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THE INFLUENCE OF KARATE PRACTICE LEVEL AND SEX ON PHYSIOLOGICAL AND PERCEPTUAL RESPONSES IN THREE MODERN KARATE TRAINING MODALITIES

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ABSTRACT: Objective: The aim of the present study was to examine the influence of karate practice level (national vs international level) and sex (women vs men) on physiological and perceptual responses in three modern karate training modalities (tactical-technical (TT), technical-development (TD), and randori). Method: The study included 18 karatekas participating in an eight-session training camp of four TT, two TD, and two randori. During each session, the percentage of maximal heart rate (HR), blood lactate concentration [La^-], and rating of perceived exertion (RPE) were assessed. Results: The main results showed that the percentage of maximal HR was significantly higher in women than in men regardless of practice level or training modality (70.3 ± 4.1 vs 66.2 ± 6.3, respectively). Moreover, [La^-] and RPE were significantly lower in international-level karatekas compared with their national-level counterparts whatever the sex or training modality ([La^-] = 11.4 ± 2.6 vs 8.3 ± 2.4 mmol·L^{-1} and RPE = 3.6 ± 1.2 vs 4.3 ± 1.5, respectively). Last, physiological and perceptual responses were significantly higher during randori in comparison with TT and TD for both sexes. Conclusion: The combination of [La^-] and RPE thus seems to be a good indicator for discriminating between national- and international-level karatekas, and randori seems to be an effective means to reproduce official karate sparring.

KEY WORDS: martial arts, ratings of perceived exertion, effort perception, heart rate, blood lactate concentration

INTRODUCTION

Karate has evolved from a traditional martial art into a modern-day global sport [7], which explains its two predominant features today: karate is both a "traditional" practice for self-defence and a "modern" sport with preparation for competitive sparring as the main objective. The rise in the number of karate sparring competitions (i.e., modern karate) has prompted researchers to investigate the factors that improve karate performance [7], but most studies have primarily focused on traditional karate (i.e., for self-defence). Indeed, few studies have focused on the physiological responses in modern karate, and they were conducted under simulated karate sparring conditions while the karatekas wore a respiratory gas analysis system (e.g., Douglas bag) [4,17], which was surely uncomfortable. We therefore investigated the physiological responses of karatekas during modern karate sparring using equipment that would be less likely to interfere with technical skills.

Modern karate (i.e., competitive karate) requires thorough preparation, which generally includes a variety of training modalities over the training sessions [5]. More often than not, these modalities are: tactical-technical training sessions (TT), technical-development training sessions (TD), and randori training sessions (i.e., free karate sparring). Imamura et al. [18] investigated the physiological responses (oxygen uptake: $\dot{V}O_2$, heart rate: HR, and blood lactate concentration: [La^-]) and the ratings of perceived exertion (RPE) but only during traditional karate exercises (i.e., non-competitive karate exercises including basic techniques with or without movements, sparring techniques with or without an opponent, and kata: pre-established sequences of defensive and offensive techniques and movements). Their study [18] showed that male karatekas usually reach 47.4 ± 5.9% of maximal $\dot{V}O_2$ ($\dot{V}O_2$max) and 72.6 ± 9.2% of maximal HR (i.e., HRmax), with

[La^-] less than 3 mmol · L^{-1} and RPE between 12.6 ± 0.8 and 14.3 ± 1.4, whatever the traditional karate exercise. However, no study to the best of our knowledge has investigated the physiological responses and RPE across the modern karate training modalities (i.e., TT, TD and randori).

During an international karate competition, each country is represented by only one karateka in each weight category [30], and thus selecting the best athlete is not always easy for the coach. Recently, Casolino et al. [6] reported that the [La^-] accumulation and RPE of taekwondo practitioners, as measured in various training modalities during one week of a training camp, could be used to discriminate the best athletes, with lower values for the international taekwondo practitioners. The authors thus concluded that selecting the best athlete should take into consideration the physiological and perceptual responses [6]. However, the physiological responses and RPE of karatekas with national and international levels have never been compared.

