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RESEARCH

Additional high intensity intermittent training improves aerobic and anaerobic performance in elite karate athletes

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Abstract

This study aimed to examine whether a period of high intensity intermittent training (HIIT) training influences aerobic and anaerobic performance in elite Karate athletes. Sixteen elite karate athletes volunteered to participate in this study. The athletes were randomly and gender-specifically divided into high intensity intermittent training (HIIT) group performed three times/week in addition to normal training for 6 weeks, and a traditional training (TT) group completing regular karate training. Body composition and maximal oxygen consumption as well as muscle power, speed, agility, and anaerobic power variables were assessed before and after the intervention. In addition, the blood lactate levels were measured in rest, after a warm-up period, and immediately, 5, 30, and 60 min after a Wingate test. The level of significance set $\rho \leq 0.05$ for the study. A significant difference was observed in VO_{2max} between HIIT and TT groups in post-test ($p = 0.006$). Furthermore, a significant difference observed between the muscle power ($p = 0.001$), speed ($p = 0.013$), agility ($p = 0.004$), peak power (PP) ($p = 0.002$), average power (AP) ($p = 0.004$), VO_{2max} ($p = 0.002$), and level of the blood lactate concentration 60 min after Wingate test ($p = 0.001$) in HIIT group from pre- to post-test. A time × group interaction in muscle power ($p = 0.001$), speed ($p = 0.021$), and VO_{2max} ($p = 0.005$) was observed. HIIT positively influences aerobic and anaerobic power in elite karate athletes compared to TT.

Keywords Karate athletes · Fatigue · Peak power · Speed · Agility · Blood lactate

Introduction

Karate literally translated means "empty hand" and it is derived from a martial art developed in Okinawa, Japan, in the early seventeenth century just after the Japanese conquered this island and banned the use of all weapons [1]. Karate is a popular combat sport that officially debuted at the Tokyo 2020 Olympic Games, whose performance requires athletes to possess a specific physical and physiological profile and technical expertise of the discipline [2]. Karate is a competitive sport that requires a high level of physical, physiological, complex technical skills and tactical excellence [3]. A karate athlete in the Olympic Games competed five times in only 1 day to reach the final stage. To win, an athlete must either reach an 8-point advantage within the 3-min round or have the most points at the end of the bout [4], which causes large variation in duration of fights.

The nature of karate competitions is intermittent, that consists of numerous repetitions of high intensity actions per fight lasting 1–3 s each, separated by low-intensity hopping–stepping movements (18 s) and short referees' breaks (~ 9 s). Elite karate athletes (especially kumite) usually require training with a combination of aerobic and anaerobic training [5]. A well-developed aerobic capacity enhances recovery between subsequent bouts of fighting activities and between single matches during a competition [6]. In addition, it prevents fatigue accumulation during training, and it accelerates the recovery process between training sessions

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[7, 8]. Anaerobic power and capacity is crucial to achieve the most decisive high-intensity scoring actions during the match [6, 9] and to resist fatigue [10]. The high intensity intermittent training (HIIT) is an effective method to improve physiological systems of importance for both aerobic and anaerobic performance [11–13]

HIIT consists of short bursts of exercise completed at intensities ≥ 80% HR_{max}, which are interspersed with recovery periods, and today, it is considered one of the most effective forms of exercise for improving the physical performance of athletes[14, 15]. These exercises have been shown to increase maximal activity in both oxidative and glycolytic key enzymes [16, 17]. Moreover, a wide range of adaptations have been shown after intense interval training including increased resting glycogen content of skeletal muscle, improved muscle K^+ regulation, buffering of H^+ ions [16, 17], an increase in VO_{2max}, and finally, an improvement in aerobic and anaerobic performance [18, 19]. During a controlled study following 6 weeks of HIIT, the researchers concluded that they improved maximum power output in the HIIT group, and HIIT exercises were comparable to the endurance training group [20]. In addition, studies in competitive volleyball [21] and football [22] have showed improved overall performance after addition HIIT combined with normal training. However, this has not yet been investigated in combat sports such as Karate.

In a preliminary study, a markedly elevated accumulation of blood lactate has been observed after karate bouts competition in elite athletes with values above 10 mmol. L^{-1} [3, 23, 24]. In a study investigating the effect of HIIT on anaerobic adaptations in the regular karate program of elite karateka athletes, it has been shown that, a clear difference was observed in blood lactate and pH kinetics [25]. In addition, after 2 weeks of daily HIIT, muscle citrate synthesis and muscle oxidative duration and endurance capacity during the aerobic cycle have been shown to increase [26]. Moreover, Ojeda et al. [27], after examining 6 weeks of HIIT with emphasis on speed and jumping in karate athletes, reported that after the training course, the jump height increased and both speed and changing direction records decreased [27]. Thus, HIIT may be well-suited in Karate.

However, to the best of our knowledge, previous studies have not studied the effect of additional HIIT in combination with normal training on comprehensive indicators such as aerobic (VO_{2max}), anaerobic (muscle power, speed, agility), and the blood lactate kinetics after the Wingate test in elite Karate athletes. Therefore, present study is the first comprehensive study that has to examine the effect of additional HIIT on broad-spectrum performance indicators in karateka athletes. We hypothesized that a period of additional high intensity intermittent training (HIIT) has a beneficial effect on aerobic and anaerobic performance in elite Karate athletes.

