Effects of gradual weight loss on anaerobic capacity and muscle strength in elite taekwondo ITF athletes

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

Ewa Bakońska-Pacoń[1ABCDE], Wioletta Dziubek[2BCDE], Gabriela Forgiel[1ABC], Eugenia Murawska-Ciałowicz[1CE], Marek Zatoń[1CE], Kazimierz Witkowski[3BDE]

[1] Department of Physiology and Biochemistry, University School of Physical Education, Wroclaw, Poland
[2] Faculty of Physiotherapy, Department of Rehabilitation in Internal Diseases, University School of Physical Education, Wroclaw, Poland
[3] Department of Martial Arts, University School of Physical Education, Wroclaw, Poland

Received: 07 March 2017; **Accepted:** 31 March 2017; **Published online:** 28 April 2017

AoBID: 11469

Abstract

Background & Study Aim: Intentional reduction of body weight is a well-known and common practice among athletes, especially in weight category sports. The aim of this study was the effects of a 6-week gradual weight loss (GWL) program on anaerobic capacity, body composition and muscle strength of taekwondo athletes.

Material & Methods: The study included 9 men and 9 women practicing taekwondo ITF athletes (proficiency second dan). The following indicators were determined during the anaerobic capacity test: maximum power Pmax (W; $W \cdot kg^{-1}$), time to maximum power t_{Pmax} (s), time of maintenance power tmP (s), total work Wtot ($J \cdot kg^{-1}$) and fatigue index % FI. The list of determined body composition indicators included: relative content of fatty tissue (%FAT), lean body mass (LBM) and total body water (TBW). Moreover, we calculated body mass index BMI ($kg \cdot m^{-2}$) of the athletes. Concentration of lactate was determined in the arterialized blood from the finger pulp, obtained immediately prior to the warm-up and proper Wingate test, as well as 3 minutes post-exercise. Blood lactate concentration (La) was determined enzymatically using a LP400 Photometer (Dr Lange, Germany).

Results: After GWL, both men and women showed a significant decrease in body weight ($p<0.05$). Also the relative content of fatty tissue (% FAT) decreased significantly ($p<0.05$) in both men and women, by 2.99% and 1.69% on average, respectively. GWL resulted in changes in the analyzed indicators of anaerobic capacity. Maximum power (W) decreased significantly ($p<0.05$), by 82.10 and 11.78 in men and women, respectively. Following the GWL program, both women and men presented with significantly lower values of the peak torque and average power in dominant limbs tested at both angular velocities. However, the decrease in these indicators did not correlated significantly with maximum power determined during a Wingate test.

Conclusions: The GWL programs may exert beneficial effects as a method of weight control in taekwondo athletes if followed by an individualized control of training effects. Changes in body weight and composition, including a decrease in BMI, did not alter significantly the indices of anaerobic capacity.

Key words: balanced diet • body composition • muscle balance • training workloads • water balance • Wingate test

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The research was approved by the Local Bioethics Committee

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: Departmental sources

Author's address: Ewa Bakońska-Pacoń, Department Physiology and Biochemistry University School of Physical Education in Wroclaw, Aleja Paderewskiego 35, 51-612 Wroclaw, Poland; e-mail: ewa.bakonska-pacon@awf.wroc.pl

Gradual Weight Loss (GWL) – the mechanism involving metabolic changes and negative energy balance in weight loss studies with or without different type of training more than 3 weeks. Prevents the reduction in performance capacity.

BIODEX System – is an isolated joint isokinetic system which allows one to measure the amount of strength produced at different velocities. A device that measures: force, moment of force (torque), power and strength of different muscle groups. It provides a useful method for performance testing and rehabilitation methods for the joints: ankle, knee, hip, wrist, elbow and shoulder.

Dan (dan'i) – a term used to denote one's technical level or grade [44].

Dan – *noun* **1.** one of the numbered black-belt levels of proficiency in martial arts such as judo and taekwondo. Also called **dan grade 2.** somebody who has achieved a dan [45].

Kick – *verb* **1**. to strike a ball with the foot **2.** to strike something or somebody with the foot, e.g. in martial arts **3.** to make a thrashing movement with the legs, e.g. when fighting or swimming **4.** (*in cricket*) to bounce up high and quickly [45].

Kick – *noun* **1.** a blow with the foot, e.g. in martial arts **2.** a thrashing movement with the leg when swimming **3.** the striking of a ball with the foot [45].

Punch – *verb* to strike someone or something with the fist, e.g. in boxing or martial arts [45].

Taekwondo – *noun* a Korean martial art that resembles karate but also employs a wide range of acrobatic kicking moves [45].

Taekwon-do ITF – an informed use of one's body in combat; a taekwon-do fighter's body has reached its peak capacity through consistent and intense physical and mental training. Taekwon-do is a martial art that mainly involves striking the opponent. To put it simply, it is an unarmed fighting style created to aid in self-defence. In addition, taekwon-do constitutes an original system of education that approaches human physical and mental

INTRODUCTION

Intentional reduction of body weight is a well-known and common practice among athletes, especially in weight category sports. The latter include combat sports: judo, karate, taekwondo and boxing, as well as other disciplines, such as wrestling and rowing. The fraction of combat sport athletes who intentionally reduce their body weight prior to the competition is estimated at up to 60-76% [1, 2]. Rapid, uncontrolled reduction of body weight may have a number of unfavourable consequences, inter alia associated with disruption of water-electrolyte balance of the body [3, 4].

Decreased intake of food, low-calorie diet and dehydration 24-48 hours prior to the competition may affect homeostasis, especially with regards to muscle work, circulatory and thermoregulatory functions, and is associated with increased risk of injury. Gradual weight loss (GWL) is defined as a modestly reduced energy intake, modest increase in energy expenditure, change of energy % in diet and loss of 0.5-1 kg per week within ≥1 week. In contrast, rapid weight loss (RWL) is defined as an active or passive dehydration, very low energy intake or fasting, and increased energy expenditure within 12 to 96 hours. Due to potential negative consequences of RWL associated with the dramatically limited energetic value of the diet, the recommended method of weight control is GWL with only modestly reduced energy intake and weekly loss of 0.5-1 kg [5].

Prior studies of combat sport athletes showed that reduction of body weight by means of dehydration constitutes a common practice irrespective of age category [4]. This results from contest rules, according to which the interval between the measurement of body weight and participation in the competition can be as long as 3 to 24 hours. Interestingly, there is an evidence suggesting that rapid weight loss does not affect performance during a specific judo exercise, 5-minute combat and a Wingate anaerobic test, if followed by a 4-hour recovery and appropriate rehydration [6]. However, another study revealed that water-electrolyte balance of most athletes cannot be normalized up to 48 hours after rapid reduction of body weight [7]. Furthermore, Tipmann et al. [8] showed that rapid weight loss, especially resulting from dehydration, is associated with lowered performance of combat sport athletes.

Taekwondo combat requires acyclic efforts, predominated by few-second-long exchanges of blows, representing short-term components of a prolonged exercise. Short-term maximal muscle contractions require an athlete to present with a considerable level of power, which is determined by an anaerobic potential. ITF taekwondo combats are comprised of kicks (60%) and punches (40%) [9].

Overall strength of an athlete can be determined on the basis of muscle torque for major muscle groups, measured during isolated work of the selected extensors or flexors. The measurements are taken at a special units and under specific conditions [10-12]. Muscle torque is one of the most important physical indicators characterizing condition of an athlete and determining his/her sport achievements. It affects the velocity of movements, ability to jump, and mechanical energy that can be developed against low external resistance [13]. Taking into account relatively sparse published data on the isokinetic indicators of taekwondo athletes subjected to GWL programs, we decided to determine these indicators at selected angular velocities.

