REVIEW ARTICLE

Sports Med 2012; 42 (10): 829-843
0112-1642/12/0010-0829/$49.95/0

Physical and Physiological Profile of Elite Karate Athletes

Helmi Chaabène,[1,2] *Younés Hachana,*[1,2] *Emerson Franchini,*[3] *Bessem Mkaouer*[2] and *Karim Chamari*[2,4]

1 Research Unit, Analysis and Evaluation of Factors Affecting the Sport Performance, Higher Institute of Sports and Physical Education, Ksar Said, Tunisia
2 Higher Institute of Sports and Physical Education, Manouba University, Tunis, Tunisia
3 Martial Arts and Combat Sports Research Group, School of Physical Education and Sport, University of Sao Paulo, Sao Paulo, Brazil
4 Tunisian Research Laboratory 'Sport Performance Optimisation', National Centre of Medicine and Science in Sport, Tunis, Tunisia

Contents

Abstract

This review focuses on the most important physical and physiological characteristics of karate athletes from the available scientific research. It has been established that karate's top-level performers require a high fitness level. Top-level male karate athletes are typified by low body fat and mesomorphic-ectomorphic somatotype characteristics. Studies dealing with body composition and somatotype of females are scarce. Aerobic capacity has been reported to play a major role in karate performance. It prevents fatigue during training and ensures the recovery processes during rest periods between two subsequent bouts of fighting activity within a fight and between two consecutive matches. It has been established that there is no significant difference between male and female kata (forms) and kumite (sparring/combat) athletes with regard to aerobic performance. Nevertheless, further studies are needed to support these findings. Concerning anaerobic performance, there is a difference in maximal power explored by the force-velocity test between national and international level karatekas (karate practitioners) but, for the maximum accumulated oxygen deficit test there is no difference between them. Muscle explosive power plays a vital role in a karateka's capacity for high-level performance. However, it has been revealed that vertical jump performance, maximal power and maximal velocity differed between national- and international-level karatekas. Moreover, it has been reported that karate performance relies more on muscle power at lower loads rather than higher ones. Thus, karate's decisive actions are essentially dependent on muscle explosive power in both the upper and lower limbs. With regard to dynamic strength, limited research has been conducted. The maximal absolute bench press, half-squat one-repetition maximum and performance of isokinetic tasks differed significantly between highly competitive and novice male karatekas. Studies on female karate athletes do not exist. Concerning flexibility, which is important for the execution of high kicks and adequate range of action at high speeds, it has been demonstrated that karate athletes' ranges of bilateral hip and knee flexion are greater compared with non-karate athletes. Finally, reaction time is a crucial element in karate because high-level performance is based essentially on explosive techniques. A significant difference in the choice reaction time between high-level and novice karatekas exists. Further research is needed concerning the physiological characteristics of female karatekas, the differences between kata and kumite athletes and variations based on weight categories.

1. Introduction

Karate literally translated means 'empty hand', and it is derived from a martial art developed in Okinawa, Japan, in the early 17th century just after the Japanese conquered this island and banned the use of all weapons. After World War II, karate spread throughout the world, and it is currently one of the most attractive combat sports, a fact confirmed by the millions of people who practice karate worldwide. Many karate styles exist, but only four are recognised by the World Karate Federation (WKF): Goju, Shito, Shotokan and Wado. Each of them follows specific ideas, which result in variations of techniques.[1] Karate is divided into kata and kumite. Kata is a set form in pre-established sequences of offensive and defensive techniques and movements. Karatekas (karate practitioners) have a time range of 60–80 seconds to finish the kata, and every second over or under the fixed duration is penalized according to the WKF.[1] In national and international competitions, kata performance judgement is essentially based on assessing the following: technique, rhythm, power, expressiveness of movement and kime (short isometric muscle contractions performed when a technique is finished). The last assessment category represents the most important criterion of proper kata execution. Kumite, in contrast, is a real match/combat between two competitors under strict rules; they are free to move, kick and punch in defensive and offensive manners. Sports fight rules in karate set the following values: 1 point (Yuko); 2 points (Waza-Ari); and 3 points (Ippon). Ippon is adjudicated for leg kicks to the head and the techniques of cleaning and throwing, which result in a final fall of the opponent or a final punch. Waza-Ari is adjudicated for kicks to the trunk and punches to the back, including the back of the head and neck. Finally, Yuko is awarded for single arm punches to the head and body.[1]

The criteria for kumite performance judgement include good form, fair play, vigorous application of kicks and punches, awareness (*zanshin*), good timing, and adequate distance. In karate, attacks are limited to the following areas: head, face, neck, abdomen, chest, back and side.[1] The time limit of kumite competitions is 3 minutes for male senior athletes and 2 minutes for senior females, as well as the junior and cadet divisions of both genders.[1] The main competition in karate, for both kumite and kata, is the World Championship for each age category (cadets 14–15 years; junior 16–17 years; and senior 18+ years). It should be noted that the age of junior team kata is approximately 14–17 years, and senior teams and individual kata athletes are generally 16+ years. Additionally, karate competitions are organized according to weight classes. There are five weight categories among senior kumite karate athletes for both male (<60 kg, <67 kg, <75 kg, <84 kg and >84 kg) and female karatekas (<50 kg, <55 kg, <61 kg, <68 kg and >68 kg).[1] As in other combat sports, the main objective of weight class divisions is to create equitable combat matches among competitors in terms of strength, agility and leverage.[2,3]

The physiological characteristics of athletes are generally measured by testing their components' fitness and skill. The fitness components usually include cardiorespiratory endurance, muscular strength, muscular endurance, flexibility and body composition.[4] On the other hand, skill-related components usually include speed, agility, power, balance, coordination and reaction time.[4] Most combat sports require a mix of technique, strength, aerobic fitness, power and speed. Generally, no single performance characteristic dominates in combat sports.[5]

Karate athletes have to perform several high-intensity actions during the match. Top-level karate athletes have high fitness levels and, according to Baker and Bell,[6] karate fighting is considered a high-intensity event.

One of the most important challenges confronting coaches and athletes is to understand the main physiological factors contributing to the success or failure of a karateka. Having information about the different fitness components of karatekas by reviewing the literature may be useful. This can become the basis to reveal strengths and relative weaknesses and promote the development of optimal future training programmes. Thus, this study was conducted to review some of the physiological factors available in the scientific literature related to high-level karate competitors.

The search for scientific literature relevant to this review was performed using the US National Library of Medicine (PubMed), Web of Science, SPORTDiscus™ and Google Scholar databases. The literature search period used was from January 1980 to December 2011. The specific terms utilized included 'karate', 'karate AND performance', 'karate AND physical fitness', 'karate AND anthropometric characteristics', 'karate AND aerobic energy system', 'karate AND anaerobic energy system', 'karate AND muscular power' and 'karate AND muscular strength'. The retrieved studies were further selected based on their purpose, methodology, and number and characteristics of karate athletes studied. In some cases, articles cited in these previous investigations retrieved during the original search were also included when the authors considered that they could contribute in specific topics.

