Journal of Combat Sports and Martial Arts
© MEDSPORTPRESS, 2016; 1(2); Vol. 7, 73-79
DOI: 10.5604/20815735.1225636

ORIGINAL ARTICLE

Effect of high intensity interval training on cardiopulmonary function in Taekwon-do ITF athletes

Amit Batra(A,B,C,D), **Marek Zatoń**(A,B,C,D)
University School of Physical Education in Wroclaw, Poland

Key words: Martial Arts, Physical conditioning; Human, Energy metabolism, Exercise

Summary

Introduction. The purpose of the study was to investigate the effect of high intensity interval training on cardiorpulmonary function of Taekwondo ITF athletes.

Material and methods. The study recruited 20 male ITF-style taekwondo practitioners. The sample was randomly divided into experimental (n =10) and control (n = 10) group. Aerobic capacity and ventilatory variables were measured pre- and post-training by an incremental treadmill exercise test continued until volitional exhaustion. The experimental group (E) completed an 8- week interval training program targeting glycolytic capacity. Their current training regime of traditional TKD methods and techniques (three sessions per week) was supplemented with an additional two interval training sessions per week (three regular taekwondo trainings and two interval training per week). Each session involved 30 s of maximal kicking drills (round middle kick) separated by 90 s of rest. The control group (C) continued their current training regime involving traditional TKD methods and techniques in 90 min daily sessions five times per week for the same 8-week period in group E.

Results. Post-training VO_2max increased significantly only in group E : 50.13 ± 3.81 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. 53.16 ± 2. $ml \cdot kg^{-1} \cdot min^{-1}$ ($p \leq 0.05$). There was no significant differences between and in groups in blood pH, maximal heart rate and in ventilatory variables during incremental treadmill test before and after training intervention.

Conclusions. The administration of 8-weeks of glycolytic-based interval training enhanced maximal oxygen uptake (VO_2max) in our sample of ITF taekwondo practitioners.

Introduction

International Taekwondo Federation-sanctioned competition involves two rounds of 2 min sparring interspersed with a 1 min rest period. The organizational structure of taekwondo (TKD) results in a physical activity characterized by concomitant low- and high-intensity efforts that require specific training adaptations for athletic performance [1]. Research on the physiological demands of competitive TKD has found it involves significant anaerobic energy expenditure supported throughout by the aerobic pathway [2,3,4]. Matsushige et al. [5] further articulated this interaction finding that muscle anaerobic metabolism is critical during the striking phases whereas the aerobic system is dominant during active recovery while also a significant contributor to the body's ability to regenerate energy. It can be therefore assumed that a block, kick, or punch delivered with high power–speed mobilizes anaerobic ATP resynthesis and that only during the low-intensity recovery periods characterized by defensive movements between attacks is aerobic metabolism and the removal of excess lactate (LA^-) stimulated.

The fighting dynamics of TKD as well as the adopted movement patterns (especially in lower weight classes) often elicit maximum heart rate and very high blood lactate levels (11-14 mmol/l plasma) [3,4]. The intensive nature of TKD therefore requires athletes with highly developed glycolytic capacity so as to present sufficient defense mechanisms against respiratory acidosis and, consequently, reduced performance. For this reason, the physiological and metabolic adaptations induced by interval training seem ideally suited for TKD and other combat sport athletes. Research on this training modality, such as by Burgomaster et al. [6], found that interval training increases pyruvate oxidation via enhanced pyruvate dehydrogenase and citrate synthase activity, both of which are important enzymes in the aerobic energy system. These results are consistent with those presented in other studies [7,8], who in addition to changes in the enzymatic activity of the glycolytic and aerobic energy systems also observed improved aerobic and anaerobic performance. Another confirmation of the positive effects of glycolytic-based interval training on aerobic capacity is through significant improvements in endurance efforts at lower respiratory minute volume and a decreased respiratory quotient [9]. Of interest is the fact that Burgomaster et al. [9], despite the significant improvement in endurance performance testing, observed no increase VO_2max. This is in contrast to the works of other authors [7,10,11,12,13,14].

