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Impressive anaerobic adaptations in elite karate athletes due to few intensive intermittent sessions added to regular karate training

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The aim of this study was to investigate the effects of adding a high-intensity intermittent session twice a week during a 7-week karate training (KT) on markers of aerobic and anaerobic metabolisms in elite class karate athletes. Two groups were studied: a KT group ($n = 8$, age 20.1 ± 0.9 years, 70.0 ± 8.8 kg) that followed traditional KT, and a group that followed combined traditional karate and a high-intensity intermittent training (HIT group, $n = 9$, age 24.4 ± 3.1 years, 67.0 ± 7.8 kg). The subjects undertook a supramaximal exercise and a maximal oxygen uptake test before and after the training. Blood lactate, pH and plasma ammonia were determined at rest, immediately at the end of the supramaximal exercise and during the recovery period at 2, 4, 6, 8, 10 and 15 min. After the training period, no changes occurred in the KT group. However, in the HIT group, the time to exhaustion, MAOD and $\dot{V}O_{2\,max}$ in the maximal oxygen uptake test were significantly improved by 23.6%, 10.3% and 4.6%, respectively. A clear-cut discrepancy was observed in the time course of lactate and pH in the supramaximal test after the training in the HIT group. We observed a significantly higher peak for lactate and a lower extreme value for pH with a shorter delay of appearance. At the end of the test, the lactate concentration increased significantly (+53.7%) and pH declined significantly, when compared with the values obtained after the same test before the training period. Ammonia was not influenced. The addition of high-intensity intermittent sessions twice per week during the period of KT induced beneficial physiological adaptations in athletes, allowing improvement in the duration of intense physical exercise before a state of fatigue is reached.

Karate training (KT) consists of many repetitions of short sequences (bursts techniques and hopping movement) interrupted by recovery periods. The main energy pathway involved in karate performance has not really been identified. It has been argued that aerobic metabolism is the main source of energy involved during the fights (Beneke et al., 2004). However, anaerobic metabolism has been considered to be an important energy source during KT (Imamura et al., 1999). In a preliminary study, we have observed a markedly elevated accumulation of lactate in blood after karate fight competition in elite athletes (Ravier & Rouillon, 2002). Owing to the needs of aerobic and anaerobic demands during KT, elite class karate athletes are usually getting a mixed training combining both demands. The physiological profile of elite competitors has been presented recently (Ravier et al., 2006) showing the needs of developing both metabolisms in karate athletes.

The effects of high-intensity intermittent training on both anaerobic and aerobic adaptations are well documented (Medbø & Burgers, 1990; Linossier et al., 1993; Hirai & Tabata, 1996; Tabata et al., 1996; Dawson et al., 1998) and are relevant in the required physiological adaptations in karate. Although it is believed that the more demanding the training, the greater the benefit will be, one has to consider the whole training volume of the athletes in order to avoid overtraining-related disturbances.

Anaerobic capacity has traditionally been estimated through the maximal accumulated oxygen deficit (MAOD) method (Medbø et al., 1988), which is sensitive to high-intensity intermittent training (Medbø & Burgers, 1990; Tabata et al., 1996). After intense exercise, the determination of blood markers of anaerobic metabolism may provide an insight into this metabolism. An accumulation of lactate [La] and hydrogen ion [H^+] in plasma is a well-known indicator of anaerobic glycolysis in active muscle. The increase in peak blood lactate levels after supramaximal exercise is a well-established adaptation to high-intensity exercise training (Jacobs et al., 1987; Strobel et al., 1999; Zouhal et al., 2001). In addition, after short intense exercise, an accumulation of ammonia in blood $[NH_4^+]$ suggests the activation of the myokinase pathway in the energy supply in active muscles. Exercise ammonia level is also sensitive to sprint and endurance training (Snow et al., 1992; Yuan et al., 2002).

The present study was therefore specifically designed to evaluate the effectiveness of a combined karate and a 7-week additional high-intensity intermittent training carried out in a field condition (on track run) and performed twice per week (with a frequency adapted to the training load). This training was evaluated in elite class athletes through the responses of anaerobic markers after exhaustive supramaximal and $\dot{V}O_{2max}$ tests before and after the training period.