2. Anthropometric Characteristics

2.1 Body Composition

In karate, the morphological characteristics of an athlete are extremely important. Studying the anthropometric characteristics of karate athletes can provide specific details on the morphological and functional biotype best suited for this combat sport. Indeed, in sports activities, particularly those in which athletes compete based on well defined weight categories like karate, a weight increase due to fat accumulation may lead to poor athletic performance or, worse, to competition in a heavier weight category, which dramatically reduces the performance capacity of the karateka.[7] Thus, assessing the body fat percentage of karatekas requires special attention. In table I, the percentage of body fat of top-level karatekas of different nationalities is presented.

Karatekas' weight categories range from <60 kg to >84 kg for male and from <50 kg to >68 kg for female athletes.[1] It is desirable that karate athletes have a small percentage of body

Table I. Body fat (%) in karate athletes

Participants (n)	Body weight (kg) [mean ± SD]	Body fat (%) [mean ± SD]	Prediction equation reference	References
French male:			8	9,10
Junior international level (10)	71.3±11.9	13.1±4.4		
Junior national level (12)	69.2±10.4	13.4±3.8		
Italian male:			11	12
Amateur (8)	72.25±6.36	11.49±4.15		
Japanese male:			13	14
Elite (6)	66.8±8.9	7.5±1.6		
Novice practitioners (8)	59.9±7.3	10.1±4.4		
French male:			NR	15
International level (10)	71.9±11.4	13.7±4.1		
National level (8)	70.7±12.2	13.6±4.5		
Portuguese male:			NR	16
International level (10)	71.13±9.35	14.1±3.46		
British male:			17	18
International level (11)	78.8±10.3	16.5±4.6		
Japanese male:			13	19
High level (7)	66.3±8.2	10.7±2		
Novice level (9)	60.1±6.9	12.6±4.5		
Botswana male:			20	21
National level (10)	68.2±8.9	12.2±4.6		
Polish male:			22	23
International level (14)	86.1±8.25	16.8±2.51		
National level (16)	81.4±11.99	15.8±1.93		
Italian male:			24	7
Elite level (14)	72.4±8.7	8.1±2.4		
Amateur level (21)	69.2±8.9	8.9±3.3		
Elite level (14)	72.4±8.7	9.8±1.6	25	
Amateur level (21)	69.2±8.9	11.2±3.7		
Botswana female:			20	21
National level (7)	59.6±4.5	18.6±3.2		
American male practitioners:			11,26	27
4 white belts, two blue belts, two brown belts and one black belt (9)	72.8±7.8	12.4±6.4		
Brazilian college male athletes (12)	68.0±11.1	10.5±3.0	11	28
Japanese male (6 with 2 from national team)	65.0±5.9	12.8±6.0	8,17	29
Polish skilled practitioners (12)	79.1±9.6	12.6±3.3	NR	30

NR = not reported; **SD** = standard deviation.

fat. However, the body fat percentage range of top-level male karatekas extends from approximately 7.5% for Japanese[14] to 16.8% for Polish elite-level karatekas.[23] The percentage of body fat for male karate athletes from the French international-level team was 13.7%.[15] Imamura et al.[19] reported that there is no significant difference regarding the mean body fat percentage between highly competitive and novice karate athletes. In contrast, the lean body mass is significantly different between groups, being higher in top-level competitors compared with novice karate competitors.[19] Giampietro et al.[7] revealed that the body composition of two groups of athletes practicing karate at high and medium competitive levels was similar, while much lower body fat was presented by elite compared with medium-level karate athletes.

There is only one study dealing with the relationships between the karateka's competition success rate and body fat percentage,[31] and the results indicated that there was no difference in skinfold thickness between the winning group versus the defeated group. Though not conclusive, these studies showed that some elite karatekas have low levels of body fat, similar to that of elite endurance runners, while others had higher percentages of body fat that did not prevent them from high-level performance. Thus, we can conclude from the presently available data that body fat does not seem to be a karate performance determinant.

2.2 Somatotype

Regarding the somatotype, Giampietro et al.[7] reported that karate athletes competing at high and medium levels appear to have the same somatotype characteristics. This group concluded that the dominant anthropometric feature among top-level athletes is prominent vertical skeletal development. Katic et al.[32] reported longitudinal skeletal development to be one of the predictors of karate performance. Moreover, elite karateka athletes have greater development of their vertical physical build, highlighted by an average somatotype (mesomorphic-ectomorphic).[7] In karate, a sport where the body must be propelled through space as fast as possible, being more endomorphic is suggested to be detrimental to performance.[7,32,33] Pieter and Bercades[34] revealed that karatekas were more ectomorphic, which confirms the findings of Giampietro et al.[7] for Italian male karatekas. In addition, Fritzschel and Raschka[35] reported that German elite male karatekas are more ectomorphic than their lower ranked colleagues. Table II summarizes studies dealing with the somatotype of karate practitioners. In general, top-level male karate athletes have high rates of mesomorphic-ectomorphic characteristics and less endomorphic characteristics.

Concerning female karate athletes, they have similar rates of mesomorphic and endomorphic somatotypes.[21,34,35] Somatotype differences between top-level kata and kumite athletes have not yet been reported. Thus, it seems that the karateka somatotype has an impact on overall karate performance.

2.3 Bone Mineral Density

Andreoli et al.[36] revealed that karate practitioners had a higher bone mineral density (mean ± standard deviation [SD]: 1.36 ± 0.08 g/cm^2) than age-matched untrained individuals (1.27 ± 0.06 g/cm^2). More recently, Drozdzowska et al.[37] revealed significant differences in bone mineral density assessed by a quantitative ultrasound method that compared karate athletes with control subjects. These authors suggested that karate is a

Table II. Somatotype of karate practitioners

Karateka characteristics (n)	Endomorphy (mean ± SD)	Mesomorphy (mean ± SD)	Ectomorphy (mean ± SD)	References
Italian male:				
Elite level (14)	2.1 ± 0.6	3.5 ± 1.0	3.1 ± 0.8	7
Amateur level (21)	2.6 ± 0.9	4.2 ± 1.2	2.7 ± 1.2	
Amateur level (21)	3.7 ± 1.1	5.8 ± 0.8	1.3 ± 0.6	23
National level (16)	3.5 ± 1.1	5.0 ± 0.9	2.0 ± 0.6	
Botswana male:				
National level (10)	2.5 ± 1.1	3.9 ± 0.9	3.0 ± 1.2	21
Botswana female:				
National level (7)	4.4 ± 0.8	4.7 ± 1.2	1.3 ± 1.1	
Philippine male:				
National level (12)	2.42 ± 0.72	4.70 ± 0.95	2.55 ± 1.10	34
Philippine female:				
National level (5)	3.05 ± 0.91	3.68 ± 0.89	2.38 ± 1.03	

SD = standard deviation.

sport with a positive influence on skeletal status with the most significant benefits occurring in adults. Prouteau et al.[38] found total bone mineral density (mean ± SD) of 22 male judoists to be 1.40 ± 0.10, but only 1.28 ± 0.06 g/cm^2 for untrained men. Judoists local lumbar spine bone mineral density was 1.28 ± 0.13, but 1.12 ± 0.11 g/cm^2 for untrained men. Accordingly, hip bone mineral density of judoists was 1.29 ± 0.11, but only 1.18 ± 0.12 g/cm^2 for untrained men. All of these findings suggest that practicing combat sports may help enhance bone mineral density. Bone mineral density and body composition may contribute to the athlete's maintenance of his performance ability during compromising training or competition positions, and they may decrease the incidence of injury.