The aim of this study was the effects of a 6-week gradual weight loss program on anaerobic capacity, body composition and muscle strength of taekwondo athletes.

MATERIAL AND METHODS

Participants

The study included 9 men and 9 women practicing taekwondo ITF (proficiency second dan). Detailed characteristics of the participants are presented in Table 1. All subjects gave their written consent for participation in the study, were informed about its potential risks and possibility of withdrawal at any stage.

Experimental protocol

The protocol of the study was approved by the Local Bioethics Committee.

All the measurements were taken twice, at the Laboratory of Exercise Testing, Department of Physiology and Biochemistry, and at the Laboratory of Functional Testing in Internal Diseases, University School of Physical Education in Wroclaw (Poland).

We assumed that the GWL program will result in a 5% body weight loss. The program was based on the restriction of caloric intake, by 300-500 kcal · day^{-1} depending on individual body weight and total metabolic rate, adjusted for normal water balance. The diet was rich in protein 1.4-1.9 g · kg^{-1} body weight per day [14]. The athletes drank up to 2 litres of water daily (with additional 500-700 ml during the training days). During the course of the GWL program, the athletes did not use sauna, diuretics and any other substances that might affect their water balance. During the 6-week-long period between before and after GWL the athletes participated in regular trainings. As the study was conducted during the preparatory phase of a cycle, both men and women participated in four 90-minute training sessions per week. Moreover, they participated in additional individually-scheduled 30-45-minute aerobic trainings twice a week.

The anaerobic capacity

The anaerobic capacity of the athletes was determined twice at 6-week interval during a 30-second Wingate test [15] before and after GWL on a cycling ergometer (Monark 894E, Sweden). The test was conducted in line with its author's instructions, and was preceded by a 5-minute warm-up at individually-adjusted pace. Individual load during the proper test equalled 0.075 kg · kg^{-1} body weight. Both the study before and after GWL were conducted between 9:00 a.m. and 12:00 p.m., after a light breakfast. Before the test, each participant drank the same amount (ca. 300 ml) of fluid. The following indicators were determined during the anaerobic capacity test: maximum power Pmax (W; W · kg^{-1}), time to maximum power t_{Pmax} (s), time of maintenance power tmP (s), total work Wtot (J · kg^{-1}) and fatigue index % FI.

Body composition

Body composition of the athletes was determined twice by means of a near-infrared irradiation spectrophotometry with a Futrex 6100/XL analyser (Futrex Inc., USA). The list of determined body composition indicators included: relative content of fatty tissue (%FAT), lean body mass (LBM) and total body water (TBW). Moreover, we calculated body mass index BMI (kg · m^{-2}) of the athletes.

Concentration of lactate

Concentration of lactate was determined in the arterialized blood from the finger pulp, obtained immediately prior to the warm-up and proper

development in a versatile manner. It combines Eastern traditions with Mediterranean culture and revolves around human instincts and natural needs. Translated literally, tae means jumping, flying, performing fighting techniques using one's legs; kwon means "fist" or to strike or destroy with one's hand; and do indicates an art or a path and the proper behavioural norms created and developed by ancient scholars [46, 47].

WTF taekwondo – Olympic sport where two competitors are engaged in direct combat.

Balanced diet – *noun* a diet that contains the right quantities of basic nutrients [45].

Wingate test – the most common test used to evaluate anaerobic capacity – peak and mean power, fatigue index as well as time to reach peak power.

Water balance – *noun* a state in which the water lost by the body, e.g. in urine or sweat, is made up by water absorbed from food and drink [45].

Training load – "A simple mathematical model of training load can be defined as the product of qualitative and quantitative factor. This reasoning may became unclear whenever the quantitative factor is called 'workload volume' or 'training volume' interchangeably with 'volume of physical activity'. Various units have been adopted as measures i.e. the number of repetitions, kilometres, tons, kilocalories, etc. as well as various units of time (seconds, minutes, hours) (...) As in the real world nothing happens beyond the time, the basic procedure of improvement of workload measurement should logically start with separation of the time factor from the set of phenomena so far classified together as '*workload volume*'. (...) Due to the fact that the heart rate (HR) is commonly accepted as the universal measure of workload intensity, the product of effort duration and HR seems to be the general indicator of *training load* defined as the amount of workload. It is useful in analyses with a high level of generality. (...)In current research and training practice the product of effort duration and HR was referred to as conventional units' or further calculations have been made to convert it into points." [48, p. 238].

Table 1. Characteristics of men and women taekwondo athletes according to the Polish Taekwondo Association.

Statistic indicator	Age (years)	Height (m)	Body mass (kg)	BMI (kg · m^{-2})	Training experience (years)	Best result*
Men (n = 9)						
Mean ± SD	22.0 ±1.5	1.76 ±0.04	75.4 ±11.6	24.3 ±3.1	11 ±3.25	PNC (n = 2)
Min	20.0	1.72	67.0	22.4	8	EC (n = 3)
Max	24.0	1.84	102.0	32.2	15	WC (n = 4)
Women (n = 9)						
Mean ± SD	23.0 ± 2.2	1.66 ± 0.03	61.9 ±7.4	22.4 ±3.2	8 ±4.22	PNC (n = 2)
Min	20.0	1.61	53.7	19.0	5	EC (n = 4)
Max	27.0	1.72	77.0	28.6	13	WC (n = 3)

* Legend best result: PNC medal during the Polish National Championships (1st-3rd place); EC medal during the European Championships, European Cup (1st-3rd place); WC medal during the World Championships, World Cup (1st-3rd place)

Wingate test, as well as 3 minutes post-exercise. Blood lactate concentration (La) was determined enzymatically using a LP400 Photometer (Dr Lange, Germany).

Muscle torque of the lower extremities in isokinetic conditions

A study of muscle torque of the lower extremities in isokinetic conditions was performed using Biodex's Multi-Joint 3 Isokinetic Dynamometer (Biodex Medical System, New York, USA). All subjects were assessed regarding the functionality of the right (R) and left (L) knee flexors (F) and extensors (E) muscles that act on the knee joint in both limbs: peak torque (PTQ), total work (TW) and average power (AVGP). The measurements were taken twice, before and after the GWL program, on the same day as the body composition determination. The measurements were taken between 12:00 p.m. and 2:00 p.m. Prior to each test, the chair, dynamometer and proper unit were adjusted in such way that the dynamometer's tip was placed in the axis of rotation of the examined joint. The extents of flexion and extension were the same for all the participants at 90° (S 0-0-90), and the measurements were corrected for gravitation. The thigh and pelvis of the examined athlete were stabilized with belts fixed to the chair in order to eliminate the movements in the adjacent joints. The baseline position was set as the maximum flexion of the knee joint. The test started with warm-up: each participant performed up to 3 submaximal flexions and extensions of each knee joint, followed by one maximal movement, in order to familiarize with the load. The warm-up was followed by the proper test, i.e. measurement of muscle torque at two different angular velocities, $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$. Each participant performed 5 repetitions at $60° \cdot s^{-1}$, and then 20 repetitions at $180° \cdot s^{-1}$. Functional indicators of the muscles, i.e. PTQ (N · m), TW (J) and AVGP (W), were registered at both angular velocities. The tests at different angular velocities were separated by a 1-minute recovery. The athletes were asked to achieve a maximum muscle power in a shortest time possible during each movement. Moreover, agonist/antagonist ratio (%) was determined along with the relative difference between a dominant and non-dominant limb (%); the latter was considered acceptable if no greater than 10% [16-19].

$$\text{Agonist / Antagonist Ratio (\%)} = \frac{\text{Peak torque HS}}{\text{Peak torque QS}} \times 100\%$$

The literature data on isometric tests and slow speed isokinetic tests suggests that the normal HQ ratio varies between 31% and 80%, and the recommended optimum HQ ratio between 50% and 80% [16].

