



RELATIONSHIPS BETWEEN ANTHROPOMETRIC FEATURES, BODY COMPOSITION, AND ANAEROBIC ALACTIC POWER IN ELITE POST-PUBERTAL AND MATURE MALE TAEKWONDO ATHLETES

original paper

doi: 10.1515/humo-2017-0032

MICHAŁ BORACZYŃSKI¹, TOMASZ BORACZYŃSKI¹, ROBERT PODSTAWSKI²,
JAMES LASKIN³, DARIUSZ CHOSZCZ², ADAM LIPIŃSKI²

¹ Józef Rusiecki Olsztyn University College, Olsztyn, Poland

² University of Warmia and Mazury in Olsztyn, Olsztyn, Poland

³ University of Montana, Missoula, USA

ABSTRACT

Purpose. The paper describes the relationships between anthropometric features, body composition, and anaerobic alactic power (AAP) in elite post-pubertal and mature male taekwondo athletes.

Methods. The sample of 41 taekwondo athletes was divided into two groups: post-pubertal (P-P, $n = 19$, $M_{age} = 15.6 \pm 1.1$ years) and mature (M, $n = 22$, $M_{age} = 20.7 \pm 2.8$ years). Anthropometric features (WB-150, ZPU Tryb-Wag, Poland), body composition (BC-418 MA, Tanita, Japan), maturational status (Pubertal Maturational Observational Scale), and AAP (10-s version of the Wingate Anaerobic Test) were assessed.

Results. Post-hoc testing revealed significant between-group differences (3.2–20.4%, $p < 0.01$) in all anthropometric and body composition measures, with effect sizes (ES) between -0.79 and -1.25 ($p < 0.001$), except for fat content and percentage of skeletal muscle mass (SMM) ($p \geq 0.05$). In group M, the maximal power output (P_{max}) was greater (ES = -1.15 , $p < 0.001$) and the time of its attainment shorter (ES = 0.59 , $p < 0.001$) than in group P-P. Correlation analyses indicated notably strong associations between body mass (BM) and P_{max} in group P-P ($r = 0.950$ [95% CI, 0.85–0.98], $p < 0.001$) and M ($r = 0.926$ [95% CI, 0.81–0.97], $p < 0.001$), and similar-sized strong correlations between fat-free mass (FFM) and P_{max} in group P-P ($r = 0.955$ [95% CI, 0.86–0.99], $p < 0.001$) and M ($r = 0.924$ [95% CI, 0.82–0.96], $p < 0.001$). Additionally, a strong correlation was found between body height and P_{max} in groups P-P and M ($r = 0.805$ [95% CI, 0.54–0.92], $p < 0.001$ and $r = 0.819$ [95% CI, 0.58–0.93], $p < 0.001$, respectively). Linear regression analyses demonstrated that FFM, BM, and absolute SMM best explained the variance in P_{max} in both groups (r , 0.939–0.951; r^2 , 0.882–0.909).

Conclusions. The strong correlations observed in both groups between BM, FFM, SMM, and P_{max} demonstrate the significant effects of body size and composition on AAP. By determining the current levels of these measures for individual athletes and via regressive modelling, one can anticipate the individual developmental dynamics of AAP. On the basis of anthropometric profiling, we recommend the recruitment and selection of tall and lean individuals with high anaerobic predisposition in taekwondo. Such a profile may enable coaches to better predict future athlete development, particularly in AAP.

Key words: combat sports, physical features, anaerobic capabilities, Wingate Anaerobic Test

Introduction

Taekwondo (TKD) is a combative, full contact, free sparring, weight-classed competitive sport. This Korean martial art form is considered one of the more physically demanding combat and self-defence techniques. Competitive TKD fighting involves three 3-min rounds interspersed with 1-min rest periods. If the score is tied at the end of the third round, a fourth sudden death or 'golden round' is held. Sparring in TKD involves bouts of intensive effort of 3–5 s, alternating with low inten-

sity periods at an average ratio of 1:3 to 1:4 [1]. Practitioners of TKD believe that the leg, as the longest and strongest extremity, has the greatest potential to exact powerful strikes, at the same time minimizing successful retaliation. For this reason, a successful kick is considered to be dependent on the athlete's ability to generate great muscular force together with speed and unpredictability [2, 3]. TKD training generally involves developing sport-specific skills such as muscular performance, agility, balance, and reaction time [4]. Studies have found that movement speed and coordination are

Correspondence address: Tomasz Boraczyński, Faculty of Physical Education, Józef Rusiecki Olsztyn University College, ul. Bydgoska 33, 10-243 Olsztyn, Poland, e-mail: boraczyński@osw.olsztyn.pl

Received: December 13, 2016

Accepted for publication: August 10, 2017

Citation: Boraczyński M, Boraczyński T, Podstawski R, Laskin J, Choszcz D, Lipiński A. Relationships between anthropometric features, body composition, and anaerobic alactic power in elite post-pubertal and mature male taekwondo athletes. Hum Mov. 2017;18(4):30–40; doi: 10.1515/humo-2017-0032.

the most fundamental components of successful TKD performance [2, 5].

As established in numerous studies, one of the key factors determining the effectiveness of a TKD athlete is body size [6–9]. It was concluded that a number of anthropometric and physiological characteristics appeared to be highly correlated with performance in TKD [4, 9, 10]. For instance, Heller et al. [1] determined that the physiological profile of male and female TKD black belts consisted of very low percentage body fat (%BF) and high fat-free mass (FFM) along with high anaerobic potential. A physiological analysis of competitive sparring has suggested that high performance in TKD is associated with the ability to generate short-term anaerobic power and also to quickly recover after fights [11–13].

Given our knowledge of the various metabolic processes available to supply energy to a working muscle, short-duration maximal intensity activity (up to 5 s) is believed to be met by a ca. 85% contribution of the phosphagen (ATP-PCr) pathway, whereby ca. 10% is met by the glycolytic and ca. 5% by the oxidative pathways [14]. A series of studies [1, 15–19] have further indicated that TKD sparring is an activity that requires large anaerobic alactic power (AAP), explosive strength expressed via the stretch-shortening cycle, agility, and aerobic power. These findings are in line with the metabolic profile of a typical TKD match as developed by Campos et al. [12]. Studying a simulated competition (three 2-min rounds interspersed with 1-min recovery), they found that the anaerobic alactic and lactic processes contributed to $30 \pm 6\%$ and $4 \pm 2\%$ of total energy expenditure, respectively.