Overall, a proportionally low body fat mass in various body parts will surely allow the karateka to accelerate and decelerate rapidly, as is required by this sport.[39] Generally, top-level male karate athletes are characterized by low body fat and mesomorphic-ectomorphic properties at the elite level. However, further studies are needed to precisely establish the somatotype of elite-level female karate athletes.

3. Physiological Profile

3.1 Aerobic Profile

One of the most important factors governing an athlete's performance is their level of cardiorespiratory endurance. Cardiorespiratory endurance involves the ability to sustain prolonged exercise involving both the cardiovascular and respiratory systems. The body's demand for oxygen during strenuous activity is dependent on the efficiency as well as the ability of these systems to work together. Maximum oxygen uptake ($\dot{V}O_{2max}$) is considered a key determinant of an individual's current level of cardiorespiratory fitness. $\dot{V}O_{2max}$ is widely used by researchers to indicate an athlete's level of cardiovascular functional capacity. It is defined as the largest amount of oxygen that an individual can utilize during an exercise of increasing intensity.[40]

$\dot{V}O_{2max}$ is considered to be a valid indicator of respiratory, cardiovascular and muscular system cooperative function.[41] For activities where body mass is used to classify athletes in weight categories, such as karate, oxygen uptake is measured relative to body mass in mL/kg/min. It has been reported that the $\dot{V}O_{2max}$ (mean ± SD) of national and international male karate practitioners ranges from 47.8 ± 4.4 to 61.4 ± 2.6 mL/kg/min (table III), and from 32.75 ± 4.1 to 42.9 ± 1.6 mL/kg/min for females (table III). The disparities in findings presented in table III regarding the $\dot{V}O_{2max}$ values may reflect differences in the mode of exercise testing. In some studies, a cycle ergometer was used, which results in 8–10% lower $\dot{V}O_{2max}$ values compared with those achieved during treadmill tests.[49,50]

The $\dot{V}O_{2max}$ of male karatekas from the French national- and international-level team was above 60 mL/kg/min after a period of high-intensity interval training.[45] In comparison to other top-level athletes in various sports, the $\dot{V}O_{2max}$ of top-level karate athletes was similar to those of established taekwondo athletes[51,52] and wrestlers;[53] however, it was lower than those values reported in boxers.[54] More recently, Campos et al.[55] showed that karate required a much higher percentage contribution of aerobic metabolism when compared with taekwondo (mean ± SD; 66 ± 6%, 30 ± 6% and 4 ± 2%, respectively, for aerobic, anaerobic alactic and anaerobic lactic systems). This difference may be due to the difference in kumite duration or the use of more upper limb techniques in karate compared with taekwondo.[55] Aerobic capacity is necessary to prevent fatigue during training, during the breaks between subsequent bouts of fighting activity within a fight and to improve the recovery process between consecutive matches.[19,56] Although most studies revealed that both experienced and elite karate practitioners had similar values of $\dot{V}O_{2max}$[15,19] (table III), these findings suggest that $\dot{V}O_{2max}$ seemed not to be influenced by the level of karate performance.[15]

The study of Doria et al.[44] comparing aerobic performance of both top-level male and female kata and kumite athletes reported that there was no difference in $\dot{V}O_{2max}$ relative to body mass between top-level male kata and kumite practitioners and top-level female kata and kumite practitioners. Nevertheless, the findings of Doria et al.[44]

Table III. Aerobic fitness of karate athletes

Study	Sample characteristics (n)	Ergometer	$\dot{V}O_{2max}$ (mL/kg/min) [mean ± SD]
Francescato et al.[12]	Amateur level male (8)	Cycle ergometer	36.83 ± 5.35
Imamura et al.[14]	Japanese male:	Treadmill	
	Elite level (6)		59 ± 6.6
	University level (8)		57.5 ± 5.2
Imamura et al.[19]	Japanese male:	Treadmill	
	Elite level (7)		57.5 ± 5.2
	Novice level (9)		57.2 ± 4.9
Imamura et al.[42]	Practitioners (9)	Treadmill	58.6 ± 6.8
Imamura et al.[43]	Japanese female: University level (6)	Treadmill	42.7 ± 5.1
Ravier et al.[10]	French males:	NR	
	International level (10)		57.2 ± 4.1
	National level (12)		58.5 ± 3
Doria et al.[44]	Italian males:	Cycle ergometer	
	Elite kata (3)		47.8 ± 4.4
	Elite kumite (3)		48.5 ± 6
	Italian female:		
	Elite kata (3)		42.4 ± 1
	Elite kumite (3)		42.9 ± 1.6
Ravier et al.[45]	French national- and international-level males (17: EG = 9; CG = 8) [$\dot{V}O_{2max}$ here measured before and after a high-intensity intermittent running training (20 sec/15 sec; 7–9 sets; 140% $\dot{V}O_{2max}$)]	Treadmill	EG before: 58.7 ± 3.1 EG after: 61.4 ± 2.6 CG before: 58.2 ± 3.1 CG after: 58.1 ± 4.4
Yoshimura and Imamura[46]	Japanese female: Collegiate level (15)	Treadmill	32.75 ± 4.1
Shaw and Deutsch[27]	American male practitioners: (9: 4 white belts; 2 blue belts; 2 brown belts and 1 black belt)	Treadmill	56.1 ± 5.4
Zehr and Sale[47]	Practitioners (4 black belt [one 1st dan, two 2nd dan, one 5th dan])	Cycle ergometer	45.5 ± 5.0
Iide et al.[48]	Japanese male: Black belt karatekas with more than 2 years' experience (12)	Treadmill	51.2 ± 4.3

CG = control group; **EG** = experimental group; **NR** = not reported; **SD** = standard deviation; $\dot{V}O_{2max}$ = maximal oxygen uptake.

cannot be considered conclusive because of the very small sample size. Moreover, Koropanovski et al.[57] reported that there is no difference between kata and kumite male karatekas regarding aerobic endurance as measured by the field shuttle run test,[58] confirming the previous results. It must to be noted that $\dot{V}O_{2max}$, when expressed relative to body mass, is usually expressed in mL/kg/min. Nevertheless, recent studies have shown that it is much more appropriate to express $\dot{V}O_{2max}$ according to allometric scaling, i.e. in mL/kg$^{0.75}$/min.[59] In this context, the classical expression of aerobic capacity, i.e. in mL/kg/min, underestimates the aerobic capacity of heavier subjects. Because no investigation has reported the $\dot{V}O_{2max}$ of karatekas in mL/kg$^{0.75}$/min, it was impossible for us to report such values. It would be advised for future studies to present aerobic capacity in both classically and allometrically scaled manners.

