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Assessment of Maximal Cardiorespiratory Performance and Muscle Power in the Italian Olympic Judoka

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ABSTRACT. Sbriccoli, P., I. Bazzucchi, A. Di Mario, G. Marzattinocci, and F. Felici. Assessment of maximal cardiorespiratory performance and muscle power in the Italian Olympic judoka. *J. Strength Cond. Res. 21(3):738–744. 2007.*—The main purposes of this study were to describe the cardiorespiratory fitness and lower limbs maximal muscle power of a selected group of Olympic Italian male (M) and female (F) judokas. Eleven subjects (6 M, 5 F) underwent 3 different tests. The $\dot{V}O_2max$ and ventilatory threshold (VT; V-slope method) were assessed during a graded maximal treadmill test. Lower limbs muscle peak power (PP) and mean power (MP) were determined during a 30-second Wingate test (WIN). Post-WIN blood lactate peak was also measured. Subjects were tested also during a 5-minute combat test (CT), during which blood lactate and heart rate (HR) were monitored. $\dot{V}O_2max$ (mean ± *SD*) was 47.3 ± 10.9 and 52.9 ± 4.4 $ml\cdot kg^{-1}\cdot min^{-1}$ for M and F judokas, respectively. The VT corresponded to 80.8% (M) and 86.5% (F) of $\dot{V}O_2max$. Both PP and MP, measured during the WIN, were significantly higher ($p < 0.05$) in M than in F judokas (PP: 12.1 ± 2.4 vs. 9.5 ± 1.1 $W\cdot kg^{-1}$; MP: 5.4 ± 1.1 $W\cdot kg^{-1}$; F: 4.3 ± 0.5 $W\cdot kg^{-1}$). Post WIN blood lactate peak was 6.9 ± 2.8 $mmol\cdot l^{-1}$ and 6.1 ± 1.8 $mmol\cdot l^{-1}$ for M and F judokas, respectively (not significant). During the CT blood lactate peak was 9.9 ± 3.0 $mmol\cdot l^{-1}$ (M) and 9.2 ± 2.0 $mmol\cdot l^{-1}$ (F); these values being significantly higher than those obtained after the WIN ($p < 0.05$). In conclusion, Italian Olympic judokas showed high levels of muscle power but accompanied by a moderate engagement of the aerobic metabolic pathway, which is well in accordance with the characteristics of judo. Having these results in top-level athletes may represent a useful contribution to the work of coaches and trainers in optimizing training programs for the achievement of the best performance of the judoka.

KEY WORDS. judo, maximal aerobic power, blood lactate, combat test

INTRODUCTION

Judo, from a physiologic standpoint, can be classified among those sport activities that require the concomitant or alternative metabolic involvement of aerobic and anaerobic pathways (14,24). A judo combat, in fact, is characterized by the presence of brief intense muscular actions (15- to 30-second duration; 11, 21) in which the anaerobic system is primarily involved. Evidence of a significant engagement of the anaerobic (lactic) system is also demonstrated by the high quantities of lactate that have been measured in these athletes during and after a judo combat (14, 25). On the other hand, the entire duration of a judo combat (5 minutes plus time intervals between subsequent muscular actions) implies the involvement of the aerobic system, especially toward the end of the combat (24). In addition, in the attempt to improve the spectacular aspect of judo combats, the International Judo Federation (17) has recently introduced a new rule (the "golden score") consisting of the possibility of allowing a 5-minute extra-time in case no final verdict is gained at the end of the normal 5-minute combat. Furthermore, the need for an adequate aerobic conditioning in this sport activity is further justified by the fact that each judoka can be involved in a different number of combats within the same competition day.

Following what was reported in the international literature, the physiologic profile of judo competitors, in terms of the relative intervention of aerobic and anaerobic metabolism, is not easy to determine. This may be partly attributed to the fact that these athletes are subdivided in weight divisions (9, 24), and differences related to body mass, stature, and body composition may significantly influence fighting strategies (including technical and tactical skills) and consequently the physiologic profile of these athletes.