Methods

Ethical information

The study was approved by the local ethics committee at the Franche-Comté area, France. Written informed consent was obtained from each subject.

Subjects

Seventeen male karate practitioners, members of the French National team or having an international level from the city of Paris and Montpellier participated in this study. Top-class karate athletes completed the same program established by the national French federation: usually, they practiced KT four to five times a week and performed one aerobic and one strength training weekly. During the experiment, they maintained their normal karate activity. Athletes were assigned to two groups depending on their geographic origin. Subjects were assigned either to the combined karate and high-intensity intermittent training group (HIT) or to the karate training group (KT, i.e., control group) in accordance with the coach's request. This study was conducted at the end of the sport season, and it could be assumed that the major physiological adaptations due to KT may occur at the beginning of the season when the athletes are somewhat untrained. It could be hypothesized that during the experiment with maintained training, no systematic changes occurred in the KT group. The characteristics of the subjects are presented in Table 1.

Table 1. Pre-training physical characteristics of the karate athletes

Characteristics of the athletes	HIT ($n = 9$)		KT ($n = 8$)	
	Mean	SD	Mean	SD
Age (years)	24.4	3.1	20.1	0.9
Body mass (kg)	67.0	7.8	70.0	8.8
Height (cm)	175.9	8.3	177.5	6.3
Body fat (%)	12.2	1.9	12.1	3.0

Body fat was estimated from the skin fold measurements (Durnin & Rahaman, 1967). Combined high-intensity intermittent and karate training group (HIT) and karate training group (KT) were compared. Statistical analysis was performed with Mann-Whitney test. No significant difference was found between the two groups.

Design of the study

The subjects were tested before and after the training period using identical protocols. All subjects participated in four treadmill exercise tests that included two submaximal runs, one incremental test and a supramaximal test to exhaustion.

Submaximal, $\dot{V}O_{2max}$ and MAOD tests

According to Medbø et al. (1988), the linear relationship between exercise intensity (treadmill speed) and the oxygen demand (steady-state oxygen consumption) was established individually from $\dot{V}O_2$ measured at rest and two treadmill runs (10 min at gradient of 10%) performed in 1 day. The first treadmill run was performed at 2.50 m/s (10% inclination), and after a period of rest (1 h) the subject chose the intensity of the second run between 2.36, 2.64 and 2.78 m/s (10% inclination). The oxygen uptake ($\dot{V}O_2$) was averaged for the last 2 min of each 10-min period of exercise.

After a period of rest (2–3 h), an incremental exercise that lasted until exhaustion was performed in order to determine the $\dot{V}O_{2max}$. This session started with a 15-min rest period while the subject was in a seated position. The average $\dot{V}O_2$ measured during the last 2 min of the resting period provided the resting $\dot{V}O_2$. The progressive exercise started at 2.50 m/s (at gradient of 2%) and was incremented by 1 km/h (0.28 m/s) every 2 min. The average $\dot{V}O_2$ determined during the last minute before exhaustion was defined as the $\dot{V}O_{2max}$. Each exercise was preceded by a 10-min warm-up (3 min at 1.11 m/s and 7 min at 2.22 m/s) on the treadmill at a 2% inclination.

Separated by at least 24 h, the MAOD was determined according to the method of Medbø et al. (1988), from treadmill run at a gradient of 10% using speed leading to exhaustion after 2–3 min. The duration of supramaximal exercise, which enables to calculate the MAOD, has been established to be 2–3 min. However, tests that are lasting 1.5 min or longer than 3 min have been shown to be acceptable (Medbø et al., 1988; Gastin et al., 1995). Therefore, when the time to exhaustion was lower than 1.5 min or longer than 3.5 min, the subject was re-evaluated. The MAOD corresponds to the difference between total energy demand (estimated from the oxygen cost of the surpamaximal exercise) and accumulated oxygen uptake during the supramaximal run. The accumulated oxygen uptake was estimated from the area that was found by integrating the curves.