Many women practice modern karate (i.e., competitive karate), but coaches do not separate them from men during the training sessions [3]. Moreover, the data on the physiological responses to traditional karate mostly concern men. Only two studies [12,25] have investigated both male and female karatekas, but the first study did not report the results separately [25] and the second study included only three women [12]. Furthermore, these two studies [12,25] investigated traditional karate, not modern karate (i.e., competitive karate).

The aim of the present study was thus to examine the influence of karate practice level and sex on physiological and perceptual responses in three modern karate training modalities (i.e., TT, TD and randori).

MATERIALS AND METHODS

Subjects. Eighteen black-belt karate practitioners volunteered to take part in this study. Nine karatekas (4 women and 5 men) were at a national level and nine karatekas (4 women and 5 men) were at an international level (Table 1). Two karatekas represented each weight category (i.e., 1 male and 1 female in each weight category). All had been training at least seven times per week for at least three years (excluding the off-season periods).

Prior to the study, all karatekas provided written informed consent concerning the investigation purposes and procedures. The experiments were performed in accordance with the ethical standards of the Helsinki Declaration. Moreover, the study was approved by the local Clinical Research Ethics Committee and the local Ethics Committee of the National Center of Medicine and Sport Sciences.

Materials

The height, body mass and skinfold thickness of each karateka were measured with a wall stadiometer (model 220, Seca®, Hamburg, Germany), a calibrated scale (TBF 543; Tanita®, Tokyo, Japan) and a skinfold caliper (HSK-B1, Body Care®, Warwickshire, United Kingdom), respectively.

Cardiorespiratory variables were determined using a breath-by-breath system with an open-circuit metabolic card (ZAN 680, Messgeräte®, Oberthulba, Germany). This respiratory gas analysis system was calibrated in accordance with the manufacturer's guidelines before each graded exercise test. During the exercise test (performed on a treadmill; ErgoXELG 90; Woodway®, Weil, Germany), HR was determined from a 12-lead electrocardiogram.

During the modern karate training sessions, HR was recorded at 5-s intervals using a Polar® Team System HR monitor (Kempele, Finland) and downloaded to a computer using Advantage software (Polar®, Oy, Finland).

[La^-] was analyzed with the Lactate Pro analyzer (Arkray®, Tokyo, Japan).

Effort perception was expressed using Borg's Category Ratio-10 (CR-10), which was recently validated in French by Haddad et al. [16]. This scale comprises 11 numerical ratings (between 0 and 10) associated with verbal cues, from "0 = no exertion" to "10 = maximal." The karateka was asked, "How was your workout?"

Procedures

Before the first training session, anthropometric data were recorded (height, body mass, percentage of body fat). Percentage of body fat was calculated according to the method of Durnin and Womersley [13] based on four skinfold measurements (biceps, triceps, sub-