It is also interesting to note that karate training in general, and karate kata in particular, have been claimed to enhance cardiovascular fitness.[60,61] Additionally, in a recent study by Yoshimura and

Imamura[46] with sedentary collegiate women, it has been demonstrated that 10 weeks of 30 minutes of basic karate exercise could reach the minimal threshold level to increase cardiovascular fitness in sedentary women. It should be noted that all $\dot{V}O_{2max}$ protocol cited above are not karate specific. Recently, it has been demonstrated by Chaabène et al.[62,63] that the karate-specific aerobic test (KSAT), which includes the most frequently applied karate techniques, is reliable and presents good construct validity. Further studies confirming the criterion-related validity of the KSAT protocol are required, since it offers the major advantage of measuring intermittent performance (which is characteristic of karate) while taking into account the most frequently utilized techniques observed in karate competition.

3.2 Anaerobic Profile

According to the rules of the WKF,[1] a formal karate competition should consist of 3 minutes of fighting for male senior athletes or 2 minutes for each female senior, female or male junior and female or male cadet divisions. Beneke et al.[56] observed that the 'exercise : rest ratio' was 2 : 1, with the exercise period lasting for 18 seconds and the rest period for 9 seconds; both time lengths were decided by the referee. The same authors suggested that these 'activity periods' included 16.3 high-intensity actions per fight, each lasting 1–3 seconds. Another combat analysis performed by Iide et al.[48] revealed that the duration of performing the shortest offensive and/or defensive techniques was 0.3 seconds. Moreover, the duration of the longest series of offensive and/or defensive combination techniques during a 3-minute bout of sparring was 1.8 seconds, with the mean total accumulated time of performing the offensive and defensive techniques during the 3 minutes of sparring lasting approximately 19.4 seconds. These findings imply that kumite karate consists of very short periods of high-intensity intermittent movements that are interspersed with recovery periods. It has been reported that high-intensity intermittent sports rely mostly on anaerobic energy sources, with determinant actions being a function of explosive movement.[64] Thus, karatekas' decisive actions depend mainly on anaerobic energy pathways.[12,56] There is no specific test protocol for assessing the anaerobic fitness level of karate athletes. The Wingate anaerobic power test is a widely used and accepted protocol for assessing anaerobic power characteristics. The 30-second cycle ergometer protocol requires a maximal effort by the subject against a resistance based on body mass. The results of this test provide data including peak, mean power output and percentage of fatigue over the 30 second period. The Wingate anaerobic test has been used by one study to assess the anaerobic profile of karate athletes.[44] The available results are presented in table IV. Similar results exist between high-level male kata and kumite karatekas on peak power output measured by the Wingate test.[44] The same result has been found for female karate athletes, thought Doria et al.[44] who demonstrated that peak power and mean power were higher in male compared with female athletes in both kata and kumite. Ravier et al.[10] found a significant difference between national (mean ± SD; 10.9 ± 1.5 W/kg) and international level (12.5 ± 1.3 W/kg) karate athletes in maximal power determined by the force-velocity test. This result demonstrated that maximal power output performance can discriminate karate athletes at different competitive levels. However, because the power assessed by the force-velocity test is mainly anaerobic, i.e. 50% is alactic anaerobic and 50% is lactic anaerobic,[66] the Wingate test protocol raises other methodological issues. Indeed, Granier et al.[67] reported that a significant part of the energy supply for 30 seconds of effort, once presented as a means to assess anaerobic capacity, was performed by the aerobic system. Thus, the Wingate performance has to be interpreted with caution even if anaerobic pathways remain predominant with respect to aerobic metabolism.

Another study by Ravier et al.[15] revealed that the results obtained from the maximal accumulated oxygen deficit (MAOD) test, a method proposed to estimate anaerobic capacity,[68] were similar between both the national- (mean ± SD; 64.5 ± 6.4 mL/kg) and international-level groups (67.76 ± 8 mL/kg) of karate athletes. It can be concluded that the MAOD test was uninfluenced

Table IV. Anaerobic test performance in karate athletes

Study (test)	Sample characteristic (n)	PP (W) [mean ± SD]	PP (W/kg) [mean ± SD]	MP (W) [mean ± SD]	MP (W/kg) [mean ± SD]
Doria et al.[44] (Wingate)	Italian:	NR		NR	
	Elite male kumite (3)		9.1 ± 1.1		7.9 ± 0.6
	Elite female kumite (3)		7.8 ± 0.6		6.6 ± 0.4
	Elite male kata (3)		9.7 ± 0.6		7.8 ± 0.2
	Elite female kata (3)		7.7 ± 0.5		6.5 ± 0.3
Ravier et al.[10] (force-velocity)	French:	NR		NR	NR
	Junior international level (10)		12.5 ± 1.3 (P_{max})		
	Junior national level (12)		10.9 ± 1.5 (P_{max})		
Buśko and Wit[65] (force-velocity)	Polish national level (9)	NR	10.8 ± 0.85	NR	NR
Steven Baker and Davies[18] (maximal sprint of 8 sec)	British international level (11)	1164 ± 137 (TBW) 1289 ± 145 (FFM)	NR	NR	NR

FFM = fat-free mass (resistive force value from fat-free mass); **MP** = mean power (average power maintained during the test); **NR** = not reported; P_{max} = highest power achieved during the force-velocity test; **PP** = peak power (highest power achieved during the test); **SD** = standard deviation; **TBW** = total body weight; **W** = Watts.

by the karateka's competitive level.[15] Furthermore, karate's performance seems to be dependent on anaerobic-based power more so than anaerobic capacity itself. There is no study investigating the comparison between different weight categories and age groups. Additionally, the similarity in power performance between kata and kumite athletes in both genders is not conclusive, and further research is needed to support these results.