For the above reasons, training adaptations in TKD need to be based on the improvement of sport-specific skills, dominated by anaerobic processes. Although the contribution of anthropometric features and body composition in TKD performance was to some extent recognized in adult athletes, these variables in relation to AAP have not been well-studied in elite-level adolescent (pubertal and post-pubertal) or young adult (mature) athletes. This deficiency is pertinent as while body size is one of the factors determining TKD performance, it is confounded by variation in maturity status. The effects of growth- and maturity-related changes in puberty need to be considered when administering exercise tests and comparing outcome measures, particularly during the talent identification stage [20]. It is natural that as biological age increases, the anthropometric features and body tissue components change, and subsequent maturation of the nervous, endocrine, muscular, and cardiovascular systems is generally associated with enhanced neuromuscular function [20, 21]. In this context, an unexplained interaction in TKD athletes of various age groups (who are often highly differentiated by maturational status) are the relationships between the individual body size, body composition, and measures of the anaerobic alactic and lactic energy systems. The short-

age of detailed knowledge regarding these complex relationships and the adaptive processes triggered by the use of specialized loads in TKD training represents a challenge for those working with young elite-level athletes. Problematic is also the lack of a gold standard in the assessment of anaerobic power in TKD [22]. Previous investigations have frequently applied the Wingate Anaerobic Test (WAnT) to ascertain the anaerobic profile of TKD and other martial arts athletes [23]. While non-specific to the movement structure in TKD, the WAnT has been validated by the more TKD-specific Adapted Anaerobic Kick Test, showing strong correlations across six anaerobic variables (r , 0.543–0.865) [24]. This has been explained by the intermittent activity of TKD competition, which elicits a high neuromuscular activation of the lower extremities [23]. Presently, the WAnT still remains the most common and most universal method of assessing peak anaerobic power and capacity and is considered the most appropriate in evaluating the anaerobic profile of TKD competitors [24].

Therefore, the aim of this study was to examine the quantity and relationships between anthropometric features, body composition, and AAP variables in elite male TKD athletes of two different age brackets, those biologically immature (post-pubertal) and mature (young adults), and consequently at different stages in their training career. It was assumed that as age and training experience increased, so would AAP owing to the impact of specialized TKD training loads (i.e. efforts based on overcoming large external resistance with maximal velocity) whose energy demands were primarily met by anaerobic metabolism. With this in mind, we formulated the following research questions:

- What are the anthropometric, body composition, and AAP characteristics of TKD athletes of different ages and training experience?
- To what extent do the values of these anthropometric and body composition measures and AAP variables differentiate athletes of different ages and training experience?
- Are the correlations between anthropometry, body composition, and AAP in mature athletes, with longer training and competitive experience, different than in post-pubertal athletes?

Material and methods

Ethical approval

The study was approved by the institutional review board and conducted in accordance with the ethical standards established by the Declaration of Helsinki. Informed consent was obtained from all participants over legal age, otherwise from their parent or legal guardian.

Participants

In this investigation, a non-experimental, descriptive correlational design was adopted to study a sample of male TKD athletes ($n = 41$; age range, 13.6–26.2 years). The inclusion criteria were: (a) good health status, (b) minimum 3 years training experience, and (c) elite-level competitive experience – the minimum requirement was being a medallist in the Polish championships. In addition, each participant needed to be medically cleared and certified for exercise testing. All the athletes were free from any lower body injury or neuromuscular disorder. The majority of the recruited athletes had achieved a significant competitive success. In total, 22 were junior or senior Polish championships masters, 7 were internationally ranked athletes (1st and 3rd places in the European championships), and 2 were ranked 5th and 6th in the World Taekwondo Championships; 36 of the participants were also under the supervision of 2 former national team coaches during the study duration.

The total sample was divided into two groups according to the maturational status: post-pubertal (P-P, $n = 19$, $M_{age} = 15.6 \pm 1.1$ years) and mature (M, $n = 22$, $M_{age} = 20.7 \pm 2.8$ years). In group P-P, the age distribution was 13 years ($n = 2$), 14 years ($n = 4$), 15 years ($n = 5$), and 16 years ($n = 8$). In group M, the age distribution was 19 years ($n = 5$), 20 years ($n = 7$), 21 years ($n = 6$), 22 years ($n = 3$), and 24 years ($n = 1$). The distribution of the athletes according to weight class was < 58 kg ($n = 4$), < 68 kg ($n = 10$), < 80 kg ($n = 3$), and > 80 kg ($n = 2$) in group P-P and < 68 kg ($n = 5$), < 80 kg ($n = 8$), and > 80 kg ($n = 9$) in group M. Twelve athletes from group P-P were holders of 1st–3rd *poom* and 7 were holders of 4th *poom*. Sixteen athletes from group M had black belts (1–3 *dan*). The training experience of group M was almost twice that of group P-P (11.2 ± 3.3 and 6.9 ± 2.1 years, respectively).

Strength and conditioning training programs

This study was conducted over a timeframe of 4 weeks during a training mesocycle in a pre-competition period. Athletes from group P-P participated in 16 training sessions, four 1.5–2-h sessions per week. Athletes in group M attended 24 training sessions, 6 times per week, 2–2.5 hours per day. The training intensity was monitored throughout to ensure that a standardized training stimulus was administered by recording heart rate (HR) with a portable transmitter (Polar T-31, Polar Electro OY, Kempele, Finland). Because maximal heart rate (HR_{max}) is determined by age, we adopted the equation:

$$HR_{max} = 205 - 0.5 \times \text{age}$$

to individually determine HR_{max} for each athlete [25]. This method was used to quantify the internal training load.

Table 1 presents the detailed training characteristics (training zones and loads) of groups P-P and M. For group P-P, slight differences (14.3%) were present between the amount of training involving targeted and specialized exercises, although both mainly involved the contribution of the aerobic and anaerobic pathways (2 and 3). Training conducted in the zones developing the lactic (4) and alactic (5) anaerobic systems accounted for 16.6% of the total training load. Training designed to actively recover aerobic capacity at very low intensity (1) involved only general exercises. For group M, the volume and intensity of aerobic training was identical to that of group P-P. However, there was a greater share of aerobic training performed by group M at lower intensity (2). The greatest differences between the training structure of group M and group P-P concerned the amount of specialized training employed at moderate

Table 1. Training loads (min) corresponding to the types of training and intensity zones during the selected training microcycle in post-pubertal (P-P) and mature (M) taekwondo athletes

	Type of training	Training intensity zone						Σ 1–5
		1	2	3	4	5	[6]	
Group P-P	G	75					60	75
	T		60	30	7.5	7.5		105
	S		45	30	7.5	7.5		90
	Σ G/T/S	75	105	60	15	15	60	270
Group M	G	75						75
	T		75				90	75
	S		75	150	45	30		300
	Σ G/T/S	75	150	150	45	30	90	450

Types of training: G – general, T – targeted, S – specialized

Training zones:

1 – aerobic active recovery (65% HR_{max} [120 beats/min])

2 – aerobic endurance (< 85% HR_{max} [160–180 beats/min])

3 – mixed (aerobic–anaerobic, > 95% HR_{max} [> 180 beats/min])

4 – anaerobic lactic (> 95% HR_{max} [> 190 beats/min])

5 – anaerobic alactic (65–90% HR_{max} [130–180 beats/min])

6 – muscular hypertrophy (highly varied HR)

to high intensities (3–5). For example, mixed training (3) in group M involved 5 times more specialized exercises than in group P-P. Totalled across the entire microcycle, the specialized exercises performed by group P-P accounted for only 30% of those performed by group M.