TABLE I. ANTHROPOMETRIC CHARACTERISTICS IN MALE AND FEMALE KARATEKAS AT NATIONAL AND INTERNATIONAL LEVELS

	Age (y)	Height (m)	Body mass (kg)	Body fat (% body mass)	Maximal oxygen uptake (mL · kg^{-1} · min^{-1})
Women with international level	23.0 ± 2.1	1.69 ± 0.05	60.2 ± 9.3	20.5 ± 4.7	48.0 ± 2.6
Women with national level	22.2 ± 2.1	1.70 ± 0.04	59.3 ± 8.6	19.9 ± 4.8	44.0 ± 2.9
Women regardless of practice level	22.6 ± 1.2	1.69 ± 0.04[a]	59.8 ± 8.4[a]	20.2 ± 4.4[a]	46.0 ± 3.3[a]
Men with international level	25.9 ± 1.1	1.78 ± 0.06	70.9 ± 8.4	7.2 ± 0.7	57.2 ± 3.7
Men with national level	22.5 ± 1.8	1.78 ± 0.08	71.5 ± 10.5	9.2 ± 2.8	56.0 ± 1.6
Men regardless of practice level	24.2 ± 2.3	1.78 ± 0.07[a]	71.2 ± 9.0[a]	8.2 ± 1.3[a]	56.6 ± 2.7[a]
Men and women with international level	24.7 ± 2.2	1.74 ± 0.07	66.2 ± 10.0	13.1 ± 7.6	53.3 ± 5.7
Men and women with national level	22.4 ± 1.8	1.74 ± 0.08	66.2 ± 11.2	13.9 ± 6.4	50.7 ± 6.7
Men and women regardless of practice level	23.5 ± 2.2	1.74 ± 0.07	66.1 ± 10.3	13.5 ± 6.8	51.9 ± 6.2

Legend: [a] - Women are significantly different from men.

scapularis, and suprailiac). All karatekas then performed a graded exercise test on a flat treadmill [9] to measure $\dot{V}O_2$max and HRmax. During this exercise test, the initial speed was set at 9 km·h^{-1} for 3 min and was then increased by 1 km·h^{-1} every 1 min until voluntary exhaustion. The karatekas were instructed to reach the highest possible speed. Exhaustion was assumed when the following criteria were met [9]: 1) a plateau in $\dot{V}O_2$ despite an increase in treadmill speed, 2) respiratory exchange ratio value ≥ 1.1, and 3) blood lactate concentration after test cessation > 6 mmol·L^{-1}. When these three criteria were not met, the test was repeated. The highest HR and $\dot{V}O_2$ values recorded over 15 s at the end of the exercise test were considered as HRmax and $\dot{V}O_2$max, respectively [10].

All karatekas took part in a seven-day training camp under the supervision of the same coach. Eight training sessions (duration between 65 and 75 min) were held: four TT, two TD, and two randori.

TT included a general then a specific warm-up (15 min). Then, each athlete practised various karate techniques (kicking, punching, striking and blocking) in different tactical sparring situations (offensive and/or defensive) for 45 min. In the offensive situation, athletes must continually attack their partners in the body or in the head. During the defensive situations athletes can counter-attack, riposte and/or block. All these exercises were performed in 3-min effort bouts separated by 60-s passive recovery periods. After every three bouts, however, a 3-min passive recovery period was imposed. TT ended with a 10-min period of free karate sparring.

TD was based on technical kumite repetitions. This training modality began with a general 15-min warm-up. Then, eight repetitions of 4-min effort bouts separated by 90-s passive recovery periods were performed. During technical repetitions, each athlete carried out a variety of karate techniques (kicking, punching, combination of lower and upper limb, and throwing) performed in either stationary or variable positions. TD ended with a 10-min period of general stretching.

Randori included an individual, free 15-min warm-up period. After the warm-up, seven repetitions of 3-min free karate sparring bouts separated by 2-min passive recovery periods were performed. This training modality ended with simulated karate sparring, 2 min for women and 3 min for men. National-level karatekas served as sparring partners during randori sessions.

All of the athletes followed the same training sessions during the camp. Thus, the intensity of exercises was the same regarding the subgroups (levels and sexes). During each training session, HR was measured continuously and the mean percentage of HRmax was then determined (from HRmax obtained during the graded exercise test on a flat treadmill). Moreover, [La$^-$] values were determined from fingertip blood sampling from the seated karatekas, 3 min after each training session. Finally, the instructions on the CR-10 scale were read to all karatekas 30 min after each training session (as proposed by Haddad et al. [16]) and RPEs were obtained.

Statistical analysis

Anthropometric parameters (i.e., age, height, body mass and body fat) and $\dot{V}O_2$max were compared via a two-way (i.e., 2 × practice levels: national vs international level, and 2 × sexes: women vs men) analysis of variance (ANOVA). If significant differences were obtained, a Tukey post-hoc test was conducted.