Data analysis

Statistical analysis was conducted with Statistica Poland, version 9.0. Mean values and their standard deviations were calculated for each of the analysed indicators, and the Student t-test for dependent variables and non-parametric Wilcoxon signed-rank test were conducted. The results of both the tests were considered significant at p<0.05. Moreover, the Spearman's coefficients of rank correlation were calculated. A correlation was considered significant at p<0.05.

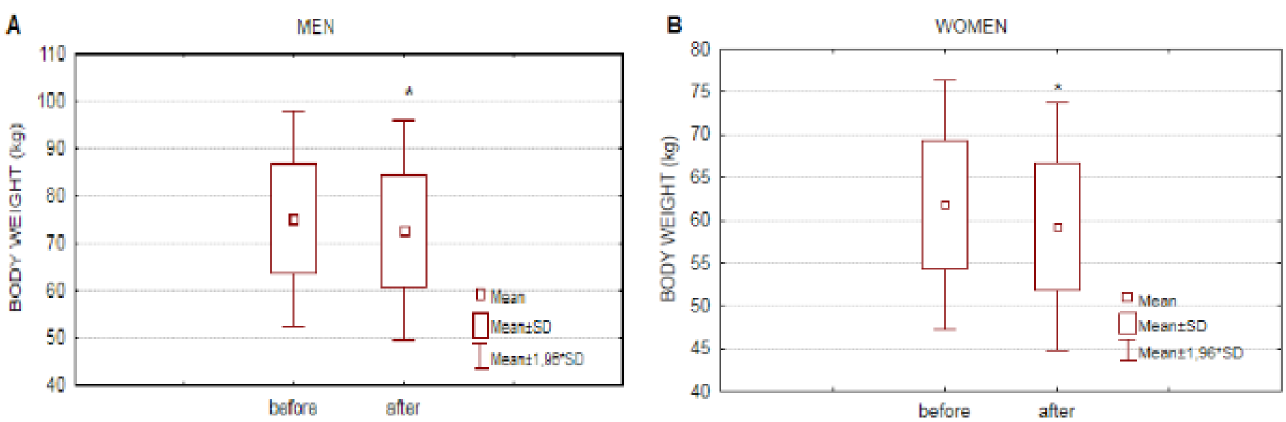

Figure 1. Body weight of men (A) and women (B) determined before and after gradual weight loss (GWL).
*p<0.05

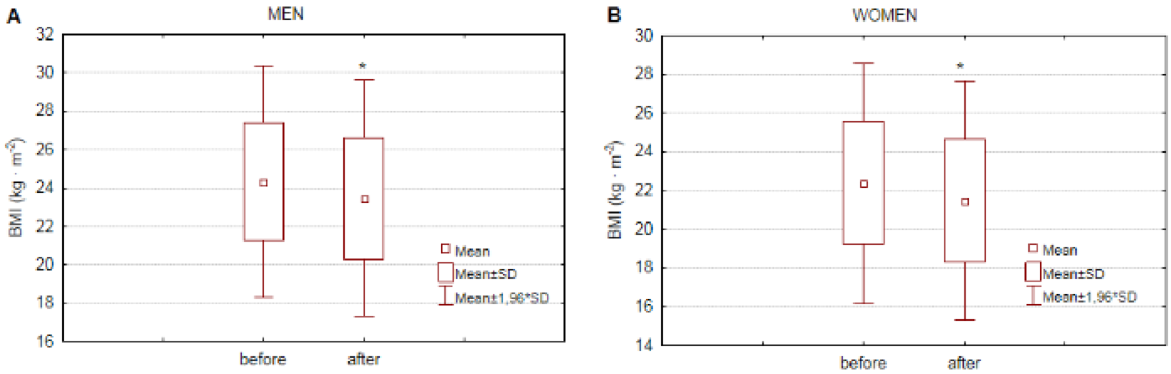

Figure 2. BMI of men (A) and women (B) determined before and after gradual weight loss (GWL).
*p<0.05

RESULTS

After GWL, both men and women showed a significant decrease in body weight (Figure 1). Mean body weight loss in men amounted to 2.68 kg, which corresponded to 3.6% of their baseline body weight on average. Mean body weight loss in women was 2.54 kg, which represented 4% of their baseline body weight on average. The decrease in body weight turned out to be statistically significant in both men and women ($p<0.05$). Both men and women presented with a significant decrease in BMI (Figure 2). Mean decrease in BMI amounted to 0.87 kg · m^{-2} and 0.91 kg · m^{-2} in men and women, respectively.

Also the relative content of fatty tissue (% FAT) decreased significantly ($p<0.05$) in both men and women (Figure 3), by 2.99% and 1.69% on average, respectively. After GWL, both men and women presented with higher relative contents of total body water (Figure 4). While the average increase in men corresponded to l.93% of the baseline value and was statistically significant, a 1.12% increase in women did not reach the threshold of statistical significance. We documented a significant ($p<0.05$) increase in lean body mass (% LBM), from 85.80 ±4.90 % to 88.78 ±1.96% in men, and from 76.58 ±4.53% to 78.27 ±4.77% in women.

Table 2. Anaerobic capacity indicators (mean ±standard deviation) of taekwondo athletes determined before and after gradual weight loss (GWL).

Variable (indicator)	Men (n = 9)		Women (n = 9)	
	before	after	before	after
P_{max} (W)	**808.78 ±10.19**	**726.68 * ±72.44**	546.67 ±83.12	534.89 ± 90.31
$P_{max \cdot kg}^{-1}$ (W·kg^{-1})	10.76 ±0.45	10.69 ±0.45	8.81 ±0.47	8.98 ±0.54
tPmax (s)	4.87 ±0.90	4.98 ±0.44	6.0 ±1.2	5.35 ±0.71
tmP (s)	3.60 ±0.54	3.99 ±1.43	3.76 ±0.54	3.69 ±1.24
FI (%)	24.11 ±1.90	22.68 ±3.34	22.22 ±4.6	23.33 ±5.52
Wtot (kJ)	**19.01 ±2.81**	**17.39* ±1.66**	12.91 ±1.52	12.42 ±1.59
Wtot (J · kg^{-1})	252.44 ±11.25	254.0 ±7.42	208.89 ±6.25	209.22 ±7.03
La (mmol · l^{-1}) at rest	2.2 ±1.2	1.4 ±0.5	1.7 ±0.8	1.2 ±0.3
La (mmol · l^{-1}) post-exercise	**12.1 ±1.3**	**14.1* ±1.8**	**10.4 ±1.3**	**11.3* ± 1.4**