The enhanced glycolytic capacity afforded by interval training also conveys a number of integrated training adaptations that include improved blood flow via capillary angiogenesis, minimized diffusion distance within skeletal muscle, increased arteriovenous oxygen difference, greater motor unit recruitment during exercise, and improved conduction velocity in muscle fiber [7,8,15,16]. The literature has also identified many metabolic and performance effects following a glycolytic-based interval training regime that are normally associated only after endurance training. These inter-modality similarities involve increased pre-exercise muscle glycogen stores, reduced consumption of glycogen, decreased lactate levels during submaximal exercise, increased maximal fat oxidation, improved muscle and tissue vascularization, and enhanced general physical performance as measured by VO_2max [6,9,17,18].

The majority of studies analyzing the effects of interval training focus on a number of parameters associated with the muscular and/or cardiorespiratory system. There is however a paucity of data on pulmonary function, which is responsible for oxygen delivery and limited by the transfer rate from the lungs to the bloodstream, an inherently difficult to measure variable. However, pulmonary function can be the first step in capping peak exercise performance. Another issue worth considering is that the most prevalent interval training protocols are based on the Wingate test, a procedure most commonly performed on a cycle ergometer. The movement structure inherent in this test may not be applicable for a variety of sports disciplines [19]. For these reasons, the aim of this study was to assess the aerobic and cardiorespiratory response (with a focus on pulmonary function) to a taekwondo-based interval training program.

Material and methods

A control group of TKD athletes continued their regular training regime of five 90-min daily sessions per week over an 8-week period. An experimental group of the same TKD athletes had two of the regular training sessions replaced with a 45-min TKD-specific interval training protocol. Weekly training volume was therefore approximately 360 and 450 min for the experimental and control groups, respectively. Training intensity, based on heart rate, varied in the experimental group from 65–95 % HRmax depending on the exercise and technical proficiency of the participant. Each high intensity interval training session (HIIT) involved 30 s of maximal kicking drills (round middle kicks to the pad) separated by 90 s of rest. Performance was measured by the number of kicks performed alternately with the left or right foot in each 30-s bout. Exercise was continued until volitional exhaustion or if the number of kicks performed in 30 s decreased by a minimum of four kicks from the recorded maximum in the first kicking repetition. During the 8-week training period, the participants were able to perform a maximum of two sets of kicking drills, in which they averaged 4–6 repetitions.

Cardiopulmonary function was evaluated before and after the training intervention using an incremental treadmill test. The first training session involved familiarizing the participants with the training protocol that was to be used in the succeeding 16 interval training sessions over the 8 week period. As the familiarization session involved glycolytic-based training, it was included in the dataset.

The study recruited 20 male ITF-style taekwondo practitioners. Minimum training experience was 6.3 ± 1.1 years and all participants competed in national and international events. The sample was randomly divided into an experimental (*n* = 10, age 24 ± 5.2 years, weight 73.1 ± 9.26, height 178 ± 7.02 cm) and control (*n* = 10, age 24.9 ± 3.0, weight 71.63 ± 10.97, height 177.60 ± 7.35) group. The project was approved by the local ethical committee of University School of Physical Education in Wroclaw and written informed consent was gained from all subjects. The study conformed to the ethical requirements of the 1975 Declaration of Helsinki.

Aerobic capacity was measured pre- and post-training by an incremental treadmill exercise test continued until volitional exhaustion. All participants had experience with treadmill running. All testing sessions were performed under similar environmental conditions (105–115 m altitude, 20–25 C, 35–40% relative humidity) and all testing sessions were performed at the same hour of the day to avoid any influence of circadian rhythm. Twenty-four hours before the testing sessions the participants were to refrain from alcohol and caffeine ingestion. The first training session did not commence until seven days after the first testing session. Further, a one week recovery period of no training was required between the last training session and the post-training test.