A three-way ANOVA for repeated measures was used to compare HR, [La$^-$] and RPE during TT, TD and randori according to practice level (i.e., national vs international level) and sex (i.e., women vs men). The sphericity was checked by the Mauchly test. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse-Geisser procedure. The Bonferroni post-hoc test was used to identify the significant differences. The magnitude of these differences was assessed by effect sizes (η^2).

Statistical significance was set at $P < 0.05$ and all analyses were performed with the Statistical Package for the Social Sciences (release 20.0, Chicago, IL, USA).

RESULTS

A main effect of sex was found for height (P = 0.012; η^2 = 0.37), body mass (P = 0.021; η^2 = 0.32), body fat (P < 0.001; η^2 = 0.82) and $\dot{V}O_2$max (P < 0.001; η^2 = 0.82; Table 1).

TABLE 2. PERCENTAGE OF MAXIMAL HEART RATE (% HRMAX) DURING TECHNICAL-TACTICAL (TT), TECHNICAL-DEVELOPMENT (TD), AND RANDORI TRAINING SESSIONS IN MALE AND FEMALE KARATEKAS AT NATIONAL AND INTERNATIONAL LEVELS

	HR (% HR_{max})			
	TT	TD	Randori	All training modalities
Women with international level	70.2 ± 1.8	64.4 ± 1.4	74.1 ± 0.8	69.7 ± 4.0
Women with national level	71.6 ± 2.1	65.5 ± 1.2	75.3 ± 2.3	71.0 ± 4.2
Women regardless of level	70.9 ± 2.0[a,b,c,e]	65.0 ± 1.3[a,b,d,f]	74.7 ± 1.7[c,d,g,h]	70.3 ± 4.1[a]
Men with international level	64.4 ± 3.0	59.7 ± 2.7	73.4 ± 2.6	65.4 ± 6.0
Men with national level	66.2 ± 4.6	62.5 ± 5.8	72.9 ± 5.9	66.9 ± 6.6
Men regardless of level	65.3 ± 3.8[a,b,c]	61.1 ± 4.5[a,b,d,e,h]	73.1 ± 4.3[c,d,f]	66.2 ± 6.3[a]
Men and women with international level	67.0 ± 3.9	61.8 ± 3.3	73.7 ± 2.0	67.3 ± 5.6
Men and women with national level	68.6 ± 4.5	63.8 ± 3.9	74.0 ± 4.6	68.7 ± 6.0
Men and women regardless of practice level	67.8 ± 4.6[b,c,g]	62.8 ± 4.4[b,d]	73.9 ± 4.6[c,d]	68.1 ± 5.8

Legend: [a] - Women are significantly different from men; [b] - TT is significantly different from TD; [c] - TT is significantly different from randori; [d] - TD is significantly different from randori; [e] - Women during TT are significantly different from men during TD; [f] - Women during TD are significantly different from men during randori; [g] - Women during randori are significantly different from men during TT; [h] - Women during randori are significantly different from men during TD.

HR was higher in women than in men (P = 0.023; η^2 = 0.32; Table 2). Moreover, HR during TD was lower than that measured during both TT and randori (P < 0.001; η^2 = 0.91; Table 2). HR during TT was also lower in comparison with during randori (P < 0.001; η^2 = 0.90; Table 2). In addition, interaction effects were noted between sex and training modality (P = 0.014; η^2 = 0.27; Table 2).

Lower [La-] values were found in karatekas at an international level compared with those at a national level (P < 0.001; η^2 = 0.76; Table 3). A main effect of training modality (P < 0.001; η^2 = 0.90) was also noted, with lower [La-] in TD compared with TT and randori, as well as lower [La-] in TT compared with randori (P < 0.001; Table 3).

