REVIEW ARTICLE

Sports Med 2011; 41 (2): 147-166
0112-1642/11/0002-0147/$49.95/0

Physiological Profiles of Elite Judo Athletes

Emerson Franchini,[1] *Fabrício B. Del Vecchio*,[1,2] *Karin A. Matsushigue*[1] and *Guilherme G. Artioli*[1,3]

1 Martial Arts and Combat Sports Research Group, School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil
2 Superior School of Physical Education, Federal University of Pelotas, Pelotas, Brazil
3 Laboratory of Applied Nutrition and Metabolism, School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil

Contents

Abstract . . . 147
1. Introduction . . . 148
2. Somatotype and Body Composition . . . 149
3. Maximal Strength . . . 149
3.1 Isometric Strength . . . 150
3.2 Dynamic Strength . . . 152
4. Muscle Power . . . 155
5. Muscular Endurance . . . 156
6. Anaerobic Profile . . . 156
7. Aerobic Profile . . . 158
8. Conclusions and Future Directions . . . 164

Abstract

To be successful in international competitions, judo athletes must achieve an excellent level of physical fitness and physical condition during training. This article reviews the physiological profiles of elite judo athletes from different sex, age and weight categories. Body fat is generally low for these athletes, except for the heavyweight competitors. In general, elite judo athletes presented higher upper body anaerobic power and capacity than non-elite athletes. Lower body dynamic strength seems to provide a distinction between elite and recreational judo players, but not high-level judo players competing for a spot on national teams. Even maximal isometric strength is not a discriminant variable among judo players. However, more studies focusing on isometric strength endurance are warranted. Although aerobic power and capacity are considered relevant to judo performance, the available data do not present differences among judo athletes from different competitive levels. Typical maximal oxygen uptake values are around 50–55 mL/kg/min for male and 40–45 mL/kg/min for female judo athletes. As for other variables, heavyweight competitors presented lower aerobic power values. The typical differences commonly observed between males and females in the general population are also seen in judo athletes when analysing anaerobic power and capacity, aerobic power, and maximal strength and power. However, further research is needed concerning the differences among the seven weight categories in which judo athletes compete.

1. Introduction

Currently, there are seven weight categories for both male (<60 kg, 66 kg, 73 kg, 81 kg, 90 kg, 100 kg and >100 kg) and female judo competitors (<48 kg, 52 kg, 57 kg, 63 kg, 70 kg, 78 kg and >78 kg). Judo competitions are also divided according to athletes' age, as follows: cadets (15–16 years of age), junior (17–19 years of age), senior (>20 years of age, although younger athletes might compete) and master (>30 years of age). The main competitions in judo are the Olympic Games and World Championship for each age category. Each weight division implies marked differences in technical and tactical aspects as well as in physiology, performance and body composition among competitors of the different weight classes. Thus, it directly influences some key aspects of athletes' preparation, including the management of bodyweight and body composition.

Judo is a dynamic, high-intensity intermittent sport that requires complex skills and tactical excellence for success.[1] As judo athletes have to perform a great number of actions during each match, the physical demand of a single match is high. Typically, judo medalists perform five to seven matches during international competitions, with each match having a 5-minute time limit. If a judo athlete obtains an *ippon* (full point), the match ends. On the other hand, since 2003, when the time allotted for the contest finished and the scores/penalties are equal for both athletes (i.e. the match draws), the result of the contest is decided by a 'Golden Score'. If neither athlete obtains any score in the Golden Score period the match continues for another 3 minutes and is decided by the referees (Hantei decision). Thus, a judo match may last from a few seconds to 8 minutes, depending on the scores obtained by the contestants. However, a typical high-level judo match lasts 3 minutes, with 20- to 30-second periods of activity and 5–10 seconds of interruption.[2,3] Moreover, a significant portion of the matches last 3–4 minutes.[2]

To be effective, judo techniques should be applied with accuracy, within a good 'window of opportunity', with strength, velocity and power. This short burst of energy is supplied mainly by anaerobic metabolism. In contrast, the maintenance of the intermittent work performed during a match, as well as the recovery process during the short intervals, are mainly supported by aerobic metabolism. Additionally, aerobic metabolism is especially important for an effective recovery between matches.[4]

With these facts, it can be established that judo is a complex sport with demands comprising a number of specific characteristics to achieve a high level in competition. It is well known that understanding the characteristics of elite athletes can provide insightful information regarding what is needed for competitive success. Therefore, the objective of the present narrative review is to present and discuss the knowledge currently available on the main physical and physiological characteristics of judo competitors. When available, specific considerations will be directed to age, sex, weight and competitive level differences across groups of athletes. For this purpose, a literature search of PubMed, SportDiscus® and ISI Web of Knowledge was performed with the specific keywords 'judo', 'judo and performance', 'judo and physical fitness', 'judo and body composition', 'judo and aerobic fitness', 'judo and anaerobic fitness', 'judo and strength' and 'judo and physiology'. The retrieved studies were further selected based on their purpose, methodology, and number and characteristics of the judo athletes evaluated. Additionally, references cited in these articles were considered whenever limited information in a specific topic was evident.

2. Somatotype and Body Composition

In judo, as occurs in any other combat sport, where competitors are divided by weight classes, optimal body composition is a major concern.[5] Thus, judo athletes attempt to maximize the amount of lean tissue, minimize the amount of body fat, and minimize total bodyweight. Considering the broad range of weight classes (48 kg to >78 kg for female judo athletes and 60 to >100 kg for male judo athletes), it is impossible to establish a single body type or anthropometric profile for all judo athletes.[6] Nevertheless, there is some similarity throughout much of the range in terms of characteristic somatotypes and a predominance of mesomorphy (table I).[8,10]

In terms of somatotype, the judo athlete is generally thought to have a profile that accentuates the mesomorphic properties (very high muscularity, low linearity and low fat). Among females, the endomorphic component has values near to the mesomorphic one. However, caution should be exercised when interpreting these results as they could have been influenced by the inclusion of heavyweight athletes. Table II presents the body composition of high-level judo athletes.

World and Olympic level male judo athletes usually have <10% body fat.[6,14,32] However, caution is needed when using this value as a reference, because most studies predicted body fat by skinfold thickness measurements and, therefore, the specific mean error of estimate of each equation should be taken into consideration. Ideally, a prospective judo athlete should employ sound nutrition and aerobic training principles to reach a steady-state fat percentage of 7–10%.[26] Since they compete at their weight categories, it is not surprising that they are very strong per kilogram of bodyweight. This means that they must have a very small percentage of body fat compared with an average male of the same height and age. Indeed, the range of fat percentage extends from approximately 4% to 9%, with the exception of the heavyweights (>78 kg for females and >100 kg for males). Only one study presented a significant difference in body fat among best-ranked judo athletes and lower ranked athletes.[19]

3. Maximal Strength

Maximal strength can be defined as the maximal torque that a muscle or a muscle group can generate at a specified or determined velocity.[33] It depends upon the ability of the nervous system to recruit motor units, the ability of the muscle to utilize the energy anaerobically (mainly adenosine triphosphate and phosphocreatine) for muscle contractions, the amount of motor units simultaneously

Table I. Somatotype of high-level judo athletes

Athlete characteristics	Endomorphy (mean ± SD)	Mesomorphy (mean ± SD)	Ectomorphy (mean ± SD)	Reference
Male				
Hungarian team (n = 18)	3.6 ± 1.9	7.0 ± 1.5	1.6 ± 0.9	Farmosi[7]
Japanese (n = 13)	3.4 ± 2.0	8.5 ± 1.4	1.0 ± 0.6	Kawamura et al.[8]
French (n = 10)	1.2 ± 0.5	7.6 ± 0.9	1.5 ± 0.7	Kawamura et al.[8]
Brazilian team 1999 (n = 7)	2.7 ± 1.3	7.9 ± 1.6	1.1 ± 0.6	Silva et al.[9]
WCP under 71 kg (n = 18)	2.3 ± 0.4	5.6 ± 0.5	1.9 ± 0.4	Claessens et al.[10]
WCP 71–86 kg (n = 9)	3.0 ± 0.5	6.0 ± 0.7	1.7 ± 0.7	Claessens et al.[10]
WCP >86 kg (n = 11)	4.1 ± 0.9	6.2 ± 0.6	1.3 ± 0.4	Claessens et al.[10]
Brazilian university team 1996 (n = 6)	2.7 ± 1.8	6.2 ± 1.5	1.6 ± 1.2	Franchini et al.[11]
Female				
Brazilian university team 1996 (n = 7)	4.1 ± 1.3	5.0 ± 1.1	1.7 ± 1.2	Franchini et al.[11]
Brazilian team 1999 (n = 7)	4.3 ± 1.3	5.1 ± 0.9	1.1 ± 1.0	Franchini et al.[12]
Brazilian elite (n = 28)	3.6 ± 1.9	5.1 ± 1.7	1.5 ± 0.9	Mello and Fernandes Filho[13]

WCP = World Championship players.