Maturation status

The maturational status of group P-P was determined with a slightly modified version of the Pubertal Maturational Observational Scale (PMOS) [26]. The PMOS utilizes parental questionnaires and investigator observations to classify individuals into four pubertal categories (pre-pubertal, early pubertal, pubertal, post-pubertal) and was used to affirm the P-P cohorts as pubertal ($n = 4$, equivalent to Tanner stage IV) and post-pubertal ($n = 15$, equivalent to Tanner stage V). The PMOS has shown high reliability and can be applied to differentiate pubertal stages on the basis of indicators of adolescent growth, axillary and leg hair growth, muscular development, presence of acne, and evidence of sweating during physical activity [26, 27].

Anthropometry and body composition

Measurements of body height (BH) to the nearest 0.1 cm and body mass (BM) to the nearest 0.1 kg were performed with a scale/stadiometer (WB-150, ZPU Tryb-Wag, Poland) in the morning in a fasted state. Body mass index (BMI) was calculated to determine the weight status. Body composition, including %BF, fat mass (FM), and FFM, was determined by bioelectric impedance analysis (BC-418 MA, Tanita, Japan). Total-body skeletal muscle mass (SMM) was calculated on the basis of an equation developed by Lee et al. [28]

$$\text{SMM [kg]} = 0.244 \times \text{BM} + 7.80 - \text{BH} - 0.098 \times \text{age} + 6.6 \times \text{sex} + \text{race} - 3.3$$

where sex is 1 for male and 0 for female, and race is 1.4 for African American, 0 for white or Hispanic, and -1.2 for Asian ethnicity. Additionally, total-body SMM was also indicated as a percentage (%SMM). All anthropometric measurements were carried out by the same certified investigator in compliance with the procedures recommended by the International Society for Advancement of Kinanthropometry (ISAK).

Anaerobic alactic power (Wingate Anaerobic Test protocol)

AAP was assessed with the use of a 10-s variant of the WAnT on a calibrated cycle ergometer (874-E, Monark Exercise, Sweden) integrated with a PC. The WAnT is the most commonly applied test to assess anaerobic power and capacity, with previous studies confirming

its reliability [29] and validity [30]. The WAnT was performed in accordance with standardized methodology [31], in which exercise lasting up to 10 s is believed to employ predominantly the phosphagen system. For the purposes of our study, we accepted that a 10-s version of WAnT could provide a valid measure of short-term maximal AAP.

On the day prior to testing, the participants performed a shortened 1.5-h training session at low and moderate intensity (65–85% HR_{max} training zone). The WAnT was implemented before noon (10:00–12:00), with resistance individually adjusted relative to BM (7.5% of BM). In accordance with standardized procedures [31], the testing was preceded by a 10-min warm-up on a cycle ergometer (load, 2.0 W/kg BM), with the participant's pedalling at 60 rpm interspersed with three all-out sprints (ca. 90 rpm) lasting 2–3 s in order to elicit HR between 150 and 160 beats/min. The participants then rested for 5 min before performing the WAnT. During the test, they were instructed to remain seated and were verbally encouraged by the researchers and other participants to provide maximal effort in the full 10 s of the test.

Four variables were adopted to analyse AAP: maximal power output (P_{max}), defined as the average value of power during the time at or above 97.7% of peak power (P_{peak}) and expressed in W; relative P_{max} (P_{max}/BM), determined by dividing P_{max} by BM and expressed as W/kg; time of attained P_{max} (T_{at}), expressed in s; and time of sustained P_{max} (T_{su}), also expressed in s. Real time P_{peak} was recorded at the frequency of 1000 Hz.

Statistical analysis

Data are presented as means or relative changes (%) with standard deviations ($\pm SD$). Coefficients of variance (CV) were also calculated for all measures. The distribution of the data was analysed with the Shapiro-Wilk test. To test the assumption of homogeneity of variance, Levene's test was applied. To detect any significant differences between the mean values, one-way analysis of variance (ANOVA) was used. The alpha level of 0.05 was assumed as statistically significant. Multiple pairwise comparisons were made post hoc with the Tukey's honestly significant difference test (HSD). The differences were expressed as Cohen's d at 95% confidence intervals ($\pm 95\% \text{ CI}$) with the use of pooled SD . Threshold values for effect sizes (Cohen's d) were 0.2 (small), 0.5 (medium), and 0.8 (large) [32]. Pearson's product-moment correlation coefficients (r) were determined between the values of age, training experience, BH, BM, body composition, and the AAP variables. For the interpretation of correlational effects (the magnitudes of r), the benchmarks established by Cohen were applied: < 0.10 (trivial), 0.10–0.29 (small), 0.30–0.49 (moderate), and ≥ 0.50 (large) [32]. The independent associations of age, BH, BM, body fat, and SMM with P_{max} were evaluated with a linear regression model. The Statistica 10 package (StatSoft Inc., Tulsa, USA) was used for all statistical analyses.

Ethical approval

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

Results

Statistical testing confirmed the normal distribution of the data set in each group (normal Gaussian distribution) and the assumption of homogeneity of variance between the groups for all variables. Subsequent analysis of the groups' training characteristics during the studied pre-competition period proved that group M implemented greater training loads and at a higher intensity (particularly specialized loads), conceivably owing to the developmental maturation and longer training experience of the group. Table 2 presents the body size, body composition, and AAP variables. As the participants from group P-P were younger and in a period of rapid development, they were unsurprisingly characterized by a number of significantly lower anthropometric and body composition values ($p < 0.01$). The only body tissue components that did not differ between the groups ($p \geq 0.05$) were fat content, both as %BF and total measure (FM), and percentage skeletal muscle mass (%SMM). The remaining anthropometric features and body tissue components that significantly differentiated the groups were: BH (by 3.2%; $d = -0.79, p < 0.001$), BM (by 18.8%; $d = -1.06, p < 0.001$), FFM (by 20.4%; $d = -1.25, p < 0.001$),

SMM (by 20.2%; $d = -1.22, p < 0.001$), and BMI (by 11.6%; $d = -1.08, p < 0.01$). It should be noted that these variables are interdependent: BMI is a derivative of BH and BM; SMM is the main part of FFM, which itself is a component of BM. Group M was found with significantly larger values of P_{max} and $P_{max/BM}$, as confirmed by the large effect sizes. However, the magnitude of these differences was quite different. There was a greater difference between the two groups in P_{max} (by 26.4%; $d = -1.15, p < 0.001$) than in $P_{max/BM}$ (by 7.0%; $d = -0.87, p < 0.01$). The T_{at} in group M was significantly shorter (by 10.8%; $d = 0.59, p < 0.001$). Although the T_{su} was also shorter (by 8.9%) in group M, this difference was not statistically significant ($p = 0.2428$).