The maximal incremental running test was performed on an Insportline 2440 (Czech Republic). Starting running speed was set at 6 km/h and increased by 2 km/h every 3 min until volitional exhaustion. Heart rate was continually recorded with a V800 heart monitor (Polar Electro, Finland). Respiratory function was measured 3 min prior and continued 2 min after the test using a Quark b^2 metabolic analyzer (Cosmed, Italy) on a breath-by-breath basis. The following parameters were considered: maximal oxygen uptake (VO_2max), maximal pulmonary ventilation (VE), respiratory quotient (RQ), tidal volume (VT), ventilation rate (VR), and the ventilatory equivalent ratios for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2) in the last minute of effort (averaged into four 15 s intervals). Gas calibration prior to each test was performed automatically with a reference gas concentration of O_2 = 16% and CO_2 = 5%. Arterialized capillary blood from the fingertip was drawn immediately before and 3 min after the test in order to determine lactate concentration (LA^-) using a LP400 photometer (Dr. Lange, Germany)

Statistical analysis

Descriptive statistics (arithmetic mean [x], standard deviation [SD], and minimum and maximum values [Min-Max]) were calculated for all measures using Statistica 9.0 software (StatSoft, USA). To compare cardiopulmonary and metabolic data before and after the training analysis of variance (ANOVA) with repeated measures was conducted. When a significant main effect over time was observed, paired t-tests within each group were conducted. Statistical significance was set at the $p < 0.05$ level.

Results

In pre-training, maximal oxygen uptake (VO_2max) did not differ significantly in either the control or experimental group (53.45 ± 2.06 vs. 50.13 ± 3.81 ml·kg^{-1}·min^{-1}, respectively). However, post-training VO_2max increased significantly only in group E to 53.16 ± 2.45 ml·kg^{-1}·min^{-1} (^{2} = 0.54, p = 0.02). (Fig. 1).

Table 1 presents maximal heart rate, blood pH level and lactate concentration (LA^-). Blood pH and lactate concentration was measured in 3rd min after the incremental treadmill test (mean ± *SD*). Blood lactate (LA^-) values were significantly higher compared to pre-training values in group E (^{2} = 0.73, p = 0.0002). A group x time interaction was observed for blood lactate values (*p* = 0.0014). There was no difference in maximal heart rate and blood pH measures at either time point between the groups.

Figures 2 and 3 illustrate the mean number of kicks performed during each interval training session (17 total over the

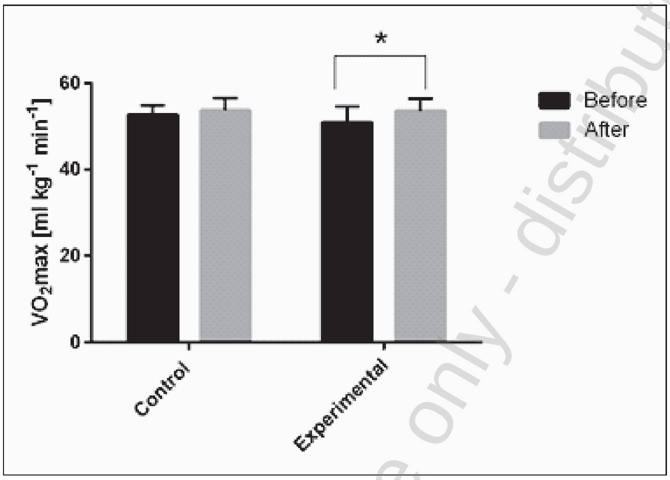

Figure 1. Maximal oxygen uptake (VO_{2max}) before and after training intervention in both groups (experimental and control)
* statistical significance $p \le 0.05$

Table 1. Maximal heart rate (HRmax), lactate concentration (LA-), and blood pH (mean ± SD) * $p \le 0.05$ post-training difference in group E