Table II. Percentage body fat in judo athletes

Athlete characteristics	Body mass (kg) [mean ± SD]	Body fat (%) [mean ± SD]	Prediction equation reference	Reference
Male				
Hungarian team (n = 7)	60–70[a]	8.9 ± 0.8	Enilina[14]	Farmosi[7]
Hungarian team (n = 11)	>70[b]	14.0 ± 7.3	Enilina[14]	Farmosi[7]
Canadian team 1987 (n = 22)	75.4 ± 12.3	9.3 ± 2.1	Lohman[15]	Thomas et al.[16]
US (elite; n = 8)	91.5 ± 2.7	10.8 ± 1.9	Jackson and Pollock[17]	Callister et al.[18]
US (elite; n = 18)	83.1 ± 3.8	8.3 ± 1.0	Jackson and Pollock[17]	Callister et al.[19]
Canadians (n = 17)	79.3 ± 14.6	10.5 ± 1.0	Drinkwater and Ross[20]	Little[21]
Brazilian university team (n = 6)	86.9 ± 34.4	11.1 ± 5.1	Drinkwater and Ross[20]	Franchini et al.[11]
Polish (n = 15)	82.9 ± 16.4	13.7 ± 3.4	Slaughter et al.[22]	Sterkowicz et al.[23]
Brazilian university team 2000 (n = 13)	89.0 ± 16.0	13.7 ± 5.2	Drinkwater and Ross[20]	Franchini et al.[24]
Brazilian Olympic team 2000 (n = 7)	NR	7.0 ± 3.0	Lohman et al.[25]	Koury et al.[26]
Croatians (elite; n = 6)	NR	12.0 ± 1.2	NR	Sertic et al.[27]
Brazilian team A (n = 7)	90.6 ± 23.8	11.4 ± 8.4	Jackson and Pollock[17]	Franchini et al.[6]
Brazilian team B (n = 15)	86.5 ± 16.3	10.1 ± 5.7	Jackson and Pollock[17]	Franchini et al.[6]
Female				
Polish team (n = 22)	59.1 ± 7.9	20.9 ± 2.0	Piechaczek[28]	Obuchowicz-Fidelus et al.[29]
Canadians (n = 8)	62.3 ± 5.2	15.2 ± 2.1	Drinkwater and Ross[20]	Little[21]
US (elite; n = 7)	56.3 ± 0.9	15.8 ± 1.2	Jackson et al.[30]	Callister et al.[18]
US (elite; n = 9)	53.8 ± 1.6	15.2 ± 1.0	Jackson et al.[30]	Callister et al.[19]
Brazilian university team (n = 7)	66.9 ± 16.3	16.1 ± 3.0	Drinkwater and Ross[20]	Franchini et al.[11]
Brazilian Olympic team 2000 (n = 9)	66.0 ± 8.0	22.0 ± 5.0	Jackson et al.[30]	Koury et al.[31]
Croatians (n = 8)	NR	16.6 ± 4.3	NR	Sertic et al.[27]

a Athletes body mass ranged from 60 kg to 70 kg.

b Athletes body mass was >70 kg.

NR = not reported.

active and the size of cross-sectional area of muscle fibres present. Because of the relationship to cross-sectional area and size, strength is often analysed relatively to bodyweight; the so-called relative strength is especially informative in bodyweight classified sports such as judo.[34] As muscle contractions might occur in different manners, they will be discussed separately in the next sections.

3.1 Isometric Strength

An isometric action results in no change in muscle length and although force is developed, as no movement occurs, no work is performed.[33] As judo athletes have to grip the opponent's uniform (judogi), early studies have focused on isometric grip strength. Table III presents the grip strength of different groups of judo athletes.

Isometric grip strength has not been investigated in detail for different weight categories, while only two studies[7,36] have addressed this topic. In one study,[36] greater left isometric grip strength was observed in the middle weight category compared with the light weight category. However, there is no mention concerning the number of left-handed athletes in each group, which prevents any conclusion on whether the difference is caused by the weight category or by the number of left-handed athletes in the first group. The other study did not identify any difference among weight categories.[7] A third study presented in table III did not perform any statistical comparison among the different weight groups, but it seems that the isometric strength increases according to the weight category.[35] When correlation analysis is conducted, one study[16] identified a positive relationship (r = 0.76) between body mass and isometric grip strength.

Sex differences were reported in only one study.[11] The male group presented higher absolute right and left isometric grip strength compared with the female group. However, when values were presented relative to body mass, no difference was observed. In Canadian judo players,[21] no statistical comparison between male and female athletes was reported, but it is possible to infer that both absolute and relative isometric grip strength were higher for the male group.

Table III. Isometric handgrip strength (IHGS) of judo athletes

Study	Athlete characteristics; sex	Right IHGS (kgf) [mean ± SD][a]	Left IHGS (kgf) [mean ± SD][a]
Matsumoto et al.[35]	Japanese university athletes (~66 kg); M (n = 12):		
	1967	43.8	43.8
	1968	49.3	49.3
	Candidates to the 1967 World Championship	44.9	45.1
	World Championship university athletes (~73 kg; n = 18):		
	1967	50.8	47.7
	1968	53.3	52.2
	Candidates to the 1967 World Championship	56.8	52.0
	University athletes (~83 kg; n = 8):		
	1967	55.3	49.5
	1968	59.6	55.6
	Candidates to the 1967 World Championship	54.2	51.5
Claessens et al.[36]	High-level Belgian judo athletes:		
	All (n = 24)	64.9 ± 8.9	59.7 ± 8.8
	<71 kg (n = 13)	56.8 ± 7.7	54.4 ± 7.5
	71–86 kg (n = 9)	59.7 ± 6.1	59.3 ± 7.6
Farmosi[7]	Hungarian team; M:		
	All (n = 18)	59.9 ± 11.2	55.7 ± 10.7
	<71 kg (n = 7)	54.3 ± 5.4	50.9 ± 5.4
	>71 kg (n = 11)	63.9 ± 12.8	59.0 ± 12.4
Franchini et al.[37]	Brazilian judo athletes; M:		
	Elite (n = 26)	51.0 ± 10.0	49.0 ± 10.0
	Non-elite (n = 66)	42.0 ± 11.0	40.0 ± 10.0
Franchini et al.[24]	Brazilian university team (2000); M:		
	All (n = 13)	54.3 ± 8.3	53.2 ± 7.4
Franchini et al.[11]	Brazilian university team (1996):		
	M (n = 6)	49.5 ± 12.8	47.2 ± 12.4
	F (n = 7)	32.3 ± 7.6	32.2 ± 7.8
Thomas et al.[16]	Canadian team (1987); M:		
	All (n = 22)	56.4 ± 6.6	55.7 ± 6.6
Little[21]	Canadian athletes:		
	Junior F (n = 9)	32.1 ± 3.5	29.3 ± 5.3
	Senior F (n = 8)	31.8 ± 5.8	30.6 ± 5.4
	Cadet M (n = 17)	39.8 ± 12.7	39.4 ± 10.0
	Junior M (n = 9)	52.0 ± 8.3	50.6 ± 8.5
	Senior M (n = 17)	57.7 ± 9.0	54.0 ± 10.4

a Data for Matsumoto et al.[35] presented as mean values.

F = female; **kgf** = kilogram force; **M** = male.

Thus, it can be hypothesized that high-level male and female judo athletes differ less in isometric grip strength when compared with lower level male and female judo athletes, probably because high-intensity training can decrease the difference in relative strength.

Differences in isometric grip strength were reported between cadet judo athletes and both junior and senior judo athletes.[21] However, when an index of isometric strength (including grip, back and arm) was expressed relative to body mass, only cadet and senior athletes differed.[21]

It is also interesting to note that the isometric grip strength of high-level judo athletes has not exhibited an increase over the last 40 years, because the values measured in Japanese athletes during the 1960s[35] are quite similar to those reported later in more recent studies.

Furthermore, an important aspect for consideration is the fact that no difference was observed between elite and non-elite judo players,[37] and most of the groups on table III would be classified only as 'good' compared with the US population.[38] Thus, it is likely that measurement of isometric strength endurance may be more relevant to judo athletes' evaluation than the measurement of maximal strength, since the athletes have a near continuous grip during a judo match and the maximal strength is not maintained for a long period. However, no studies were found concerning isometric grip strength endurance in judo athletes.

3.2 Dynamic Strength

The one-repetition maximum (1RM) test has been used for both evaluating and prescribing strength training.[39] However, 1RM data from judo athletes are limited in the literature. Table IV presents the 1RM results found in judo athletes from different levels and for different exercises.

In one study,[34] maximal absolute and relative squat strength differed between recreational and international level judo athletes, while no differences were found among groups for the bench press exercise. However, when athletes of similar competitive level were compared (main team vs reserves in a national squad) no differences were reported for bench press, row and squat 1RM values.[6] It is important to highlight that the bench press values presented in table IV are in the 60–80th percentile of the US population,[38] which suggests that these judo athletes do not present an excellent maximal strength profile. Studies on female judo athletes' maximal strength are scarcer, but one study[32] has reported values lower than their male counterparts and comparable to those verified in non-athletes.[38]

Some studies[40,41] presented values of strength on specific judo machines, which can provide a more realistic perspective and a more specific and performance-related evaluation.