Methods

Participants

The randomized controlled trail (RCT) study was conducted accordance with the last version of the Declaration of Helsinki and the study design and procedures were approved by the ethics committee of Sports Sciences Research Institute with the approval number IR.SSRC.REC.1402.102 to protect human subjects. In addition, all subjects were informed about the main goal of the study and provided written informed consent. As the timeline and overview of this study presented in Fig. 1, 20 elite female and male karateka (10 women, 10 men) athletes who had the study criteria were volunteered to participate in this study. The entering criteria included; (a) having a black belt in karate; (b) having a regular karate training during the last 6 months with high experience in national and professional level; (c) with first to third ranking in national and international championships in the last 1–5 years; and (d) and not having had injuries or illnesses in the 2 months prior to the study. Subjects who (a) did not meet these conditions; (b) did not participate in practice or variable measurement sessions; and (c) were injured; were excluded from the research process. Finally, 16 elite karate (kumite) athletes [$n = 16$ (6 women and 10 men); age: 20 ± 1 years, body mass: 70.2 ± 3.7 kg; height: 176 ± 3 cm)] randomly (lottery method) divided in two groups (3 women and 5 men in each group) including high intensity intermittent training (HIIT) (age: 20 ± 3 years; body mass: 70.2 ± 15.4 kg; height: 177 ± 12 cm; BF%: 12 ± 4.6; BMI: 22.2 ± 2.3; FFMI:18.8 ± 2.0) and traditional training (TT) (age: 19 ± 2 years; body mass: 69.7 ± 13.2 kg; height: 175 ± 10 cm; BF%: 14.4 ± 6.7; BMI: 22.8 ± 3.8; FFMI: 18.5 ± 2.5) groups and run the research process.

Procedures

As outlined in Fig. 2, 5 days before beginning HIIT and TT programs, eligible individuals were recruited to the sports laboratory (Razi University, Kermanshah, Iran) for familiarization session, at 08:30 am, following blood sampling (to determine baseline blood lactate level) in medical laboratory at 07:00–08:00 am. In the familiarization session, the researchers informed participants about the benefits and possible risks of the study. Then, the anthropometric characteristics of players include height (stadiometer, Seca 206, Germany) and body mass (digital scale, Zeus 9.9 PLUS, Jawon, South Korea), and body fat percentage (BF%) were measured in fasted state at 09:00–09:30 am. BMI was calculated by the conventional formula of