*p<0.05

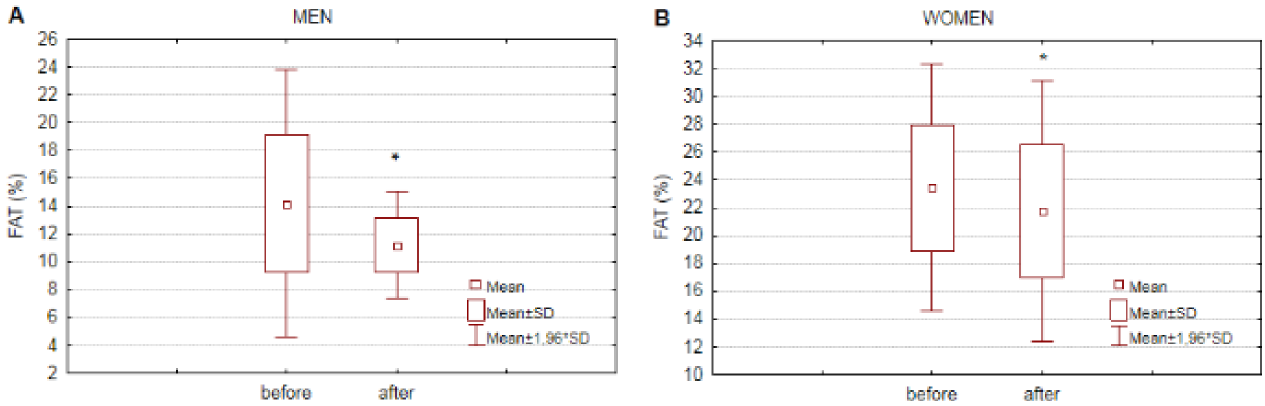

Figure 3. Fatty tissue content in men (A) and women (B) determined before and after gradual weight loss (GWL). *p<0.05

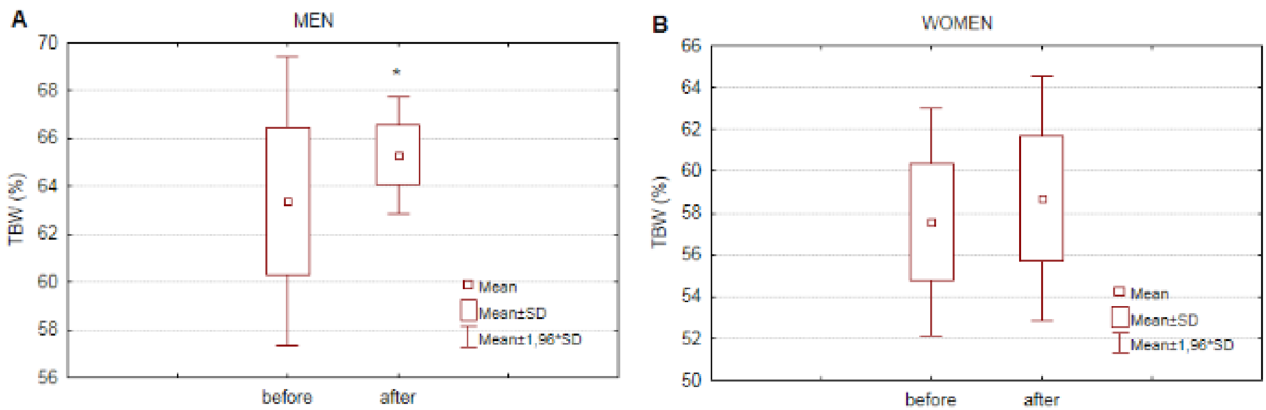

Figure 4. Force-velocity indicators in dominant leg of men determined before and after gradual weight loss (GWL) at $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$. *p<0.05

Indicators of anaerobic capacity

GWL resulted in changes in the analysed indicators of anaerobic capacity. Maximum power (W) decreased significantly ($p<0.05$), by 82.10 and 11.78 in men and women, respectively. Both men and women showed an increase in the post-exercise concentration of lactate, from 12.1 to 14.1 $mmol \cdot l^{-1}$ in men, and from 10.4 to 11.3 $mmol \cdot l^{-1}$ in women. This difference turned out to be statistically significant ($p<0.05$) in the case of men (Table 2).

Baseline P_{max} of men was shown to correlate significantly with their body weight (r = 0.98), body height (r = 0.76), BMI (r = 0.95) and TBW (r = 1.0). Also the baseline P_{max} of women correlated significantly with all these indicators except from body height. The only significant association observed after GWL of men was a positive correlation between P_{max} and TBW (r = 0.84). In the case of women, the profile of correlations observed after GWL resembled that documented at the baseline, i.e. P_{max} (W) correlated significantly with all the morphological indicators and body composition indices except from body height (Table 3).

The isokinetic indicators

Analysis of the isokinetic indicators of our taekwondo athletes (Tables 4 and 5) revealed that after GWL both women and men achieved lower values of the force-velocity indicators, PTQ, TW, and AVGP, than at the baseline. In men, the PTQE of a dominant limb examined at $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ decreased by 5.94% and 3.74%, respectively. In women, the decrease in the PTQE of a dominant limb corresponded to 10.80% and 5.91% of the baseline values, respectively. These changes turned out to be statistically significant in both men and women. Our athletes scored higher during the tests for a dominant limb. PTQ, AVGP and TW for the knee extensors turned out to be higher than the respective indicators for the knee flexors.

Table 3. Correlations between maximum power and selected morphological indicators and body composition measures determined before and after gradual weight loss (GWL).

Variable (indicator)	Before		After	
	Pmax (W)	Pmax (W · kg^{-1})	Pmax (W)	Pmax (W · kg^{-1})
men (n = 9)				
Body weight (kg)	**0.98***	−0.24	0.59	0.41
Body height (m)	**0.76***	−0.28	0.54	0.28
BMI (kg · m^{-2})	**0.95***	−0.31	0.59	0.41
% fatty tissue (FAT)	0.53	**−0.76***	0.00	−0.57
Total body water (TBW) (l)	**1.00***	−0.12	**0.84***	0.41
Total body water (%)	−0.53	**0.76***	0.05	**0.66***
women (n = 9)				
Body weight (kg)	0.95*	0.70*	0.88*	0.68*
Body height (m)	−0.46	−0.25	−0.61	−0.60
BMI (kg · m^{-2})	0.93*	0.73*	0.92*	0.75*
% fatty tissue (FAT)	0.83*	0.61	0.85*	0.70*
Total body water (TBW) (l)	0.87*	0.67*	0.82*	0.60
Total body water (%)	−0.83*	−0.61	−0.85*	−0.69*

* $p<0.05$

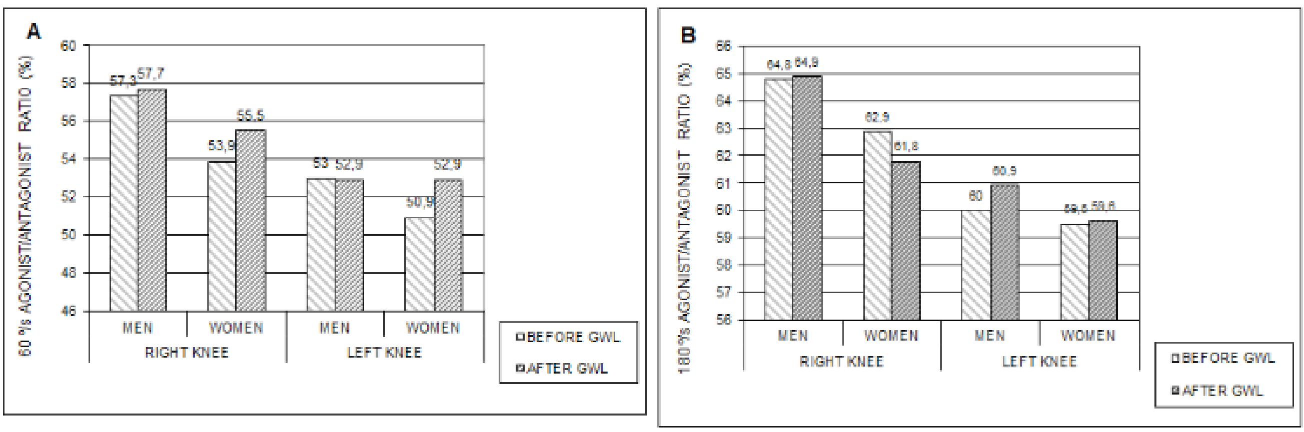

Figure 5. Agonist/antagonist ratio at 60° · s^{-1} (A) and 180° · s^{-1} (B) for both limbs in men and women before and after gradual weight loss (GWL).