Tests conducted on isokinetic equipment, although not specific to judo movements, seem to be important to establish relations of torque or strength among muscles with antagonist actions as well as different speeds of movement. Table V presents the results of strength tests conducted on isokinetic equipment in judo athletes.

When judo athletes from different age classes are compared,[43] both knee and shoulder flexion and extension strength (measured in two velocities, 60°/s and 240°/s) were higher in seniors compared with juniors. Only one study presented a statistical comparison between male and female judo athletes.[19] The results showed a similar trend to that observed in non-athletes, i.e. the male athletes presented a higher absolute strength. This difference decreased when the value was relative to the fat-free mass.[19] In a study conducted with the 1996 Japanese Olympic Team,[44] women's elbow extension was lower than that measured in men using both 60°/s (92% of men values) and 180°/s (88% of men values). However, when values were expressed relative to the cross-sectional area, a different result was obtained, with higher dynamic strength in females.

Both men and women were stronger in their knee extensor than in their knee flexor muscles. Women were also stronger in their elbow extensor than in their elbow flexor muscles (flexor values represented 77% from that measured in the extensor muscles). However, men attained almost the same value for both elbow muscle groups (extensor and flexor).[19] Other studies with male judo

Table IV. One-repetition maximum (1RM) data in different exercises performed by judo athletes

Study	Sample characteristics; sex	Exercise	1RM (kg) [mean ± SD]
Thomas et al.[16]	Canadian team (1989); M (n = 22)	Bench press	100 ± 21
Fagerlund and Häkkinen[34]	Finnish athletes; M:		
	International (n = 7)	Bench press	96 ± 20
		Squat	185 ± 25
	National (n = 7)	Bench press	96 ± 12
		Squat	166 ± 32
	Recreational (n = 7)	Bench press	87 ± 20
		Squat	140 ± 36
Franchini et al.[6]	Brazilian team (2002); M:		
	Main team (n = 7)	Bench press	110 ± 25
		Row	116 ± 21
		Squat	104 ± 27
	Reserves (n = 13)	Bench press	110 ± 23
		Row	115 ± 24
		Squat	104 ± 18
Sbriccoli et al.[32]	Italian Olympic team (2004):		
	M (n = 6)	Bench press	160 ± 30
		Lat machine	142 ± 15
		Leg press	397 ± 8
		Deadlift	127 ± 11
		Leg curl	77 ± 4
	F (n = 5)	Bench press	74 ± 13
		Lat machine	84 ± 11
		Leg press	305 ± 19
		Deadlift	94 ± 6
		Leg curl	40 ± 4

F = female; **M** = male.

athletes reported similar values of extensor-flexor ratio for shoulder (71–77%)[43] and knee (74%).[42]

Trunk flexion corresponded to 71–81% of the extension value.[45] Despite the fact that right-handed judo athletes (i.e. the right hand grabs the lapel on judogi) perform a left trunk rotation in many techniques, no difference was observed in the dynamic strength between sides, suggesting that rotation dominance seems to be determined more by coordination than by strength.[45]

A comparison among weight categories using isokinetic equipment was not found in the literature. The available information on this aspect indicates that in absolute values heavier athletes are stronger than lighter athletes. The half-heavyweight category (<95 kg when the study was conducted) were considered the weakest among the seven weight classes;[19] however, there is no clear explanation for this finding.

When judo athletes of different competitive levels are compared, the only evidence found was that higher ranked female US judo athletes tend to present a higher elbow flexor and extensor muscles isokinetic strength compared with lower ranked athletes.[19]

Tumilty et al.[43] have compared isokinetic shoulder flexion and extension between judo athletes and other athletic groups. The authors have found that the Australian junior judo athletes were weaker, and the senior group were stronger. The results presented by Kort and Hendriks[45] for trunk flexion, extension and rotation demonstrated higher values for judo athletes compared with cyclists.

Table V. Torque (Nm or Nm/kg) or strength (N or N/cm^2) during isokinetic maximal tests performed by judo players

Study	Sample characteristics; sex	Exercise	Result (mean ± SD)
Taylor and Brassard[42]	1979 Canadian team; M (n = 19)	Knee extension:	
		right	148.0 ± 41.0 Nm
		left	146.0 ± 28.0 Nm
		Knee flexion:	
		right	105.0 ± 17.0 Nm
		left	108.0 ± 23.0 Nm
Tumilty et al.[43]	Australian junior; M (n = 9)	Shoulder:	
		60°/s extension	1.1 ± 0.2 Nm/kg
		60°/s flexion	0.8 ± 0.1 Nm/kg
		240°/s extension	0.7 ± 0.2 Nm/kg
		240°/s flexion	0.6 ± 0.1 Nm/kg
		Knee:	
		60°/s extension	2.6 ± 0.4 Nm/kg
		60°/s flexion	1.6 ± 0.3 Nm/kg
		240°/s extension	1.4 ± 0.2 Nm/kg
		240°/s flexion	1.1 ± 0.2 Nm/kg
	Senior; M (n = 8)	Shoulder:	
		60°/s extension	1.4 ± 0.2 Nm/kg
		60°/s flexion	1.1 ± 0.1 Nm/kg
		240°/s extension	1.0 ± 0.1 Nm/kg
		240°/s flexion	0.8 ± 0.1 Nm/kg
		Knee:	
		60°/s extension	3.1 ± 0.4 Nm/kg
		60°/s flexion	2.0 ± 0.4 Nm/kg
		240°/s extension	1.7 ± 0.2 Nm/kg
		240°/s flexion	1.4 ± 0.2 Nm/kg
Ichinose et al.[44]	Japanese Olympic team (1996):	Elbow extension:	
	M (n = 5)	60°/s	215.9 ± 11.8 N
		180°/s	188.8 ± 16.9 N
	F (n = 6)	60°/s	198.2 ± 14.9 N
		180°/s	165.7 ± 4.6 N
	M (n = 5)	60°/s	14.5 ± 1.0 N/cm^2
		180°/s	12.7 ± 1.1 N/cm^2
	F (n = 6)	60°/s	16.7 ± 0.9 N/cm^2
		180°/s	14.3 ± 1.2 N/cm^2
Kort and Hendriks[45]	Dutch national and international levels; M (n = 28)	Trunk flexion:	
		30°/s	3.3 ± 0.3 Nm/kg
		60°/s	3.3 ± 0.2 Nm/kg
		90°/s	3.3 ± 0.2 Nm/kg
		120°/s	3.3 ± 0.3 Nm/kg
		Trunk Extension:	
		30°/s	4.7 ± 0.8 Nm/kg
		60°/s	4.6 ± 0.6 Nm/kg
		90°/s	4.6 ± 0.5 Nm/kg
		120°/s	4.1 ± 0.5 Nm/kg

Continued next page

Table V. Contd

Study	Sample characteristics; sex	Exercise	Result (mean ± SD)
		Trunk rotation:	
		30°/s	2.8 ± 0.4 N • m/kg
		60°/s	2.8 ± 0.5 N • m/kg
		90°/s	2.8 ± 0.5 N • m/kg
		120°/s	2.8 ± 0.5 N • m/kg

F = female; **M** = male.

4. Muscle Power

Muscle power has been characterized in judo athletes through the use of free weight exercises[34] or vertical jump tests.[16,36,43,46]

A study conducted with Finnish judo athletes[34] demonstrated that international level athletes presented higher values in the strength-velocity curve for the squat jump compared with a group of recreational practitioners: the time to achieve half of the maximal strength was shorter for the international level group. Given that the muscle groups mainly activated during a judo throwing technique are those of the lower body, and considering that these techniques have to be performed at high speed and against a great resistance from the opponent, this difference can be a consequence of this adaptation. However, when the bench press exercise was used to determine the strength-velocity curve, no difference was found in international, national or recreational level groups. This may be due to the multiple actions (power, endurance and strength) performed by the upper body during a typical judo

Table VI. Vertical jump height in judo athletes of different age, weight categories and competitive levels

Study	Athlete characteristics; sex	Height (cm) [mean ± SD][a]
Ishiko and Tomiki[46]	Judo practitioners from Kodokan; M:	
	20–29 y (n = 5)	51.6
	30–39 y (n = 6)	45.7
	40–49 y (n = 7)	46.3
	50–59 y (n = 10)	37.1
	60–69 y (n = 5)	29.8
	70–79 y (n = 2)	20.0
Claessens et al.[36]	Belgian athletes; M:	
	Total (n = 24)	52.5 ± 6.7
	<71 kg (n = 13)	53.3 ± 6.4
	71–86 kg (n = 9)	50.2 ± 7.4
Farmosi[7]	Hungarian team; M:	
	Total (n = 18)	53.3 ± 5.6
	<71 kg (n = 7)	50.6 ± 5.5
	>71 kg (n = 11)	55.2 ± 5.0
Tumilty et al.[43]	Australian athletes; M:	
	Junior (n = 9)	44.0 ± 7.0
	Senior (n = 8)	52.0 ± 8.0
Sertic et al.[27]	Croatian athletes:	
	M (n = 6)	58.3 ± 5.4
	F (n = 8)	40.8 ± 4.3

a Data for Ishiko and Tomiki[46] presented as mean values.