Variable	Control group		Experimental group	
	Pre-training	Post-training	Pre-training	Post-training
HRmax [bpm]	189.1 ± 12.3	190.6 ± 11.37	191.5 ± 5.7	190.7 ± 6.51
LA [mmol/l]	10.49 ± 1.12	11.08 ± 1.2	10.49 ± 1.88	12.03 ± 1.92 *
Blood pH	7.21 ± 0.03	7.22 ± 0.05	7.23 ± 0.04	7.22 ± 0.04

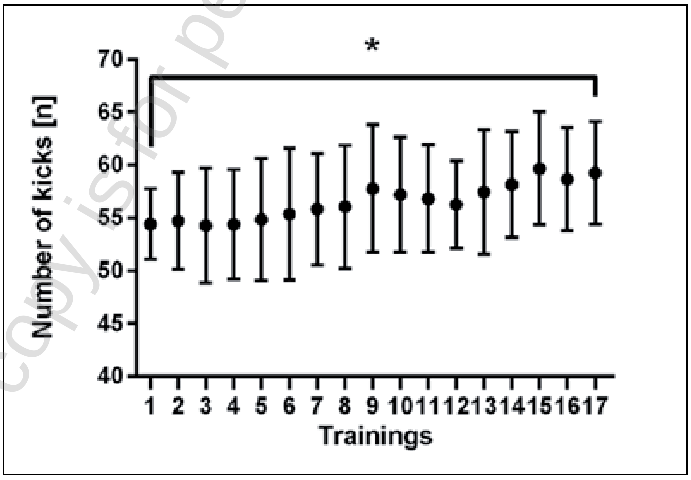

Figure 2. Number of kicks performed per 30-s repetition in each interval training session – first set
* $p < 0.05$ compared with the first training session

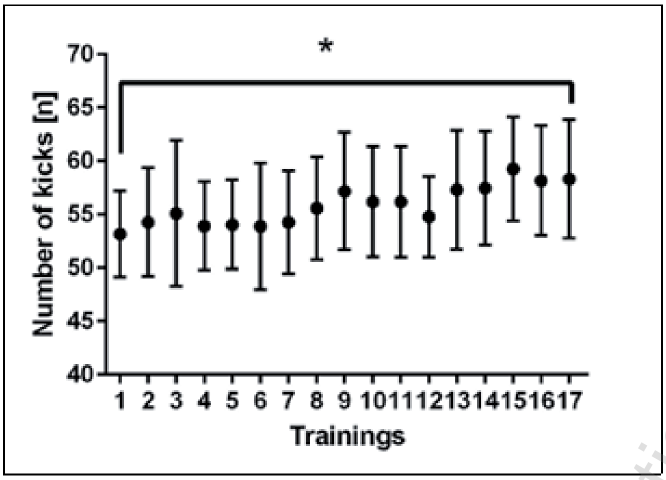

Figure 3. Number of kicks performed per 30-s repetition in each interval training session – second set
* $p < 0.05$ compared with the first training session

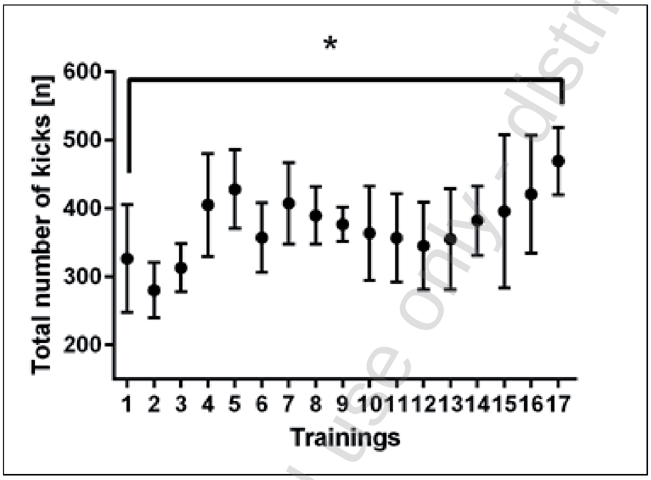

Figure 4. Total number of kicks performed (first and second set) in each interval training session
* $p < 0.05$ compared with the first training session