The linear relationship between the two submaximal intensities and $\dot{V}O_2$ at rest was extrapolated to predict the oxygen cost of the surpramaximal run and to determine the treadmill speed for the supramaximal run to exhaustion. The supramaximal intensity to achieve exhaustion was set at 140% of the $\dot{V}O_{2max}$ velocity (Strobel et al., 1999). The supramaximal exercise speed determined for the test (performed before training period) was conserved for the test realized after the training period.

The MAOD test started with a 15-min rest period, during which the subject was in a sitting position. Exercise was preceded by a 10-min warm-up (3 min at 1.11 m/s and 7 min at 2.22 m/s) on the treadmill at 2% inclination, followed by 10 min of recovery (Medbø et al., 1988). After a sign from one of the investigators, the subject stepped onto the treadmill, which was moving at the predetermined velocity (10% inclination), and ran to complete volitional exhaustion. Immediately after the end of the exercise, the subject recovered in a supine position for 30 min. A rating of perceived exertion (RPE) using a 6–20 scale (Borg, 1970) was requested immediately after the exhaustive running test.

Training

Karate training was used as a control period lasting 6–7 weeks, during which time the athletes maintained their normal karate activity of four to five times per week.

Combined karate and high-intensity intermittent training included the normal karate activity (four to five times per week) and additionally a training session carried out on a track run twice a week for six to seven weeks. The high-intensity intermittent training conducted to exhaustion consisted of 7–9 sets of a 20-s running exercise at an intensity of about 140% of $\dot{V}O_{2\,max}$ velocity with a 15-s rest between each bout. The high-intensity intermittent training was a modified version of the training of Tabata et al. (1996) conducted on a cycle ergometer. When the athletes could complete more than nine sets of the exercise, running velocity was increased by 5%. The exhaustive intermittent training was preceded by a 10-min warm-up and followed by a 10-min recovery period.

Measurements

Oxygen uptake measurement

All experiments were conducted on a treadmill ergometer (Gymrol 2500, Tecmachine, Andrézieux-Bouthéon, France). The $\dot{V}O_2$ was recorded breath by breath with no delay using an automatic gas analyzer (CPX analyser-Medical Graphics Corporation-MSE, Strasbourg, France) running with Breeze v3 software. A calibration procedure for delay response analyzers and concentration was completed before each test using two known mixtures of high and low concentrations. Each gas analysis was calibrated using room air (20.96% O_2; 0.03% CO_2) and with a standard certified commercial gas preparation (gases of known concentrations: 12% O_2; 5% CO_2). The pneumotachometer was calibrated for volume using three inspiratory strokes with a 3-Liter syringe.

The $\dot{V}O_2$ and heart rate, which was displayed by an electrocardiogram (Cardiolife, Nihon Kohden Corporation, Tokyo, Japan), were measured continuously.

Blood specimen collection and analyte determination

Blood specimens (2 mL) were collected using a catheter within the cephalic vein or in the superficial radial vein in the far distal third of the forearm when determining the MAOD. Specimens were collected before the supramaximal exhaustive run (at the end of the 15-min rest period), immediately after the end of exercise and during the passive recovery at 2, 4, 6, 8, 10 and 15 min post exercise. The following analytes were determined: plasma ammonia $[NH_4^+]$, which was analyzed with an Amon (Dade Behring, Paris, France) apparatus, lactate [La], which was analyzed with a specific Dade Behring apparatus, and pH from specimens collected into heparinized syringe using a Corning 178 blood gas analyzer (Medfield, Massachusetts, USA).