F = female; **M** = male.

match. Table VI presents the vertical jump test results in judo athletes.

One of the first studies of power characteristics of judo athletes used the vertical jump test[46] to compare different age groups. It demonstrated a significant decrease after the athletes reached 50 years of age. Another study[43] compared junior and senior judo players and found a higher performance in the vertical jump test in seniors compared with juniors. Only one study presenting results from male and female athletes was found,[27] but no comparison between groups was made.

A comparison among weight categories was conducted in 729 college judo athletes.[47] When all the weight categories were considered, a small variation was observed from the under 60 kg to the under 95 kg weight categories, being lower than values found in the over 95 kg category. As no correction by weight was presented, only the absolute power of these athletes can be fully compared.

The relevancy of this measurement (vertical jump height) can be inferred from one study that presented a positive correlation between the percentage of winnings during the European World Cup competitions and the vertical jump performance in male judo athletes ($r = 0.69$). This can be an indicator that lower body power is important for judo performance, probably because a powerful action is needed during many throwing techniques.[48]

5. Muscular Endurance

Muscular endurance is the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time.[33] In judo, most of the studies on muscular endurance have evaluated this capacity using sit-ups and push-ups.[16,42,49] The results from these studies are presented in table VII.

Based on the results depicted above, it is possible to conclude that judo athletes are, in general, above the 90th percentile for push-ups, and between the 80th and 90th percentile for sit-ups in classificatory tables.[38] This can be interpreted as a high need for muscular endurance in these muscle groups for a successful judo performance.

6. Anaerobic Profile

High-intensity, intermittent sports rely mostly on anaerobic sources, as the decisive actions depend on powerful movements.[50] During a judo match, the anaerobic contribution seems to be very important, although other sources also contribute significantly to the total work performed.[1]

The anaerobic evaluation is quite complex because no gold standard test is available.[51] However, as is seen in other sports, the Wingate test has been used to evaluate the anaerobic profile of judo athletes.[16,32] The typical Wingate test evaluates variables (peak power, mean power and fatigue index)[52] that have been reported for upper and lower body actions in judo athletes.[21,23,29,37]

In athletes from sports in which upper body actions are important, such as wrestling and judo, the upper body Wingate test has been used more often than the lower body test.[52-54] Table VIII presents the main results of studies evaluating judo players' anaerobic performance.

Table VII. Muscular endurance in different exercises performed by judo athletes

Study	Athlete characteristics; sex	Exercise	Result (repetitions) [mean ± SD]
Taylor and Brassard[42]	Canadian team (1979); M (n = 19)	Push-ups	72 ± 16
		Sit-ups	48 ± 10
Thomas et al.[16]	Canadian team (1989); M (n = 22)	Bench press at 70% 1RM	16 ± 3
Sertic et al.[27]	Croatian athletes:		
	M (n = 6)	Sit-ups	58 ± 6
	F (n = 8)		55 ± 4
Krstulovic et al.[49]	Croatian junior athletes; M (n = 40)	Push-ups	56 ± 8
		Sit-ups	42 ± 12

1RM = one-repetition maximum; **F** = female; **M** = male.

Table VIII. Upper body Wingate test performance in judo players

Study	Athlete characteristics; sex	AMP (W) [mean ± SD]	RMP (W/kg) [mean ± SD]	APP (W) [mean ± SD]	RPP (W/kg) [mean ± SD]
Little[21]	Canadians (various competitive levels); M:				
	Cadet (n = 17)	282 ± 70	4.9 ± 1.0	407 ± 172	7.1 ± 1.6
	Junior (n = 9)	395 ± 62	5.7 ± 0.6	573 ± 117	8.4 ± 1.1
	Senior (n = 17)	447 ± 87	5.6 ± 0.5	675 ± 133	8.5 ± 0.7
	Canadians (various competitive levels); F:				
	Junior (n = 9)	219 ± 48	3.8 ± 0.6	322 ± 88	5.5 ± 1.1
	Senior (n = 8)	253 ± 41	4.0 ± 0.6	366 ± 59	5.9 ± 0.9
Franchini et al.[12]	Brazilian team (1999 Panamerican Games); F (n = 5)				
	70 days before	NR	4.3 ± 0.2	NR	5.8 ± 0.3
	30 days before	NR	4.5 ± 0.6	NR	5.8 ± 0.8
Franchini et al.[37]	Brazilians; M:				
	Elite (n = 34)	468 ± 63	5.7 ± 0.8	623 ± 80	7.6 ± 1.0
	Non-elite (n = 56)	394 ± 53	5.4 ± 0.8	493 ± 92	7.0 ± 1.3
Franchini et al.[24]	Brazilian university team; M (n = 13)	555 ± 63	6.2 ± 0.7	724 ± 67	8.1 ± 0.8
Mickiewitz et al.[55]	Polish juniors (n = 85)	671 ± 89	8.8 ± 0.8	NR	NR
Sharp and Koutedakis[56]	British team; M (n = 6)	736 ± 221	8.5 ± 0.5	916 ± 301	10.6 ± 0.8
Thomas et al.[16]	Canadian team; M (n = 22)	653 ± 87	8.7 ± 1.2	852 ± 131	11.3 ± 0.8
Obuchowicz-Fidelus et al.[29]	Polish team; F (n = 20)	253 ± 36	4.3 ± 0.5	331 ± 50	5.7 ± 0.6

AMP = absolute mean power; **APP** = absolute peak power; **F** = female; **M** = male; **NR** = not reported; **RMP** = relative mean power; **RPP** = relative peak power.

The values presented by the judo athletes from a range of different national teams were quite high and their performance during the upper body Wingate test was above the 90th percentile for lower body values measured in non-athletes.[57] This result has been interpreted as a consequence of the high upper body demand during judo-specific activities performed in the training sessions.[16]

A comparison among age groups using the upper body Wingate test[21] has shown that cadet judo athletes have lower absolute peak and mean power when compared with both junior and senior athletes, and lower relative peak power compared with senior judo athletes. These differences are probably related to maturational aspects and have also been reported in wrestlers[58] and in non-athletes.[59-62]

When athletes from different competitive levels are compared for performance in the upper body Wingate test, higher values of peak and mean power were measured in elite (national or international medalists) than in non-elite athletes (non-medalists).[37] Further evidence supporting the relevance of upper body anaerobic performance for judo was found in a correlational study,[48] which reported moderate and significant correlations between the percentage of wins during European World Cup competitions and upper body Wingate test peak power ($r = 0.66$) and mean power ($r = 0.68$) in female judo players. In high-level male judo athletes there was a moderate, yet significant, correlation ($r = 0.76$) between relative total work performed in two consecutive upper body Wingate tests (separated by 3-minute intervals) and the number of attacks performed during a match simulation.[48]

Although the comparison of upper body anaerobic performance of judo athletes in different weight categories has not been carried out with a large number of athletes, it is possible to conclude that the athletes from heavyweight categories have higher absolute values of both peak and mean power than the lighter athletes. In contrast, when body mass values are considered (i.e. relative mean and peak power are the variables), lighter athletes present higher power than the heavyweight athletes. This fact is probably due to the higher percentage body fat of heavier athletes compared with lighter athletes combined with the fact that a higher percentage fat has been associated with lower relative total work during two Wingate tests ($r = -0.87$) in high-level judo athletes.[24]

When sexes are compared, females present values of approximately 70% of those observed in males, which is similar to what has been observed in the general population.[52] However, it is important to note that high-level female judo athletes showed values similar to that presented by males from lower competitive levels or from younger age groups, indicating that the strategy of mixed training sessions by sex is possible when anaerobic fitness is the variable considered. In fact, it is common in actual training environments for high-level female judo athletes to perform 'randori' (free sparring) with male athletes of lower age or less skill.

Performance of judo athletes in lower body Wingate tests has also been investigated. Table IX presents the main published results.

When different competitive level groups are compared for performance, the pattern largely differs from that observed in the upper body Wingate test (i.e. the lower body Wingate test is not an adequate performance predictor compared with the upper body test). This probably occurs due to the low demand imposed on the lower body in judo. However, it is possible to verify differences between weight categories and to confirm the inferences raised in the upper body test concerning the lower relative results presented by heavyweight categories compared with lighter categories in both males and females.[65]

Additionally, it is possible to verify that women's values are about 80% of the male values, which are slightly higher than the percentage observed in the upper body test and somewhat similar to that observed in non-athletic groups.[57]

In healthy male non-athletes, the ability to perform anaerobic work with their arms was about 51% of the capacity to perform anaerobic work with the lower limbs, while data of Canadian Judo Team athletes[16] show a ratio of 81%. When analysing a group of judo players at the regional level[66] the ratio was closer to the healthy subjects than the elite wrestling or judo athletes. The highest upper/lower body ratio may be due to differences in distribution of muscle fibre type in the upper and lower body (a higher percentage of fast twitch fibres in the upper body) and/or due to a greater emphasis on training directed to the upper body rather than the lower body.[66,67]

Other studies have assessed judo athletes in a variety of anaerobic tests. Some have used cycle ergometer tests,[43,68] jumps[69,70] or tests involving a running time trial.[42,49]

Based on these studies it can be concluded that judo athletes of both sexes show great power and anaerobic capacity when exercise involves the upper body, and this aspect is a potential discriminating factor in performance. Moreover, power and anaerobic capacity values from the lower body are not prominently higher than that observed in other athletic groups[68] or even in active individuals.[38,52,57] Additionally, these variables do not appear to be predictors of performance and success in judo.