Tables 3 and 4 independently present the correlation analyses (intercorrelation matrices) performed in groups P-P and M, respectively. Many of these relationships are very high, given that the individual body tissue components are interdependent. There were a number of similar-sized correlations in group P-P. This group demonstrated statistically significant relationships between P_{max} with age ($r = 0.616$ [95% CI, 0.23–0.83], $p < 0.01$) and training experience ($r = 0.560$ [95% CI, 0.15–0.81], $p < 0.05$). However, no significant relationships were observed in group M between P_{max} , age, and training experience (all $p \geq 0.05$) as these correlations were classified as trivial to small. Group P-P demonstrated a statistically significant relationship between $P_{max/BM}$ and age ($r = 0.527$ [95% CI, 0.17–0.78], $p \leq 0.05$), but much larger with training experience ($r = 0.714$ [95% CI, 0.22–0.85], $p < 0.001$). Concurrently,

Table 2. Age, training experience, body mass and composition, and AAP variables between the post-pubertal (P-P) and mature (M) groups of taekwondo athletes

Variables		Age	TE	BH	BM	BF	FM	FFM	SMM	SMM	BMI	P_{max}	$P_{max/BM}$	T_{at}	T_{su}
		(years)	(years)	(cm)	(kg)	(%)	(kg)	(kg)	(%)	(kg)	(kg/m ²)	(W)	(W/kg)	(s)	(s)
Group P-P	Mean	15.55	6.9	175.2	64.7	14.0	9.22	55.5	44.9	29.0	21.0	719.2	11.0	4.8	3.3
	SD	1.08	2.13	7.07	11.23	2.50	2.89	8.75	1.55	4.37	2.41	168.22	0.97	0.75	0.95
	95% CI <	15.03	5.96	171.8	59.28	12.81	7.83	51.26	41.62	26.86	17.79	638.11	10.56	4.40	2.80
	95% CI >	16.07	8.01	178.6	70.10	15.21	10.61	59.70	47.36	31.07	22.11	800.19	11.50	5.12	3.72
	CV%	6.96	30.44	4.03	17.4	17.9	31.38	15.8	3.5	15.1	11.5	23.39	8.8	15.9	29.2
Group M	Mean	20.70	11.2	180.8	76.8	12.9	10.03	66.8	45.3	34.8	23.4	908.7	11.8	4.3	3.0
	SD	2.80	3.31	7.27	11.83	3.12	3.53	9.46	1.84	5.22	2.16	165.71	0.83	0.98	0.60
	95% CI <	19.46	9.76	177.6	71.59	11.52	8.46	62.60	39.91	32.50	22.42	835.23	11.43	3.82	2.69
	95% CI >	21.94	12.71	184.0	82.09	14.28	11.60	71.00	48.73	37.12	24.34	982.21	12.17	4.68	3.22
	CV%	13.53	29.47	4.02	15.4	24.2	35.18	14.2	4.06	15.0	9.2	18.2	7.0	23.0	20.3
Effect size (<i>d</i>)	-2.39	-1.52	-0.80	-1.07	0.39	-0.25	-1.25	-0.12	-1.22	-1.08	-1.15	-0.87	0.59	0.39	
ANOVA (<i>p</i>)	≤ 0.001	≤ 0.001	0.0160	0.0018	0.2190	0.4271	≤ 0.001	0.4762	≤ 0.001	0.0016	≤ 0.001	0.0091	≤ 0.001	0.2428	
Difference (%)	33.2	60.5	3.2	18.8	8.0	8.9	20.4	1.1	20.2	11.6	26.4	7.0	10.8	8.9	

TE – training experience, BH – body height, BM – body mass, BF – body fat, FM – fat mass, FFM – fat-free mass, SMM – skeletal muscle mass, BMI – body mass index, P_{max} – absolute maximal power output, $P_{max/BM}$ – relative maximal power output, T_{at} – time of attained maximal power output, T_{su} – time of sustained maximal power output, SD – standard deviation, CI – confidence interval, CV – coefficient of variance

Table 3. Intercorrelation matrix for age, training experience, body mass and composition, and AAP variables in the post-pubertal (P-P) group of taekwondo athletes

Variables	Age	TE	BH	BM	BF	FM	FFM	%SMM	SMM	BMI	P _{max}	P _{max} /BM	T _{at}	T _{su}
Age (years)	X	0.634**	0.609**	0.574**	-0.086	0.298	0.639**	0.099	0.678**	0.435	0.616**	0.527*	-0.517*	0.018
TE (years)		X	0.451*	0.393	-0.010	0.255	0.421	0.045	0.449	0.261	0.560*	0.714***	-0.309	-0.285
BH (cm)			X	0.820***	0.305	0.638**	0.842	-0.466*	0.843***	0.560*	0.805***	0.556*	-0.473*	0.178
BM (kg)				X	0.564*	0.892***	0.989**	-0.677**	0.984***	0.931***	0.950***	0.536*	-0.425	0.171
BF (%)					X	0.871***	0.436	-0.597**	0.508*	0.632*	0.437	-0.010	0.244	-0.017
FM (kg)						X	0.815***	-0.717***	0.851***	0.890***	0.802***	0.324	-0.119	0.073
FFM (kg)							X	-0.632**	0.982***	0.901***	0.955***	0.581**	-0.564**	-0.452*
%SMM (%)								X	-0.542**	-0.705***	-0.605**	-0.254	0.120	-0.092
SMM (kg)									X	0.892***	0.941***	0.552*	-0.557**	-0.440
BMI (kg/m ²)										X	0.863***	0.424	-0.302	0.138
P _{max} (W)											X	0.766***	-0.487*	0.018
P _{max} /BM (W/kg)												X	-0.472*	-0.238
T _{at} (s)													X	-0.230
T _{su} (s)														X

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$; TE – training experience, BH – body height, BM – body mass, BF – body fat, FM – fat mass, FFM – fat-free mass, SMM – skeletal muscle mass, BMI – body mass index, P_{max} – absolute maximal power output, P_{max}/BM – relative maximal power output, T_{at} – time of attained maximal power output, T_{su} – time of sustained maximal power output

Table 4. Intercorrelation matrix for age, training experience, body mass and composition, and AAP variables in the mature (M) group of taekwondo athletes