The individual extreme recorded values of $[NH_4^+]$, [La] and pH determined during the recovery period after the supramaximal test were defined as the peak concentrations of ammonia ($[NH_4^+]_{ext}$) and lactate ($[La]_{ext}$) and as the nadir value for pH (pH_{ext}), respectively. The difference in the concentration of lactate between $[La]_{ext}$ and [La] measured immediately after the end of the exhaustive test ($[La]_{0\text{-}ext}$) was individually calculated (expressed in mmol/L) and the same applied for ammonia ($[NH_4^+]_{0\text{-}ext}$) in order to study the magnitude of the increase in the concentration of these markers in response to the supramaximal test. The difference in pH between pH_{ext} and pH measured immediately after the end of the exhaustive test ($pH_{0\text{-}ext}$) was individually calculated. In the same way, the decrease in these markers was estimated from the variations between extreme values and the concentrations obtained 15 min after the end of the exercise for lactate ($[La]_{ext\text{-}15}$), ammonia ($[NH_4^+]_{ext\text{-}15}$) and pH ($pH_{ext\text{-}15}$).

Statistics

Results are expressed as their mean and standard deviation. A Mann–Whitney test was used to evaluate differences between the two groups before the training period. For each group, the effect of training period was tested using a Wilcoxon test. The time course of the blood pH and the concentrations of lactate and ammonia after the end of the supramaximal test were studied using a two-way ANOVA (time, group or period) for repeated measurements and Fisher's PLSD when appropriate. The level of significance was set at $P < 0.05$. Statistics were calculated with Statview software (Abacus Concepts Inc., v4.55, Berkeley, California, USA).

Results

The volunteers' characteristics before the training are presented in Table 1. No significant differences were detected in our two groups in the results of submaximal, incremental and supramaximal tests.

Global responses in the submaximal, incremental and supramaximal tests before and after the training period

The KT group presented similar values before and after the training in the slope of "treadmill speed–oxygen uptake" regression, $\dot{V}O_{2\,max}$, MAOD, relative exercise intensity and the time to exhaustion in the supramaximal test (Table 2). No differences in RPE were observed. However, in the HIT group $\dot{V}O_{2\,max}$ and MAOD increased significantly (4.6% and 10.3%, respectively, $P < 0.05$) after training (Table 2). Moreover, in the supramaximal test, time to exhaustion increased (23.6%, $P < 0.05$) after the training period. The relative intensity (around 138% of the $\dot{V}O_{2\,max}$ before training) during the supramaximal test declined after training as a consequence of the improved maximal oxygen uptake (Table 2).

The slope of the linear regression between the treadmill speed (submaximal intensity) and oxygen uptake was not modified by the high-intensity intermittent training (Table 2).

Blood determination in the supramaximal test before and after the training

The data reported have been achieved in eight HIT and seven KT subjects. Blood specimens from two subjects were hemolyzed and discarded.

Before the training period, the rest values measured before the supramaximal exercise test for lactate, pH and ammonia were similar between the HIT and the KT groups (2.1 ± 0.4 vs 2.4 ± 0.4 mmol/L; 7.37 ± 0.02 vs 7.33 ± 0.04;

Table 2. Profile of the karate athletes before and after the training

	HIT ($n = 9$)		KT ($n = 8$)	
	Before	After	Before	After
$\dot{V}O_{2\,max}$ (mL/kg/min)	58.7 ± 3.1	61.4 ± 2.6*	58.2 ± 3.1	58.1 ± 4.4
MAOD (mL/kg)	63.9 ± 6.2	70.5 ± 6.4*	65.5 ± 7.3	62.0 ± 10.0
Slope of "treadmill speed-oxygen uptake" regression (mL/kg/m)	0.317 ± 0.013	0.316 ± 0.014	0.310 ± 0.011	0.301 ± 0.015
Time to exhaustion (supramaximal test)(s)	115.5 ± 20.7	142.8 ± 36.9*	135.7 ± 28.8	128.8 ± 20.9
Relative intensity in the supramaximal test (% $\dot{V}O_{2\,max}$)	137.7 ± 7.3	131.6 ± 7.1*	138.7 ± 5.6	135.3 ± 6.6
RPE	16.7 ± 0.5	16.7 ± 1.2	17.2 ± 0.8	17.2 ± 0.8

Results are expressed as the mean ± SD. Abbreviations: MAOD: maximal accumulated oxygen deficit; RPE: rating of perceived exertion.
*Significantly different from pretraining values, $P < 0.05$.