The role of aerobic and anaerobic conditioning and other physiologic aspects related to the practice of judo has been documented in elite judokas belonging to different national teams (8–10, 20, 23, 24). Nevertheless, a few issues should be addressed in this regard. First of all, the more recent studies on this topic were conducted 15 years ago or more, before the rules were changed. For instance, as a judoka now may be involved, in view of the golden score rule, in 5- to 10-minute combats, a different (possibly higher) involvement of aerobic metabolism should be considered. As a consequence, not only the fighting strategies but also the training regimens may have been readjusted to accomplish this requirement. Second, in the previously cited studies (8–10, 20, 23, 24) the judokas were tested by means of the standard aerobic and anaerobic power tests, whereas, to our knowledge, only a few data obtained during a real competition or an actual judo combat have been reported so far.

Based on the previous considerations, the present study was designed to describe the main physiologic characteristics of a group of elite Italian male (M) and female (F) judokas belonging to the Olympic squad. Although this study is limited in term of number of participants, dealing with top-level athletes may help identify some of the major determinants needed to attain the best performance, and such information may be successfully applied to less qualified athletes (lower ranking), helping coaches and trainers establish adequate training programs and thereby optimizing the performance capacity in judo competitors.

TABLE 1. Anthropometric data.*

	Age (y)	Body mass (kg)	Stature (m)	BMI ($kg \cdot m^{-2}$)
Mean M	26.0	109.0	1.8	31.7
SD	3.8	29.3	0.07	6.7
Mean F	28.1	63.8	1.7	22.7
SD	0.8	10.5	0.07	1.9

* Data are mean ± *SD*. M = male; F = female; BMI = body mass index.

METHODS

Experimental Approach to the Problem

The present work was designed to study some of the major physiologic determinants in a selected group of top-level M and F judokas (Olympic Club) all participating in the Olympic Games (Athens 2004). These athletes have been subjected to a selected training program by the national staff (coaches and trainers) in the 4-year period preceding the Olympic Games.

The maximal aerobic power and lower limbs mechanical power were assessed in the laboratory by means of standard human performance measurements (graded maximal treadmill test and Wingate test [WIN], respectively). Furthermore, the physiologic responses of the judoka during an actual judo combat were also evaluated.

At the time of the experiment, training and fitness level was high in all athletes. All tests were performed in the pre-Olympic year, namely during the season prior to the Olympic Games.

Subjects

With ethical committee approval, and after signing a written consent, 11 subjects (6 M, 5 F) volunteered to participate in the study (anthropometric data are reported in Table 1). All subjects belonged to a special selection (Olympic Club) including all the Italian athletes who participated in the Olympic Games (Athens 2004). All athletes were requested to attend 3 different sessions, separated by at least 1 week, to perform the following tests: (a) the maximal aerobic power and the ventilatory threshold (VT) and (b) the maximal lower limbs muscle power adopting a WIN; finally, subjects were tested during a judo match mimicking a real competition (combat test [CT]).

Procedures

Maximal Aerobic Power Assessment. The oxygen consumption ($\dot{V}O_2max$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), and pulmonary ventilation ($\dot{V}E$) were measured breath by breath (continuously) by a portable telemetric transmission metabolimeter (k4b²; Cosmed, Italy) during a graded maximal aerobic power test performed on a treadmill (Technogym, Italy). Heart rate (HR) was monitored continuously (Polar Vantage NV sport-testing, Kempele, Finland).

Prior to the test, a baseline assessment of all the previously mentioned parameters was done at rest while subjects were seated. The test started with a 3-minute warm-up at 7 $km \cdot h^{-1}$ (treadmill slope: 1%), then the speed was set at 9 $km \cdot h^{-1}$ and increased by 1 $km \cdot h^{-1}$ every minute while the treadmill slope was kept constant (slope: 1%) during the test. The test was performed to volitional exhaustion.

At the end of the test, subjects were asked not to stop running abruptly but to continue running at a slow pace for 3 minutes (speed: 7 $km \cdot h^{-1}$), while all parameters were monitored. The $\dot{V}O_2max$ was considered attained if at least 3 of the following criteria were fulfilled: (a) the $\dot{V}O_2$ did not increase by more than 150 $ml \cdot kg^{-1} \cdot min^{-1}$ over 2 consecutive steps; (b) the maximal HR measured during the test was above or higher (± 5 $b \cdot min^{-1}$) than the 90% of the individual maximal HR (HRmax) in accordance with the formula [207 $b \cdot min^{-1}$ − (0.7 × age in years)] proposed by Tanaka et al. (22); and (c) RER was equal or higher than 1.1.