Significantly lower RPEs were reported in karatekas at an international level compared with those at a national level (P = 0.019; η^2 = 0.33; Table 4). RPEs were significantly lower in TD compared with both TT and randori (P < 0.001; η^2 = 0.84), and in TT compared with randori (P < 0.001; Table 4). Furthermore, interaction effects of sex and training modality were also observed (P = 0.012; η^2 = 0.27; Table 4).

DISCUSSION

The aim of the present study was to examine the influence of karate practice level and sex on the physiological and perceptual responses in three modern karate training modalities (i.e., TT, TD and randori). The main results showed that HR was significantly higher in women than in men (whatever the practice level or training modality). Moreover, [La^-] and RPE were significantly lower in karatekas at an international level compared with their national-level counterparts in all training modalities. The study also showed that physiological (i.e., HR and [La^-]) and perceptual responses were significantly higher during randori in comparison with the other training modalities (i.e., TT and TD) regardless of practice level or sex.

Firstly, the HR results (70.3 ± 4.1 vs 66.2 ± 6.3% HRmax, respectively for women and men; Table 2) agree with the findings of Imamura and colleagues, who indirectly assessed HR and reported

TABLE 3. BLOOD LACTATE CONCENTRATION ([LA-]) AT 3 MIN AFTER TECHNICAL-TACTICAL (TT), TECHNICAL-DEVELOPMENT (TD), AND RANDORI TRAINING SESSIONS IN MALE AND FEMALE KARATEKAS AT NATIONAL AND INTERNATIONAL LEVEL

	[La-] (mmol · L^{-1})			
	TT	TD	Randori	All training modalities
Women with international level	8.1 ± 0.8	5.3 ± 0.7	12.0 ± 0.4	8.4 ± 2.5
Women with national level	11.3 ± 0.8	8.1 ± 0.3	15.0 ± 0.8	11.5 ± 2.5
Women regardless of level	9.7 ± 1.8	6.7 ± 1.5	13.5 ± 1.6	9.9 ± 2.9
Men with international level	8.3 ± 0.8	5.3 ± 0.5	11.4 ± 0.6	8.4 ± 2.3
Men with national level	11.3 ± 0.8	7.9 ± 0.6	14.5 ± 1.2	11.3 ± 2.6
Men regardless of level	9.8 ± 1.7	6.6 ± 1.4	13.0 ± 1.8	9.8 ± 2.8
Men and women with international level	8.2 ± 0.8	5.3 ± 0.6	11.7 ± 0.6	8.3 ± 2.4[i]
Men and women with national level	11.3 ± 0.8	7.9 ± 0.5	14.7 ± 1.1	11.4 ± 2.6[i]
Men and women regardless of practice level	9.7 ± 1.7[b,c]	6.6 ± 1.4[b,d]	13.2 ± 1.7[c,d]	9.9 ± 2.9

Legend: [b] - TT is significantly different from TD; [c] - TT is significantly different from randori; [d] - TD is significantly different from randori; [i] - Karatekas at national level are significantly different from karatekas at international level.

TABLE 4. RATING OF PERCEIVED EXERTION (RPE) DURING TECHNICAL-TACTICAL (TT), TECHNICAL-DEVELOPMENT (TD), AND RANDORI TRAINING SESSIONS IN MALE AND FEMALE KARATEKAS AT NATIONAL AND INTERNATIONAL LEVELS