Variables	Age	TE	BH	BM	BF	FM	FFM	%SMM	SMM	BMI	P _{max}	P _{max} /BM	T _{at}	T _{su}
Age (years)	X	0.782***	-0.171	-0.083	-0.251	-0.252	-0.010	0.141	-0.025	0.028	0.073	0.407	-0.297	-0.356
TE (years)		X	0.134	0.136	-0.051	-0.004	0.171	0.063	0.169	0.113	0.333	0.566**	-0.489*	-0.240
BH (cm)			X	0.844***	0.023	0.434*	0.893***	0.193	0.899***	0.527*	0.819***	0.272	-0.425*	-0.358
BM (kg)				X	0.359	0.753***	0.969***	-0.150	0.961***	0.899**	0.926***	0.228	-0.520*	-0.354
BF (%)					X	0.870***	0.870***	-0.868***	0.121	0.540**	0.233	-0.196	-0.008	0.281
FM (kg)						X	0.568**	-0.685**	0.561**	0.825***	0.626**	-0.024	-0.232	0.025
FFM (kg)							X	0.068	0.993***	0.816***	0.924***	0.294	-0.507*	0.196
%SMM (%)								X	0.124	-0.382	-0.080	0.138	-0.095	-0.299
SMM (kg)									X	0.798***	0.907***	0.267	-0.454	0.184
BMI (kg/m ²)										X	0.801***	0.139	-0.500*	-0.301
P _{max} (W)											X	0.576**	-0.578**	-0.343
P _{max} /BM (W/kg)												X	-0.395	-0.187
T _{at} (s)													X	0.578**
T _{su} (s)														X

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$; TE – training experience, BH – body height, BM – body mass, BF – body fat, FM – fat mass, FFM – fat-free mass, SMM – skeletal muscle mass, BMI – body mass index, P_{max} – absolute maximal power output, P_{max}/BM – relative maximal power output, T_{at} – time of attained maximal power output, T_{su} – time of sustained maximal power output

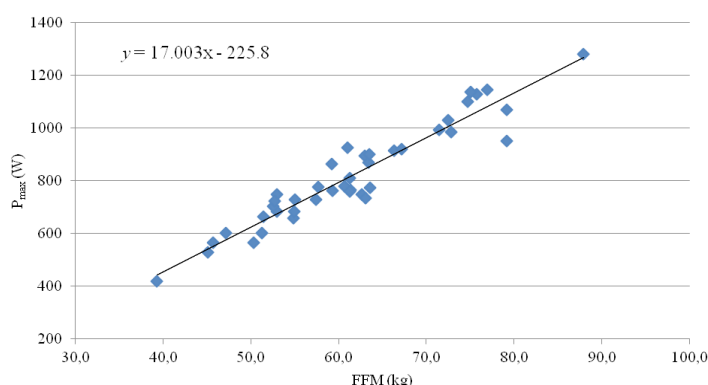


Figure 1. Relationship between fat-free mass (FFM) and absolute maximal power output (P_{max}) for the whole sample ($n = 41$; $r = 0.953$, $r^2 = 0.909$, $p < 0.01$)

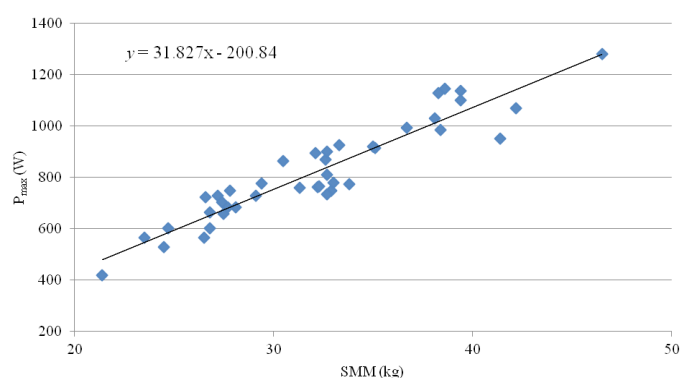


Figure 3. Relationship between absolute skeletal muscle mass (SMM) and absolute maximal power output (P_{max}) for the whole sample ($n = 41$; $r = 0.939$, $r^2 = 0.882$, $p < 0.001$)

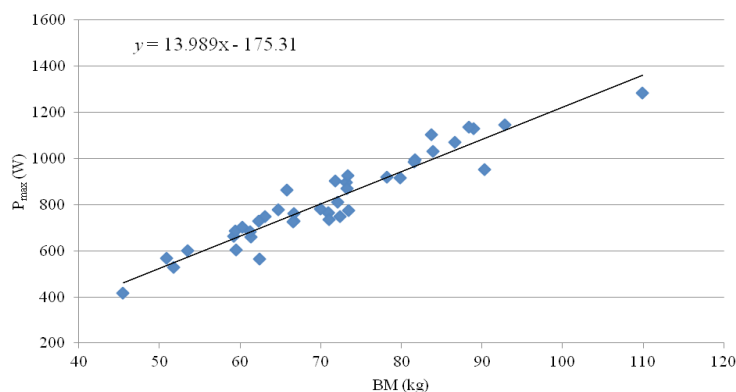


Figure 2. Relationship between body mass (BM) and absolute maximal power output (P_{max}) for the whole sample ($n = 41$; $r = 0.951$, $r^2 = 0.905$, $p < 0.001$)

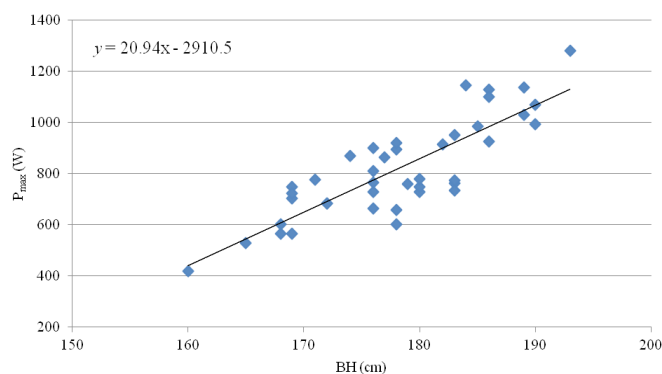


Figure 4. Relationship between body height (BH) and absolute maximal power output (P_{max}) for the whole sample ($n = 41$; $r = 0.840$, $r^2 = 0.705$, $p < 0.001$)

group M was found to present a statistically significant relationship between P_{max}/BM and training experience ($r = 0.566$ [95% CI, 0.16–0.80], $p < 0.01$), but not between P_{max}/BM and age ($p \geq 0.05$).