7. Aerobic Profile

Although decisive actions in judo are mainly dependent on anaerobic metabolism, aerobic fitness seems to be important in high-intensity intermittent exercise,[71] which is the case with judo, as it permits better recovery during the short rest periods between efforts.

The aerobic fitness of judo players has been assessed essentially via maximal oxygen uptake ($\dot{V}O_{2max}$) or peak oxygen uptake ($\dot{V}O_{2peak}$) for the aerobic power component and via the so-called anaerobic threshold for the aerobic capacity component. Both aerobic power and capacity have been considered relevant to judo performance because it has been hypothesized that a higher value for these variables should allow judo athletes to maintain a higher intensity during the match, delay the accumulation of metabolites associated with fatigue processes (e.g. H^+ and Pi) and improve the recovery process between two consecutive matches.[63,72]

In fact, there is some evidence that judo athletes who normally obtain their scores in the final

Table IX. Lower body Wingate test performance in judo athletes from different levels and nationalities

Study	Sample characteristics; sex	AMP (W) [mean ± SD]	RMP (W/kg) [mean ± SD]	APP (W) [mean ± SD]	RPP (W/kg) [mean ± SD]
Gariod et al.[63]	French athletes (inter-regional and national); M:				
	Endurance (n = 10)	860 ± 74	12.0 ± 1.0	1051 ± 65	14.6 ± 0.9
	Explosive (n = 6)	861 ± 67	12.0 ± 0.9	1166 ± 79	16.2 ± 1.1
Wojczuk et al.[64]	Polish junior class (different levels); M (n = 19)	666 ± 91	8.7 ± 1.0	870 ± 100	11.3 ± 1.0
Mickiewitz et al.[55]	Polish (different levels); M:				
	Junior (n = 109)	871 ± 115	11.4 ± 1.2	NR	NR
	Senior (n = 257)	917 ± 149	11.5 ± 1.2	NR	NR
	F senior (n = 16)	571 ± 66	9.6 ± 0.9	NR	NR
Sterkowicz et al.[23]	Polish (high-level); M (n = 15)	713 ± 120	8.6 ± 0.7	942 ± 194	11.4 ± 0.9
Sbriccoli et al.[32]	Italian Olympic team (2004):				
	M (n = 6)	558 ± 86	5.4 ± 1.1	1236 ± 202	12.1 ± 2.4
	F (n = 5)	286 ± 11	4.3 ± 0.5	635 ± 21	9.5 ± 1.1
Thomas et al.[16]	Canadian M team (n = 22)	804 ± 138	10.7 ± 0.7	1032 ± 161	13.7 ± 1.1
Borkowski et al.[65]	Polish team 1994–7[a]; M:				
	<60 to >95 kg	NR	8.8 ± 0.8	NR	12.1 ± 1.2
	<60–95 kg	NR	9.0 ± 0.8	NR	12.4 ± 0.8
	+95 kg	NR	7.1 ± 0.9	NR	9.6 ± 1.0
	Polish team 1998–9[b]; M:				
	<60 to <100 kg	NR	9.1 ± 0.6	NR	12.5 ± 0.9
	Polish team 1994–9[c]; M:				
	Principal	NR	9.0 ± 0.5	NR	12.3 ± 0.9
	Reserves	NR	9.0 ± 0.6	NR	12.1 ± 0.9
Borkowski et al.[65]	Polish team 1994–7[d]; F:				
	<48 to >72 kg	NR	7.8 ± 0.7	NR	10.5 ± 1.0
	<48 to <72 kg	NR	8.0 ± 0.6	NR	10.7 ± 0.8
	>72 kg	NR	6.7 ± 0.8	NR	8.9 ± 1.1
	Polish team 1998–9[e]; F:				
	<48 to <78 kg	NR	7.8 ± 0.5	NR	10.6 ± 0.6
	Polish team 1994–9[f]; F:				
	Principal	NR	7.7 ± 1.0	NR	10.3 ± 1.3
	Reserves	NR	7.7 ± 0.8	NR	10.2 ± 1.0

a Fifty-eight subjects, no specifications about the number in each category.

b Seventeen subjects, no specifications about the number in each category.

c Seventy-five subjects, no specifications about the number of principal and reserve athletes.

d Forty-nine athletes, no specifications about the number in each category.

e Eighteen athletes, no specifications about the number in each category.

f Sixty-seven athletes, no specifications about the number of principal and reserve athletes.

AMP = absolute mean power; **APP** = absolute peak power; **F** = female; **M** = male; **NR** = not reported; **RMP** = relative mean power; **RPP** = relative peak power.

moments of a match present higher $\dot{V}O_{2max}$ values and were able to resynthesize gastrocnemius creatine phosphate faster compared with others who score earlier in the match and had better performance in lower body Wingate tests.[63] Furthermore, a faster recovery after high-intensity intermittent exercise has also been associated with aerobic fitness.[73,74] Athletes with higher aerobic power are probably able to perform supramaximal activities at a relatively lower intensity compared with those with lower aerobic power. This would be even more important considering the matches that last several minutes and probably explains the importance of aerobic power for judo performance.[75] Table X presents the aerobic power of male and female judo players.

Although the studies reported on table X have used different protocols and exercise modes, it seems that most of the male judo players have $\dot{V}O_{2max}$ values between 50 and 60 mL/kg/min, while most of the females have values between 40 and 50 mL/kg/min. This difference between sexes is quite similar to that reported in non-athletic groups.[89]

Regarding the influence of aerobic power on judo performance, it is important to consider that the studies comparing elite versus non-elite male judo athletes,[37] principals versus reserves in national teams[6,65] or athletes involved in direct competition,[81] did not observe any significant difference between these groups. Thus, although aerobic power can be relevant to judo performance, its development is not enough to discriminate the competitive level of judo athletes. When considering female judo athletes, the only study found comparing members and reserves of the Brazilian Olympic judo team, also did not find any difference in aerobic power between the groups.[48]

However, it is important to point out that most of these studies were cross sectional and analysed lower body modes of exercise (e.g. treadmill or cycle ergometer) to determine $\dot{V}O_{2max}$. In fact, one study reported a decrease in lower body aerobic power in judo athletes prior to their main competition, but conversely presented an increase on upper body aerobic power at the same period.[48] Thus, if the high demand on the upper body during a typical judo match was taken into the analysis it is possible to suggest that the upper body aerobic power should be of greater focus and study than lower body aerobic power.

When weight categories are compared, it is possible to note a decrease in relative aerobic power (mL/kg/min) parallel to an increase in the body mass.[16,32] It is common to find values <50 mL/kg/min in heavyweight male and <45 mL/kg/min in heavyweight female judo athletes. However, only one study statistically compared $\dot{V}O_{2max}$ among weight categories. Male heavyweights presented lower values compared with athletes from all other weight classes, yet, $\dot{V}O_{2max}$ among female athletes was similar regardless of weight class.[65]

Aerobic capacity in judo players has been evaluated through the so-called anaerobic threshold velocity (ATV). Table XI presents the ATV of judo athletes.

As shown in table XI, judo athletes of different levels have similar ATV, which is not as high as in aerobically trained athletes. Additionally, ATV did not change in the final phase of competitive preparation in highly trained female judo players.[12] Thus, based on these observations, in the evaluation process of judo athletes, other aspects should be focused on. On the other hand, Franchini et al.[88] reported a negative, significant correlation between the ATV and blood lactate after a judo match simulation ($r = -0.69$ to -0.87, depending on the moment blood lactate was measured) and a positive, significant correlation between ATV and mean power in an upper body Wingate test performed 17 minutes after the judo match simulation either when the recovery after this simulation was passive ($r = 0.61$) or active ($r = 0.84$). This suggests that a higher aerobic capacity could be important in the recovery process between consecutive matches. In view of this, future studies should focus on the effect of aerobic capacity training, especially for the upper body on the recovery process between typical judo matches.