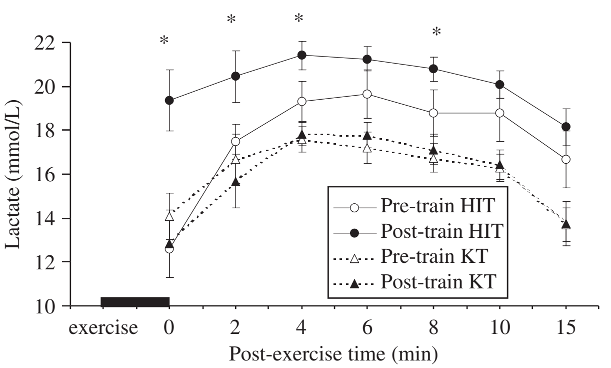

Fig. 1. Time course of the concentration of blood lactate after a supramaximal test. Open circles represent the data obtained from the combined karate and high-intensity intermittent training group (HIT) after the supramaximal test before the training (pre-train), and the filled circles the data from the same group after the same test after the training period (post-train). Similarly, the open and the filled triangles represent the data obtained before and after the training period in the karate training group (KT) after the supramaximal test. Error bars denote standard error.
The significant differences between the periods (pre-train and post-train) were specified for each time post-exercise with Wilcoxon's test. Significant differences were observed for the HIT group (*$P < 0.05$). The concentrations of blood lactate during the entire recovery period were higher after the training ($P < 0.05$) for the HIT group. The time course of lactate was significantly different ($P < 0.001$) between the periods (pre-train vs post-train) for the HIT group. Fisher's PLSD showed significant differences between end of the exercise and at 2, 4, 6, 8 and 10 min.

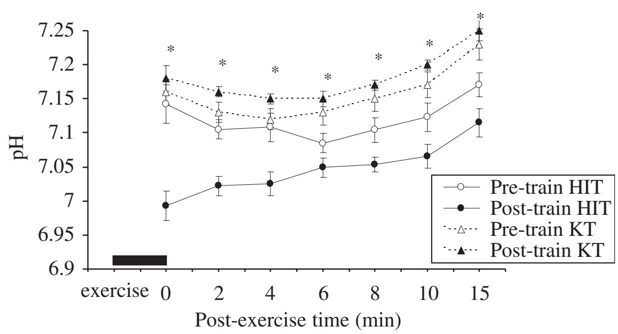

Fig. 2. Time course of blood pH after the supramaximal test. For the legends, see Fig. 1. The significant differences between the periods (pre-train and post-train) were specified for each time post-exercise with Wilcoxon's test. Significant differences were observed for the HIT group (*$P < 0.05$). The concentrations of blood pH during the entire recovery period were lower after the training ($P < 0.001$) for the HIT group. The time course of pH was significantly different ($P < 0.01$) between the periods (pre-train vs post-train) for the HIT group. Fisher's PLSD showed significant differences between 15 min and at 0, 2, 4, 6, 8 and 10 min.

42.6 ± 14.6 vs 40.9 ± 16.7 μmol/L, respectively). Rest values were not influenced by training.

After 7 weeks of KT, the concentrations of the analytes that we determined in blood after the end of the supramaximal test were not influenced by the training period in the KT group (Figs 1–3 and Table 3). Neither the extreme values of [La], [NH_4^+] and pH nor the time course of plasma lactate, ammonia and pH response differed.

After 7 weeks of combined karate and high-intensity intermittent training, the responses in blood lactate and pH after the end of the supramaximal test were markedly modified (Table 3). The training did not influence plasma ammonia response. During the entire recovery period, the concentrations of lactate were higher and pH was lower after the training ($P < 0.05$ and $P < 0.001$, respectively). Concerning the extreme values of lactate and pH, $[La]_{ext}$ significantly increased by 12.9% and pH_{ext} decreased significantly. Concerning the concentration of ammonia and lactate in blood before the training after the supramaximal test, their concentration markedly increased to the peak values and displayed a transitory plateauing before a decreasing phase. Before the training, pH declined before an increasing phase. After the training, clear-cut differences in the time course of lactate and pH were observed. An attenuated increase to the extreme value was observed for lactate while the pH curve was characterized by the absence of the descending phase. Blood pH increased after the end of the test (Fig. 2).

