportion of muscle mass in particular body segments.

Maladaptation – negative impact of physical load on a body.

Kyū (**kyu**) – is a Japanese term used in modern martial arts (in judo from **6** to **1 kyu**; which is the highest) as well as in tea ceremony, flower arranging.

Judogi – is the formal Japanese name for the traditional uniform used for judo practice and competition.

Ippon – one point. Achieved through the execution of a valid technique on the opponent.

particular body segments to avoid the risks mentioned above.

The aim of the study was the gender differences in body composition, muscle strength in upper limbs, upper and lower limb morphology and upper limb strength among adolescent judo athletes.

MATERIAL AND METHODS

Participants

The study involved 59 judo athletes (39 boys and 20 girls), all members of the Czech cadet and junior teams. Basic anthropometric indicators observed in boys were as follows: age 12.08 ±1.47 years, body height 154.64 ±13.64 cm, body mass = 46.59 ±15.37 kg, body mass index 19.21 ±3.05; the same indicators in girls: age 12.38 ±1.43 years, body height 149.69 ±7.89 cm, body mass 43.71 ±7.4 kg, body mass index 19.4 ±1.89. All participants practised judo at a competition level and regularly participated in national and international tournaments. The average period of contact with judo was 3 to 8 years, and the level of competency was up to 1 kyu. Their time of the load was 270 minutes a week in both junior and cadet-athletes in the preparatory period, and 15 tournaments in cadets and 4 to 50 tournaments in junior athletes in the competitive period.

Procedures

Anthropometric assessment and body composition

Body height was measured using a digital stadiometer (SECA 242, Hamburg, Germany), and body mass was measured using a digital scale (SECA 769, Hamburg, Germany).

Data identifying body composition were recorded under the same conditions, in the morning; the participants used no medication; they did not reduce their body weight prior to the measurement, neither radically nor in the long-term before competitions. To assess whole-body bio-impedance, we used a Tanita MC-980MA multi-frequency bio-impedance analyser (Tanita Corporation, Japan). Standardized conditions of the bio-impedance measurement were kept [20].

The following indicators were observed: body height (BH), body mass (BM), body mass index (BMI), lean body mass (LBM), relative lean body mass (LBMr), percentage of fat mass (FM), bone mass, protein mass, basal metabolic rate, total body water and segmental proportion of muscle mass, fat mass and phase angle (A) and percentage differences between the upper extremities (ΔUE) and lower extremities (ΔLE).

Strength assessment

Strength was assessed using a calibrated hand dynamometer (Takei, TKK 5401, Takei Scientific Instruments, Tokyo, Japan). Judo athletes gripped the dynamometer with maximal effort in a sitting position with full extension of the elbow in two trials for each limb and with a rest interval lasting 60 seconds between the trials. Only the best performance in the trial was processed in the further analysis. As the preferred upper limb, we used the participants' writing hand.

Statistical analysis

To compare the selected indicators from the perspective of gender, we used the inter-group comparison of means using a general linear model. Indicators on the paired limbs (arms, legs) were compared using a parametric t-test for dependent samples. Its suitability was verified using the Shapiro-Wilk test for assessing normality of data distribution in the Gaussian curve. We also used Cohen's "d" to assess the effect size between the groups [21]. It was calculated as the difference of the means of the compared indicators and divided by a "pooled" standard deviation. The coefficient was assessed as follows: d = 0.20: small effect, d = 0.50: medium effect and d = 0.80: large effect [21].

The probability of type I error (alpha) was set at 0.05 in all statistical analyses. Statistical analysis was performed using IBM® SPSS® v21 (Statistical Package for Social Science, Inc., Chicago, IL, 2012).

RESULTS

The comparison of the monitored indicators between boys and girls already showed several significant differences at such a young age (8 – to 16 years). Body height, body mass, fat mass (absolute values) and lean body mass showed no differences concerning gender. However, the difference in percentage of body fat between boys and girls was significant (boys: 17.27 ±5.02 %, girls: 23.38 ±4.28 %, F = 22.48, p = 0.00, d = 1.31).

Tokui-waza – "favourite" or "best" technique. It is the throw that fits naturally to athlete body type.

Throwing techniques (***nage-waza***): hand techniques (sub classification: ***te-waza***); hip techniques (sub classification: ***goshi-waza***); leg techniques (sub classification: ***ashi-waza***); rear-fall and side-fall judo throws, synonym: "dedication throws" (sub classification: ***sutemi-waza***).

Table 1. Statistically significant differences between compared groups of adolescent judo athletes.