Table 2. Ventilatory response to the incremental treadmill test in group C and E before and after training intervention

Variable	Control group		xperimental group	
	Pre-training	Post-training	Pre-training	Post-training
Rf	55.18 ± 7.92	55.04 ± 8.17	58.7 ± 6.59	60.13 ± 7.53
VT	2.55 ± 0.55	2.55 ± 0.52	2.37 ± 0.33	2.39 ± 0.38
VE	139 ± 25.42	138.51 ± 25.44	138.35 ± 15.04	143.3 ± 24.29
VE/VO$_2$	37.63 ± 4.32	37.61 ± 4.17	37.36 ± 2.61	36.99 ± 2.49
VE/VCO$_2$	34.48 ± 4.04	34.44 ± 4.04	32.99 ± 2.83	33.51 ± 2.57
RQ	1.08 ± 0.05	1.08 ± 0.05	1.12 ± 0.03	1.10 ± 0.04

Rf – respiration frequency, VT – tidal volume [l/min], VE – minute ventilation [l/min], VE/VO$_2$ – ventilatory equivalent ratio for oxygen [l/min], VE/VCO$_2$ – ventilatory equivalent ratio for carbon dioxide [l/min], RQ – respiratory quiotent

8 week period) in the experimental group. The means were calculated based on the number of kicks performed in the 30-s repetitions in a set (on average 4–6 repetitions). At training outset in the first set, group E performed 54.4 ± 3.69 kicks in a 30-s bout. This increased to 59.3 ± 5.36 kicks upon the conclusion of training program, although the highest obtained mean value was 59.7 ± 5.88 in the fifteenth training session. The difference in the number of kicks between the first and last training session was statistically significant (^{2} = 0.86, $p \leq 0.0001$) (Fig. 2).

In the second set, mean kicks per 30-s bout in the first training session was 53.14 ± 4.42 and increased to 58.29 ± 6.16 kicks in the last session. This difference was also statistically significant (^{2} = 0.81, $p \leq 0.0001$) (Fig. 3).

In the first training session, the mean total number of kicks performed in one training session (first and second set) was 326.5 ± 87.29 kicks. This increased to 469.7 ± 52.53 total kicks in the last training session, which was also the highest obtained value. In turn, the fewest total kicks performed was 279.9 ± 43.98 in the second training session. The difference between the total number of kicks performed between the first and last training session was statistically significant (^{2} = 0.87, $p \leq 0.0001$) (Fig. 4).

Table 2 presents the pre- and post-training variables related to cardiorespiratory function. No significant between-group differences were observed nor any significant differences in pre- and post-measures in groups E and C.

Discussion

The literature finds that a key physiological adaptation of endurance, and interval, training is increased tidal volume accompanied by a reduction in respiratory frequency. This results in a lower ventilatory equivalent ratio for oxygen uptake and indicates improved respiratory efficiency [20,21]. However, the present study showed no training effects on respiration as indicated by the lack of significant pre- and post-training differences in maximal pulmonary ventilation (VE), ventilation rate (VR), tidal volume (VT), respiratory quotient (RQ), and the ventilatory equivalent ratios for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2). It can be inferred that the lack of change in gas exchange accompanied by a concomitant increase in VO_2max is indicative that interval training promotes adaptive changes in skeletal muscle oxygen extraction. Similar results were reported by Dunham and Harms [22], who also observed an improvement in VO_2max minus any significant global changes in pulmonary function. Here, spirometry testing showed only a 43% increase in maximal inspiratory pressure following 4 weeks of interval training compared with an increase of 25% after a conventional endurance training program of similar duration. While interval training was found to be more effective in developing inspiratory muscle strength than endurance training, it did not induce greater aerobic performance or significantly improve the remaining pulmonary parameters under investigation.