The delayed extreme value in pH decreased significantly after the training compared with the values obtained before under similar circumstances, and the same trend was observed for lactate but the difference did not reach significance ($P = 0.064$). Clear-cut differences were observed when comparing pH (pH_0) and the concentration of lactate ($[La]_0$) immediately after the end of the supramaximal test. $[La]_0$ increased significantly (53.7%) after the training when compared with the results obtained before the training (Table 3). pH_0 increased significantly after the training. When pH_0 is expressed in hydrogen ion concentration, $[H^+]_0$ increased significantly by 40.2% after the training. $[La]_{0\text{-ext}}$ also decreased (from 7.7 ± 3.7 to 3.4 ± 3.2 mmol/L, $P < 0.05$) and $[H^+]_{0\text{-ext}}$ tended to be lower (from 12.5 ± 5.7 to 7.1 ± 13.6 nmol/L; $P = 0.067$) when comparing the results obtained after the training period with those obtained before.

Moreover, $[La]_{\text{ext-15}}$ and $[H^+]_{\text{ext-15}}$ increased after training (from 3.6 ± 1.7 to 4.6 ± 2.4 mmol/L, $P < 0.05$ and 17.8 ± 7.2 to 32.5 ± 12.7 nmol/L, $P < 0.05$, respectively).

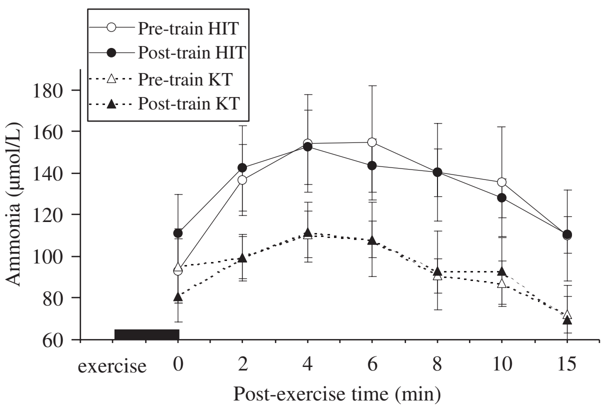

Fig. 3. Time course of the concentration of ammonia in plasma after the supramaximal test. For the legends, see Fig. 1. No significant differences were observed between the periods either for each time post-exercise or for the time course of concentrations after the supramaximal test.

When the HIT and KT groups were compared with each other after the training, we observed that the concentrations of lactate ($P < 0.001$) and pH ($P < 0.001$) were significantly different between these two groups during the entire recovery period after the supramaximal test. The time course of pH after the supramaximal test was also different ($P < 0.01$) between the HIT and the KT groups. However, the time course of lactate and ammonia after the supramaximal test was not significantly different between these two groups before and after the training. Nevertheless, a higher concentration of lactate ($P < 0.05$) and lower pH values ($P < 0.001$) were observed immediately after the end of the supramaximal test in the HIT group compared with those of the KT group.

Discussion

The main finding in our study is that high-intensity training twice a week for 7 weeks induced an improvement in $\dot{V}O_{2\,max}$ and in the anaerobic capacity in already very well-trained elite karate athletes. In line with this, a higher anaerobic capacity after training was accompanied by a higher blood lactate concentration and a lower pH after the supramaximal test.

Effects of the traditional karate training

The control group (KT) that completed its normal karate activity did not show changes in its performances during a period with maintained training, which was to be expected. The absence of any benefits on aerobic and anaerobic abilities suggests that the energetic stress demand of a regular KT at the end of the sport season may allow only slight changes in aerobic and anaerobic energy metabolism in trained karate athletes.