	RPE (arbitrary unit)			
	TT	TD	Randori	All training modalities
Women with international level	3.8 ± 0.8	2.8 ± 0.5	4.4 ± 0.3	3.6 ± 1.1
Women with national level	5.3 ± 0.5	3.8 ± 0.8	6.0 ± 0.5	5.0 ± 1.2
Women regardless of level	4.5 ± 1.0[a,b,e]	3.3 ± 0.8[b,d,f]	5.2 ± 0.9[d]	4.4 ± 1.3
Men with international level	3.4 ± 0.7	2.5 ± 0.5	5.3 ± 0.4	3.6 ± 1.3
Men with national level	3.6 ± 1.0	2.6 ± 1.0	5.5 ± 1.4	3.8 ± 1.5
Men regardless of level	3.5 ± 0.8[a,b,c]	2.6 ± 0.7[b,e]	5.4 ± 1.0[c,f]	3.7 ± 1.4
Men and women with international level	3.6 ± 0.7	2.6 ± 0.5	4.9 ± 0.6	3.6 ± 1.2[i]
Men and women with national level	4.3 ± 1.1	3.1 ± 1.0	5.7 ± 1.1	4.3 ± 1.5[i]
Men and women regardless of practice level	3.9 ± 1.2[b,c]	2.9 ± 0.9[b,d]	5.3 ± 1.1[c,d]	4.0 ± 1.4

Legend: [a] - Women are significantly different from men; [b] - TT is significantly different from TD; [c] - TT is significantly different from randori; [d] - TD is significantly different from randori; [e] - Women during TT are significantly different from men during TD; [f] - Women during TD are significantly different from men during randori; [i] - Karatekas with national level are significantly different from karatekas with international level.

higher values for female karatekas [19] than their male counterparts [18] during traditional karate exercises. These results are unsurprising, as it has been well established that cardiac output for the same submaximal exercise is similar in men and women [22,29]. However, as men have higher stroke volume (because of higher left ventricle and blood volume), women compensate with higher HR [22,29]. On the other hand, HRmax is generally the same in both sexes [22,29]. Consequently, as HRmax is not influenced by sex and HR is higher in women for the same submaximal exercise, it was logical to find a higher percentage of HRmax in the women of the present study compared with that of the men.

Moreover, the percentage of HRmax was significantly higher during randori (73.9 ± 4.6% HRmax) compared with both TT and TD (67.8 ± 4.6 vs 62.8 ± 4.4% HRmax, respectively; Table 2) regardless of practice level or sex. Also, although the highest percentage of HRmax was found during randori (i.e., free karate sparring), these values were still under the values observed in previous studies [12,17]. Indeed, Iide et al. [17] reported a percentage of HRmax equal to 85.2 ± 6.5% and 93.2 ± 4.4% during 2- and 3-min bouts of simulated karate sparring, respectively. However, this study included both adults and children, and the latter are known to have slightly higher submaximal HR [28]. Nevertheless, it is not certain that this slightly higher submaximal HR in children explains the discrepancy with our results because children also have higher HRmax, which would reduce the difference between adults and children when HR is expressed in percentage of HRmax. Moreover, Doria et al. [12] reported higher HRmax (compared with the current study) during simulated karate sparring in adult karatekas at an international level (i.e., 97 ± 6 vs 92 ± 2% HRmax for women and men, respectively). Although this result from Doria et al. [12] is very interesting, it is nevertheless difficult to draw any conclusions because of the small sample size (only three karatekas from both sexes). Further studies must be conducted to confirm and explain this finding.

Whatever the karate training modality, muscular contractions occur due to the liberation of energy. This energy is generated in cells from adenosine triphosphate (ATP) through a combination of three metabolic pathways: the ATP-phosphocreatine system, the glycolytic system, and the oxidative system [22,29]. The first two systems can operate in the absence of oxygen and are termed the anaerobic alactic and lactic metabolisms, respectively. However, anaerobic alactic metabolism has a limited capacity (only a few seconds) to generate ATP for energy [22,29]. Consequently, when exercise lasts more than a few seconds, anaerobic lactic metabolism becomes the major pathway. This metabolism requires numerous enzymatic reactions for the breakdown of glycogen into pyruvic acid, which is then converted to lactic acid (without oxygen) [22,29], which is in turn dissociated into hydrogen and lactate ions. As a portion of the lactate ions can be used as a fuel source during exercise (i.e., gluconeogenesis), [La^-] represents the difference between the production of lactate ions from the anaerobic lactic metabolism and their use as a fuel source. [La^-] is thus considered as an indicator of anaerobic lactic metabolism activation.