The VT was assessed by means of a gas exchange method (V-slope) (26, 27). Briefly, the $\dot{V}CO_2$ measured during the maximal aerobic power test was plotted as a function of $\dot{V}O_2$; the break point in this plot was considered as the VT. The $\dot{V}O_2$ and HR measured in correspondence with the VT ($\dot{V}O_{2VT}$ and HR_{VT}, respectively) were then computed and reported also as a percent of maximum.

Maximal Lower Limbs Muscle Power Assessment. The anaerobic power was assessed by means of a 30-second WIN for the lower limbs (1, 2) performed on an electrodynamically braked cycle ergometer (Lode Excalibur Sport, Gronigen, The Netherlands). Before starting the WIN a blood sample (25 μl) was taken from the earlobe of each subject, and basal blood lactate concentration was determined by a portable lactate analyzer (Accusport Lactate Analyzer, Boehringer Mannheim, Mannheim, Germany) for which reliability has already been determined in exercise testing (5, 19). The WIN session started with a 5-minute warm-up, with the subjects pedaling at a self-selected pace. At the end of the warm-up phase, subjects were asked to perform 2 "all-out" sprints (4–8 seconds) followed by a 5-minute rest. Afterward, the WIN started. This consisted of an all-out cycling for 30 seconds, with the braking force set at its full intensity right from the start (0.77 and 0.8 × body weight (Nm) for F and M athletes, respectively). To reduce the subjectivity in the administration of the WIN, the timing of starting the braking force at the flywheel was determined by a computer. Subjects were instructed to pedal as fast as possible throughout the 30-second WIN. After completing the test, subjects were asked to pedal against a reduced resistance (freely programmable) for 1 minute. Then, a passive recovery phase started. Blood lactate concentrations were determined, as described previously, at the end of the test and then every 3 minutes during the 15- to 20-minute recovery period.

From the WIN, 2 indices of muscle power were computed: the peak power (PP) and the mean power (MP). The PP, calculated as the highest value achieved within the first 5 seconds of the test, represents the highest mechanical power that is generated during the test and is considered to be an expression of the anaerobic power (2, 3, 18). The MP corresponds to the average mechanical power obtained across the 30 seconds of the test and is thought to reflect the ability of muscles to sustain extremely high power demands (2). It is important to stress that MP reflects the contribution of both anaerobic and aerobic metabolic sources to the performance (2, 3). The PP and MP values have been normalized to body mass thus obtaining the correspondent normalized indices (PP_{NORM} and MP_{NORM}, respectively).

Combat Test. Blood lactate concentration and HR were monitored during a CT. This consisted of a judo combat performed in accordance with the international rules (5-minute combat plus pauses between subsequent fighting actions); this was ensured by the presence of an inter-

TABLE 2. Maximal aerobic power test results.*

	$\dot{V}O_2max$ ($l \cdot min^{-1}$)	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR $\dot{V}O_2max$ ($b \cdot min^{-1}$)	$\dot{V}O_{2VT}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR_{VT} ($b \cdot min^{-1}$)
Mean M	4.9†	47.3	185	38.2	160
SD	0.7	10.9	8	9.5	11
Range	4.2–6.8	37.4–61.8	177–194	34.6–46.1	144–174
Mean F	3.3	52.9	182	46.1	163
SD	0.3	4.4	10	5.8	13
Range	3.0–3.9	49.9–56.8	166–190	39.4–50.3	154–178

* Data are mean ± *SD*. M = male; F = female; HR = heart rate; VT = ventilatory threshold.
† $p \leq 0.05$.

national referee. To obtain a maximal effort and engagement by the athletes, each athlete had to fight against 2 opponents, each of them fighting for half of the combat time (2.5-minute effective time each). Heart rate was monitored continuously during the entire combat and also over 15–20 minutes of passive recovery, and blood lactate was determined prior to the CT, at the end of the test, and then every 3 minutes during the recovery phase.