Group M was observed to show a large negative correlation between P_{max} and T_{at} ($r = -0.578$ [95% CI, 0.17–0.85], $p < 0.01$) and also a large but positive correlation between T_{at} and T_{su} ($r = 0.578$ [95% CI, 0.19–0.84], $p < 0.01$). Group P-P demonstrated no such relationship between P_{max} and T_{at} ($p \geq 0.05$) or T_{at} and T_{su} ($p \geq 0.05$). Correlation analyses revealed notably high coefficient values (r) between BM and P_{max} in groups P-P ($r = 0.950$ [95% CI, 0.85–0.98], $p < 0.001$) and M ($r = 0.926$ [95% CI, 0.81–0.97], $p < 0.001$) and similarly-sized large correlations between FFM and P_{max} in groups P-P ($r = 0.955$ [95% CI, 0.86–0.99], $p < 0.001$) and M ($r = 0.924$ [95% CI, 0.82–0.96], $p < 0.001$). Additionally, a strong correlation was found between P_{max} and BH in groups P-P and M ($r = 0.805$ [95% CI, 0.54–0.92], $p < 0.001$ and $r = 0.819$ [95% CI, 0.58–0.93], $p < 0.001$, respectively).

Linear regression analyses were employed to examine the relationships between P_{max} and the measures of age, training experience, BH, BM, BF (% and kg), FFM, SMM (% and kg), and BMI. Figures 1–4 present the lin-

ear regressions of the four variables that best explain P_{max} (W) in the whole sample of 41 TKD athletes ($r = 0.939$ – 0.953 , $r^2 = 0.882$ – 0.909). Regression analysis for P_{max} and BH was also performed, and a strong relationship between the two variables was observed ($r = 0.840$, $r^2 = 0.705$). Regression analyses performed separately for each group demonstrated that FFM, BM, and absolute SMM offered the best overall explanation of P_{max} (W) in group P-P ($r = 0.941$ – 0.955 , $r^2 = 0.879$ – 0.912). A similar relationship (with high predictive r^2 values) was also observed in group M ($r = 0.907$ – 0.926 , $r^2 = 0.814$ – 0.855).

Discussion

This study aimed to determine the relationships between anthropometric features, body composition, and measures of AAP in post-pubertal (P-P) and mature (M) elite male TKD athletes. To date, only a limited number of studies have compared the associations between the aforementioned variables in these two populations [7]. This is regrettable as differences in anthropometry and other physiological characteristics at various training stages can influence TKD performance and competitive

success [6]. Body size and composition are particularly important attributes in weight-sensitive sports such as TKD [4, 33]. Available studies on these characteristics have reported a variety of findings. Research on elite male TKD somatotypes has proved the ecto-mesomorphic body type most dominant [8]. In a study by Noh et al. [8], the –80 kg weight class had the highest mesomorphic and the lowest endomorphic component value. Other works have indicated that even 8 weeks of pre-season TKD training is beneficial in reducing BM, %BF, and fat tissue [9], thus impacting technical skills and moves. The beneficial effects of TKD training were also indicated by Toskovic et al. [13], who estimated that around 30 min of TKD practice three times per week was sufficient in controlling BM and enhancing fat loss. In the present study, athletes from group M had 8.0% lower %BF than those from group P-P, but this difference was not statistically significant ($p = 0.2190$) owing to large inter-individual differences (17.9% CV in P-P, 24.2% CV in M). This finding was anticipated, as it is well known that both body size (BH and BM) and body tissue components (FFM and SMM) increase during maturation and reach peak values after puberty [34]. SMM also increases with age until the end of adolescence, approximating 54% of BM in boys at 17 years of age [34]. In group M, the significantly higher values of BM, FFM, and SMM, lower levels of BF, with relatively minor differences in BH were undoubtedly the result of more advanced development, longer training experience, and larger training loads.

As mentioned, various anthropometric measures were found to be highly correlated with TKD performance [4, 9, 10]. This was confirmed by our study, where the very high correlations observed between BM, FFM, SMM, and P_{\max} are indicative of a series of cause-effect relationships. One study involving professional athletes also proved a relationship between measures of BH and lower limb anaerobic power [35]. Our results point to the existence of a strong correlation between BH and P_{\max} in elite-level male TKD athletes; this relationship was noted both in group P-P ($r = 0.805$ [95% CI, 0.54–0.92], $p < 0.001$) and in group M ($r = 0.819$ [95% CI, 0.58–0.93], $p < 0.001$). Accordingly, the selection of future TKD athletes should take into account the BH.

The biggest difference that we observed between groups P-P and M concerned P_{\max} (26.4%, $p < 0.001$), followed by the difference in FFM (20.4%, $p < 0.001$) and SMM (20.2%, $p < 0.001$). The significant difference in P_{\max} could be attributed to increased FFM (mainly SMM) and enhanced anaerobic performance, itself associated with the effects of intensive TKD training [1, 16]. Increased SMM in group M may also explain the significant between-group differences in P_{\max} and other AAP variables found in our study. Strength and power development during puberty is known to be influenced by the linear increase of skeletal muscle size and mass [5, 36–38]. Even a slight increase in SMM in males be-

fore puberty can raise their work efficiency [39]. One must also take into account that efficient and effective motor performance has a genetic aspect. Furthermore, muscle strength and power are especially subject to modification by resistance training which modifies maximal motor unit recruitment. It has been demonstrated that, compared with adults, adolescents show decreased recruitment and/or are unable to utilize full motor unit potential during resistance training [40] because of inefficient and ineffective neuromuscular activation. Therefore, the significant between-group difference in P_{\max} compared with the differences in BM, FFM, and SMM could result from a higher level of neuromuscular coordination in group M.

A number of studies have reported that TKD training could improve muscular strength and power in young and experienced athletes [1, 13, 17]. In a sample of post-pubertal males ($n = 19$, $M_{\text{age}} = 13.8 \pm 2.2$ years), Melhim [17] found significant increases in peak anaerobic power (28%, $p < 0.05$) after 8 weeks (three 50-min sessions per week) of specific TKD training. The intense utilization of AAP in TKD has been found to result in high post-sparring concentrations of blood lactate in elite athletes [18]. Another research group [5] studied 7 international-level female TKD fighters ($M_{\text{age}} = 22.9 \pm 3.5$ years) to find mean post-fight blood lactate of 11.7 ± 1.8 mmol/l. A similar value (11.9 mmol/l ± 2.1) was obtained by Bridge et al. [11] in 8 male TKD black belts ($M_{\text{age}} = 22.0 \pm 4.0$ years) following competition. Given these insights, the significant differences in P_{\max} compared with the differences in FFM and SMM between groups P-P and M appear to be rather a result of TKD AAP-oriented skills and specialized training. This kind of training protocol may elicit biochemical adaptations in skeletal muscles and associated enhanced enzymatic activity, catalysing energy generation and higher concentrations of phosphagens in skeletal muscles [1, 15–18, 41].