Both the male and female international karatekas had lower [La^-] than their national counterparts (8.3 ± 2.4 vs 11.4 ± 2.6 mmol·L^{-1}, respectively; Table 3). In taekwondo, it was shown that the athletes selected for the national team had lower [La^-] than their non-selected counterparts [6]. This difference suggests that the contribution of the anaerobic lactic metabolism was higher in the athletes at national level than in the athletes at international level. As previously indicated, anaerobic lactic metabolism generates not only lactate but also hydrogen ions, which decrease the blood pH. This disturbance in acid-base balance may impair the capacity of muscles to generate ATP, reduce muscle contractility, and thus generate fatigue [22,29]. Consequently, as [La^-] is correlated with pH and the national-level karatekas had higher [La^-] than their international counterparts, it is possible that these national karatekas experienced greater fatigue because of the higher activation of the anaerobic lactic metabolism (and lower activation of aerobic metabolism), explaining their lower practice level. However, it should be kept in mind that this hypothesis is based on the assumption that the national-level karatekas had the same resting and maximal [La^-] as the international-level karatekas.

[La^-] was not significantly different between the sexes (9.9 ± 2.9 vs 9.8 ± 2.8 mmol·L^{-1} for women and men, respectively; Table 3). These results agree with those of Imamura et al. [18], who reported no significant difference between men and women regarding [La^-] after various kinds of traditional karate training modalities, which suggests that men and women activate the anaerobic lactic metabolism similarly.

Arriaza [2] reported that [La^-] ranged between 8.7 and 12.7 mmol·L^{-1} during karate kumite organized within the world karate championships. The present [La^-] results during the randori training sessions (i.e., free karate sparring) were higher (13.2 ± 1.7 mmol·L^{-1}) than during the other training modalities (i.e., 9.7 ± 1.7 mmol·L^{-1} during TT and 6.6 ± 1.4 mmol·L^{-1} during TD; Table 3) and slightly higher than those noted by Arriaza [2]. This result suggests that the karatekas of the present study were fully engaged during randori, as if they were participating in an official competition. Randori thus seems to be an effective means to reproduce official karate sparring.

According to Noble and Robertson [23] and more recently Coquart [11], RPE can be used to compare the physical fitness of two athletes. Indeed, for the same given training session, the athlete reporting the lower RPE (e.g., an athlete rating RPE = 5, which is "hard" vs an athlete rating RPE = 7, which is "very hard") will be the more physically fit (i.e., the athlete rating RPE = 5). In the present study, RPE was significantly lower in international-level karatekas (RPE = 3.6 ± 1.2) compared with those at national level (RPE = 4.3 ± 1.5; Table 4), regardless of sex or training modality, and we therefore confirm that RPE can be used to help to select the best athlete.

Accordingly, Casolino et al. [6] reported that perceptual (and physiological) responses can be used to discriminate the taekwondo

practitioners who are selected or not selected for the national team. Indeed, the selected athletes in their study reported significantly lower RPE and showed significantly lower [La^-] accumulation. The current study showed similar results for karatekas. We therefore suggest that modern karate coaches take into account the physiological and perceptual responses during training sessions to help them select the best karatekas.

Moreover, recording the [La^-] and RPE responses during the first and last training sessions of training camp has other uses; notably, the [La^-]/RPE ratio may be used to help detect overreaching or overtraining [11]. For example, Snyder et al. [26] found that this ratio (multiplied by 100) was decreased (for the same workload) after 2 weeks of an intensive interval-training programme that generated an overreached status in male competitive cyclists. This decline in the [La^-]/RPE ratio was explained by a reduction in [La^-], whereas RPE remained stable. More recently, Garcin et al. [14] confirmed this result in high-level middle-distance runners. It may therefore be interesting to use the [La^-]/RPE ratio to help detect overreaching or overtraining in modern karate, but further studies must first be conducted.