Research suggests that regular training targeting the anaerobic glycolytic system increases oxidative enzyme activities such as citrate synthase (CS), β-Hydroxyacyl-CoA dehydrogenase (β-HAD), and cytochrome oxidase as well as promotes numerous structural, neuronal, and molecular adaptations, all of which result in increased VO_2max [6,8,9,23]. The potential hypernymic mechanisms can be traced to the recruitment and adaptation of type II muscle fibers, which from a cell-signaling perspective depends on the type of exercise being performed, whether endurance- or strength-related and aerobic or anaerobic in nature. It is suggested that interval training activates signaling pathways responsible for both increased muscle mass (via the mechanistic target of the rapamycin pathway) and mitochondrial biogenesis (via monophosphate-activated protein kinase) that cross over to generate a remodeling response that would be inhibited if performing a strict aerobic or anaerobic effort [23]. This causes interval training to mediate oxidative enzyme activity with further adaptations as evidenced by citrate synthase activity that, in contrast to type I fibers, is dependent on exercise duration and intensity in type II fibers.

Gibala et al. [17] and Burgomaster et al. [9,24) both demonstrated that, despite the improvement in cycle ergometer time trial performance, the lack of an interval training-induced increase in VO_2max indicates that buffering capacity and other molecular and cellular adaptations in skeletal muscle are responsible for improved exercise capacity. Similar conclusions can be drawn from the blood pH and lactate concentrations observed in our experimental group. The results suggest that the interval training intervention improved intracellular buffering capacity, as a higher concentration of LA was accompanied by only a minimal change in blood pH. Numerous studies suggest that training modalities which successfully enhance anaerobic glycolysis and induce profound metabolic acidosis improve both muscle and blood buffering capacity [25,26].

The steady increase we observed in both total work output and number of kick in a 30-s repetition during the intervention signifies that glycolytic capacity is subject to training effects. These two variables also serve as the best indicators of performance and, appropriately, the best measures on the efficacy of interval training and when it should be ended. Wołkow [27] recommended that a set of exercise or the entire training session be concluded if work output decreases in subsequent repetitions, as high-energy compound consumption is linearly related to the amount of power needed to execute an exercise drill.

One of the main problems underlying the administration of an interval training protocol is exercise load and volume. As mentioned, the present study showed a steady increase in the number 30-s repetitions in the first and seconds sets as well as an increase in mean kicks in a single exercise session. By the ninth training session (or the beginning of the 5th week of training) peak performance was reached in the first set as indicated by the increase in mean kicks performed in a 30-s bout. This was then followed by a slight reduction in work output until the twelfth training session, which reversed and then continued to increase until the end of the study (Fig. 2). However, the second set shows far greater variance in the number of kicks performed in a 30-s repetition. From the beginning of the training program until the third session, there was a continuous increase in the mean kicks (Fig. 3). This was followed by a relative plateau for four training sessions (two weeks). Only from the seventh training session was a sharp increase observed that again plateaued until the twelfth training session. Afterwards, work output and therefore glycolytic capacity continually increased until the experiment was concluded. In effect, when considering the total number of kicks performed in each training session during the intervention, several phases can be identified: a period of growth until the fifth session, a decline from the fifth to the twelfth session, and then a second phase of growth from the thirteenth to the final seventeenth session. This variance may be explained by insufficient recovery. Parra et al. [28] and Rodas et al. [13] conducted two different investigations on one study sample to determine that a high-frequency interval training prescription may lead to reduced metabolic and enzyme activities, and stressed the importance of rest in counteracting action potential propagation impairments. This suggests that a reduction in performance, measured by a direct method such as the decrease in the number of kicks in a 30-s bout, is indicative of the need for extended recovery intervals between consecutive exercise sessions.