Statistical Analyses

All parameters measured during the maximal aerobic power test ($\dot{V}O_2max$, HR, $\dot{V}O_{2VT}$, and HR_{VT}), during the WIN (PP, MP, PP_{NORM}, MP_{NORM}, blood lactate concentration), and during the CT (HR, blood lactate) were expressed as mean ± *SD* for the 2 groups (M and F).

Differences between the mean ± *SD* obtained in F and M athletes for all the previously considered parameters were assessed by an unpaired *t*-test.

Furthermore, after having determined the effect size *f* (0.71) and the statistical power (80%) according to our experimental design, a 1-way analysis of variance (ANOVA) was used to assess the effect of different test procedures (WIN and CT) on blood lactate concentration peak (α level = 0.05) (StatView 5.0.1. software, SAS Institute, Cary, NC). For all statistical tests the level of significance was set at $p \leq 0.05$.

RESULTS

Maximal Aerobic Power Test

The mean data obtained for the maximal aerobic power test are shown on Table 2.

The mean (absolute) $\dot{V}O_2max$ obtained was 4.9 ± 0.7 $l \cdot min^{-1}$ (M group); this value was significantly higher ($p \leq 0.05$) than that obtained for the F group (3.3 ± 0.3 $l \cdot min^{-1}$), whereas no significant differences were observed between M and F judokas with regard to the mean (relative) $\dot{V}O_2max$. Maximal HR measured during the maximal aerobic power test was 185 ± 7.9 $b \cdot min^{-1}$ for M athletes and 182 ± 10.5 $b \cdot min^{-1}$ for F athletes that corresponded to 97.5% and 96.6% HRmax in M and F athletes, respectively (differences observed between the 2 groups were not significant).

Data concerning the VT results are also shown in Table 2. Female judokas reached VT at 86.5% $\dot{V}O_2max$. This value was higher, although not significantly, than that obtained in M athletes (VT: 80.8% $\dot{V}O_2max$, $p = 0.08$). The HR_{VT} corresponded to 84.2% and 86.3% of HRmax for the M and F group, respectively. This difference was not significant.

Wingate Test

An example of the mechanical power generated during the WIN test in 1 F athlete is presented in Figure 1.

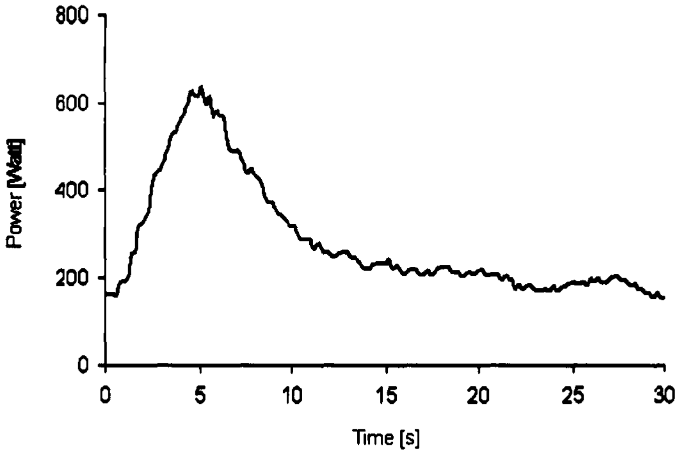

FIGURE 1. A typical example of a Wingate test in 1 female subject.

All the mean ± *SD* data obtained for all considered parameters (PP, MP, PP_{NORM}, MP_{NORM}, and blood lactate) in M and F groups are shown on Table 3.

Male athletes exhibited higher PP, PP_{NORM} ($p < 0.05$) and MP ($p < 0.01$) than F athletes, whereas MP_{NORM} was not different in the 2 groups ($p = 0.2$).

Prior to the WIN, the basal blood lactate concentration was 1.6 ± 0.3 $mmol \cdot l^{-1}$ and 1.5 ± 0.5 $mmol \cdot l^{-1}$ for M and F groups, respectively. The blood lactate peak was on average 6.9 ± 2.8 $mmol \cdot l^{-1}$ (M group), whereas in the F group the peak blood lactate concentration was 6.1 ± 1.8 $mmol \cdot l^{-1}$ (NS, $p = 0.6$). Blood lactate concentration peak was reached on average between the third and the sixth minute of recovery. After blood lactate peak was reached, a slow decrease in blood lactate concentration was observed across the remaining 12 minutes of recovery. At the end of the recovery phase, blood lactate concentration was 3.4 ± 0.5 $mmol \cdot l^{-1}$ (M group) and 3.2 ± 1.6 $mmol \cdot l^{-1}$ (F group).