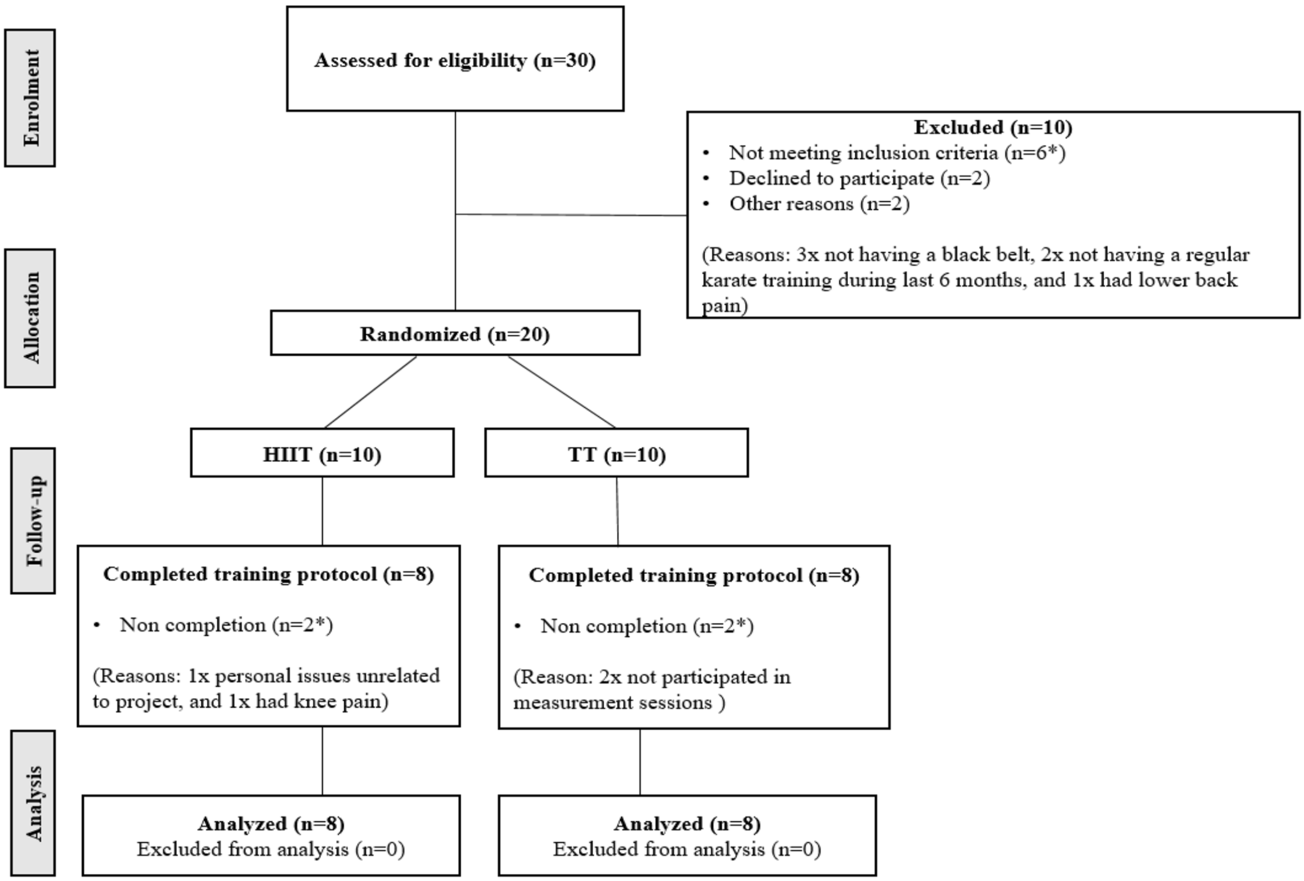

Fig. 1 Study flowchart; *HIIT* high intensity intermittent training, *TT* traditional training

dividing body mass by the square of height [28]. For BF% assessments, 7-site skinfolds (chest, abdominal, thigh, triceps, subscapular, suprailiac, and midaxillary) was taken (caliper, SH5020, Seahan, South Korea), then BF% was calculated by the A and B formulas [29] for female and male, respectively:

$$\text{A: BF\%} = 495/(1.097 - 0.00046971 \times X) + (0.0000005 \times X^2) - (0.00012828 \times Y) - 450;$$

$$\text{B: BF\%} = 495/(1.112 - (0.00043499 \times X) + (0.00000055 \times X^2) - (0.00028826 \times Y) - 450$$

where X is the sum of 7-site skinfold (mm), and Y is age (year).

After that, at 10:00–11:00 am, the participants warmed up for 10–15 min including moderate intensity running and dynamic stretching movements. Then, muscle power (Sargent jump test) (ICC = 0.99, CI 95%, 0.98–0.99, $P = 0.001$), agility (4 × 9 m) (ICC = 0.83, CI 95%, 0.64–0.93, $P = 0.002$) and speed (40 yard) (ICC = 0.94, CI 95%, 0.84–0.97, $P = 0.001$) were performed two trials and recorded values. Two trials were separated by 5 min full recovery. In addition, to assess the intra-class correlation (ICC) for sergeant jump, 40-yard speed, and 4 × 9-m agility tests, tests were repeated 72 h at 10:00–11:00 am after the first test repetition. At the first day, five days before programs from 12:00 to 01:00 pm, anaerobic capacity and power test was evaluated via Wingate anaerobic test (WAnT) in 30 s (894E, Monark, Sweden) [30] after 1 h full recovery. In addition, the blood lactate levels were measured at the rest period (as a baseline), after warm up, and immediately, 5, 30, and 60 min after the Wingate test. Four days before beginning HIIT and TT programs, Bruce test (h/p/cosmos, Pulsar, Germany) [31] was used to determine the maximum oxygen consumption (VO_{2max}) of the participants at 09:00 am after 24 h full recovery. In addition, maximum heart rate (HR_{max}) and blood lactate level were measured immediately and 4 min, respectively, after the Bruce test. The participants were asked to avoid to any physical activity 48 h before the tests and asked to avoid from coffee, caffeine, alcohol, and painkillers 24 h before assessing. Tests were separated by at 48 h to allow to recovery. Finally, all the mentioned indicators were measured and recorded two days after the last training session of the 6-week program as in the pre-test, Fig. 2. The environmental conditions of all the participants were the same in a room