Table 3. Blood analytes before and after the training

Analytes	HIT ($n = 8$)		KT ($n = 7$)	
	Before	After	Before	After
$[La]_{ext}$ (mmol/L)	20.2 ± 2.8	$22.8 \pm 2.6^*$	17.9 ± 1.3	18.1 ± 1.2
pH_{ext}	7.07 ± 0.04	$6.96 \pm 0.05^*$	7.12 ± 0.04	7.14 ± 0.03
$[NH_4^+]_{ext}$ (µmol/L)	162.6 ± 72.1	160.5 ± 50.5	123.3 ± 24.7	113.7 ± 38.5
Delayed $[La]_{ext}$ (min)	6.2 ± 2.2	3.2 ± 3.2	4.9 ± 2.5	3.7 ± 2.7
Delayed pH_{ext} (min)	4.5 ± 2.6	$1.5 \pm 2.3^*$	4.3 ± 1.4	4.3 ± 2.1
Delayed $[NH_4^+]_{ext}$ (min)	5.5 ± 2.3	5.0 ± 2.6	3.4 ± 1.9	3.7 ± 1.4
$[La]_0$ (mmol/L)	12.6 ± 3.7	$19.3 \pm 4.1^*$	13.3 ± 2.5	13.3 ± 3.0
pH_0	7.14 ± 0.08	$6.99 \pm 0.06^*$	7.16 ± 0.05	7.18 ± 0.05
$[NH_4^+]_0$ (µmol/L)	93.1 ± 44.2	111.4 ± 51.6	92.6 ± 26.2	87.6 ± 25.4

Results are expressed as the mean ± SD. Abbreviations : $[X]_{ext}$ stands for the extreme concentration of the compound X; $[X]_0$ stands for the concentration of the compound X at the end of the supramaximal test.

High-intensity intermittent sessions and benefits on $\dot{V}O_{2\,max}$ and MAOD

The slope of the linear regression between the treadmill speed and oxygen uptake, determined individually from two intensities closed to the maximal oxygen uptake, was not modified by the high-intensity intermittent training. The slopes we obtained with a simplified procedure defined by Medbø et al. (1988) were close to values of these authors established by repeated 20 trials at different submaximal intensities (0.298 mL/kg/m and ranged from 0.272 to 0.320 mL/kg/m).

After the combined karate and high-intensity intermittent training period, maximal oxygen uptake increased by 4.6%, while MAOD increased by 10.3% and time to exhaustion in the supramaximal test increased by 23.6%. Such adaptation both in maximal aerobic power and in anaerobic capacity seems to be relevant to the required physiological adaptations in karate (Beneke et al., 2004; Ravier et al., 2006).

Tabata et al. (1997) have evaluated previously the magnitude of the changes in the aerobic and anaerobic energy release systems during a high-intensity intermittent exercise (bouts of 20 s separated by 10 s and repeated seven times until exhaustion), which was actually quite similar to the one carried out in our study. They were able to show that during this exercise, the peak oxygen uptake measured during the last bout of exercise reached the $\dot{V}O_{2\,max}$ of the subjects. In addition, the overall accumulated oxygen deficit determined in the intermittent training was similar to the MAOD of the subjects. Such a high-intensity intermittent exercise seems to tax both anaerobic and aerobic energy-releasing systems almost maximally.

Because anaerobic glycolysis provided the main part (60–77%) of the anaerobic energy during intense exercise (Bangsbo, 1998), changes in the production of anaerobic glycolysis could account for the improvement of MAOD observed in our study. Jacobs et al. (1987) reported an increase in phosphofructokinase activity in response to a 30-s sprint training. The increase in $\dot{V}O_{2\,max}$ could have likely been caused by an increased stroke volume of the heart. It has been shown that stroke volume response to incremental exercise to $\dot{V}O_{2\,max}$ was influenced by training status (Zhou et al., 2001). Helgerud et al. (2007) showed that high-intensity interval training (15 s running at 95% maximal heart rate with 15 s of active recovery) was more effective than lower intensity training in improving $\dot{V}O_{2\,max}$ and stroke volume. The authors suggested a close link between the two.