Regarding upper body aerobic capacity, one study has used onset blood lactate accumulation (OBLA; 4 mmol/L of blood lactate concentration) to evaluate this variable in high-level Polish judo athletes.[65] The author found that male athletes presented their OBLA at a higher intensity (2.08 ± 0.29 to 2.25 ± 0.24 W/kg, depending on the weight category) than female judo athletes (1.10 ± 0.24 to 1.79 ± 0.32 W/kg, depending on the weight category). No difference was found in upper body cycle ergometry OBLA between principals and reserves in either male (principals = 2.17 ± 0.26 W/kg; reserves = 2.11 ± 0.26 W/kg) or female groups (principals = 1.64 ± 0.28 W/kg;

Table X. Aerobic power of judo athletes

Sample characteristics	Ergometer	$\dot{V}O_{2max}$ (mL/kg/min) [mean ± SD]	Reference
Male			
US judo players (elite; n = 8)	Treadmill	53.2 ± 1.4	Callister et al.[18]
US judo players (elite; n = 18)	Treadmill	55.6 ± 1.8	Callister et al.[19]
Japanese team (n = 13)	Treadmill	45.9 ± 4.8	Ebine et al.[76]
Japanese (university level; n = 17)	Bicycle	40.0 ± 5.5	Ikai et al.[77]
Japanese (university level; n = 6)	Treadmill		Sugiyama[78]
pre-training		50.5 ± 3.0	
after 1-y judo training		52.5 ± 3.4	
Koreans (elite; n = 29)	Treadmill	61.1 ± 10.6	Oh et al.[79]
Canadian	Treadmill		Little[21]
cadets (n = 17)		57.6 ± 3.4	
juniors (n = 9)		59.3 ± 4.0	
seniors (different levels; n = 17)		53.8 ± 5.6	
Junior French (different levels; n = 9)	NR	59.8 ± 8.5	Majean and Gaillat[80]
Polish	NR		Mickiewitz et al.[55]
juniors (n = 54)		60.2 ± 6.8	
seniors (different levels; n = 157)		60.2 ± 8.7	
Canadian team (n = 19)	NR	57.5 ± 9.5	Taylor and Brassard[42]
Canadian team (n = 22)	Treadmill	59.2 ± 5.2	Thomas et al.[16]
Australians (elite; n = 17)	Bicycle	53.2 ± 5.1	Tumilty et al.[43]
Spanish	Bicycle		Suay et al.[81]
winners (n = 14)		52.8 ± 0.8	
defeated (n = 14)		50.4 ± 1.11	
Spanish (n = 17)	Bicycle	45.6 ± 1.5[a]	Salvador et al.[82]
French	Bicycle		Gariod et al.[63]
endurance profile; regional level (n = 10)		63.2 ± 7.9	
power profile; regional level (n = 6)		54.6 ± 3.0	
Polish team 1994–7[b]	Bicycle		Borkowski et al.[65]
<60 to >95 kg		56.6 ± 5.6	
<60 to 95 kg		57.6 ± 4.6	
>95 kg		45.2 ± 3.9	
Polish team 1998–9[c]			
<60 to <100 kg		55.6 ± 3.2	
Polish team 1994–9[d]			
principal		54.5 ± 4.9	
reserves		54.4 ± 5.6	
Polish (national level; n = 15)	Treadmill	50.1 ± 6.5	Sterkowicz et al.[23]
French (regional level; n = 16)	Bicycle	55.0 ± 0.5[a]	Degoutte et al.[1]
French (regional level; n = 16)	Bicycle	55.0 ± 2.9	Degoutte et al.[83]
French (national level; n = 10)	Bicycle	44.5 ± 6.0	Cottin et al.[84]
Spanish (7 men and 1 woman; national and international level)	Treadmill	48.4 ± 7.4	Bonitch et al.[85]
French (regional level; n = 8)	Bicycle	53.8 ± 5.2	Vidalin et al.[86]
	Bicycle (indirect)	50.9 ± 7.0	

Continued next page

Table X. Contd

Sample characteristics	Ergometer	$\dot{V}O_{2max}$ (mL/kg/min) [mean ± SD]	Reference
French (different levels)	NR		Maejan and Gaillat[80]
junior (n = 8)		53.0 ± 5.4	
juvenile (n = 13)		46.3 ± 7.8	
French (practitioners; n = 8)	Bicycle	52.0 ± 5.3	Ahmaidi et al.[87]
French regional and inter-regional levels (n = 20)	Bicycle (indirect)	47.6 ± 7.1	Frings-Dresen et al.[68]
Brazilians	Treadmill		Franchini et al.[88]
national and international levels (n = 5)		63.0 ± 10.3	
state level (n = 7)		62.9 ± 9.3	
city level (n = 5)		64.9 ± 5.5	
Brazilians	Treadmill		Franchini et al.[37]
elite (n = 15)		58.1 ± 10.8	
non-elite (n = 31)		63.3 ± 10.6	
Brazilian team	Cooper test		Franchini et al.[6]
principal (n = 7)		48.3 ± 8.1	
reserves (n = 15)		49.6 ± 5.5	
Italian Olympic team 2004 (n = 6)	Treadmill	47.3 ±10.9	Sbriccoli et al.[32]
Female			
Polish team 1994–7[e]	Bicycle		Borkowski et al.[65]
<48 to >72 kg		49.9 ± 6.6	
<48 to <72 kg		50.7 ± 5.5	
>72 kg		39.5 ± 12.0	
Polish team 1998–9[f]			
<48 to <78 kg		49.9 ± 4.8	
Polish team 1994–9[g]			
principals		48.6 ± 8.6	
reserves		47.2 ± 6.0	
French (regional level; n = 4)	Bicycle	44.0 ± 14.7	Vidalin et al.[86]
	Bicycle (indirect)	43.0 ± 11.8	
Polish seniors (different levels; n = 15)	NR	49.9 ± 5.1	Mickiewitz et al.[55]
Canadians (different levels)	Treadmill		Little[21]
juniors (n = 9)		45.1 ± 3.7	
seniors (n = 8)		43.7 ± 3.5	
US (elite; n = 7)	Treadmill	51.9 ± 0.8	Callister et al.[18]
US (elite; n = 9)	Treadmill	52.0 ± 1.4	Callister et al.[19]
Cuban team (n = 8)	NR	47.4 ± 10.3	Pujadas et al.[73]
Japanese team (n = 16)	Treadmill	42.1 ± 4.4	Ebine et al.[76]
Italian Olympic team 2004 (n = 5)	Treadmill	52.9 ±4.4	Sbriccoli et al.[32]

a Standard error.

b Fifty-eight athletes, no details concerning number of judo players per weight category.

c Seventeen athletes, no details concerning number of judo players per weight category.

d Seventy-five athletes, no details concerning the number of principal and reserve members.

e Forty-nine athletes, no details concerning the number of judo athletes per weight category.

f Eighteen athletes, no details concerning the number of judo athletes per weight category.

g Sixty-seven athletes, no details concerning the number of principal and reserve judo athletes per weight category.

NR = not reported; $\dot{V}O2_{max}$ = maximal oxygen uptake.

Table XI. Anaerobic threshold velocity (ATV) in judo players

Study	Sample characteristics	ATV (km/h) [mean ± SD]
Sterkowicz et al.[23]	Polish (national level; n = 15)	12.0 ± 0.9
Franchini et al.[12]	Female Brazilian team (n = 5):	
	70 days before the Panamerican Games (1999)	9.3 ± 1.60
	30 days before the Panamerican Games (1999)	9.7 ± 1.3
Franchini et al.[88]	Brazilians:	
	National and international levels (n = 5)	10.7 ± 0.8
	State level (n = 7)	9.3 ± 1.7
	City level (n = 5)	9.2 ± 1.5
Franchini et al.[37]	Brazilians:	
	National and international level (n = 16)	10.8 ± 1.5
	State level (n = 40)	10.8 ± 1.7

reserves = 1.69 ± 0.29 W/kg), suggesting that this variable is not discriminant for judo performance, at least in this level. Similar findings were observed with running as the exercise model. In the same study, both male and female heavyweight judo athletes presented their OBLA at a lower intensity compared with judo players from other weight categories,[65] confirming the findings from Thomas et al.[16] concerning the lower aerobic fitness (in that case measured by $\dot{V}O_{2max}$) of heavyweight judo players.

Ventilatory threshold (VT) has also been used to evaluate the aerobic capacity of judo players. The main results are presented in table XII.

Table XII. Ventilatory threshold (VT) intensity in judo athletes during treadmill exercise

Study	Sample characteristics	VT (%$\dot{V}O_{2max}$) [mean ± SD]
Ebine et al.[76]	Japanese team (VT1):	
	M (n = 13)	57.5 ± 3.3
	F (n = 16)	57.0 ± 4.3
Oh et al.[79]	Elite Korean (VT1; n = 29)	66.3 ± 18.7
Bonitch et al.[85]	8 Spanish (7 men and 1 woman; national and international level):	
	VT1	63.7 ± 6.6
	VT2	79.3 ± 7.2
Little[21]	Canadians (different levels; VT2)	
	M:	
	Cadets (n = 17)	78.6 ± 4.8
	Juniors (n = 9)	77.0 ± 5.5
	Seniors (n = 17)	78.7 ± 6.6
	F:	
	Juniors (n = 9)	80.7 ± 7.8
	Seniors (n = 8)	85.1 ± 5.7
Callister et al.[19]	Americans (elite):	
	M (n = 18)	84.4 ± 1.0
	F (n = 9)	87.9 ± 1.2
Sbriccoli et al.[32]	Italian Olympic team (2004):	
	M (n = 6)	80.7 ± 20.0
	F (n = 5)	87.1 ± 11.0

F = female; **M** = male; **%$\dot{V}O2_{max}$** = percentage of maximal oxygen uptake.