4. Physical Profile

4.1 Muscle Power

Reaching the highest performance level in karate is possible by applying high kinetic energy to one body segment over a short amount of time. Thus, muscle explosive power plays a major role in achieving top karate performances.[9,69,70] According to the WKF,[1] kumite performance depends on the speed and power of the karateka's actions. Greater muscular power, specifically in terms of vertical jump performance for international junior karatekas, has been reported in the study of Ravier et al.[10] when compared with their national-level counterparts (table V). Moreover, Ravier et al.[10] found that international karatekas had higher maximal power output and maximal velocity values on a friction-braked cycle ergometer when compared with their national-level counterparts. Thus, we suggest that movement velocity could help explain performance levels for explosive muscular action involved in karate and that karate displacement depends more on contraction velocity rather than muscle strength.[10] Indeed, maximal velocity and explosive strength represent the main determinant of the muscle mechanical factors involved in karate performance.[10,31]

Another study by Roschel et al.[31] suggested that karate performance relies more on muscle power at low rather than high loads. A comparison between winning versus losing karate players revealed that there were no significant differences between them in terms of power performance at high loads (60% of one-repetition maximum [1RM]). Alternatively, at low loads (30% 1RM), significant differences in power performance were established for bench press and squat exercises; winners had higher values. Contrary to power performance with an associated load, no significant difference existed between winning and losing karatekas during the vertical jump test.[31] Regarding the comparison between kata and kumite karatekas, the study of Doria et al.[44] revealed that the explosive strength did not differ between kata and kumite athletes during either squat jump (SJ) or countermovement jump (CMJ) power tests in male or female athletes. This result was confirmed in a recent study by Korapanovski et al.[57]

Table V. Vertical jump height performance of karate athletes

Study	Sample characteristic (n)	Height (cm) [mean ± SD]
Ravier et al.[10]	French male:	
	Junior international level (10)	CMJ = 44.9 ± 5.9 SJ = 42.3 ± 4.8
	Junior national level (12)	CMJ = 40 ± 3.8 SJ = 37 ± 3.6
Roschel et al.[31]	Brazilian elite level male (14):	
	Winners	CMJ = 48.8 ± 3.4
	Defeated	CMJ = 50.8 ± 2.6
Doria et al.[44]	Italian:	
	Elite male kumite (3)	SJ = 40.1 ± 3.2 CMJ = 42.8 ± 4.2
	Elite male kata (3)	SJ = 38.9 ± 1.1 CMJ = 42.7 ± 4.4
	Elite female kumite (3)	SJ = 37 ± 1.1 CMJ = 39.2 ± 2.4
	Elite female kata (3)	SJ = 36.9 ± 1.5 CMJ = 38.3 ± 1
Koropanovski et al.[57]	Serbian elite level male:	
	Kumite (9)	CMJ = 46.1 ± 4.4
	Kata (2)	CMJ = 48.6 ± 8.1

CMJ = counter movement jump; **SD** = standard deviation; **SJ** = squat jump.

conducted using Serbian high-level karatekas. They found no significant difference in CMJ performance between kumite and kata male practitioners (table V). In contrast, the former authors[57] found a significantly higher ability to accelerate the whole body, as assessed by both the 10 m sprint test and the standing triple jump test, in the kumite competitors compared with their kata counterparts. They concluded that the obtained difference may be explained by the specific requirements of typical kata and kumite competitions (i.e. the ability to rapidly initiate changes in body position in the horizontal plane determine the success of both the attacking and defensive kumite skills). Zehr et al.[71] reported that experienced karate players had higher values of peak elbow extension velocity, both without a load and with 10% of maximal voluntary isometric contraction, when compared with novice karate players.

A comparison between offensive and defensive karate athletes' behaviours revealed that the former was characterized by significantly higher CMJs (+15%) and SJs (+18% SJ).[10] The same authors concluded that CMJs and SJs could be relevant evidence of karatekas' attack propensity, which is considered a crucial element in the analysis of the mechanical muscle characteristics of karate practitioners. Pozo et al.[72] studied the execution time, kinetics and kinematics of the mae-geri kick between national and international karate athletes and found that international karatekas were faster than their national counterparts for all phases of the mae-geri kick, whereas there were no differences in impact force. They concluded that this similarity in force may be due to the specific learned strategy of better control of the kicking leg. In this context, the rules of high-level international competitions for Shotokan karate state that karate competitors should control most technical actions at the impact to avoid hurting their opponents during sparring. The respect of these rules could be the reasons for which international karatekas 'brake' the mae-geri kick just before impact.[72,73]

From all the results presented above, it can be concluded that decisive actions during kumite karate (kick or punch) are mainly dependent on muscular explosive power, and karate match performance is exclusively influenced by higher levels of upper and lower limb power/speed production.

4.2 Maximal Dynamic Strength

The most traditional way to assess dynamic strength is to determine how much an individual can lift for 1RM.[74] In consideration of dynamic strength, limited research has been reported for karate practitioners (table VI). Maximal absolute bench press and half squat 1RM differed significantly between highly competitive and novice karate athletes, which led the authors to suggest that the bench press and half squat are indicative of top-level competitive karatekas.[19] However, a further study comparing winning and losing karatekas revealed similar 1RM performance for bench press and squat exercises.[31] These results were similar to those of Toskovic et al.,[75] who compared experienced with novice taekwondo athletes. Thus, these results suggest that maximal dynamic strength is not decisive in kumite karate performance and other variables, such as contraction velocity, may play a more important role.[31] Unfortunately, there are no studies about female karate athletes that compare dynamic strength between kata and kumite karatekas or differences between weight category classes.

When comparing top-level with amateur karatekas, Sbriccoli et al.[73] reported that experienced karatekas had more knee flexion torque than amateurs during isokinetic tasks. Top-level karate athletes had higher biceps femoris conduction velocity values at all angular velocities. Conversely, no significant difference was found between groups with regard to knee extension torque or vastus lateralis conduction velocity.[73] The same authors revealed that during isokinetic tasks, top-level karatekas had reduced antagonistic activation of both the vastus lateralis and biceps femoris at all angular velocities. Probst et al.[76] compared isokinetic knee flexion and extension between karatekas and a group of subjects that did not practice karate. The authors found that the karate group showed greater relative peak torque at 60°/seconds and 180°/seconds in the left and right hamstrings compared with the control group.

4.3 Flexibility

Flexibility is one of the basic fitness components for some sports, including karate.[77,78] However, there is currently very little data on the flexibility of karate athletes. Flexibility refers to the range of motion in a given joint or sequence of joints. In addition to promoting ease and grace of movement, flexibility may help to prevent injuries.[79,80] Increasing joint range of motion and flexibility are extremely important in combat sports, and particularly for high-level karate performance. Flexibility is crucial in karatekas to execute high kicks and perform full-range movements at high speeds.