The high-intensity intermittent training used in our study was adapted from Tabata et al. (1996) and Hirai and Tabata (1996)'s training. These authors have reported a higher increase in the MAOD and $\dot{V}O_{2\,max}$ values in physical education students (16–28% and 10–14%, respectively). The smaller improvement in our study could be explained by the lower number of sessions per week but the main reason is most likely the subjects' physical abilities before the training period, which were higher in the elite athletes compared with the students.

Physiological adaptations in aerobic and anaerobic capacities may allow an increased time in intense exercise before a state of fatigue is reached. The magnitude of the increase in the time to exhaustion observed in our study was similar to those reported by Harmer et al. (2000) following a 7-week sprint training with untrained men. In our study, the time to exhaustion in the supramaximal test was 23.6% greater at the end of the training period compared with the one observed before the training.

Changes in the anaerobic metabolism in the HIT group

After 7 weeks of high-intensity intermittent training provided twice per week, blood lactate and hydrogen ion concentrations markedly increased in the entire recovery period after the supramaximal test and particularly immediately after the end of the test (+53.7% and +40.2%, respectively) when compared with the pre-training data. Moreover, extreme values of lactate and hydrogen ion increased by 12.9% and 28.0%, respectively. However, the training did not influence the plasma ammonia response.

The extreme blood lactate concentration we observed at the end of our supramaximal exercise test was similar to that obtained by Tabata et al. (1997) after a high-intensity intermittent exercise. The extreme values of lactate and pH we obtained before the training were close to those of Strobel et al. (1999) for anaerobic-trained subjects (19.4 and 7.09 mmol/L, respectively). These values are much higher for lactate and much lower for pH than those observed in aerobically trained athletes (15.0 and 7.16 mmol/L, respectively) in response to a similar supramaximal test (Strobel et al., 1999).

The concentration of lactate in blood generally reflects the potential of the anaerobic glycolysis energy-providing process (Cheetham et al., 1986). However, in response to sprint training (4–10-fold 30-s sprint), Harmer et al. (2000) reported that immediately at the end of a supramaximal test (leading to exhaustion after 83 s, at 130% peak oxygen uptake), muscle lactate accumulation was unchanged and muscle hydrogen ion concentration was reduced. In contrast, in the blood compartment, the concentrations of both lactate and hydrogen ion were higher after the training period than before, suggesting a higher release in the blood compartment. Moreover, Juel et al. (2004) have shown that 7 weeks of high-intensity intermittent training increased lactate and hydrogen ion release from active muscle during exercise.

Changes in blood lactate concentrations and pH observed in the HIT group in response to the supramaximal exercise test might suggest that after the training period these subjects produced more lactate and/or released more lactate into the blood from the muscle during exercise. Nevertheless, the relationship between the amount of lactate released from muscle and measured concentration in blood after intense exercises is highly sensitive to variations in the distribution volume of the release lactate (Medbø & Toska, 2001). Therefore, discussions on changes in blood lactate concentrations should be treated with caution.

In the present study, the removal of both lactate and hydrogen ions from blood (estimated from the variations between the extreme values and the concentrations obtained 15 min after the end of the surpamaximal test) increased after the training period. It has been well documented that endurance training improved lactate removal (oxidation) during and after exercise (Mac Rae et al., 1995). In addition, after 7 weeks of high-intensity intermittent training, Juel et al. (2004) reported an increased systemic lactate and hydrogen ion clearance from the blood during the recovery period after incremental exercise conducted until exhaustion.

Perspectives

This study has shown that 7 weeks of high-intensity intermittent training twice per week can improve both the aerobic and the anaerobic performance considerably even for very well-trained elite karate athletes. Thus, the current training programs in use may easily be improved. Similar intermittent training including upper body exercise may likely have a similar effect. Modern karate consists of many repetitions of bursts of punching, kicking and hopping movements with short breaks. 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 involving different muscles.

Key words: anaerobic training, karate athletes, physiological adaptations.

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