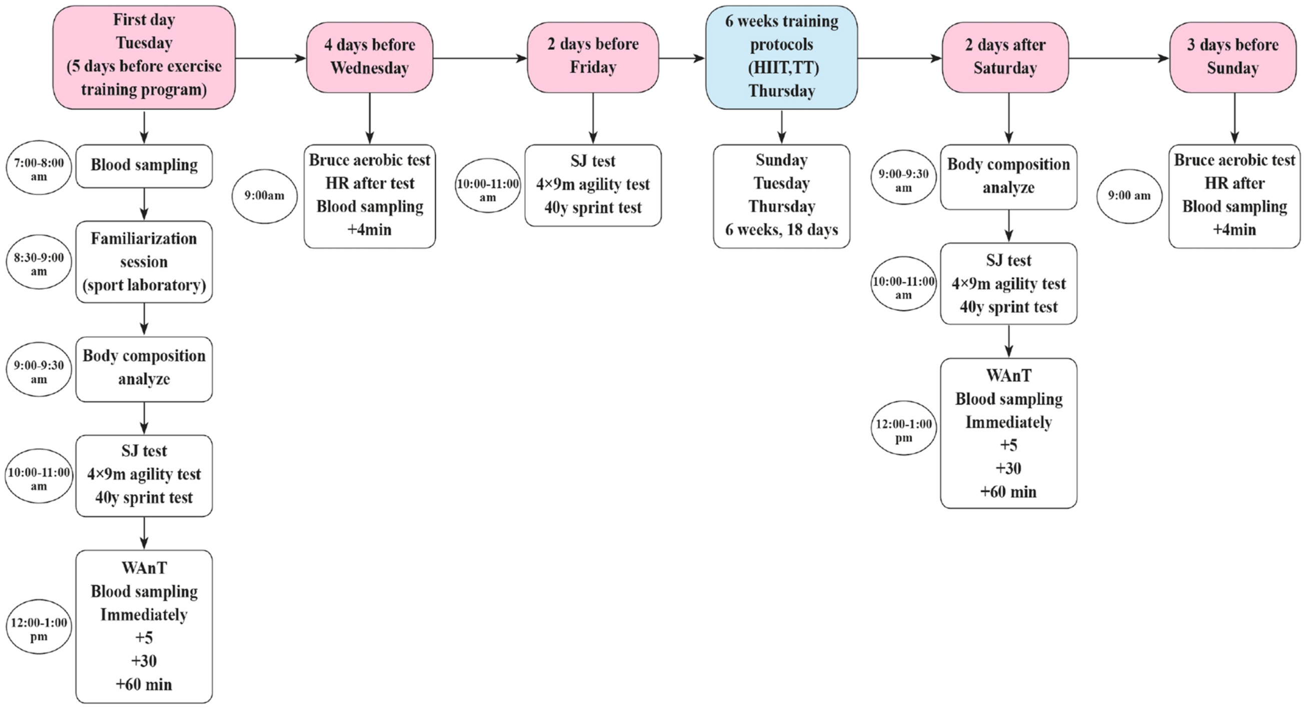

Fig. 2 Schematic overview of the current study timeline. *SJ* Sargent jump, *WAnT* Wingate anaerobic test, *HIIT* high intensity intermittent training, *TT* traditional training

with a stable temperature of 22 ± 2 °C and relative humidity of 48% ± 3%.

Blood sampling

2.5 cc blood sample was drawn from brachial vein and poured into disposable vacuum tubes and placed in a centrifuge (Hastaran Teb, Iran) at 3000 rpm for 5 min and were immediately frozen at −25 °C after plasma separation using sampler 1000. Then, lactate concentration was evaluated by AUDIT lactate kit (Darman Part, Iran). In addition, blood sampling was gathered according to the research plan in the rest (baseline), after 5 min warm-up, immediately, 5, 30, and 60 min after the Wingate test, and 4 min after Bruce test (G [25].

Training program

Except that, the HIIT program (18–24 min), the rest of the sections training were the same for both HIIT and TT protocols. Both HIIT and TT had a warm-up program at the beginning. HIIT group performed high intensity intermittent training after warm up and at the beginning of the sections training. During this time, TT group continued with their regular traditional Kumite training includes various offensive and/or defensive techniques (kicking, punching, and blocking) in either stationing or variable position. After HIIT training, HIIT group as TT group joined with their karate routine program. Finally, the training sessions finished with cooling down. The HIIT protocol consisted of 6 weeks 3×/week with an intensity of 80–100% HR_{max}. The HR was monitored with Polar monitors (Polar, Kempele, Finland). Each session involved 6–8 sets of 30 s HIIT training with 2.5 min' rest between sets. Exercise protocols gradually increased exercise volume from six to eight sets on a weekly basis. During the last 2 weeks, training loads were reduced to six sets (Table 1).

Statistical analyses

Data are presented as means and standard deviations (SD). The normality of data was tested and confirmed using the Shapiro–Wilk test. An independent sample *t* test, that were not significant, was used to evaluate the condition between groups in pre-training data. The assumptions of a repeated measure ANOVA including the normality of data (Shapiro–Wilk's test), sphericity (Mauchly's test), and significant outliers was confirmed for all variables; the epsilon adjustments (Greenhouse–Geisser or Huynh–Feldt) were applied if sphericity was not assumed. Paired sample test was used to analyze differences within groups. The effect size (ES) was also calculated as the change score divided by the SD of the change score to examine the magnitude of differences while controlling for the influence of the sample size [32], with

Table 1 HIIT exercise training program including training content, number of sets, and duration during 6 weeks

Weeks	Training content	Number of sets	Duration (min)
1st week	3 sets of CMJ for 30 s, 2.5 min rest between sets, 3 reps of 5m sprint for 30 s, 2.5 min rest between sets	6	18
2nd week	3 sets of CMJ for 30 s, 2.5 min rest between sets, 4 reps of 5m sprint for 30 s, 2.5 min rest between sets	7	21
3rd week	4 sets of CMJ for 30 s, 2.5 min rest between sets, 4 reps of 5m sprint for 30 s, 2.5 min rest between sets	8	24
4th week	4 sets of CMJ for 30 s, 2.5 min rest between sets, 4 reps of 5m sprint for 30 s, 2.5 min rest between sets	8	24
5th week	3 sets of CMJ for 30 s, 2.5 min rest between sets, 4 reps of 5m sprint for 30 s, 2.5 min rest between sets	7	21
6th week	3 sets of CMJ for 30 s, 2.5 min rest between sets, 3 reps of 5m sprint for 30 s, 2.5 min rest between sets	6	18

CMJ countermovement jumps, *rep* repetition

0.2 considered as a small ES, 0.5 as a moderate ES and > 0.8 as a large ES [33]. The significance level in all statistical operations was less than 0.05 ($P < 0.05$). SPSS 26 statistical software was used to analyze the data.

Results

As show in Table 2, physical characteristics data as well as descriptive information of karate athletes' for pre- and post-training in HIIT and TT groups are presented.