In a study comparing the level of joint flexibility between karate practitioners and control subjects that assessed knee flexion and extension, hip flexion and extension, hip medial rotation, hip lateral rotation, dorsiflexion, plantar flexion and foot inversion and eversion, Probst et al.[76] revealed that karatekas had greater flexibility only in their right and left hip flexion compared with control subjects. Moreover, karatekas also appeared to have significantly greater flexibility in their right and left knee flexion.[76] The greater hip flexor flexibility of the karate group may be induced by a training effect related to repeated flexion of the hip muscles during the early phase of kicking.[81] Surprisingly, Probst et al.[76] found that the karate group was not more flexible than the control group concerning other measured variables, particularly for the hamstrings. Violan et al.[82] studied the effects of 6 months of karate training on flexibility in 8- to 13-year-old boys with no previous martial art experience and compared them with a group of boys involved in recreational sports. These authors showed that the boys participating in karate training had improvements in static flexibility, particularly in their quadriceps (Ely test),[83] when compared with the control group. Koropanovski et al.[57] revealed that there was no difference between kata and kumite athletes'

Table VI. Performance in one-maximum repetition by karate athletes

Study	Sample characteristics (n)	Exercise	1RM (kg) [mean ± SD]
Roschel et al.[31]	Brazilian national team male (14)	Bench press (winners)	76.3 ± 16.8
		Squat (winners)	113.3 ± 15.1
		Bench press (defeated)	70.3 ± 11.5
		Squat (defeated)	128.6 ± 20.5
Imamura et al.[19]	Japanese male:		
	Top level (7)	Bench press	87.1 ± 12.5
		Squat	137.5 ± 12.5
	Novice level (9)	Bench press	74.4 ± 7.3
		Squat	120 ± 13.2

SD = standard deviation.

flexibility (side leg splits test). Research comparing successful karatekas with their less successful counterparts in both males and females is lacking. Additionally, research should be conducted to illustrate the range of motion necessary for karate's successful performance. Indeed, reaching extremely high ranges of motion is probably not necessary for karatekas. Furthermore, the distinction has to be made with regard to static and dynamic flexibility. According to karate characteristics, it seems that it is much more important to have good dynamic flexibility rather than static flexibility, though it is easier to assess the latter.

4.4 Reaction Time

Reaction time, or the speed at which a person moves in response to a stimulus, is a critical element in most sports, including karate, because high-level performance is essentially based on explosive techniques. Furthermore, karate is a good example of a competitive sport with high levels of temporal and spatial constraints, which require rapid reactions.[84] However, research on reaction time in martial artists is scarce. The available literature about both simple reaction time and choice reaction time for different forms of martial arts is controversial. While Layton's[85] study revealed no significant difference in simple reaction time between experienced karate practitioners of different competitive levels, Fontani et al.[86] did find 3rd and 4th dan black belt karatekas to react faster than 1st and 2nd dan black belt athletes. Additionally, while Layton[85] suggested that karate black belt practitioners had a lower simple reaction time when compared with novice karate athletes, Williams and Elliot[87] and Mori et al.[84] showed no significant difference in simple reaction time between high-level and novice karatekas. These findings are supported by the recent study of Neto et al.,[88] conducted in kung-fu athletes, who showed that both advanced and intermediate level athletes had similar simple reaction times. Lee et al.[89] reported that the reaction time to perform ballistic finger extension movements was significantly shorter in karate athletes' compared with sedentary subjects.

Regarding the choice reaction time, which could be considered more important to karate, Mori et al.[84] reported significant differences between high-level and novice karate athletes, with the latter being slower than the elite karatekas.

Overall, the studies available that investigate either simple or choice reaction times reveal notable controversy. Further highly accurate studies on reaction time between successful and less successful karate athletes are needed, and assessments more specific to karate performance should be used.

5. Conclusion and Future Research

Relatively little is known regarding the physiological characteristics of karate athletes, and very few studies have assessed female karatekas. Top-level male karate athletes are characterized by relatively low body fat and mesomorphic-ectomorphic properties, whereas female karatekas appears to be characterized by more endomorphic with some mesomorphic traits. Further study is needed to precisely establish the ideal somatotype of high-level female karatekas. Moreover, karate practitioners were found to have a higher bone mineral density than age-matched controls. $\dot{V}O_{2max}$ seemed to be uninfluenced by a karateka's competitive level; however, $\dot{V}O_{2max}$ may play a major role in preventing fatigue during training, during the rest period between subsequent bouts of fighting, within a fight and in improving the recovery between consecutive combats. Similar results have been reported in terms of the anaerobic power and capacity measured through the Wingate test when comparing international- and national-level karate players. Similar results were also obtained with the MAOD test. Top karateka performance levels have been demonstrated to be essentially related to muscle explosive power. Indeed, karate final match results are mainly influenced by higher levels of upper and lower limb power production. Furthermore, highly competitive karate athletes require both rapid acceleration and deceleration of body segments and muscular explosive power training. Overall, studies on karate and physical fitness are still limited. Further research is necessary to validate and identify the most representative tests that focus on athletes' success within karate. It also seems necessary to elucidate differences in results from each weight category class and gender, as well as differences between kumite and kata competitors. Additionally, investigations using multivariate methods to assess the contribution of different factors to karate performance are also extremely relevant to improve the knowledge of the inter-relationship among these methods.

Acknowledgements

The Ministry of Higher Education and Scientific Research, Tunis, Tunisia, has partially financially participated in the preparation of this manuscript. The authors have no conflicts of interest to declare that are directly relevant to the content of this review.