The percentage of $\dot{V}O_{2max}$ (%$\dot{V}O_{2max}$) in which the VT identified was similar to those found in physically active individuals, but lower than in highly aerobically trained athletes.[89] This fact strengthens the belief and provides more evidence that aerobic metabolism is not highly developed in high-level judo athletes. Additionally, the only study comparing different age groups did not find any difference for VT.[21] When males and females are compared, the results seem to indicate higher values (%$\dot{V}O_{2max}$) in males, although no detail about this aspect was given in these studies.[19,21,32,76]

8. Conclusions and Future Directions

Successful judo athletes have very low levels of body fat – both male and female – with the exception of heavyweight athletes. Mesomorphy is the most predominant somatotype component in male athletes, while females have similar components of mesomorphy and endomorphy. Moreover, high-level competitive judo athletes present with highly developed dynamic strength, muscular endurance, anaerobic power and capacity as well as aerobic power and capacity. These variables seem to be more prominent in the upper body than in the lower body, suggesting that physical preparation should focus on improvement in the upper body. Muscle power, in contrast, appears to be better developed in the lower body. Isometric grip strength is only slightly above the average of the non-athlete population. However, aerobic power and capacity are not highly developed in these athletes. Although the above-mentioned characteristics have been consistently demonstrated in high-level judo athletes and, therefore, this may be considered as an ideal profile when preparing an athlete for engaging in high-level judo, much less is known regarding the differences among weight classes and sexes. Indeed, the development of evaluation tools more specific to judo and more longitudinal studies, would greatly contribute to elucidating the determination of weight class- and sex-specific profiles. Moreover, studies using allometric scaling would be of great importance for a better characterization of the weight classes and for understanding the differences among them.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

References

1. Degoutte F, Jouanel P, Filaire E. Energy demands during a judo match and recovery. Br J Sports Med 2003; 37 (3): 245-9
2. Castarlenas JL, Planas A. Estudio de la estrutura temporal del combate de judo. Apunts: Educ Fís Deportes 1997; 1 (47): 32-9
3. Van Malderen K, Jacobs C, Ramon K, et al. Time and technique analysis of a judo fight: a comparison between males and females. In: Hoppeller H, et al., editors. Annals of the 11th Annual Congress of the European College of Sport Science. Cologne: Sportverlag Strauss, 2006: 101
4. Franchini E, Bertuzzi RCM, Takito MY, et al. Effects of recovery type after a judo match on blood lactate and performance in specific and non-specific judo tasks. Eur J Appl Physiol 2009; 107 (4): 377-83
5. Burke LM, Cox GR. Nutrition in combat sports. In: Kordi R, Maffulli N, Wroble RR, et al., editors. Combat sports medicine. London: Springer, 2009: 1-20
6. Franchini E, Nunes AV, Moraes JM, et al. Physical fitness and anthropometrical profile of the Brazilian male judo team. J Physiol Anthropol 2007; 26: 59-67
7. Farmosi I. Body-composition, somatotype and some motor performance of judoists. J Sports Med 1980; 20 (l): 431-4
8. Kawamura T, Asami T, Takeuchi Y, et al. An analysis of somatotypes and postures of judoists: in the case of Japanese and French judoists. Bull Assoc Sci Study Judo 1984; 6: 107-16
9. Silva S, Moraes J, Pinto M, et al. Perfil morfológico de atletas brasileiros participantes dos Jogos Pan-Americanos de Winnepeg. XXII Simpósio Internacional de Ciências do Esporte – Atividade Física: da comunidade ao alto rendimento. São Paulo, 1999: 130
10. Claessens A, Beunen G, Wellens R, et al. Somatotype and body structure of world top judoists. Sports Med Phys Fitness 1987; 27 (1): 105-13
11. Franchini E, Takito MY, Matheus L, et al. Composição corporal, somatotipo e força isométrica em atletas da seleção brasileira universitária de judô. Âmbito Med Desp 1997; 3 (3): 21-9
12. Franchini E, Matsushigue KA, Kiss MAPDM, et al. Estudo de caso das mudanças fisiológicas e de desempenho de judocas do sexo feminino em preparação para os Jogos Pan-Americanos. Rev Bras Cienc Mov 2001; 9 (2): 21-7
13. Mello MV, Fernandes Filho J. Perfil dermatoglífico, somatotípico e de composição corporal de judocas brasileiras de alto rendimento. Fitness Perf J 2005; 3 (3): 340-50
14. Enilina TA. Poverhnoszt tela u. tjazseloatletov. Teorija Prakt Fiz Kult 1966; 29 (4): 51-3
15. Lohman TG. Skinfolds and body density and their relation to body fatness: a review. Hum Biol 1981; 53: 181-225
16. Thomas SG, Cox MH, LeGal YM, et al. Physiological profiles of the Canadian National Judo Team. Can J Sport Sci 1989; 14 (3): 142-7

17. Jackson AS, Pollock ML. Generalized equations for predicting body composition of men. Br J Nutr 1978; 40: 497-504
18. Callister R, Callister RJ, Fleck SJ, et al. Physiological and performance responses to overtraining in elite judo athletes. Med Sci Sports Exerc 1990; 22 (6): 816-24
19. Callister R, Callister RJ, Staron RS, et al. Physiological characteristics of elite Judo athletes. Int J Sports Med 1991; 12: 196-203
20. Drinkwater DT, Ross WD. Anthropometric fractionation of body mass. In: Ostyn M, Beunen G, Simons J, editors. Kinanthropometry II. Baltimore (MD): University Park Press, 1980: 177-89
21. Little NG. Physical performance attributes of junior and senior women, juvenile, junior and senior men judokas. J Sports Med Phys Fitness 1991; 31: 510-20
22. Slaughter MH, Lohman TG, Boileau RA, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol 1988; 60 (5): 709-23
23. Sterkowicz S, Zuchowicz A, Kubica R. Levels of anaerobic and aerobic capacity indices and results for the special judo fitness test in judo competitors. J Human Kinetics 1999; 21 (2): 115-35
24. Franchini E, Takito MY, Bertuzzi RCM. Morphological, physiological and technical variables in high-level college judoists. Arch Budo 2005b; 1 (1): 1-7
25. Lohman TG, Roche AF, Martorell R. Anthropometric standardization reference manual. Champaign (IL): Human Kinetics, 1988
26. Koury JC, Oliveira CF, Portella ES, et al. Effect of the period of resting in elite judo athletes. Biol Trace Elem Res 2005; 107 (3): 201-11
27. Sertic H, Segedi I, Molanovic D. Anthropological and fitness status of Croatian judoists. Arch Budo 2006; 2 (1): 24-7
28. Piechaczek H. Oznaczenie calkwitego tluszczu ciala metodami densytometryczna I antropometryczna. Mat I Prace Antrop 1975; 89: 3-4
29. Obuchowicz-Fidelus B, Marchocka M, Majle B, et al. Anthropometric, strength and power characteristics of female kayak and judo athletes. Biol Sport 1986; 3 (1): 5-17
30. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body composition of women. Med Sci Sports Exerc 1980; 12: 175-82
31. Koury JC, Lopes GC, Oliveira Jr AV, et al. Plasma zinc, copper, leptin, and body composition are associated in elite female judo athletes. Biol Trace Elem Res 2007; 115 (1): 23-30
32. Sbriccoli P, Bazzucchi I, Di Mario A, et al. Assessment of maximal cardiorespiratory performance and muscle power in the Italian Olympic judoka. J Strength Cond Res 2007; 21 (3): 738-44
33. Komi PV. Strength and power in sport. Oxford: Blackwell Science Ltd, 2003
34. Fagerlund R, Hakkinen H. Strength profile of Finnish judoists: measurement and evaluation. Biol Sport 1991; 8 (3): 143-9
35. Matsumoto Y, Ogawa S, Asami T, et al. A follow-up study of the physical fitness of judoists (report I and II). Bull Assoc Sci Study Judo 1972; 4: 1-26
36. Claessens ALM, Beunen G, Lefevre J, et al. Body structure, somatotype, and motor fitness of top-class Belgian judoists. In: Day JAP, editor. Perspectives in kinanthropometry. Champaign (IL): Human Kinetics, 1984: 155-63
37. Franchini E, Takito MY, Kiss MAPDM, et al. Physical fitness and anthropometrical differences between elite and non-elite judo players. Biol Sport 2005; 22: 315-28
38. Heyward VH. Advanced fitness assessment and exercise prescription. Champaign (IL): Human Kinetics, 1997
39. 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
40. Leplanquais F, Cotinaud M, Lacouture P. Propositions pour une musculation spécifique: exemple du judo. Cinésiologie 1994; 34 (160): 80-6
41. Blais L, Trilles F, Lacouture P. Validation of a specific machine to the strength training of judokas. J Strength Cond Res 2007; 21 (2): 409-12
42. Taylor AW, Brassard L. A physiological profile of the Canadian Judo Team. J Sports Med 1981; 21: 160-4
43. Tumilty DM, Hahn AG, Telford RD. A physiological profile of well-trained male judo players. In: Watkins J, Reilly T, Burwitz L, editors. VIII Commonwealth and International Conference on Sport, Physical Education, Dance, Recreation and Health 1986. London: E & F.N, 1986: 3-10
44. Ichinose Y, Kanehisa H, Ito M, et al. Morphological and functional differences in the elbow extensor muscle between highly trained male and female athletes. Eur J Appl Physiol 1998; 78 (2): 109-14
45. Kort HD, Hendriks ERHA. A comparison of selected isokinetic trunk strength parameters of elite male judo competitors and cyclists. J Orthop Sports Physio Therapy 1992; 16 (2): 92-6
46. Ishiko T, Tomiki K. Characteristics of physical fitness of middle and old age judoists. Bull Assoc Sci Study Judo 1972; 4: 27-34
47. Iida E, Nakajima T, Wakayama H, et al. Rating scales of fundamental physical fitness for college judoists: composition and application. In: National Judo Conference: International Research Symposium 1998 Sep 23; Colorado Springs (CO): USA Judo Inc., 1998: 12
48. Franchini E, Del Vecchio FB, Romano R, et al. Performance responses to a periodized judo program. Annals of the 4th World Judo Research Symposium. Cairo: International Judo Federation, 2005: 24-5
49. Krstulović S, Zuvela F, Katić R. Biomotor systems in elite junior judoists. Coll Anthropol 2006; 30 (4): 315-21
50. Glaister M. Multiple sprint work: physiological responses, mechanisms of fatigue and influence of aerobic fitness. Sports Med 2005; 35 (9): 757-77
51. Green S, Dawson B. Measurement of anaerobic capacities in humans: definitions, limitations and unsolved problems. Sports Med 1993; 15 (5): 312-27
52. Inbar O, Bar-Or O, Skinner J. The Wingate anaerobic test. Champaign (IL): Human Kinetics, 1996
53. Bar-Or O. The Wingate anaerobic test: an update on methodology, reliability and validity. Sports Med 1987; 4: 381-94
54. Koutedakis Y, Sharp NCC. A modified Wingate test for measuring anaerobic work of the upper body in junior rowers. Br J Sports Med 1986; 20 (4): 153-6