Followed by 6 weeks of HIIT training, based on the ANOVA repeated measurements, the interaction of time × group for mean muscle power [F (13,1) = 21.15; $P = 0.001$; ES = 0.61, moderate ES] were significant. However, there was no significant difference in muscle power [F (13,1) = 0.891; $P > 0.05$; ES = 0.06, small ES] between the two groups. However, the results of ANOVA repeated measurements indicated that the effect of time [F (13,1) = 30.20; $P = 0.001$; ES = 0.69, moderate ES] was significant. Therefore, paired sample t test analysis showed that there was a significant difference in muscle power in HIIT group ($t_7 = -8.91$, $P = 0.001$) but no difference in TT group ($t_7 = -0.52$, $P > 0.05$) from pre- to post-test (Fig. 3A).

Data analysis with ANOVA repeated measurements outputs showed that the interaction of time × group for mean

Table 2 Descriptive information of performance indicators of the subjects (data presented mean ± SD)

Group Variables	HIIT group ($n = 8$)		TT group ($n = 8$)	
	Pre training	Post-training	Pre training	Post-training
Muscle power (cm)	46.9 ± 11.1	50.2 ± 11.6	43.1 ± 9.6	43.4 ± 10.5
Agility (s)	9.60 ± 0.85	9.16 ± 0.92	10.33 ± 0.76	10.15 ± 0.55
Speed (s)	5.81 ± 0.64	5.53 ± 0.69	6.31 ± 0.54	6.32 ± 0.55
Wingate 30-s test variables				
PP (w/kg)	10.48 ± 3.50	11.76 ± 3.07	9.15 ± 1.88	9.68 ± 2.34
MP (w/kg)	4.32 ± 0.87	3.74 ± 1.79	3.36 ± 1.65	2.91 ± 1.99
AP (w/kg)	7.45 ± 1.89	7.88 ± 1.68	5.54 ± 2.42	6.93 ± 1.82
FI (%)	56.89 ± 10.26	66.12 ± 16.85	71.07 ± 16.65	69.79 ± 19.47
LA-base	0.85 ± 0.27	0.82 ± 0.29	0.92 ± 0.38	1.06 ± 0.53
LA-after WUp	1.35 ± 0.82	1.47 ± 1.20	1.55 ± 0.38	1.52 ± 0.42
LA-immediately	7.99 ± 2.09	7.45 ± 1.33	7.68 ± 3.05	8.40 ± 3.07
LA-5 min	8.12 ± 2.26	8.23 ± 0.95	8.56 ± 2.45	8.24 ± 2.30
LA-30 min	3.37 ± 1.95	2.24 ± 0.60	3.14 ± 1.52	3.18 ± 1.36
LA-60 min	1.41 ± 0.30	0.98 ± 0.15	1.54 ± 0.59	1.46 ± 0.29
VO_{2max} (ml/kg/min)	50.6 ± 6.9	57.2 ± 3.9	46.0 ± 5.1	46.1 ± 3.0
LA after VO_{2max} (mmol/l)	11.48 ± 1.98	12.63 ± 2.09	10.52 ± 1.84	10.44 ± 2.47
HR after VO_{2max} (bpm)	197 ± 7	197 ± 7	196 ± 12	189 ± 9

Data are presented as mean ± SD

HIIT group high intensity intermittent training group, *TT group* traditional training group, *BMI* body mass index, *FFMI* fat-free mass index, *PP* peak power, *MP* minimum power, *AP* average power, *FI* fatigue index, *LA* blood lactate, *WUP* warm up; VO_{2max} maximum oxygen consumption, *HR* heart rate