The current study also showed that RPE was significantly higher during randori compared with TT and TD. Recently, Tabben et al. [27] found significant correlations with "moderate to high" correlation coefficients between RPE, mean HR ($P = 0.02$; $r = 0.64$) and [La^-] ($P < 0.001$; $r = 0.81$) in karatekas. Consequently, as we observed that HR and [La^-] were significantly higher during randori in comparison with TT and TD, it is logical that RPE would also be higher.

Although not the main aims of the current study, we compared the anthropometric data and $\dot{V}O_2$ max in the karatekas (according to practice level and sex). $\dot{V}O_2$max in the male karatekas at international level (57.2 ± 3.7 $mL.kg^{-1} \cdot min^{-1}$) was very close to the values reported by Ravier et al. [24] (57.2 ± 4.1 $mL.kg^{-1} \cdot min^{-1}$) and Imamura et al. [20] (57.5 ± 5.2 $mL.kg^{-1} \cdot min^{-1}$). However, $\dot{V}O_2$ max was higher than the values presented by Doria et al. [12] in female (42.9 ± 1.6 $mL.kg^{-1} \cdot min^{-1}$) and male (48.5 ± 6.0 $mL.kg^{-1} \cdot min^{-1}$; Table 1) karatekas at international level. These discrepancies can perhaps be explained by the period in the competitive season. For example, the present study was conducted shortly before the world karate championship (i.e., when the karatekas were at their top level of physical fitness), whereas the study of Doria et al. [12] may have been conducted before the karatekas reached their peak physical fitness (e.g., off-season, beginning of season), which would explain the $\dot{V}O_2$max differences between the studies. However that may be, according to Beneke et al. [4] these results suggest that karate is a sport that primarily involves aerobic metabolism, although numerous decisive actions (i.e., attack and defence techniques) are performed via anaerobic lactic metabolism.

The current study revealed no significant influence of karate practice level (i.e., national level vs international level) on $\dot{V}O_2$max. This result was also reported by Ravier et al. [24] and, in a recent review, Chaabene et al. [7] confirmed that $\dot{V}O_2$max does not seem to be influenced by the karate practice level. However, these same authors [8] recently showed that the time to exhaustion during a karate-specific aerobic test was significantly shorter in regional-level karatekas (841 ± 134 s) than in national-level karatekas (1032 ± 101 s). This result highlights the importance of using a karate-specific test to differentiate between practice levels rather than a graded exercise test on a treadmill, as proposed in the present study or by Ravier et al. [24].

As expected, women had a significantly higher body fat percentage than men. The values in male karatekas at international level (7.2 ± 0.7%; Table 1) were close to those reported previously by Imamura et al. [21] and Giampietro et al. [15] (7.5 ± 1.6% and 8.1 ± 2.4%, respectively). Similarly, the values in the female karatekas at international level (20.5 ± 4.7%) were close to those obtained by Amusa and Onyewadume [1] (18.6 ± 3.2%). Moreover, no significant difference was found between the national- and international-level karatekas. This finding agrees with the conclusion of Chaabene et al. [7], who suggested that body fat is not a discriminative factor of karate performance.

CONCLUSIONS

This study showed that: 1) the percentage of maximal HR was higher in women than in men (regardless of practice level or training modality), 2) [La-] and RPE were significantly lower in karatekas at international level compared with their counterparts at national level in all training modalities, and 3) physiological and perceptual responses were significantly higher during randori in comparison with the other training modalities (i.e., TT and TD) regardless of sex. Consequently, coaches can use physiological and perceptual responses to help select the best karatekas in training camp. Moreover, randori seems to be effective when the aim is to reproduce official karate sparring.

Conflict of interest: none declared.

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