No significant differences were found in the PTQ of the knee muscles of a dominant and non-dominant limb (up to 10% difference is generally considered acceptable), in both men and women examined before and after the GWL program. The relative change between the result before and after GWL oscillated between 5.96% and 9.36% for women (except from 11.75% for the flexors tested at 60° · s^{-1}) and between 4.08% and 9.17% for men.

The coefficients of correlation between the force-velocity indicators, selected morphological indicators, body composition measures and results of a Wingate test determined before and after GWL are presented in Tables 6 and 7.

A number of significant correlations were found between the isokinetic indicators, selected morphological indicators, body composition measures and results of a Wingate test for both the study.

In both men and women, the values of H · Q^{-1} for both a dominant and non-dominant limb were lower than the respective reference limits. In men, the agonist/antagonist ratio at 60° · s^{-1} amounted to 53.01 ±9.8% and 57.3 ±10.2% for a non-dominant and dominant limb, respectively, while the agonist/antagonist ratios at 180° · s^{-1} were 59.98 ±9.2% and 64.82 ± 8.4% for a non-dominant and dominant limb, respectively. In women, the agonist/antagonist ratios for a non-dominant and dominant

Table 4. Force-velocity indicators in dominant leg of men (n= 9) determined before and after gradual weight loss (GWL) at 60° · s^{-1} and 180° · s^{-1}.

Angular velocity	Variable (indicator)	Before	After	t-test
		mean ±SD	mean ±SD	p
Knee extensors				
60° · s^{-1}	PTQ (N · m)	**233.97** ± 38.90	**220.08** ±37.04	0.0005**
	TW (J)	1330.88 ± 217.04	1288.29 ±180.60	0.431
	AVGP (W)	**156.29** ±26.50	**149.96** ±25.53	0.050*
180° · s^{-1}	PTQ (N · m)	**146.89** ±26.21	**141.40** ±8.51	0.050*
	TW (J)	3156.5 ±489.30	3067.74 ±517.60	0.261
	AVGP (W)	**229.38** ±33.48	**218.46** ±35.61	0.050*
Knee flexors				
60° · s^{-1}	PTQ (N · m)	126.02 ±14.35	118.96 ± 8.40	0.176
	TW (J)	790.20 ±138.71	748.17 ±106.14	0.441
	AVGP (W)	92.80 ±9.98	86.57 ±12.84	0.191
180° · s^{-1}	PTQ (N · m)	88.19 ±11.85	82.31 ±8.34	0.226
	TW (J)	**1914.86** ±173.07	**1826.26** ±183.40	0.050*
	AVGP (W)	**139.97** ±13.36	**128.23** ±10.69	0.025*

Legend: **PTQ** peak torque; TW total work; **AVGP** average power; * p<0.0; ** p<0.005

limb tested at 60° · s^{-1} were 50.85 ±12.1% and 53.9 ±10.6%, respectively, whereas the agonist/antagonist ratios at 180° · s^{-1} were 59.48 ±13.3% and 62.85 ±15.4%, respectively. The results obtained after GWL were similar and did not differ significantly from the abovementioned values (Figure 5).

DISCUSSION

Reduction of body weight is a common practice among combat sports athletes. However, it may have negative consequences since rapid weight loss (RWL) results in severe dehydration and electrolyte depletion, and gradual weight loss (GWL) may lead to reduction of muscle mass and resultant deterioration of physical capacity [5]. Although this problem was a subject of extensive research, the results obtained in various groups of athletes are inconclusive.

Therefore, we analysed relationships between the indicators of body composition, physical capacity and lower limb strength in taekwondo athletes subjected to a GWL regimen. Our study showed that the 6-week-long program resulted in significant reduction of body weight in both groups of taekwondo athletes. The degree of reduction achieved by men and women corresponded to 3.56% and 4.12% of their initial body weights, respectively. The body weight loss was associated with a concomitant decrease in %FAT, as well as with an increase in %TBW and %LBM. After 6 weeks of GWL program, men and women showed similar degree of changes in body weight, BMI and body composition. This observation is consistent with the results published by Inger et al. [20] and Walberg-Rankin et al. [21], who analysed the results of GWL programs in athletes practicing various sports disciplines over a 1 – to 12-week period. The

Table 5. Force-velocity indicators in dominant leg of women (n= 9) determined before and after gradual weight loss (GWL) at 60° · s^{-1} and 180° · s^{-1}.

Angular velocity	Variable (indicator)	before	after	t-test
		mean ±SD	mean ±SD	p
Knee extensors				
60° · s^{-1}	PTQ (N · m)	**159.11** ±21.96	141.94 ±26.57	0.001**
	TW (J)	864.74 ±157.03	808.84 ±156.50	0.104
	AVGP (W)	**104.09** ±17.45	**98.42** ±19.34	0.050*
180° · s^{-1}	PTQ (N · m)	**101.57** ±18.21	**95.57** ±21.84	0.050*
	TW (J)	2127.42 ±335.82	2039.62 ±365.49	0.094
	AVGP (W)	**156.39** ±22.12	**142.96** ±26.32	0.001**
Knee flexors				
60° · s^{-1}	PTQ (N · m)	84.46 ±12.90	76.02 ±18.60	0.828
	TW (J)	503.32 ±81.22	448.47 ±98.44	0.493
	AVGP (W)	60.40 ±10.17	53.07 ±11.84	0.181
180° · s^{-1}	PTQ (N · m)	61.31 ±9.67	58.87 ±16.85	0.455
	TW (J)	1314.79 ±239.70	1124.29 ±219.59	0.143
	AVGP (W)	91.04 ±16.10	82.28 ±13.46	0.156

Legend: **PTQ** peak torque; TW total work; **AVGP** average power; * p<0.05; ** p<0.001

degree of body weight loss documented in these studies corresponded to 3.1-10% of initial body weight [2, 20, 21].

In another study, analysing the results of the 12-week-long GWL program, mean rate of body weight loss corresponded to 0.9 kg weekly (9.4 kg on average during the whole analysed period), and fat mass decreased from 12.1% to 7.0% [7]. The rate of GWL in our taekwondo athletes amounted to 0.43 kg per week in women and 0.45 kg per week in men. According to many authors, the rate of weight loss should not exceed 1 kg per week and occur predominantly at an expense of adipose tissue with only minimum changes in muscle mass and water content or complete lack thereof. This effect can be achieved with an appropriately balanced diet, rich in protein and amino acids but deficient in energy, such as the diet used by our athletes [5, 22, 23].

Our study confirmed that the weight loss corresponding to less than 5% of the baseline weight does not impair physical fitness of taekwondo athletes. The indicators of anaerobic capacity determined during a 30-s Wingate test conducted at the baseline and following the GWL program did not differ significantly, and the documented values of maximum power (W · kg^{-1}) were similar to those reported previously by Umeda et al. [24], Fogelholm [7], Koral et al. [25] and Franchini et al. [26].