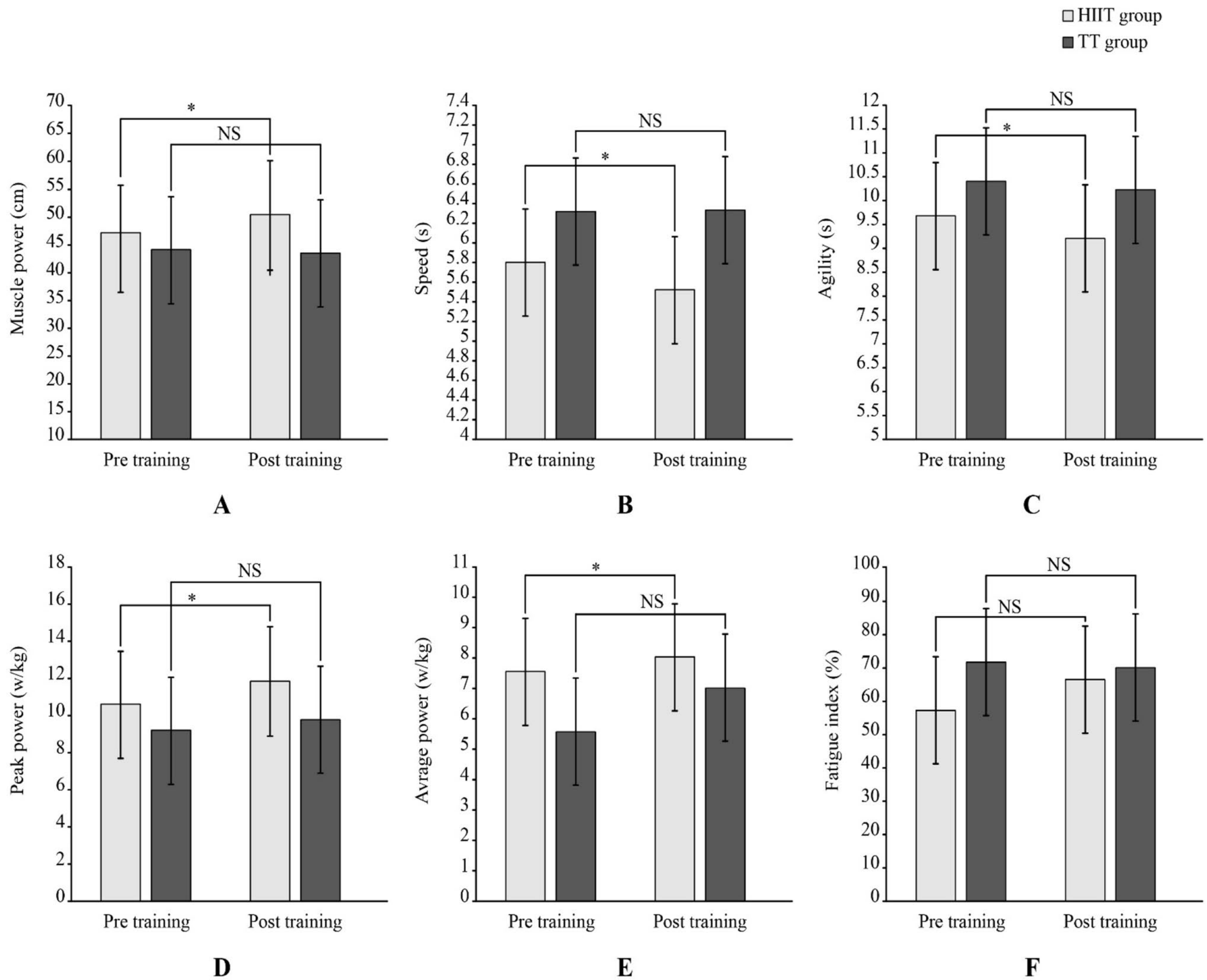

Fig. 3 HIIT group that was given the HIIT training method was able to change some indicators significantly compared to the TT group and from pre- to post-training. Asterisk: significant differences in muscle power (**A**); speed (**B**); agility (**C**); PP (**D**); and AP (**E**); in HIIT training from pre- to post-test ($P<0.05$). *NS* no significant difference in muscle power, speed, agility, PP, AP, and FI in TT training from pre- to post-test ($P>0.05$)

speed [F (13,1) = 6.87; $P=0.021$; ES = 0.34, small ES] were significant. However, there was no significant difference in speed performance [F (13,1) = 4.15; $P>0.05$; ES = 0.24, small ES] between two groups in the post-test. However, the result in speed determined that the effect of time [F (13,1) = 6.10; $P=0.028$; ES = 0.31, small ES] was significantly changed. Thus, the results of paired sample t test analysis showed that there was a significant difference in speed in HIIT group ($t_7=3.33$, $P=0.013$); however, there was no significant difference in TT group ($t_7=-0.124$, $P>0.05$) from pre to post (Fig. 3B).

Finding of ANOVA repeated measurements indicated that the interaction of time × group for mean agility was no significant [F (13,1) = 2.85; $P>0.05$; ES = 0.18, small ES]. In addition, there was no significant difference in agility [F (13,1) = 4.47; $P>0.05$; ES = 0.25, small ES] between two groups in post-test. However, the result of ANOVA repeated measurements for agility determined that the effect of measurement time [F (13,1) = 16.75; $P=0.001$; ES = 0.56, moderate ES] was significantly changed. Therefore, the result of paired sample t test analysis test showed that there was a significant difference in agility in HIIT group ($t_7=4.24$, $P=0.004$), but there was no significant difference in TT group from pre to post ($t_7=1.64$, $P>0.05$) (Fig. 3C).

Based on the ANOVA repeated measurements, the interaction of time × group for mean PP were no significant [F (13,1) = 3.91; $P>0.05$; ES = 0.23, small ES]. Moreover, there was no significant difference in PP [F (13,1) = 1.40; $P>0.05$; ES = 0.97, large ES] between groups. In contrast, the result of ANOVA repeated measurements showed that the effect of measurement time [F (13,1) = 22.73; P = 0.001; ES = 0.63, moderate ES] was significant. Thus, the results of paired sample t test analysis test showed that there was a significant difference in PP for HIIT group (t_7 = 4.83, P = 0.002); however, there was no significant difference in TT group (t_7 = –1.96, P > 0.05) from pre to post, furthermore (Fig. 3D).

The results of the ANOVA repeated measurements showed that The interaction of time × group for AP, were no significant [F (13,1) = 1.67; P > 0.05; ES = 0.11, small ES]. In addition, there was no significant in AP [F (13,1) = 2.27; P > 0.05; ES = 0.14, small ES] between groups. Whereas, the result indicated that the effect of time [F (13,1) = 6.01; P = 0.029; ES = 0.31, small ES] was significant. Therefore, the results of paired sample t test analysis showed that there was a significant difference in AP in HIIT group (t_7 = −4.20, P = 0.004) there was no significant difference in TT group (t_7 = 0.128, P > 0.05) from pre- to post-test (Fig. 3E).

The ANOVA repeated measurements indicated that the interaction of time × group for mean FI were no significant difference [F (13,1) = 0.92; P > 0.05; ES = 0.67, moderate ES]. In addition, there was no significant difference at FI [F (13,1) = 2.08; P > 0.05; ES = 0.13, small ES] between groups. In addition, the effect of time [F (13,1) = 0.53; P > 0.05; ES = 0.03, small ES] was no significant difference (Fig. 3F).