There are some limitations of the present study that need to be recognized. First, a larger sample size is needed to permit a more generalized interpretation of the present findings. While the estimated change in VO2max was statistically significant, a clear causal association is inherently limited with regard to our data. A second limitation was the lack of between-group comparisons regarding training intensity during the non-interval training sessions although training duration was recorded (360 min per week in the experimental group and 450 min of training per week in the control group). However, considering the magnified effects of interval training as is, we felt that the ultimate training volume of the groups put neither at an advantage or disadvantage. However, for the very reason that training intensity was not compared, we can only suggest that the increase of VO_2max in the experimental group was elicited by the higher training intensity (at lower volume) of HIIT. Thus, we are unable to unequivocally determine whether the higher training intensity of the experimental group could have had an effect on the observed adaptations.

Conclusions and practical applications

The administration of 8-weeks of glycolytic-based interval training enhanced maximal oxygen uptake (VO_2max) in our sample of ITF-style TKD practitioners. Evidence suggests that the increase in aerobic capacity following interval training is elicited by peripheral skeletal muscle adaptations that improve oxygen utilization in producing energy. Nevertheless additional studies are required to investigate the acute metabolic and molecular responses along with long-term muscular adaptation of the applied protocol. The variation in work distribution during the training period indicates the need for the continual monitoring of athlete adaptation/fatigue status. Furthermore, the physiological response to this training modality is subject to fluctuations, requiring its phases be identified in order to design an effective training program. A lack of proper oversight via insufficient measurement frequency may provide misleading results and insinuate a dubious strategy towards increasing cardiorespiratory fitness. Nevertheless, we found that high-intensity kicking drills (30 s work to 90 s rest) resulted in increased work capacity and power output (mean number of kicks performed in 30 seconds). We suggest that the application of the HIIT protocol to other TKD-specific drills (over a wider variety of TKD techniques including strikes and punches) can provide similar enhancements. Furthermore, the temporal structure of HIIT is much closer to that in TKD competitive sparring and would naturally favor specific adaptations beneficial for effective competition.

References

1. Batra A. Anaerobic effciency versus competitive level of Taekwon-do ITF athletes. Sport Wyczynowy 2012;4: 117 – 123.
2. 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.
3. Heller J, Peric T, Dlouhá R, Kohlíková E, Melichna J, Nováková H. Physiological profiles of males and females Taekwon-do ITF black belts. J Sports Sci 1998; 16 (3): 243-249.
4. Marković G, Vucetic V, Cardinale M. Heart rate and lactate responses to taekwon-do fight in elite women performers. Biology of Sport 2008; 25 (2): 135 – 146.
5. Matsushige, KA, Hartmann, K, Franchini E. Taekwon-do: Physiological responses and match analysis. J. Strength Cond. Res 2009; 23(4): 1112 – 1117.
6. Burgomaster KA, Howarth KR, Phillips SM., et.al. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J Physiol 2008; 586: 151–160
7. MacDougall JD, Hicks AL, MacDonald JR, McKelvie RS, Green HJ, Smith, KM. Muscle performance and enzymatic adaptations to sprint interval training. J Appl Physiol 1998: 84(6): 2138-42.
8. Ross A, Leveritt M. Long-term metabolic and skeletal muscle adaptations to short-sprint training: implications for sprint training and tapering. Sports Med 2001; 31(15): 1063-82.
9. Burgomaster KA, Hughes SC, Heigenhauser, GJ, Bradwell, SN, Gibala, MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in human. J Appl Physiol 2005; 98(6): 1985-90.
10. Barnett C, Carey M, Proietto J, Cerin E, Febbraio MA, Jenkins D. Muscle metabolism during sprint exercise in man: influence of sprint training. J. Sci. Med. Soprt. 2004; 7(3): 314-322.
11. Dawson B, Fitzsimons M, Green S, Goodman C, Carey M, Cole K. Changes in performance, muscle metabolites, enzymes and fibre types after short sprint training. Eur J Appl Physiol 1998; 78: 163-169.
12. McKenna MJ, Heigenhauser GJ, McKelvie RS, Obminski G, MacDougall JD, Jones NL. Enhanced pulmonary and active skeletal muscle gas exchange during intense exercise after sprint training in men. J Physiol 1997; 501 (3): 703-716.
13. Rodas G, Ventura JL, Cadefau JA, Cusso R, Parra , JA. A short training program for the rapid improvement of both aerobic and anaerobic metabolism. Eur J Appl Physiol 2000; 82: 480-486.
14. Tabata, I, Nishimura, K, Kouzaki, M, Hirai, Y, Ogita, F, Miyachi, M., Yamamoto, K. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. Med Sci Sport Exerc 1996; 28(10): 1327-1330.