Variable	Boys (n = 39)		Girls (n = 20)		F	Sig	d	Effect size
	x	SD	x	SD				
Body height (cm)	153.64	13.64	149.69	7.89	1.49	0.23	0.35	medium
Body mass (kg)	46.59	15.37	43.71	7.4	0.65	0.42	0.24	small
Fat mass (kg)	8.29	4.97	10.01	2.52	2.2	0.14	0.44	medium
Fat mass (%)	17.27	5.02	23.38	4.28	22.48	0	1.31	high
LBM (kg)	38.05	12.16	33.44	5.78	2.69	0.11	0.48	medium
LBMrel	0.82	0.07	0.77	0.04	1.36	0.25	0.88	high
TBW (l)	60.62	3.69	56.76	2.47	18.55	0	1.23	high
MM trunk (kg)	20.34	5.45	18.73	3.05	1.56	0.22	0.36	medium
MM left arm (kg)	1.74	0.73	1.37	0.27	5.89	0.02	0.67	high
MM right arm (kg)	1.78	0.72	1.38	0.26	4.84	0.03	0.74	high
MM left leg (kg)	6.11	2.18	4.91	0.85	5.91	0.02	0.73	high
MM right leg (kg)	6.34	2.27	5.13	0.9	5.45	0.02	0.70	high
FM trunk (%)	14.73	7.06	16.58	4.15	0.24	0.63	0.32	small
FM left arm (%)	24.91	5.65	32.48	4.49	28.26	0	1.48	high
FM right arm (%)	23.04	5.91	30.3	4.06	25.32	0	1.43	high
FM left leg (%)	23.1	5.04	30.98	3.42	41.15	0	1.83	high
FM right leg (%)	22.64	5.23	30.63	3.4	40.04	0	1.81	high
A left arm (°)	5.78	0.43	5.98	0.58	2.44	0.12	0.39	medium
A right arm (°)	5.8	0.48	5.72	0.36	0.51	0.48	0.19	small
A left leg (°)	5.63	0.51	5.63	0.42	0.01	0.95	0.00	small
A right leg (°)	5.71	0.5	5.7	0.46	0.01	0.94	0.02	small
Hand grip PA (N)	23.82	9.54	20.5	4.95	2.21	0.14	0.44	medium
Hand grip NA (N)	22.67	9.2	18.28	4.33	4.26	0.04	0.61	medium

Legend: **LBM** lean body mass; **LBMrel** relative lean body mass; **TBW** total body water; **MM** muscle mass; **FM** fat mass; **PA** preferred arm; **NA** non-preferred arm.

The boys characterised by a significantly higher proportion of muscle mass in both upper and lower extremities than girls (Table 1). In contrast, the girls characterised by a higher percentage of fat mass compared with the boys.

Bilateral comparison of mass muscle proportion between the preferred and non-preferred limb revealed a significant proportion of muscle mass in the preferred upper and lower limbs in boys (Table 2). In girls, the proportion of muscle strength in the upper limbs was not significant. Muscle strength produced by the preferred limb in boys was higher by 4.8% than the strength produced by the non-preferred limb. In girls, it was even higher (10.8%). In both cases, the difference was statistically significant, as was the effect size (Table 2).

Gender did not have any significant effect on the phase angle between the compared limbs (Table 1). In the dominant limb, we found a significant correlation between phase angle and the level of muscle strength (boys: $r = 0.64$, $p<0.01$, girls: $r = 0.61$, $p<0.01$) (Figure 1). The difference in the non-dominant limb was not significant.

DISCUSSION

Isometric strength

Isometric strength in our screened sample was at the level of adolescent sporting individuals [22, 23]. In judo, the isometric strength of the arms is important for hand grip in the execution of personal technique up to *ippon*. It has been recommended [24] that judo athletes use

Table 2. Bilateral comparison between paired extremities in both sexes of adolescent judo athletes.

	Variables Mean	Paired differences					t	Significance (two-tailed test)
		SD	Standard error	95% CI				
				lower	upper			
Boys (n = 39)	MM arms differences (kg)	–0.03	0.07	0.01	0.01	0.05	2.76	0.01
	MM legs differences (kg)	–0.23	0.16	0.03	–0.28	–0.18	–8.98	0.00
	Strength differences (%)	1.14	2.40	0.38	0.37	1.91	3.01	0.00
Girls (n = 20)	MM arms differences (kg)	–0.01	0.07	0.02	–0.04	0.02	–0.62	0.54
	MM legs differences (kg)	–0.23	0.12	0.03	–0.28	–0.17	-8.51	0.00
	Strength differences (%)	2.22	2.24	0.49	1.20	3.24	4.54	0.00

Legend: **MM** muscle mass; **CI** confidence interval.