Finding of ANOVA repeated measurements indicated that the interaction of time × group for mean VO_{2max} was significant [F (13,1) = 11.72; P = 0.005; ES = 0.47, small ES]. Moreover, there was significant difference in VO_{2max} [F (13,1) = 10.47; P = 0.006; ES = 0.44, small ES] between groups. Therefore, based on the independent sample t test analysis, there was a significant difference in VO_{2max} (t_{14} = 6.03, P = 0.001) between the HIIT and TT groups in the post-test. In addition, the result indicated that the effect of time [F (13,1) = 11.79; P = 0.004; ES = 0.47, small ES] was significant. Therefore, the results of paired sample t test analysis test showed that there was a significant difference in VO_{2max} in HIIT group (t_7 = −5.00, P = 0.002), but no significant difference in TT group (t_7 = −0.007, P = 0.99) from pre to post, furthermore (Fig. 4A).

Considering lactate data collection in six points, ANOVA repeated measurements determined that the interaction of time × group for mean level of blood lactate concentrations consumption was no significant [F (13,1) = 0.40; P > 0.05; ES = 0.03, small ES]. In addition, there was no significant difference in level of blood lactate concentrations [F (13,1) = 0.26; P > 0.05; ES = 0.02, small ES] between two groups. Moreover, independent sample t test analysis showed that there was no significant difference in level of the blood lactate concentration between HIIT and TT training in basic lactate (t_{14} = −1.100, P > 0.05), after warm up (t_{14} = −0.09, P > 0.05), immediately after (t_{13} = −0.80, P > 0.05), 5 min (t_{14} = −0.01, P > 0.05), 30 min after Wingate (t_{14} = −1.63, P > 0.05), but there was significant difference 60 min after Wingate (t_{14} = −4.02, P = 0.001) in the post-test. In addition, the result of ANOVA repeated measurements showed that the effect of time [F (143,11) = 105.09; P = 0.001; ES = 0.89, large ES] was significant. Therefore, the results of paired sample t test analysis test showed that there was a significant difference in level of the blood lactate concentration 60 min after Wingate in HIIT group (t_7 = 5.80, P = 0.001), but no significant difference in TT group (t_7 = 0.669, P > 05) from pre to post (Fig. 4B).

Discussion and implication

A main finding of this study was that the addition of high-intensity intermittent training (HIIT) to the traditional karate training (TT) was efficient to optimize VO_{2max} and lactate removal after the Wingate in HIIT group compared to TT group. In addition, muscle power, speed, agility,

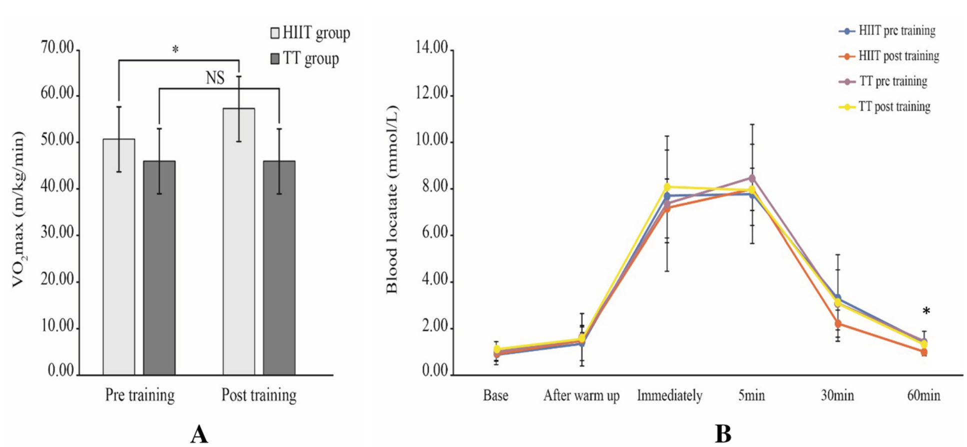

Fig. 4 **A** VO_{2max} for both HIIT and TT training in pre- and post-test; **B** level of blood lactate concentrations during the rest, after warm up, immediately, 5, 30, and 60 min after Wingate test in HIIT and TT at different times in pre- and post-test. Asterisk: significant difference in VO_{2max} in HIIT training from pre- to post-test (P < 0.05); and significant difference 60 min after between groups in the post-test; *NS* no significant difference in TT group from pre- to post-test

PP, AP, VO_{2max}, and blood lactate regulation improved in the HIIT training from pre- to post-training. However, no effects were found on FI variable and mentioned indicators in the TT exercise group.