Maximum power and other indicators of anaerobic capacity determined in our participants before and after the GWL program were similar as previously reported in elite American taekwondo athletes (8.4 ±0.3 W · kg^{-1} and 10.7 ±3.3 W · kg^{-1} for women and men, respectively), but higher than in elite Taiwanese taekwondo athletes (6.48 W · kg^{-1} and 6.83 W · kg^{-1} in women and men,

Table 6. Correlations between force-velocity indicators, selected morphological indicators, body composition measures and results of a Wingate test determined before and after gradual weight loss (GWL) of men (n = 9).

Variable (indicator)	Before				After			
	Body weight (kg)	BMI (kg · m^{-2})	Wtot (J)	Pmax (W)	Body weight (kg)	BMI (kg · m—2)	Wtot (J)	Pmax (W)
60° · s^{-1}								
PTQER (N · m)	**0.69***	**0.70***	**0.69***	**0.73***	**0.68***	**0.75***	**0.66***	0.54
TWER (J)	**0.81***	**0.78***	**0.75***	**0.83***	**0.75***	**0.73***	0.64	0.58
AVGPER (W)	**0.73***	**0.69***	**0.73***	**0.72***	0.50	0.46	**0.66***	0.55
PTQFR (N · m)	0.47	0.37	0.49	0.44	0.53	0.54	0.24	0.10
TWFR (J)	0.38	0.37	0.30	0.32	0.61	**0.67***	0.16	0.17
AVGPFR (W)	0.42	0.32	0.40	0.39	0.40	0.47	0.17	0.16
PTQEL (N · m)	**0.79***	**0.69***	**0.91***	**0.84***	0.43	0.36	0.61	0.59
TWEL (J)	**0.93***	**0.88***	**0.93***	**0.95***	0.43	0.37	**0.70***	**0.73***
AVGPEL (W)	**0.83***	**0.72***	**0.89***	**0.85***	0.17	0.16	0.48	0.44
PTQFL (N · m)	**0.73***	0.62	**0.77***	**0.69***	0.27	0.35	0.11	0.10
TWFL (J)	0.11	0.13	–0.03	0.01	0.58	0.60	0.10	0.19
AVGPFL (W)	0.73*	0.62	**0.77***	**0.69***	0.15	0.21	0.11	0.10
180° · s^{-1}								
PTQER (N · m)	**0.74***	**0.72***	**0.81***	**0.83***	**0.85***	**0.82***	0.54	0.49
TWER (J)	**0.89***	**0.88***	**0.86***	**0.93***	**0.74***	**0.66***	**0.70***	0.60
AVGPER (W)	**0.88***	**0.79***	**0.68***	**0.69***	**0.71***	**0.69***	0.52	0.46
PTQFR (N · m)	0.55	0.47	0.61	0.50	0.20	0.25	0.01	0.03
TWFR (J)	0.01	0.00	–0.01	–0.06	0.12	0.16	–0.10	0.20
AVGPFR (W)	0.01	–0.05	0.06	–0.05	0.04	0.01	–0.26	0.30
PTQEL (N · m)	**0.94***	**0.89***	**0.96***	**0.98***	0.48	0.35	**0.77***	**0.74***
TWEL (J)	**0.74***	**0.69***	**0.68***	**0.73***	0.62	0.55	0.64	0.49
AVGPEL (W)	**0.74***	**0.73***	**0.68***	**0.69***	0.61	0.55	0.56	0.43
PTQFL (N · m)	0.38	0.38	0.44	0.37	–0.39	–0.36	–0.10	–0.13
TWFL (J)	–0.32	–0.32	–0.40	–0.42	–0.37	–0.31	–0.41	–0.61
AVGPFL (W)	–0.28	–0.28	–0.35	–0.40	–0.18	–0.11	–0.41	–0.65

Legend**: PTQER** peak torque extensors right; **PTQEL** peak torque extensors left; **PTQFR** peak torque flexors right; **PTQFL** peak torque flexors left; **TWER** total work extensors right; **TWEL** total work extensors left; **TWFR** total work flexors right; **TWFL** total work flexors left; **AVGPER** average power extensors right; **AVGPEL** average power extensors left; **AVGPFR** average power flexors right; **AVGPFL** average power flexors left; **BMI** body mass index; **Wtot** total work; **Pmax** max power; * $p<0.05$

respectively) [27]. The baseline value of fatigue index documented in our female and male athletes (23% and 24%, respectively) following the GWL program stabilized at 23% in both groups. In turn, according to Lin et al. [27], the % FI of Taiwanese taekwondo athletes equalled 37.8% and 24% for women and men, respectively.

During a Wingate test conducted following the GWL program our athletes presented with slightly higher values of Wtot, similar values of Pmax and significantly higher lactate concentration than at the baseline. According to Artioli et al. [6], a 5 to 7 day regimen of weight loss did not induce significant changes in the post-exercise concentration of lactate in judokas. Yang et al. [23] analysed the influence of RWL and GWL program on the physical and mental capacity of taekwondo athletes and documented significantly better results of the latter regimen. We found a positive correlation between somatic indicators, body composition (total body, TBW, FAT) and Pmax of our taekwondo athletes.

Table 7. Correlations between force-velocity indicators, selected morphological indicators, body composition measures and results of a Wingate test determined before and after gradual weight loss (GWL) of women (n = 9).

Variable (indicator)	Before				After			
	Body weight (kg)	BMI (kg · m⁻²)	Wtot (J)	Pmax (W)	Body weight (kg)	BMI (kg · m⁻²)	Wtot (J)	Pmax (W)
60° · s⁻¹								
PTQER (N · m)	**0.70***	**0.69***	**0.78***	**0.69***	**0.74***	**0.70***	**0.74***	**0.68***
TWER (J)	**0.85***	**0.73***	**0.86***	**0.82***	**0.72***	0.58	0.45	0.40
AVGPER (W)	**0.70***	**0.68***	**0.83***	**0.68***	**0.88***	**0.85***	**0.85***	**0.77***
PTQFR (N · m)	0.27	0.24	0.27	0.39	0.60	0.58	0.54	0.32
TWFR (J)	0.62	0.63	0.65	0.65	0.34	0.37	0.06	0.10
AVGPFR (W)	0.46	0.39	0.41	0.47	**0.77***	**0.74***	**0.70***	**0.67***
PTQEL (N · m)	**0.68***	**0.69***	**0.68***	**0.68***	**0.87***	**0.84***	**0.87***	**0.72***
TWEL (J)	**0.69***	**0.71***	**0.71***	**0.68***	**0.67***	0.64	**0.67***	0.65
AVGPEL (W)	**0.69***	**0.68***	**0.69***	**0.68***	**0.72***	**0.75***	**0.85***	**0.68***
PTQFL (N · m)	**0.66***	**0.71***	0.64	**0.75***	**0.95***	**0.92***	**0.82***	**0.70***
TWFL (J)	0.57	**0.69***	0.42	0.63	**0.77***	**0.70***	0.47	0.57
AVGPFL (W)	0.52	0.49	0.49	0.47	**0.94***	**0.92***	**0.74***	**0.77***
180° · s⁻¹								
PTQER (N · m)	**0.68***	**0.68***	**0.68***	0.63	**0.70***	**0.68***	**0.80***	**0.67***
TWER (J)	0.47	0.47	0.65	0.59	**0.67***	0.63	**0.67***	0.45
AVGPER (W)	0.39	0.42	0.53	0.54	**0.85***	**0.82***	**0.88***	**0.74***
PTQFR (N · m)	0.24	0.21	0.21	0.36	**0.68***	**0.67***	0.48	**0.67***
TWFR (J)	0.41	0.57	0.21	0.34	**0.82***	**0.85***	**0.68***	**0.74***
AVGPFR (W)	0.27	0.36	0.16	0.19	**0.80***	**0.84***	**0.70***	**0.75***
PTQEL (N · m)	0.69*	0.68*	0.81*	**0.73***	**0.67***	0.61	**0.84***	**0.67***
TWEL (J)	0.59	0.58	0.74*	**0.68***	0.42	0.38	**0.68***	0.38
AVGPEL (W)	**0.68***	**0.68***	**0.82***	**0.73***	**0.67***	0.59	**0.77***	0.52
PTQFL (N · m)	**0.97***	**0.95***	**0.95***	**0.98***	**0.88***	**0.92***	**0.82***	**0.77***
TWFL (J)	**0.88***	**0.88***	**0.92***	**0.93***	0.57	0.58	**0.67***	0.42
AVGPFL (W)	**0.78***	**0.79***	**0.86***	**0.83***	**0.82***	**0.80***	**0.85***	**0.68***