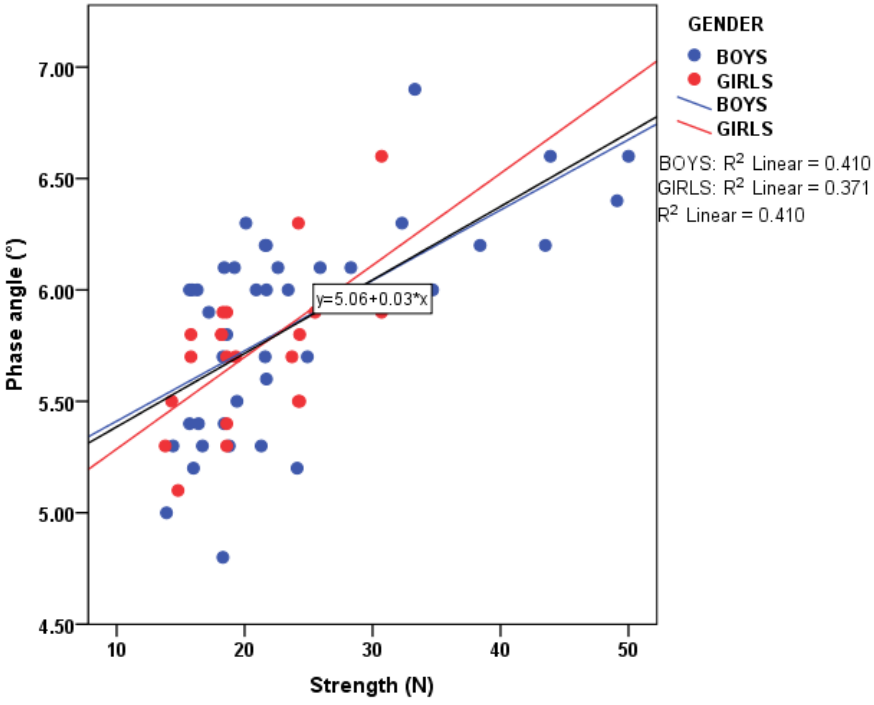

Figure 1. The relationship between muscle strength and phase angle in the preferred limb in adolescent judo athletes.

methods of strictly regulated exercise and games (taking away of ribbons, clips and bands fixed to their opponent's *judogi*), and it is very important to pay attention to the training of hand-grip strength [22]. Hand-grip strength is an indicator of predicted success in martial arts athletes [23]. Our tested girls produced lower dominant limb strength by 19.9% (20.50 kg) than adult elite judo athletes (25.58 kg) [17]. The difference in the non-preferred limb was even greater (23.6%) (present study: 18.28 kg, study by Socha et al. [17]: 23.91 kg).

Maximum hand-grip strength can be affected by numerous anthropometric measurement values, such as gender, age, height, body mass, body mass index, dominant hand, hand length and width, which can be used to estimate the handgrip strength of an individual [25]. It has been reported a positive relationship between