References

1. World Karate Federation (WKF): New Kata and Kumite Rules [version 7.1; online]. Available from URL: http://www.wkf.net/images/stories/downloads/KATA%20and%20KUMITE%20COMPETITION%20RULES%207_1%20EFFECTIVE%2001.01.2012.pdf [Accessed 2012 Jan 1]
2. Artioli GG, Gualano B, Franchini E, et al. Physiological, performance, and nutritional profile of the Brazilian Olympic Wushu (kung-fu) team. J Strength Cond Res 2009; 23 (1): 20-5
3. Langan-Evans C, Close GL, Morton JP. Making weight in combat sports. Strength Cond J 2011; 33 (6): 25-39
4. Vanhees L, Lefevre J, Philippaerts R, et al. How to assess physical activity? How to assess physical fitness? Eur J Cardio Prev Rehab 2005; 12: 102-14
5. Beekley M, Abe T, Kondo M, et al. Comparison of normalized maximum aerobic capacity and body composition of sumo wrestlers to athletes in combat and other sports. J Sports Sci Med 2006; 5 (CSSI): 13-20
6. Baker JS, Bell W. Energy expenditure during simulated karate competition. J Hum Mov Stud 1990; 19: 69-74
7. Giampietro M, Pujia A, Bertini I. Anthropometric feature and body composition of young athletes practicing karate at high and medium competitive level. Acta Diabetol 2003; 40: S145-8
8. Durnin JVGA, Rahaman MM. The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br J Nutr 1967; 21: 681-9
9. Ravier G, Grappe F, Rouillon JD. Comparison between the maximal variables of velocity, force and power from two analysis methods in the functional assessment of karate. Sci Sports 2003; 18: 134-40
10. Ravier G, Grappe F, Rouillon JD. Application of force velocity cycle ergometer test and vertical jump tests in the functional assessment of karate competitor. J Sports Med Phys Fitness 2004; 44: 349-55
11. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 1978; 40: 497-504
12. Francescato MP, Talon T, di Prampero PE. Energy cost and energy sources in karate. Eur J Appl Physiol Occup Physiol 1995; 71: 355-61
13. Brozek J, Grande F, Anderson JT, et al. Densitometric analysis of body composition: revision of some quantitative assumptions. Ann NY Acad Sci 1963; 110: 113-40
14. Imamura H, Yoshimura Y, Uchida K, et al. Heart rate, blood lactate responses and rating of perceived exertion to 1,000 punches and 1,000 kicks in collegiate karate practitioners. Appl Hum Science 1997; 16 (1): 9-13
15. Ravier G, Dugue B, Grappe F, et al. Maximal accumulated oxygen deficit and blood responses of ammonia, lactate and pH after anaerobic test: a comparison between international and national elite karate athletes. Int J Sports Med 2005; 27: 810-7
16. Rodrigues Ferreira MA, Vences Brito A. Electromechanical delay in ballistic movement of superior limb: comparison between karate athletes and nonathletes. Percept Motor Skill 2010; 111 (3): 722-34
17. Siri WB. The gross composition of the body. In: Tobias CA, Lawrence JH, editors. Advances in biological and medical physics. Vol 4. New York (NY): Academic Press, 1956: 239-80
18. Steven Baker SJ, Davies B. Variation in resistive force selection during brief high intensity cycle ergometry: implication for power assessment and production in elite karate pratctitioners. J Sports Sci Med 2006; 5 (CSSI): 42-6
19. Imamura H, Yoshimura Y, Uchida K, et al. Maximal oxygen uptake, body composition and strength of highly competitive and novice karate practitioners. Appl Human Science 1998; 17 (5): 215-8
20. Siri WE. Body volume measurement by gas dilution. In: Brozek J, Henschel A, editors. Techniques for measurement body composition. Washington, D C: National Academy of Science, National Research Council, 1961: 108-17
21. Amusa L, Onyewadume I. Anthropometry, body composition and somatotypes of Botswana national karate players: a descriptive study. Acta Kines Univ Tart 2001; 6: 7-14
22. Keys A, Brozek J. Body fat in adult man. Physiol Rev 1953; 33: 245-325
23. Sterkowicz-Przybycien KL. Body composition and somatotype of the top Polish male karate contestants. Biol Sport 2010; 27: 195-201
24. Jackson AS, Pollock ML. Practical assessment of body composition. Phys Sports Med 1985; 13: 76-90
25. Sloan AW, Weir JB. Nomograms for prediction of body density and total body fat from skinfold measurement. J Appl Physiol 1970; 28: 221-2
26. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. Med Sci Sports Exerc 1980; 12 (3): 175-82
27. Shaw DK, Deutsch DT. Heart rate and oxygen uptake response to performance of karate kata. J Sports Med 1982; 22 (4): 461-7
28. Rossi L, Tirapegui J. Avaliacao anthropometrica de atletas de Karatê. R.bras. Ci e Mov 2007; 15 (3): 39-46
29. Imamura H, Yoshimura Y, Uchida K, et al. Heart rate response and perceived exertion during twenty consecutive karate sparring matches. Aust J Sci Med Sport 1996 Dec; 28 (4): 114-5

30. Lutoslawska G, Borkowski L, Krawczyk B, et al. Changes in concentration of plasma inorganic phosphate, uric acid and blood lactate in response to supramaximal arm exercise in karate athletes. Biol Sport 1996; 13 (2): 99-103
31. Roschel H, Batista M, Monteiro R, et al. Association between neuromuscular tests and kumite performance on the Brazilian Karate National Team. J Sports Sci Med 2009; 8 (CSSI 3): 20-4
32. Katic R, Blazevic S, Krstulovic S, et al. Morphological structure of elite karateka and their impact on technical and fighting efficiency. Coll Anthropol 2005; 29 (1): 79-84
33. Sinning WE. Body composition and athletic performance. In: Clarke DH, Eckert HM, editors. Limits of human performance (the academy papers, 18). Champaign (IL): Human Kinetics, 1985: 45-56
34. Pieter W, Bercades TL. Somatotype of national elite combative sport athletes. Braz J Biomotricity 2009; 3 (1): 21-30
35. Fritzschel J, Raschka C. Sports anthropological investigation on somatotype of elite karateka. Anthropol Anz 2007; 65 (3): 317-29
36. Andreoli A, Monteleone M, Van Loan M, et al. Effects of different sports on bone density and muscle mass in highly trained athletes. Med Sci Sports Exerc 2000; 33 (4): 507-11
37. Drozdzowska B, Munzer U, Adamczyk P, et al. Skeletal status assessed by quantitative ultrasound at the hand phalanges in karate training males. Ultrasound Med Biol 2011; 37 (2): 214-9
38. Prouteau S, Pelle A, Collump K, et al. Bone density in elite judoists and effects of weight cycling on bone metabolic balance. Med Sci Sports Exerc 2006; 38 (4): 694-700
39. Pieter W, Bercades LT, Kim GD. Relative total body fat and skinfold patterning in Fillipino national combat sport athletes. J Sports Sci Med. 2006; 5 (CSSI): 35-41
40. American College of Sports Medicine (ACSM). Resource manual for guidelines for exercise testing and prescription. 7th ed. Philadelphia (PA): Lippincott William and Wilkins, 2006
41. Impellizzeri F, Marcora S. The physiology of mountain biking. Sports Med 2007; 37 (1): 59-71
42. Imamura H, Yoshimura Y, Nishimura S, et al. Oxygen uptake, heart rate, and blood lactate responses during and following karate training. Med Sci Sports Exerc 1999; 2: 342-7
43. Imamura H, Yoshimura Y, Nishimura S, et al. Oxygen uptake, heart rate and blood lactate responses during 1,000 punches and 1,000 kicks in female collegiate karate practitioners. J Physiol Anthropol 2003; 22 (2): 111-4
44. Doria C, Veicsteinas A, Limonta E, et al. Energitics of karate (kata and kumite techniques) in top-level athletes. Eur J Appl Physiol 2009; 107: 603-10
45. Ravier G, Dugue B, Grappe F, et al. Impressive anaerobic adaptations in elite karate athletes due to few intensive intermittent sessions added to regular karate training. Scand J Med Sci Sports 2009; 19: 687-94
46. Yoshimura Y, Imamura H. Effects of basic karate exercises on maximal oxygen uptake in sedentary collegiate women. J Health Sci 2010; 56 (6): 721-6
47. Zehr EP, Sale DG. Oxygen uptake, heart rate and blood lactate responses to the chito-ryu seisan kata in skilled karate practitioners. Int J Sports Med 1993; 14: 269-74
48. Iide K, Imamura H, Yoshimura Y, et al. Physiological responses of simulated karate sparring matches in young men and boys. J Strength Cond Res 2008; 22 (3): 839-44
49. Astrand PO, Rodahl K. Textbook of work physiology. New York (NY): McGraw-Hill, 1977
50. Astrand PO, Saltin B. Maximal oxygen uptake and heart rate in various type of muscular activity. J App Physiol 1961; 16: 977-81
51. Bouhlel E, Jouini A, Gmada N, et al. Heart rate and blood lactate responses during Taekwondo training and competition. Sci Sports 2006; 21: 285-90
52. Butios S, Tasika N. Changes in heart rate and blood lactate concentration as intensity parameters during simulated Taekwondo competition. J Sports Med Phys Fitness 2007; 47: 179-85
53. Yoon J. Physiological profiles of elite senior wrestlers. Sports Med 2002; 32 (4): 225-33
54. Smith M. Physiological profile of senior and junior England international amateur boxer. J Sports Sci Med 2006; 5 (CSSI): 74-89
55. Campos FAD, Bertuzzi R, Dourado AC, et al. Energy demands in taekwondo athletes during combat simulation. Eur J Appl Physiol 2012; 112 (4): 1221-8
56. Beneke R, Beyer T, Jachner C, et al. Energetics of karate kumite. Eur J Appl Physiol 2004; 92: 518-23
57. Koropanovski N, Berjan B, Bozic PR, et al. Anthropometric and physical performance profiles of elite karate kumite and kata competitors. J Hum Kinet 2011; 30: 107-14
58. Léger LA, Mercier D, Gadoury C, et al. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci 1988; 6: 93-101
59. Chamari K, Moussa-Chamari I, Boussaïdi L, et al. Appropriate interpretation of aerobic capacity: allometric scaling in adult and young soccer players. Br J Sports Med 2005; 39 (2): 97-101
60. Funakoshi G. Karate Do Kyohan (the Master text) [in Japanese]. Tokyo: Kodansha International Ltd., 1973: 3-14
61. Liyama K. Karatedo. Notto Shoin [in Japanese]. Tokyo, 1973: 18-20
62. Chaabène H, Hachana Y, Franchini E, et al. Reliability and construct validity of the karate-specific aerobic test. J Strength Cond Res. Epub 2012 Feb 15
63. Chaabène H, Hachana Y, Attia A, et al. Relative and absolute reliability of the karate specific aerobic test (KSAT) in experienced male athletes. Biol Sport 2012; 29: 211-15
64. Glaister M. Multiple sprint work: physiological responses, mechanisms of fatigue and influence of aerobic fitness. Sports Med 2005; 35 (9): 757-77
65. Buśko K, Wit B. Force-velocity relationship of lower extremity muscles of karate athletes and rowers. Biol Sport 2002; 19 (4): 373-84
66. Gaitanos GC, Williams C, Boobis LH, et al. Human muscle metabolism during intermittent maximal exercise. J Appl Physiol 1993; 75 (2): 712-9
67. Granier P, Mercier B, Mercier J, et al. Aerobic and anaerobic contribution to Wingate test performance in sprint and middle-distance runners. Eur J Appl Physiol 1995; 70 (1): 58-65