Legend**: PTQER** peak torque extensors right; **PTQEL** peak torque extensors left; **PTQFR** peak torque flexors right; **PTQFL** peak torque flexors left; **TWER** total work extensors right; **TWEL** total work extensors left; **TWFR** total work flexors right; **TWFL** total work flexors left; **AVGPER** average power extensors right; **AVGPEL** average power extensors left; **AVGPFR** average power flexors right; **AVGPFL** average power flexors left; **BMI** body mass index; **Wtot** total work; **Pmax** max power; * $p<0.05$–

Due to specific character of the discipline and type of performed movements (mostly lower limb movements), we examined our participants with an isokinetic dynamometer Biodex 3. Published data on the use of such devices for determining muscle strength in taekwondo athletes subjected to weight loss programs is sparse. Angular velocity is generally considered low if it ranges between 30° · s⁻¹ and 90° · s⁻¹, and high whenever it equals 180-500° · s⁻¹. Similar to persons practicing other combat sports, also taekwondo athletes need to satisfy specific physiological requirements with regards to dynamic active phases and kicks [28]. Aside from technical and tactical skills that should be possessed by every combat sports athletes (judokas, taekwondo athletes, fun forms of martial arts practicing), also high velocity, strength and body balance during attack constitute important determinants of outstanding achievements in this disciplines and are prerequisites of efficient offensive action against a competitor [29-32]. Although the isokinetic strength and power of the lower limb muscles, including the knee extensors, was a subject of many previous studies [33, 34], and many authors analysed the associations between the force-velocity and endurance indicators [13, 33, 35, 36], none of them examined athletes being on a weight loss regimen. Following the GWL program, both men and women participating in our study achieved lower values of force-velocity indicators. The differences observed in the case of the remaining indicators were not statistically significant, which might result from the fact that our athletes presented similar levels of physical fitness and physical capacity both before and after the GWL program. During the test, our taekwondo athletes demonstrated a linear increase in the strength of knee extensors, both at $60° \cdot s^{-1}$ and at $180° \cdot s^{-1}$. These findings are consistent with the data published by Larrat et al. [34], who observed that the power determined during examination of rugby players increased proportionally to angular velocity. The power increases proportionally to resistance, i.e. greater power is generated at lower velocities and vice versa [37].

Another important aspect of the PTQ variable is the bilateral comparison of knee flexors and extensors among athletes practicing the same sports discipline. Up to 10% difference between a dominant and non-dominant limb is generally considered acceptable [16, 19, 38]. The athletes presenting with such low levels of bilateral asymmetry were shown to be at lower risk of lower limb injury [10, 16, 39]. In our study, bilateral asymmetry determined after the GWL program at both tested velocities ($60° \cdot s^{-1}$ and $180° \cdot s^{-1}$) corresponded to 5.96 – 9.36% for women (except from 11.75% for the flexors at $60° \cdot s^{-1}$) and to 4.08-9.17% for men. As these values were lower than 10%, we assumed that our taekwondo athletes presented with appropriate balance between the muscles of a dominant and non-dominant limb. Similar results were reported previously by Machado et al. [39] in a study of combat sports athletes; the bilateral asymmetry observed in the taekwondo athletes amounted to only 1.2-1.3%.

The values of agonist/antagonist ratio documented in our taekwondo athletes suggest that the capacity of their knee flexors corresponded to 42-79.3% of the knee extensor capacity. Similar results were previously reported by Machado et al. [39] and Hewett et al. [40]. Machado et al. [39] observed that the athletes practicing taekwondo and kickboxing presented with an adequate bilateral muscle balance, with less than 50-80% difference. This likely corresponded to a low risk of muscle injury by distension in the studied population. Although the muscle injuries are relatively frequent in taekwondo and kickboxing athletes, they are predominantly represented by contusions [39, 41, 42]. Imbalances in hamstrings to quadriceps ($H \cdot Q^{-1}$) strength were demonstrated to correlate with higher incidence of lower extremity injuries in athletes [10, 37, 40].

We observed significant associations between the force-velocity indicators selected morphological characteristics, body composition and anaerobic capacity determined during Wingate test conducted before and after the GWL program. Our hereby presented findings suggest that in order to optimize achievements in sports, coaches should monitor physical preparation of their athletes, also in terms of body weight, level of hydration, muscle strength and anaerobic capacity.

In contrast, we lack a single universal test to predict the outcome in the acyclic disciplines, such as combat and team sports. As the outcome in sport is modulated by a whole spectrum of factors, it needs to be predicted on the basis of physical fitness, somatic indicators (including manipulation with body weight), motor abilities (including force-velocity indicators) and mental endurance. All these indices are helpful in the diagnosis, planning and execution of training workloads (training load), as well as in the control thereof at the end of the training process [43].

CONCLUSIONS

Our study showed that the GWL programs may exert beneficial effects as a method of weight control in taekwondo athletes if followed by an individualized control of training effects. Changes in body weight and composition, including a decrease in BMI, did not alter significantly the indices of anaerobic capacity. Following the GWL program, both women and men presented with significantly lower values of the peak torque and average power in dominant limbs tested at both angular velocities. However, the decrease in these indicators did not correlated significantly with maximum power determined during a Wingate test.

HIGHLIGHTS

The gradual weight loss programs may exert beneficial effects as a method of weight control in taekwondo athletes if followed by an individualized control of training effects. Following the 6-week weight loss program, both women and men presented with significantly lower values of the peak torque and average power in dominant limbs tested at both angular velocities. In our opinion, force-velocity indicators e.g. PTQ, TW, AVGP, AGONIST/ANTAGONIST RATIO fill in the gap in evaluation of different components of muscle strength in this group of athletes. Such a detailed analysis of force – velocity indicators in taekwondo athletes has not been conducted so far by anyone.