TABLE 3. Wingate test results.*

	PP (W)	PP_{NORM} ($W \cdot kg^{-1}$)	MP (W)	MP_{NORM} ($W \cdot kg^{-1}$)
Mean M	1,235.6†	12.1†	557.5†	5.4
SD	202.2	2.4	85.9	1.1
Range	944.7–1,450.1	9.7–13.5	439.4–646.8	4.3–6.0
Mean F	635.4	9.5	285.5	4.3
SD	21.1	1.1	10.9	0.5
Range	607.7–658.6	8.1–10.6	217.2–295.02	3.6–4.4

* Data are mean ± *SD*. M = male; F = female; PP = peak power; MP = mean power.
† $p \leq 0.05$.

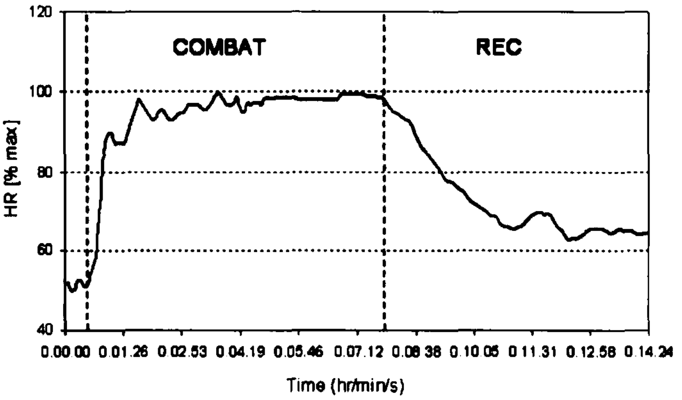

FIGURE 2. Heart rate time course during a combat test in 1 male subject. Heart rate is expressed as a percentage of HRmax. CT = combat test; REC = recovery; HR = heart rate.

Combat Test

Heart Rate and Blood Lactate. The duration of the combats (including pauses between subsequent muscular actions) was on average 402.5 ± 71.3 seconds (6.7 ± 1.1 minutes, including pauses). For the M group, the maximum HR measured during the combats was 180.2 ± 10.5 $b \cdot min^{-1}$) in M judokas, and 176.2 ± 5.6 $b \cdot min^{-1}$ for the F group (corresponding to 94.8% and 92.87% of HRmax, respectively). These differences were not significant. In Figure 2, the HR time course over the entire combat is shown for 1 M subject (HR is reported as a percentage of HRmax).

In this subject, HR increased abruptly within the first 90 seconds of the combat and then showed a slower increase up to the last minute of combat while the maximal HR was reached (184 $b \cdot min^{-1}$ in this athlete; 94.8% HRmax). Heart rate remained almost constant over the entire combat, without showing any relevant decrease during the pauses imposed by the referee. The same behavior was observed in all athletes.

The time for HR to recover to values corresponding to 60% of the HRmax was on average 12.1 ± 6 minutes (M) and 12 ± 5.6 minutes (F).

In Figure 3a, the mean ± *SD* blood lactate concentration obtained in M and F athletes during the CT is reported.

Basal blood lactate concentration was on average 1.4 ± 0.3 $mmol \cdot l^{-1}$ (M group) and 1.0 ± 0.1 $mmol \cdot l^{-1}$ (F group). The peak blood lactate was reached, in all subjects, immediately at the end of the 5-minute combat and corresponded to 10.3 ± 2.6 $mmol \cdot l^{-1}$ (range: 6.7–13.1 $mmol \cdot l^{-1}$) and 9.2 ± 2.0 $mmol \cdot l^{-1}$ (range: 7.8–10.7 $mmol \cdot l^{-1}$) for the M and F groups, respectively. No significant difference in blood lactate peak detected during the CT was revealed between the 2 groups. The passive recovery phase was characterized by a continuous decrease in blood lactate concentration that was faster in the first 6 minutes of recovery. The final blood lactate concentration was 3.9 ± 0.6 $mmol \cdot l^{-1}$ (M group) and 3.2 ± 0.8 $mmol \cdot l^{-1}$ (F group).