15. Creer AR, Ricard MD, Conlee R.K, Hoyt GL, Parcell AC. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. Int J Sports Med 2004; 25(2): 92-98.
16. Krustrup P, Hellsten Y, Bangsbo J. Intense interval training enhances human skeletal muscle oxygen uptake in the initial phase of dynamic exercise at high but not at low intensities. J Physiol 2004; 15: 335-45.
17. Gibala MJ, Little JP, Van Essen M, Wilkin GP, Burgomaster KA, Safdar A, Raha S, Tarnopolsky, MA. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. J Physiol 2006; 575: 901–911
18. Rakobowchuk, M, Tanguay, S, Burgomaster, KA, Howarth, KR, Gibala MJ, MacDonald MJ. Sprint interval and traditional endurance training induce similar improvements in peripheral arterial stiffness and flow-mediated dilation in healthy humans. Am J Physiol Regul Integr Comp Physiol 2008; 295: 236–242.
19. Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? Appl Physiol Nutr Metab 2014; 39(3): 409-12.
20. Beck KC and Johnson BD,. Pulmonary adaptations to dynamic exercise. In: American College of Sports Medicine Resource Manual for Guidelines for Exercise Testing and Prescription. J.L. Roitman, eds. Baltimore: Williams & Wilkins, 1998; 305 – 313.
21. 21McArdle WD, Katch FI, Katch VI. Exercise Physiology. Phladelphia: Lea & Febiger, 1994.
22. Dunham, CL, Harms, CA. Effects of high-intensity interval training on pulmonary function. Eur J Appl Physiol 2012; 112(8): 3061-8.
23. Gibala MJ, McGee SL. Metabolic adaptations to short-term high-intensity interval training: a little pain for a lot of gain? Exerc Sport Sci Rev 2008; 36(2): 58-63.
24. Burgomaster KA, Heigenhauser GJ, Gibala MJ. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance.J Appl Physiol 2006; 100: 2041-2047.
25. 25Bishop D, Edge J, Thomas C, Mercier J. Effects of high-intensity training on muscle lactate transporters and postexercise recovery of muscle lactate and hydrogen ions in women. Am J Physiol Integr Comp Physiol. 2008; 295(6): 1991- 1998.
26. Zatoń, M, Hebisz, R, Hebisz, P. The physiological basis of the mountain biking training. Wrocław: AWF Wrocław, 2011.
27. Wołkow, N, Gabryś, T, Szmatlatn – Gabryś, U. Interval sport training. Warszawa: AWF Warszawa, 2007
28. Parra J, Cadefau JA, Rodas G, Amigó N, Cussó R. The distribution of rest periods affects performance and adaptations of energy metabolism induced by high intensity training in human muscle. Acta Physiol Scand 2000; 169(2): 157 – 165.

Address for correspondence:
Amit Batra
ul. Gromskiego 12/3, 35-233, Rzeszów, Poland
e-mail: amit@op.pl

Received: 12.11.2015
Accepted: 24.04.2016