When compared with literature data, the between-group differences in the absolute values of P_{\max} were substantially lower than the 121% increase of P_{peak} found by Armstrong et al. [34] in a group of untrained 12–17-year-old boys. An explanation for the seemingly small differences obtained in our study may well be that the participants comprised an elite group of TKD athletes with high anaerobic potential, enhanced by their relatively extensive training experience (11.2 ± 3.3 years). In addition, the small percentage difference between the studied groups in terms of P_{\max}/BM (7.0%) compared with the significant difference in P_{\max} (26.4%) may indicate a minor impact of specific TKD training on the mechanical exercise performed on a cycle ergometer. However, a more TKD-specific evaluation of AAP in the form of a 10-s repetitive kick test proposed by Santos and Franchini [42] may have demonstrated greater differences between the groups.

The significantly higher P_{\max} and significantly shorter T_{at} found in group M could probably be due to matured

motor skills. Such functional adaptations could augment both power production (strength) and maximal movement dynamics (speed) in movements lasting less than 5 s. The effectiveness of this performance is inherently determined by the simultaneous recruitment of motor units and a high capacity for power generation [43]. On the basis of these assumptions, it can be considered that with an increase in P_{\max} , the T_{at} would be reduced. The WAnT-determined $P_{\max/\text{BM}}$ achieved by group M (11.8 ± 0.8 W/kg) was identical to that found in elite senior American TKD athletes (11.8 ± 2.0 W/kg) [44] and only slightly lower than the value observed in Czech TKD athletes (12.1 W/kg) [1]. This result confirms the high AAP level in both studied groups and simultaneously indicates the elite nature of these TKD athletes.

As reported above, the results of our study confirm the findings evidenced by a number of authors on the strong relationships between body size (anthropometric features and body composition), anaerobic power, and performance in TKD. We believe that the study highlights the importance of making comparisons as presented herein, as they could assist national TKD teams in establishing a training program focused on improving the physiological characteristics most critical in elite TKD performance.

The limitations pertaining to the study design are its cross-sectional nature, relatively wide range of age within the groups, and significant differences in body size and training experience. Additional research should address these shortcomings in order to ascertain a more detailed understanding of the associations between anthropometric characteristics (e.g., lower extremity length) and alactic and lactic AP indexes. In particular, future investigative efforts are needed to quantify these findings in elite TKD athletes during the training macrocycle (preparatory, competitive, and off-season). Finally, more applicative conclusions could be drawn by adopting an allometric scaling approach to determine the relationships between body size and composition and WAnT-determined power data.

Conclusions

The presented study is one of the few ones that have examined the complex relationships between body size and composition measures and AAP in male elite TKD athletes across developmental stages. The two examined groups of post-pubertal (group P-P) and mature (group M) TKD practitioners were exemplified with a high level of AAP although they differed in P_{\max} , with group M attaining significantly higher values in significantly less time (T_{at}). This, to a large extent, was believed to result from significantly advanced BH, BM, FFM, SMM, as well as longer training experience and larger training loads.

The relatively larger between-group differences in P_{\max} than in BM, FFM, and SMM could be a result of enhanced neuromuscular coordination in group M as a consequence of TKD AAP-oriented skills and specialized training. In turn, the relatively minor between-group differences in $P_{\max/\text{BM}}$ can be credited as a function of motor unit potential, itself determined by genetic factors that may therefore constrain the effects of training on AAP. This genetic aspect highlights the limited potential of training for developing AAP.

The strong correlations observed in both groups among BH, BM, FFM, SMM, and P_{\max} demonstrate the significant effects of body size and body composition on AAP. In light of the strong influence of genetics on both body characteristics and motor unit potential, we recommend the recruitment and selection processes in TKD focus on tall and lean individuals with high AAP predispositions. By considering such a profile, coaches may better predict future athlete development, particularly in AAP, an essential element in TKD performance.

The present findings also indicate the possibility of further enhancing AAP in TKD athletes specific resistance training aimed at increasing SMM and strength. Taking into account that group P-P executed a relatively uniform training protocol, systematic improvements could be expected in the magnitude of the AAP variables considered herein. By determining the current level of these variables for individual athletes and via regressive modelling, it is possible to anticipate the developmental dynamics of AAP on a per-individual basis.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

Authors state no conflict of interest.

References

1. Heller J, Peric T, Dlouhá R, Kohlíková E, Melichna J, Nováková H. Physiological profiles of male and female taekwon-do (ITF) black belts. *J Sports Sci.* 1998;16(3):243–249; doi: 10.1080/026404198366768.
2. Kazemi M, Perri G, Soave D. A profile of 2008 Olympic taekwondo competitors. *J Can Chiropr Assoc.* 2010;54(4):243–249.
3. Wąsik J. Structure of movement of a turning technique used in the event of special techniques in taekwon-do ITF. *Arch Budo.* 2009;5:111–115.
4. Arabacı R, Görgülü R, Çatıkkaş F. Relationship between agility and reaction time, speed and body mass index in taekwondo athletes. *Sports Sci.* 2010;5(2):71–77.
5. Marković G, Vucetić V, Cardinale M. Heart rate and lactate responses to taekwondo fight in elite women performers. *Biol Sport.* 2008;25(2):135–146.
6. Gao B, Zhao Q, Liu B. Measurement and evaluation on body composition and figure of taekwondo athlete. *J Xi'an Institute Phys Educ.* 1998;15:29–33.