The comparison between blood lactate concentration measured before, during, and after the WIN and before, during, and after the CT is reported in Figure 3b (grey bars and black bars, respectively). For the sake of clarity, and because no gender differences were observed for this parameter, blood lactate data obtained in M and F judokas during the WIN and the CT have been cumulated.

The peak of blood lactate showed a different timing in the 2 conditions; in fact, blood lactate peak was obtained at the end of the CT, whereas in the WIN the peak of blood lactate was reached on average at the sixth minute of recovery. The ANOVA demonstrated a significant effect of different test procedures on blood lactate concentration peak; the peak of blood lactate obtained after the CT was significantly higher than the corresponding value reached after the WIN (10.06 ± 2.3 vs. 6.6 ± 2.3 $mmol \cdot l^{-1}$, $p < 0.05$).

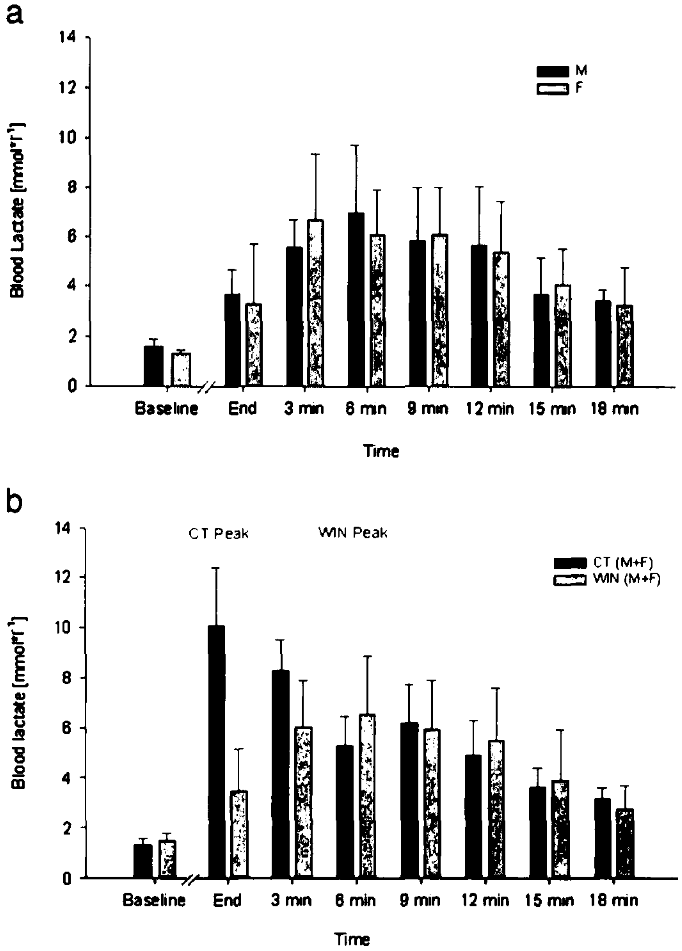

FIGURE 3. a) Blood lactate concentration obtained during the Wingate test (WIN). Data are presented as mean ± *SD* values. Black vertical bars = males (M); grey vertical bars = females (F). b) Comparison between blood lactate concentration obtained during the WIN and during the combat test (CT). Data are presented as mean ± *SD* values. Male and F data are cumulated for the sake of clarity. Black vertical bars = CT; grey vertical bars = WIN. * $p \leq 0.05$.

DISCUSSION

The main objective of the present study was to describe the cardiorespiratory fitness and lower limbs maximal muscle power of a selected group of elite Italian judokas belonging to the Olympic squad. The main results obtained in this study can be summarized as follows: (a) all athletes showed a low to moderate aerobic power capacity, with $\dot{V}O_2max$ values higher than those reported in untrained populations, yet lower than those described in endurance athletes (7); (b) the muscle power indices measured through the WIN were high in all athletes in accordance with the functional demands imposed by this sport activity and significantly higher in M compared with F judokas; and (c) the CT turned out to be the best stimulus for a maximal involvement of both the cardiovascular and musculoskeletal systems in these athletes, as they were capable of reaching high HR and keeping the HR close to HRmax throughout the entire test; this was paralleled by a significant accumulation of blood lactate.