55. Mickiewitz G, Starczenska J, Borkowski L. Judo, ovvero sforzo breve di grande intensità. Athlon 1991; 4: 42-6
56. Sharp NCC, Koutedakis Y. Anaerobic power and capacity measurements of the upper body in elite judo players, gymnasts and rowers. Australian J Sci Med Sport 1987; 19 (3): 9-13
57. Maud P, Shultz BB. Norms for the Wingate anaerobic test with comparison to another similar test. Res Q Exerc Sport 1989; 60 (2): 144-51
58. Terbizan DJ, Seljevold PJ. Physiological profile of age-group wrestlers. J Sports Med Phys Fitness 1996; 36 (3): 178-85
59. Falk B, Bar-Or O. Longitudinal changes in peak aerobic and anaerobic mechanical power of circumpubertal boys. Pediatric Exerc Sci 1993; 5: 318-31
60. Nindl BC, Mahar MT, Harman EA, et al. Lower and upper body anaerobic performance in male and female adolescent athletes. Med Sci Sports Exerc 1995; 27 (1): 235-41
61. Inbar O, Bar-Or O. Anaerobic characteristics in male children and adolescents. Med Sci Sports Exerc 1986; 18 (3): 264-9
62. Blimkie CJ, Roache P, Hay JT, et al. Anaerobic power of arms in teenage boys and girls: relationship to lean tissue. Eur J App Physiol Occup Physiol 1988; 57: 667-83
63. Gariod L, Favre-Juvin A, Novel V, et al. Evaluation du profit energetique des judokas par spectroscopie RMN du P31. Sci Sports 1995; 10 (4): 201-7
64. Wojczuk J, Wojcieszak I, Zdanowicz R. Anaerobic work capacity in athletes. Biol Sport 1984; 1 (2): 119-30
65. Borkowsky J, Faff J, Starczewska-Czapowska J. Evaluation of the aerobic and anaerobic fitness in judoists from the Polish national team. Biol Sport 2001; 18: 107-11
66. Franchini E, Teixeira S, Vecchio FB, et al. Potência aeróbia e anaeróbia para membros superiores e inferiores em judocas. III Congreso de la Asociación Española de Ciencias del Deporte, 2004 [compact disk]. Valencia: Gráficas Mari Montañana, S.L., 2004
67. Horswill CA, Miller JE, Scott JR, et al. Anaerobic and aerobic power in arms and legs of elite senior wrestlers. Int J Sports Med 1992; 13 (8): 558-61
68. Frings-Dresen M, Eterradossi J, Favre-Juvin A. Puissances maximales aérobie, anaérobie alactique et force musculaire isométrique des skieurs alpins, skiurs de fond et judokas. Med Sport 1987; 61 (2): 98-102
69. Carratalá V, Pablos C, Carqués L, et al. Valoración de la fuerza explosiva, elástico-explosiva de los judokas infantiles y cadetes del equipo nacional español [online]. Available from URL: http://www.judoinfo.com/pdf/research2.pdf [Accessed 2004 Nov 5]
70. Pujadas A, Collazo Garay BC, Rodriguez Leal EA. Aptitud anaerobia en deportistas de combate del sexo femenino. Rev Int Meda Cienc Actividad Fís Dep 2005; 19: 283-94
71. Tomlin DL, Wenger HA. The relationships between aerobic fitness, power maintenance and oxygen consumption during intense intermittent exercise. J Sci Med Sport 2002; 5 (3): 194-203
72. Castarlenas JL, Solé J. El entrenamiento de la resistencia en los deportes de lucha com agarre: una propuesta integradora. Apunts: Educ Fís Deportes 1997; 1 (47): 81-6
73. Franchini E, Takito MY, Nakamura FY, et al. Influência da aptidão aeróbia sobre o desempenho em uma tarefa anaeróbia láctica intermitente. Motriz 1999; 5 (1): 58-66
74. Muramatsu S, Horiyasu T, Sato Si, et al. The relationship between aerobic capacity and peak power during intermittent anaerobic exercise of judo athletes. Bull Assoc Sci Study Judo 1994; 8: 151-60
75. Gorostiaga EM. Coste energético del combate de judo. Apunts: Educ Fís Deportes 1988; 25: 135-9
76. Ebine K, Yoneda I, Hase H, et al. Physiological characteristics of exercise and findings of laboratory tests in Japanese elite judo athletes. Med Sport 1991; 65 (2): 73-9
77. Ikai M, Haga S, Kaneko M. The characteristics of physical fitness of judoists from the viewpoint of respiratory and cardiovascular functions. Bull Assoc Sci Study Judo 1972; 4: 43-52
78. Sugiyama M. Energy expenditure of throwing techniques in judo. IJF Judo Conference; 1999 Sep 1; Birmingham. Birmingham: International Judo Federation, 1999: 14
79. Oh JK, Han SC, Shin YO, et al. Genotypes of ACE and ApoE, cardiorespiratory fitness and blood lipid profile in elite judo players. In: Koskoulou M, Geladas N, Klissouras V, editors. Book of abstracts of the 7th Annual Congress of the European College of Sport Science 2002. Athens: European College of Sport Science, 2002: 366
80. Majean H, Gaillat ML. Étude de l'acide lactique sanguin chez le judoka en fonction des méthodes d'entraînement. Med Sport 1986; 60 (4): 194-203
81. Suay F, Salvador A, González-Bono E, et al. Effects of competition and its outcome on serum testosterone, cortisol and prolactin. Psychoneuroendocrinology 1999; 24 (5): 551-66
82. Salvador A, Suay F, González-Bono E, et al. Anticipatory cortisol, testosterone and psychological responses to judo competition in young men. Psychoneuroendocrinology 2003; 28 (3): 364-75
83. Degoutte F, Jouanel P, Filaire E. Mise em évidence de la sollicitation du cycle des purines nucléotides lors d'un combat de judo. Sci Sports 2004; 19: 28-33
84. Cottin F, Durbin F, Papelier Y. Étude comparative de l'analyse spectrale de la fréquence cardiaque au cours de l'exercice sur ergocycle et de l'entraînement en judo. Sci Sports 2001; 16 (6): 295-305
85. Bonitch J, Ramirez J, Femia P, et al. Validating the relation between heart rate and perceived exertion in a judo competition. Med dello Sport 2005; 58: 23-8
86. Vidalin H, Dubreuil C, Coudert J. Judokas ceinture noire. Suivi physiologique: études biométrique et bioénergétique – suvi de l'entraînement. Med Sport 1988; 62 (4): 184-9
87. Ahmaidi S, Portero P, Calmet M, et al. Oxygen uptake and cardiorespiratory responses during selected fighting techniques in judo and kendo. Sports Med Train Rehab 1999; 9 (2): 129-39
88. Franchini E, Yuri Takito M, Nakamura FY, et al. Effects of recovery type after a judo combat on blood lactate removal and on performance in an intermittent anaerobic task. J Sports Med Phys Fitness 2003; 43 (4): 424-31
89. Wilmore DL, Costill JH. Physiology of sport and exercise. 2nd edition. Champaign (IL): Human Kinetics, 1999

Correspondence: Dr *Emerson Franchini*, Av. Prof. Melo Morais, 65 – Cidade Universitária, São Paulo (SP), 05508-030, Brazil.
E-mail: emersonfranchini@hotmail.com