68. Medbo JI, Mohn AC, Tabata I, et al. Anaerobic capacity determined by maximal accumulated O2 deficit. J Appl Physiol 1988; 64: 50-60
69. Blazevic S, Katic R, Popovic D. The effect of motor abilities on karate performance. Coll Antropol 2006; 30 (2): 327-33
70. Katic R, Blazevic S, Zagorac N. The impact of basic motor abilities on the specific motoricity performance in elite karateka. Coll Antropol 2010; 34 (4): 1341-5
71. Zehr EP, Sale DG, Dowling JJ. Ballistic movement performance in karate athletes. Med Sci Sports Exerc 1997; 29 (10): 1366-73
72. Pozo J, Bastien G, Dierick F. Execution time, kinetics, and kinematics of the *maegeri* kick: comparison of national and international standard karate athletes. J Sports Sci 2011; 29 (14): 1553-61
73. Sbriccoli P, Camomilla V, Di Mario A, et al. Neuromuscular control adaptations in elite athletes: the case of top level karateka. Eur J Appl Physiol 2010; 108 (6): 1269-80
74. Fry AC, Newton RU. A brief history of strength training and basic principles and concepts. In: Kraemer WJ, Häkkinen K, editors. Strength training for sport. Oxford: Blackwell Science Ltd, 2002: 1-19
75. Toskovic NN, Blessing D, Williford HN. Physiologic profile of recreational male and female novice and experienced TaeKwon Do practitioners. J Sports Med Phys Fitness 2004; 44: 164-72
76. Probst MM, Fletcher R, Seelig DS. A comparison of lower-body flexibility, strength, and knee stability between karate athletes and active controls. J Strength Cond Res 2007; 21 (2): 451-5
77. Fleissman E. The analysis of speed, flexibility, balance and coordination test: the structure and measurement of physical fitness. Englewood Cliffs (NJ): Prentice Hall, 1964, 85-100
78. Pate R, Shephard R. Characteristics of physical fitness in youth. In: Gisolfi C, Lamb DR, editors. Perspective in exercise and sports medicine. Vol. 2: youth exercise and sport. Indianapolis (IN): Benchmark Press, 1989; 1-45
79. McHugh MP, Nesse M. Effect of stretching on strength loss and pain after eccentric exercise. Med Sci Sports Exerc 2008; 40 (3): 566-73
80. Smith CA. The warm-up procedure: to stretch or not to stretch a brief review. J Orthop Sports Phys Ther 1994; 19: 12-7
81. Shirely M. The taekwondo side kick: a kinesiological analysis with strength and conditioning principles. Nat Strength Cond Assoc J 1992; 14 (7-8); 72-7
82. Violan MA, Small WE, Zetaruk MN, et al. The effect of karate training on flexibility, muscle strength, and balance in 8- to- 13 years-old boys. Pediat Exerc Sci 1997; 9: 55-64
83. Anderson B, Burk ER. Scientific, medical and practical aspects of stretching. Clin Sports Med 1991; 10: 63-86
84. Mori S, Ohtani Y, Imanaka K. Reaction time and anticipatory skills of karate athletes. Hum Mov Science 2002; 21 (2) 213-30
85. Layton C. Reaction+movement-time and sidedness in shotokan karate students. Percept Motor Skill 1993; 76: 765-6
86. Fontani G, Lodi L, Felici A, et al. Attention in athletes of high and low experienced engaged in different open skill sport. Percept Motor skill 2006; 102: 791-805
87. Williams AM, Elliott D. Anxiety, expertise and visual search strategy in karate. J Sport Exerc Psycho 1999; 21: 362-75
88. Neto PO, Bolander R, Tavares Pacheko MT, et al. Force, reaction time and precision of kung-fu strikes. Percept Motor Skill 2009; 109: 295-303
89. Lee JB, Matsumoto T, Othman T, et al. Coactivation of the flexor muscle as a synergist with the extensor during ballistic finger extension movement in trained Kendo and karate athletes. Inter J Sports Med 1999; 20: 7-11

Correspondence: Mr *Helmi Chaabène*; Boucha, Azmour, Kélibia, Nabeul, 8035, Tunisia.
E-mail: chaabanehelmi@hotmail.fr