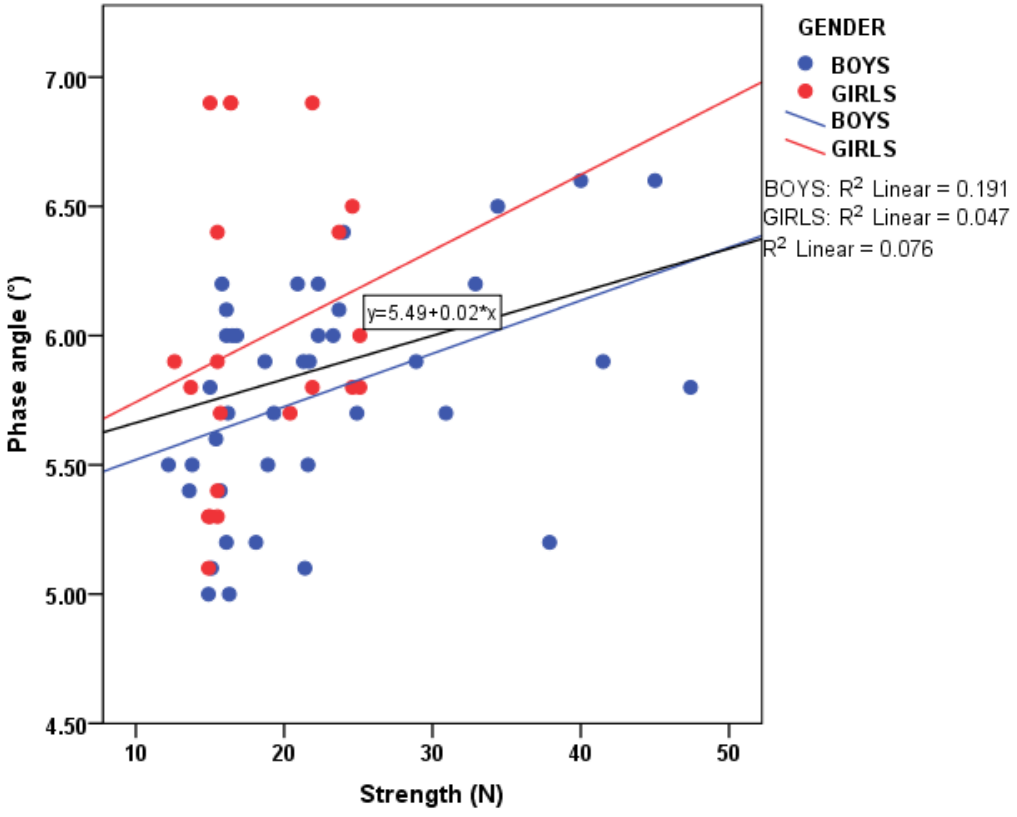

Figure 2. The relationship between muscle strength and phase angle in the preferred limb in adolescent judo athletes.

isometric strength and weight categories in judo athletes [26]. We assumed a hypothetical relationship between the phase angle and isometric strength of the upper limb. Phase angle has been suggested to be an indicator of cellular health 9° and 10°, where higher values reflect higher cellularity, cell membrane integrity and better cell function [27]. Norman et al. [28] found significant correlations between phase angle and handgrip strength in the entire study population ($p<0.0001$). In our study, we found a significant correlation between phase angle and muscle strength in the dominant limb (Figure 1). Concerning the non-dominant limb, the relationship was insignificant (Figure 2). If the phase angle is perceived as an indicator of cell state, function and integrity, we can state that limb dominancy caused better intra- and inter-muscular coordination, more efficient and faster recruitment of motor units, shortening of chronaxie and increase of rheobase in excitability of muscle tissues.

A significant difference in the absolute values of isometric strength in the non-dominant hand between boys and girls (Table 1) is in accordance with statements from the available literature concerning sex differences; boys characterised by higher absolute values of hand static strength compared with girls [29]. These differences last until adulthood when they are probably diminished because high-intensity training can decrease the difference in relative strength [30]. The boys produced muscle strength that was 4.8% higher with their preferred limb than with their non-preferred limb. This difference was even greater in girls (10.8%). In both cases, the difference was statistically significant, as was effect size (Table 2), confirming a general rule that the often-used dominant hand is approximately 10% stronger than the non-dominant hand [31]. Conversely, Socha et al. [17] did not find any significant difference between the limbs in adult elite female judo athletes (n = 25). This fact could be explained so that judo athletes at the level of national and international competition require the same strength for both limbs to eliminate the fighter's weaknesses.

Body composition and morphological asymmetries

A higher proportion of active mass and the elimination of inactive mass is desired for both

judo performance and optimal body composition for the high quality of life in adolescents. The reported percentage of body fat ranges from 9.9 ±4.4 % to 16.0 ±7.9 % in boys and from 16.1 ±3.5 % to 23.8 ±8.3 % in girls [32-37]. Compared with values of fat mass recorded in the Czech and Slovak junior national teams (n = 21, multi-frequency bio-impedance method), we can see lower values of fat mass (11.34 ±3.64 % to 11.88 ±3.68 %) than those measured in our athletes [38]. The reason for this difference could be ongoing ontogenesis and a higher frequency of training sessions in the national team. In accordance with inter-gender differences [38], girls characterised by a higher percentage of fat mass than boys, with a significantly higher proportion distributed equally across particular body segments (Table 1).

The effort to eliminate fat mass and the preference of a higher proportion of the active components is associated with a closer relationship between active mass and success in the sport. It has been reported [4], there is a significant relationship between the percentage of fat mass and the level of maximum oxygen consumption in judo athletes ($r = -0.83$; $p<0.01$). Reduction of excessive fat mass in adolescents through controlled physical activity creates appropriate conditions for a high quality of life among the general population. However, it is important to consider a very important triangle regarding "load – nutrition – regeneration". Optimal growth and muscle development are only possible when training intensity, nutritional intake and recuperation are well balanced [34].