When evaluating the results of this study, one should keep in mind that the experimental group was composed of a selected group of elite judo athletes. There were different weight categories represented within the same group (F and M), and there were few judokas for each weight category. As a consequence, the following conclusions should be considered as partial and only representative of the special group chosen for this study.

One issue addressed in the introduction dealt with the relative role of anaerobic and aerobic metabolism in judo competitors. According to the results obtained in this study, the absolute $\dot{V}O_2$max was higher in M than in F judokas. Similar $\dot{V}O_2$max results were obtained in previous studies performed on top-level judo competitors (9, 24), although the $\dot{V}O_2$max measured in these studies were higher than those obtained in the present work with regard to the M group. The lower $\dot{V}O_2$ values obtained in our M judokas compared with previous studies may be ascribed to the lack of homogeneity present within our M group, due to the coexistence of athletes belonging to different weight categories. In fact, in our M judokas, the $\dot{V}O_2$max ranged between 37.3 and 61.8 $ml \cdot kg^{-1} \cdot min^{-1}$, with an inverse relationship observed between body mass and $\dot{V}O_2$max.

As already mentioned, VT was fairly high both in M and in F judokas showing a trend to higher values in F judokas. This result may suggest a good conditioning of the aerobic pathway in our judokas, as the VT is often preferred to the $\dot{V}O_2$max to assess the efficiency of aerobic metabolism (4, 6). The tendency to higher $\dot{V}O_2$max and VT in our F judokas may suggest a tendency to better aerobic performance in this group.

On the other hand, the high VT obtained in our M and F judokas (%$\dot{V}O_2$max) could also be an expression of the ability of these athletes to sustain high intensity efforts, possibly indicating a consistent utilization of anaerobic systems for energy provision in these athletes. Actually, this may be a reasonable interpretation considering the nature of the effort required in judo combats (short-time actions performed at high intensity).

To provide a final answer about the real contribution of aerobic metabolism for a judo competitor, one should rely on the measurement of $\dot{V}O_2$ during a more specific test, for example, a real competition or a simulated combat. Unfortunately, this was not possible in the present study for obvious technical reasons. Moreover, a judo match is partially performed with raised upper arms and in a quasi-static condition. This implies a consistent engagement of the cardiovascular system with a consistent HR increase, which in turn may be paralleled by a reduced $\dot{V}O_2$. In fact, a previous study conducted on power athletes showed that at a given %HRmax, %$\dot{V}O_2$max was consistently lower than that predicted in dynamic exercises (12). As a consequence, the linearity between HR and $\dot{V}O_2$ is not ensured in this condition, and this does not allow inferences regarding the energy cost during a judo combat.

The results obtained during the WIN indicate a prevailing role of anaerobic metabolism in these athletes. The PP (absolute and normalized) values were higher in M compared with F judokas. As already mentioned, PP is considered to be an expression of anaerobic power (2, 3, 18). Then, the results obtained here are well in accordance with the need for a high power capacity required during a judo combat. In fact, PP and PP_{NORM} values obtained in our judokas were similar to those obtained in both judoka (24) and power athletes (2). The importance of power capacity in judo is further supported by the strength data collected during training in these athletes (Table 4).

TABLE 4. Strength data.*

	Bench press (kg)	Lat machine (kg)	Leg press (kg)	Weightlifting (deadlift technique) (kg)	Leg curl (kg)
Mean M	160.0	141.7	396.7	126.7	76.7
SD	29.8	15.1	8.2	10.8	4.1
Mean F	73.8	83.8	305.0	93.8	40.0
SD	13.1	11.1	19.1	6.3	4.1

* Data are mean ± *SD*. M = male; F = female.