REFERENCES

1. Sterkowicz S, Lech G, Pałka T et al. Body build and body composition vs. physical capacity in young judo contestants compared to untrained subjects. Biol Sport 2011; 28: 271-277
2. Brito CS, Roas CMAF, Brito ISS et al. Methods of Body-Mass Reduction by Combat Sport Athletes. Int J Sport Nutr Exerc Metab 2012; 22: 89 – 97
3. Morton JP, Robertson C, Sutton L et al. Making the weight: A case study from professional boxing. Int J Sport Nutr Exerc Metab 2010; 20: 80-85
4. Kazemi M, Rahman A, De Ciantis M. Weight cycling in adolescent Taekwondo athletes. J Can Chiropr Assoc 2011; 55: 318-324
5. Garthe I, Raastad T, Refsnes PE et al. Effect of two different weight-loss rates on body composition and strength and power-related performance in elite athletes. J Internat Soc Sports Nutrit 2011; 21: 97-104
6. Artioli GG, Iglesias RT, Franchini E et al. Rapid weight loss followed by recovery time does not affect judo-related performance. J Sport Sci 2010; 28: 21-32
7. Fogelholm M. Effects of bodyweight reduction on sports performance. Sports Med 1994; 18: 249-267
8. Timpmann S, Ööpik V, Pääsuke M et al. Acute effects of self-selected regimen of rapid body mass loss in combat sports athletes. J Sports Sci Med 2008; 7: 210-217
9. Pędzich W, Mastalerz A, Sadowski J. Estimation of muscle torque in various combat sports. Acta Bioeng Biomech 2012; 14: 107-112
10. Kannus P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. Int J Sports Med 1994; 15: 11-18
11. Lund H, Søndergaard K, Zachariassen T et al. Learning effect of isokinetic measurements in healthy subjects, and reliability and comparability of Biodex and Lido dynamometers. Clin Physiol Funct Imaging 2005; 25: 75-82
12. Le-Ngoc L, Janssen J. Validity and reliability of a hand-held dynamometer for dynamic muscle strength assessment. In: Kim C-T, editor. Rehabilitation Medicine. Rijeka: InTech; 2012: 53-66
13. Bartlett LR, Storey MD, Simons BD. Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. Am J Sports Med 1989; 17: 89-91
14. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009; 41: 687-708
15. Bar-Or O. The Wingate anaerobic test: update on methodology, reliability and validity. Sports Med 1987; 4(6): 381–394
16. Kannus P. Recovery Insufficient Knee: Relationship to Long-term Strength in the Anterior Cruciate Ligament Ratio of Hamstring to Quadriceps Femoris Muscles. Phys Ther 1988; 68: 961-965
17. Davies G. A compendium of isokinetics in clinical usage and rehabilitation techniques. 4th ed. Onalaska: S&S Publishers; 1992
18. Perrin D. Isokinetic exercise and assessment. Champaign: Human Kinetics Publisher; 1993
19. Dvir Z. Isokinetics: Muscle Testing, Interpretation, and Clinical Applications. 2nd ed. Tel Aviv: Tel Aviv University; 2004
20. Inger F, Sundgot-Borgen J. Influence of body weight regulation on maximal oxygen uptake in female elite athletes. Scand J Med Sci Sports 1991; 1: 141-146
21. Walberg-Rankin J, Edmonds CE, Gwazdauskas FC. Diet and weight changes of female bodybuilders before and after competition. Int J Sport Nutr 1993; 3: 87-102
22. Coufalová K, Prokešová E, Malý T et al. Body weight reduction in combat sports. Arch Budo 2013; 4: 267-272
23. Yang W-H, Grau M, Kim P et al. Physiological and psychological performance of taekwondo athletes is more affected by rapid than by gradual weight reduction. *Arch Budo 2014; 10*: 169-174
24. Umeda T, Nakaji S, Shimoyama T et al. Adverse effects of energy restriction on myogenic enzymes in judoists. J Sports Sci 2004; 22: 329-338
25. Koral J, Dosseville F. Combination of gradual and rapid weight loss: effects on physical performance and psychological state of elite judo athletes. J Sports Sci 2009; 27: 115-120
26. Franchini E, Brito CJ, Artioli GG. Weight loss in combat sports: physiological, psychological and performance effects. J Internat Soc Sports Nutrit 2012; 9: 52-57
27. Lin WL, Yen KT, Doris Lu CY et al. Anaerobic capacity of elite Taiwanese Taekwondo athletes. Sci Sports 2006; 21: 291-293
28. Bridge CA, Santos J, Chaabène H et al. Physical and Physiological Profiles of Taekwondo Athletes. Sports Med 2014; 44: 713-733
29. Casolino E, Lupo C, Cortis C et al. Technical and tactical analysis of youth taekwondo performance. J Strength Con Res 2012; 26: 1489-1495
30. Chung P, Ng G Taekwondo training improves the neuromotor excitability and reaction of large and small muscles. Phys Ther Sport 2012; 13: 163-169
31. Kalina RM, Jagiełło W, Barczyński BJ. The method to evaluate the body balance disturbation tolerance skills – validation procedure of the "Rotational Test". Arch Budo 2013; 9(1): 59-80
32. Jagiełło W, Kalina RM, Klimczak J et al. Fun forms of martial arts in positive enhancement of alldimensions of health and survival abilities. 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; 32-39
33. Wilson G, Murphy A. The efficacy of isokinetic, isometric and vertical jump tests in exercise science. Aust J Sci Med Sport 1995; 27: 20-24
34. Larrat E, Kemoun G, Carette P et al. Isokinetic profile of knee flexors and extensors in a population of rugby players. Ann Readapt Med Phys 2007; 50: 280-286
35. Haddad M, Chaouachi A, Wong del P et al. Influence of exercise intensity and duration on perceived exertion in adolescent Taekwondo athletes. Eur J Sport Sci 2014; 14: 275-281
36. Seo MW, Jung HCh, Song JK et al. 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: 101-107
37. Hammami N, Ouergui I, Zinoubi B et al. Relationship between isokinetic and explosive strength among elite Tunisian taekwondo practitioners. Sci Sport 2014; 29: 150-155

38. Soper K, Dinesh S. Effect of limb dominance on peak torque and angle of peak torque of hamstrings in recreational female football players. *Working Papers in the Health Sciences* 2013; 1: 1-6

39. Machado SM, Souza RA, Simao AP et al. Comparative study of isokinetic variables of the knee in taekwondo and kickboxing athletes. Fit Perf Journal 2009; 8: 407-411

40. Hewett TE, Myer GD, Zazulak BT. Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity. J Sci Med Sport 2008; 11: 452-459

41. Gartland S, Malik M, Lovell M. Injury and injury rates in Muay Thai kick boxing. Br J Sports Med 2001; 35: 308-313

42. Pieter W. Martial arts injuries. Med Sport Sci 2005; 48: 59-73

43. Haddad M, Chaouachi A, Castagna C et al. The convergent validity between two objective methods for quantifying training load in young taekwondo athletes. J Strength Cond Res 2012; 26: 206-209

44. Budō: The Martial Ways of Japan. Tokyo: Nippon Budokan Foundation; 2009

45. Dictionary of Sport and Exercise Science. Over 5,000 Terms Clearly Defined. London: A & B Black; 2006

46. Choi H. Taekwon-do ITF. New Zealand: International Taekwon-do Federation; 1995

47. Wąsik J. Walka sportowa taekwon-do. Podstawy rywalizacji i treningu. Częstochowa: Projack; 2013 [in Polish]

48. Kalina RM. Methodology of measurement, documentation and programming optimal workload continuous with variable intensity – applications in sports medicine, physiotherapy, geriatrics, health-related training, sport for all. Arch Budo 2012; 8(4): 235-249

Cite this article as: Bakońska-Pacoń E, Dziubek W, Forgiel G et al. Effects of gradual weight loss on anaerobic capacity and muscle strength in elite taekwondo ITF athletes. Arch Budo 2017; 13: 117-130