Since judo is determined by strength, lean body mass together with its compartment muscle mass is a predictor of muscular efficiency and sports performance as such. An average value of muscle mass measured in individual body segments was significantly higher in boys than in girls (Table 1). Muscle mass has a high affinity with basal metabolic output, as we found a significant correlation in our participants ($r = 0.655$; $p<0.01$ for boys, $r = 0.722$; $p<0.01$ for girls). Basal metabolic rate, the average value of which amounted to 1478.43 ±380.82 kcal.day^{-1} in boys and 1277.05 ±128.12 kcal.day^{-1} in girls, will be, together with muscle mass and other indicators identifying body composition, another indicator for optimal control and regulation of sports training. Amount of muscle mass is determined by genetics (constitutional type), age (ongoing ontogenesis) and type of training (energy coverage) that the athletes undergo. Judo athletes with high-quality strength training will thus achieve a higher value of muscle mass than the general adolescent population of the similar age.

A high proportion of lean body mass and muscle mass is associated with a high amount of total body water. The average value of total body water in the tested group made up 77% of body mass when boys showed a significantly higher proportion of total body water than girls (Table 1). In the case of rapid pre-competitive body mass loss with the aim of competing in the tactically most advantageous category, it is important to monitor not only total body water but also its compartments, extracellular and intracellular water. Concerning changes in intracellular and extracellular water, during rapid reduction and eventual undesired changes in the intracellular space, the extracellular space and muscle mass should also change. The extracellular and intracellular space will adversely change to the detriment of the intracellular space; moreover, the number of active cells and the protein mass will be reduced as well (8.26 ±2.62 kg in boys, 7.25 ±1.23 kg in girls).

Likewise, the relationship between the phase angle and body cell mass is that phase angles indicate a higher proportion of body cell mass and intracellular water and gender had no significant effect on the size of the phase angle between the compared limbs (Table 1). Recording of the phase angle and eventual monitoring of changes in resistances (resistance, reactance) as directly measurable indicators of the bio-impedance measurement can eliminate eventual errors in prediction equations for indirectly estimated indicators [5].

When monitoring maladaptive changes based on judo practice, it was assumed that in adolescent athletes, when personal techniques (*tokui-waza*) are being selected, techniques are unilaterally executed and that when one limb becomes more preferred in favourite *ashi-waza* (leg techniques) there will be morphological asymmetry in the proportion of muscle mass in upper and lower limbs. This hypothesis was confirmed when the bilateral comparison of the mass muscle proportion between the preferred and non-preferred limbs showed a significantly higher proportion of muscle mass in the preferred upper and lower limbs in boys (Table 2).

In girls, muscle strength in upper limbs was not significantly different from that of boys (p>0.05). Boys produced 4.8% higher muscle strength higher with their preferred limb compared with the non-preferred limb. This difference was even greater in girls (10.8%). In both cases, the difference was statistically significant, as was the effect size (Table 2). In further studies, it would be recommended that bilateral strength asymmetries between the knee and hip extensors and flexors be identified.

Available sources found asymmetries between flexor-to-extensor torque initial measurement, indicating a potential source of injury in judo athletes [12]; eventually, they present prevalence of lumbar intervertebral disc degeneration, and the symmetry and size of the cross-sectional areas of the trunk muscles in combat sports athletes [39].

Maladaptive changes and asymmetries present a potential risk of injury in adolescent judo athletes. Therefore, the detected asymmetries should be systematically monitored and compensated using specific exercises. Regarding practice, the results may be beneficial for fitness coaches, physiotherapists and doctors. Implementing new training elements and modalities may improve the performance and prevent lateral asymmetry, thus decreasing the risk of injuries [12].

CONCLUSIONS

In the present study, gender differences were confirmed when boys appeared to have better body composition quality with a higher proportion of active mass than girls. Boys also had significantly higher muscle mass than girls. Bilateral comparison of mass muscle proportion between the preferred and non-preferred limb revealed a significant proportion of muscle mass in the preferred upper and lower limb. Furthermore, we discovered a significant relationship between phase angle and muscle strength in the preferred limb. Already in adolescence, there are morphological asymmetries in judo athletes that represent a risk of injury unless they are sufficiently compensated by appropriate symmetrical development exercises, ultimately with a physiotherapist's help. It is also important to continuously monitor body composition quality with the aim of keeping optimal body mass close to the targeted competition weight category, as well as regular monitoring of both morphological and functional strength asymmetries (body composition assessment accompanied by other methods).

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