Aerobic capacity is considered an important variable in combat sports, as it may attenuate fatigue accumulation and accelerate the recovery process [6, 34]. It has been reported that VO_{2max} of national and international male and females' karatekas are from 32.7 ± 4.1 to 61.4 ± 2.6 ml/kg/min [6]. In this study, the values of VO_{2max} in the HIIT group were 50.6 ± 6.9, which increased to 57.2 ± 3.9 ml/kg/min, corresponding to 14.1%, after the HIIT intervention, which is a large increase compared to other studies. Previous studies have indicated that HIIT training improves VO_{2max} [35–37]. Two studies [25, 38] used HIIT running as the exercise training mode and observed elevation of VO_{2max} magnitude: 4.6% in karate athletes submitted to 7-week HIIT program and 5.4% for wrestlers submitted to 4 weeks of additional HIIT [38]. In addition, additional HIIT in trained female volleyball players improved endurance capacity by 13–18% [21], while a 40% increase was observed in male footballers [22]. In contrast, some studies have shown diverging results [35, 36, 39], with no effects on VO_{2max}. It seems that the training protocol and thus the type of energy system that used as well as duration of the training are the reasons for mentioned difference. Various factors can cause aerobic power adaptations following HIIT exercises including central adaptations such as hematological indices including blood volume expansion, cardiac output and stroke volume [40], as well as peripheral adaptations such as increasing capillary density and mitochondrial biogenesis [19, 38] and delaying the point of exhaustion and the degree of fatigue [41, 42]. Thus, interventions that increase aerobic power, such as HIIT, seem desirable for karate athletes, as these modalities demand a high oxidative contribution and a fast creatine phosphate (CP) re-synthesis. This would result in a faster recovery between high-intensity interactions during subsequent bouts of fighting for karate athletes.

Anaerobic power and capacity is also considered important to support high-intensity actions during combat sports such as karate sport. These actions frequently result in scores and are represented by punching, kicking, and throwing techniques [36]. A systematic review reported that the peak power of elite, national, and international levels of both female and male karate athletes were from 7.7 ± 0.5 to 12.5 ± 1.3 w/kg in Wingate and force velocity tests. They also reported the average power were from 6.5 ± 0.3 to 7.9 ± 0.6 w/kg [6]. In this study, the values of peak and average power in the HIIT group were increased, corresponding to 10.8% and 6.9%, respectively. Several studies have been reported beneficial effects of various HIIT protocols on anaerobic power [38, 39, 43] and speed/agility [21, 22]. For instance, Farzad et al. [38] evaluated the peak and mean power after 4 weeks of HIIT training in trained wrestlers. In their study, a significant increase was determined in both peak and average power [38]. Kim et al. [39], also, observed an increase in anaerobic power indices in a study on judokas after 8 weeks of HIIT training [39]. Although the literature is limited on karate physiology, it should be mentioned that elevated muscle CP concentration [44], maximum activity in anaerobic enzymes, such as CK and PFK, and a significant increase in the area of FT fibers [38] may be main reasons for anaerobic power adaptations following HIIT. Moreover, a high fatigue resistance due to improved muscle regulation [10] are also likely candidates. In this study, a faster blood lactate removal after Wingate test in our group of elite karate athletes after 6 weeks of HIIT training, may indicate improved fatigue resistance. Faster recovery time through improving lactate clearance and buffering in the muscle cell [8, 20] may lower lactate levels, as well as the muscle-to-blood lactate gradient [45] in successive competition. Thus, we could conclude that HIIT training, while increasing blood lactate accumulation, would also probably increase the indicators of lactate clearance, which makes recover the karate athletes and prepare them for next match in tournaments.

Decisive actions during kumite karate are mainly dependent on muscle power where karate match performance is exclusively influenced by higher levels of upper and lower limb power/speed production [6]. In addition, successful performance in karate requires a high level of agility that enables the karateka to avoid the opponent's attacks, and to assume optimal position for efficient performance of karate techniques [46]. The result of this study showed that an improvement of 17.7%, 4.2% and 5.1%, respectively, for muscle power, agility, and speed performance after 6 weeks of HIIT training in elite karate athletes. The findings of the present study are consistent with Ribeiro et al. [37] who found that 10 weeks of HIIT training significantly boosted the speed in jiu-jitsu athletes [37]. On the other hand, Ojeda-Aravena et al. [2] reported that the addition of an HIIT to regular training with specific techniques and based on the temporal combat structure after 4 weeks was not a sufficient stimulus to increase muscle power and agility in karate athletes [2]. The lack of volume of training load applied and the different motor patterns used during HIIT in the study by Ojeda-Aravena and colleagues may have influenced the results. In this study, we applied a combination of jumps with short sprints in the HIIT protocol due to Karate specificity. Therefore, positive changes in explosive power or jumping, speed, and agility indices were expected due to the entity of used protocol and may also have transferred value to a Karate combat scenario. Collectively, HIIT training could be a meaningful strategy for improving muscle power, agility, and speed in karateka athletes.

These results suggest that HIIT can help to improve karate athletes' recovery between both high intensity actions and matches. In addition, another benefit of high intensity intermittent training protocol was an increase in anaerobic fitness represented by improvements in anaerobic peak and average power, which can potentially benefit karate athletes because these variables are relevant to both scoring and repeated high intensity actions. The results suggest that it would be great interest for karate competitors and similar society of athletes to organize their training with intermittent short intense exercises. Due to the limitations few studies in karate, future investigations should focus on the benefits of HIIT to the match or specific tests in the karate sport.

Conclusion

Additional high intensity intermittent training (HIIT) positively influences aerobic and anaerobic power in elite karate athletes compared to traditional training alone (TT). The results suggest that it would be of great interest for karate competitors and similar groups of athletes to organize their training with intermittent short intense exercises. Due to the limitations in karate and the few studies, future investigations should focus on the benefits of HIIT to the match or specific tests in the karate sport.

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Data availability Data would be available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval and Informed consent statements This study was conducted accordance with the last version of the Declaration of Helsinki and the study design and procedures were approved by the ethics committee of Sports Sciences Research Institute with the approval number IR.SSRC.REC.1402.102 to protect human subjects. In addition, all subjects were informed about the main goal of the study and provided written informed consent.

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