7. Ghorbanzadeh B, Müniroğlu S, Akalan C, Khodadadi MR, Kirazci S, Şahin M. Determination of taekwondo national team selection criteria by measuring physical and physiological parameters. *Ann Biol Res.* 2011;2(6):184–197.
8. Noh JW, Kim JH, Kim J. Somatotype analysis of elite taekwondo athletes compared to non-athletes for sports health sciences. *J Toxicol Environ Health Sci.* 2013;5(4):189–196; doi: 10.1007/s13530-013-0178-1.
9. Seo MW, Jung HC, Song JK, Kim HB. Effect of 8 weeks of pre-season training on body composition, physical fitness, anaerobic capacity, and isokinetic muscle strength in male and female collegiate taekwondo athletes. *J Exerc Rehabil.* 2015;11(2):101–107; doi: 10.12965/jer.150196.
10. Kim HB, Jung HC, Song JK, Chai JH, Lee EJ. A follow-up study on the physique, body composition, physical fitness, and isokinetic strength of female collegiate taekwondo athletes. *J Exerc Rehabil.* 2015;11(1):57–64; doi: 10.12965/jer.150186.
11. Bridge CA, Jones MA, Drust B. Physiological responses and perceived exertion during international taekwondo competition. *Int J Sports Physiol Perform.* 2009;4(4):485–493; doi: 10.1123/ijspp.4.4.485.
12. Campos FA, Bertuzzi R, Dourado AC, Santos VG, Franchini E. Energy demands in taekwondo athletes during combat simulation. *Eur J Appl Physiol.* 2012;112(4):1221–1228; doi: 10.1007/s00421-011-2071-4.
13. Toskovic NN, Blessing D, Williford HN. The effect of experience and gender on cardiovascular and metabolic responses with dynamic Tae Kwon Do exercise. *J Strength Cond Res.* 2002;16(2):278–285; doi: 10.1519/1533-4287(2002)016<0278:TEOEG>2.0.CO;2.
14. Hultman E, Sjöholm H. Substrate availability. In: Knuttgen HG, Vogel JA, Poortmans J (eds.), *Biochemistry of exercise*. Champaign: Human Kinetics; 1983; 63–75.
15. Butios S, Tasika N. Changes in heart rate and blood lactate concentration as intensity parameters during simulated taekwondo competition. *J Sports Med Phys Fitness.* 2007;47(2):179–185.
16. Pieter W, Heijmans J. Training and competition in taekwondo. *J Asian Martial Arts.* 2003;12(1):9–23.
17. Melhim AF. Aerobic and anaerobic power responses to the practice of taekwon-do. *Br J Sports Med.* 2001;35(4):231–234; doi: 10.1136/bjism.35.4.231.
18. Bouhlef E, Jouini A, Gmada N, Nefzi A, Abdallah KB, Tabka Z. Heart rate and blood lactate responses during taekwondo training and competition. *Sci Sports.* 2006;21(5):285–290; doi: 10.1016/j.scispo.2006.08.003.
19. Marković G, Misigoj-Duraković M, Trninić S. Fitness profile of elite Croatian female taekwondo athletes. *Coll Antropol.* 2005;29(1):93–99.
20. Pearson DT, Naughton GA, Torode M. Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *J Sci Med Sport.* 2006;9(4):277–287; doi: 10.1016/j.jsams.2006.05.020.
21. Naughton G, Farpour-Lambert NJ, Carlson J, Bradney M, Van Praagh E. Physiological issues surrounding the performance of adolescent athletes. *Sports Med.* 2000;30(5):309–325; doi: 10.2165/00007256-200030050-00001.
22. Green S, Dawson B. Measurement of anaerobic capacities in humans: definitions, limitations and unsolved problems. *Sports Med.* 1993;15(5):312–327; doi: 10.2165/00007256-199315050-00003.
23. Chiodo S, Tessitore A, Cortis C, Lupo C, Ammendolia A, Iona T, et al. Effects of official taekwondo competitions on all-out performances of elite athletes. *J Strength Cond Res.* 2011;25(2):334–339; doi: 10.1519/JSC.0b013e3182027288.
24. Oliveira MP, Szmuchowski LA, Gomes Flor CA, Gonçalves R, Couto BP. Correlation between the performance of taekwondo athletes in an Adapted Anaerobic Kick Test and Wingate Anaerobic Test. In: Kalina RM (ed.), *Proceedings of the 1st World Congress on Health and Martial Arts in Interdisciplinary Approach, HMA 2015, 17–19 September 2015, Czestochowa, Poland*. Warsaw: Archives of Budo; 2015; 130–134.
25. Oja P, Tuxworth B (eds.). *Eurofit for adults. Assessment of health-related fitness*. Tampere: Council of Europe Publishing; 1995.
26. Quatman CE, Ford KR, Myer GD, Paterno MV, Hewett TE. The effects of gender and pubertal status on generalized joint laxity in young athletes. *J Sci Med Sport.* 2008;11(3):257–263; doi: 10.1016/j.jsams.2007.05.005.
27. Davies PL, Rose JD. Motor skills of typically developing adolescents: awkwardness or improvement? *Phys Occup Ther Pediatr.* 2000;20(1):19–42; doi: 10.1080/J006v20n01_03.
28. Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am J Clin Nutr.* 2000;72(3):796–803.
29. Bar-Or O. *Testing of anaerobic performance by the Wingate Anaerobic Test*. Bloomington: ERS Tech, Inc.; 1994.
30. Kaczowski W, Montgomery DL, Taylor AW, Klissouros V. The relationship between muscle fiber composition and maximal anaerobic power and capacity. *J Sports Med Phys Fitness.* 1982;22(4):407–413.
31. Inbar O, Bar-Or O, Skinner JS. *The Wingate Anaerobic Test*. Champaign: Human Kinetics; 1996.
32. Cohen J. *Statistical power analysis for the behavioral sciences, 2nd edition*. Hillsdale: Lawrence Erlbaum; 1988.
33. Kazemi M, Rahman A, De Ciantis M. Weight cycling in adolescent Taekwondo athletes. *J Can Chiropr Assoc.* 2011;55(4):318–324.
34. Armstrong N, Welsman JR, Chia MYH. Short term power output in relation to growth and maturation. *Brit J Sports Med.* 2001;35(2):118–124; doi: 10.1136/bjism.35.2.118.
35. Aouadi R, Jlid MC, Khalifa R, Hermassi S, Chelly MS, Van Den Tillaar R, et al. Association of anthropometric qualities with vertical jump performance in elite male volleyball players. *J Sports Med Phys Fitness.* 2012;52(1):11–17.
36. Beunen G, Thomis M, Peeters M, Maes HH, Claessens AL, Vlietinck R. Genetics of strength and power characteristics in children and adolescents. *Pediatr Exerc Sci.* 2003;15(2):128–138; doi: 10.1123/pes.15.2.128.
37. Blimkie CJR, Sale DG. Strength development and trainability during childhood. In: Van Praagh E (ed.), *Paediatric anaerobic performance*. Champaign: Human Kinetics; 1998; 193–224.
38. Ingle L, Sleaf M, Tolfrey K. The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. *J Sports Sci.* 2006;24(9):987–997; doi: 10.1080/02640410500457117.
39. Čular D, Miletic D, Miletic A. Influence of dominant and non-dominant body side on specific performance in taekwondo. *Kinesiology.* 2010;42(2):184–193.

40. Falk B, Usselman C, Dotan R, Brunton L, Klentrou P, Shaw J, et al. Child-adult differences in muscle strength and activation pattern during isometric elbow flexion and extension. *Appl Physiol Nutr Metab.* 2009;34(4):609–615; doi: 10.1139/H09-020.
41. Matsushigue KA, Hartmann K, Franchini E. Taekwondo: physiological responses and match analysis. *J Strength Cond Res.* 2009;23(4):1112–1117; doi: 10.1519/JSC.0b013e3181a3c597.
42. da Silva Santos JF, Franchini E. Is frequency speed of kick test responsive to training? A study with taekwondo athletes. *Sport Sci Health.* 2016;12(3):377–382; doi: 10.1007/s11332-016-0300-2.
43. Lin WL, Yen KT, Doris Lu CY, Huang YH, Chang CK. Anaerobic capacity of elite Taiwanese taekwondo athletes. *Sci Sports.* 2006;21(5):291–293; doi: 10.1016/j.scispo.2006.04.005.
44. Pieter W. Performance characteristics of elite Taekwondo athletes. *Kor J Sport Sci.* 1991;3:94–117.