The MP (absolute) values obtained in this study were higher in M than in F judokas, but this difference was absent as MP values were normalized to body mass. As far as MP is concerned, this parameter is generally considered as an expression of muscle endurance, for example, the ability of muscle to sustain extremely high power (2). A comparison between our and previous findings in regard to MP was not possible due to the lack of studies on this subject in judo competitors. Nevertheless, it has been demonstrated (16) that martial arts are characterized by leg MP values approximately 40% lower than the correspondent PP values, which is comparable to the results obtained in our study (MP values were 50% lower than PP). This unique relationship has been suggested to be a prerequisite for attaining the best performance in martial arts, and this further indicates that in addition to a high anaerobic power, our judokas show a high resistance to fatigue as well.

As reported, the CT represented the best stimulus in our M and F judokas in terms of cardiovascular, muscular, and metabolic engagement. In all subjects, HR reached high absolute values, and, most important, all judokas were able to keep the HR constantly at this high level during the entire combat regardless of the pauses allowed by the referee and those due to the changing of the opponent (half-time CT). The HR values reached (and maintained) were around 94% HRmax in all judokas. These values are well above those reached at VT, which is likely an expression of a consistent engagement of anaerobic (lactic) metabolism during the CT. This observation is supported by the high blood lactate concentration measured during the CT, and it is also in accordance with what was reported from the analysis of a judo combat (11, 21). An involvement of aerobic metabolism cannot be excluded on the basis of the high HR reached during the CT. Thus, due to the significant contribution of the isometric actions during a judo combat and because this effort is partially performed with raised upper arms (13, 15), HR response may not be able to reflect the aerobic characteristics in these athletes.

Blood lactate concentration reached during the CT was higher than that attained during the WIN in both M and F judokas, and this can be ascribed either to the longer duration of the CT or to the engagement of larger muscle masses during the combat compared with the WIN condition.

Finally, blood lactate removal was faster in those athletes that showed the highest values of blood lactate concentration and PP, suggesting a relationship between anaerobic power and lactate removal in these athletes.

In conclusion, the metabolic profile delineated for the Italian elite judoka is characterized by (a) a low to moderate contribution of aerobic metabolism and (b) a consistent and prevalent intervention of anaerobic (power) capacities, which play a major role in M athletes.

In all tests performed, and particularly in the CT, our judokas demonstrated a very high level of conditioning as expected considering that they were selected as the best in the national ranking list.

The extent of the influence of the judokas' physiologic characteristics on their performance during a judo competition is still an unresolved issue and further studies are needed to bridge this gap. Future studies may be designed in which physiologic measurements are coupled with an accurate match analysis, in an attempt to establish a more solid link between physiologic and technical skills in judo.

PRACTICAL APPLICATIONS

It is well known that the performance capacity in "open skill" sports such as judo is dependent on several factors among which the physiologic ones represent only 1 aspect. As a consequence, a solid link between physiologic adaptations to training, training level, and performance is very difficult to establish. In our opinion this study provided a deeper insight in this respect, and the present findings may be successfully used by coaches and trainers as a tool to optimize the training programs for the attainment of the best performance of the judoka. In fact, although we tested a small group of athletes, it should be noted that the results presented here were obtained at the end of a 4-year training program, and most important a strong relationship was found between the test profile outlined in our judokas and their performance capacity. In fact, the majority of them obtained relevant results either during the pre-Olympic year (World and European Championships, being qualified between the first and the third place) or during the Olympic Games of Athens 2004 (bronze medal).

The most relevant information and suggestions arise from the results obtained during the CT, which, among all the tests proposed, is the one that more strictly resembles the real competition condition. The high HR, along with the high levels of blood lactate detected during this test, suggest that specific training programs should be planned to include exercises that stimulate anaerobic and aerobic metabolism at the same time; although the latter is not crucial in the practice of judo, it should not be completely neglected. Furthermore, improving the ability to recover after a judo combat may have significant implications in managing a different number of combats within the same competition day.

In practical terms, and just to make an example, all this may be obtained by including in the same training session different series of high-intensity exercises alternated with technical actions against an opponent, allowing a short break between subsequent series. This kind of training seems appropriate to develop the ability to sustain mild to high lactate concentration and to work at an intensity that is always above the VT (high HR). Moreover, including technical actions within the training programs seems relevant, necessary, and extremely useful to mimic a real combat, this representing not only a physiologic but also a psychological stimulus for the judoka.

This study confirms the need for an individualized training program in top-level athletes. This is important because of the major roles played by sex and especially weight differences in judo competitions.

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