Original Paper DOI: 10.5604/20831862.1003446 Biol. Sport 2012;29:217-222

AEROBIC POWER IN CHILD, CADET AND SENIOR JUDO ATHLETES

Accepted for publication 03.05.2012

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ABSTRACT: The aim of the present study was to compare performance and physiological responses during arm and leg aerobic power tests of combat duration in male child, cadet and senior judo athletes. Power output and physiological parameters, i.e., peak oxygen uptake ($\dot{V}O_2$peak), peak ventilation, peak heart rate, lactate, and rate of perceived exertion, of 7 child (under 15 years: age class U15, 12.7 ± 1.1 yrs), 10 cadet (U17, 14.9 ± 0.7 yrs) and 8 senior (+20, 29.3 ± 9.2 yrs) male judo athletes were assessed during incremental tests of combat duration on an arm crank and a cycle ergometer. Children as well as cadets demonstrated higher upper body relative VO_2peak than seniors (37.3 ± 4.9, 39.2 ± 5.0 and 31.0 ± 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively); moreover, upper and lower body relative VO_2peak decreased with increasing age ($r = -0.575$, $p < 0.003$ and $r = -0.580$, $p < 0.002$, respectively). Children showed lower blood lactate concentrations after cranking as well as after cycling when compared to seniors (7.8 ± 2.4 vs. 11.4 ± 2.1 $mmol \cdot l^{-1}$ and 7.9 ± 3.0 vs. 12.0 ± 1.9 $mmol \cdot l^{-1}$, respectively); furthermore, blood lactate values after cranking increased with age ($r = 0.473$, $p < 0.017$). These differences should be considered in planning the training for judo athletes of different age classes.

KEY WORDS: **VO_2peak, physiological responses, arm performance, leg performance, specific ergometric testing, age classes**

INTRODUCTION

Judo is a martial art and an Olympic sport, comprising standing and ground wrestling. Competitors are separated by sex and organised in age classes and weight divisions. Recently (Singapore, August 2010) it has also been included in the programme of the inaugural Summer Youth Olympic Games, for young judo athletes aged 15-17 yrs, and its cadet World Championship was revised [16]. The regular duration of a match, plus the possible extra time when the initial period is finished in parity, is 3 min for children under 15 years, i.e. U15, 4 (+2) min for juveniles, i.e. cadets, U17, and for juniors, U20, and 5 (+3) min for adults, i.e. seniors, +20. During competition judokas may sustain up to 7 fights. Both arms and legs (upper and lower body) contribute to determining combat performance. Taking into account the duration and nature of a judo match, where endurance in repetitive explosive strength bouts is required throughout the fights, from a metabolic point of view judo is considered a mixed sport, aerobic and anaerobic [9,29].

Despite the rising numbers of high-level judo competitions for young athletes, very few studies have investigated U15 judokas [20, 21,24,25] and no standard ergometric test seems to have been used in child judo athletes. To our knowledge, only Little [19], Franchini et al. [12] and Pocecco et al. [22] have investigated age-dependent differences in ergometric performance regarding cadet and senior male judo competitors.

Additionally, as judo matches are characterized by high-intensity intermittent actions, aerobic power seems to be an important component to be developed [9,28]. In fact, Gariod et al. [14] identified judo athletes with aerobic or anaerobic profiles and reported that these athletes presented different recovery processes, i.e., judo athletes with an aerobic profile had a lower muscle creatine phosphate resynthesis half time and finished an exhaustive task with higher intracellular pH. Franchini et al. [13] reported that a higher anaerobic threshold velocity was correlated ($r = -0.69$ to -0.87) with lower blood lactate after combat simulation and that this aerobic capacity variable was also correlated ($r = 0.61$ to $r = 0.84$) with a better performance during the first two upper-body Wingate tests after 15-min active recovery conducted after the combat simulation. Thus, better aerobic fitness would contribute to a faster recovery between matches, which could be a determinant for a better combat performance [8].

Although elite judo athletes seem to differ from non elite ones concerning performance during upper-body [11] and lower-body Wingate tests [3], no difference was found when aerobic power and capacity were compared among elite and non elite judo athletes [11], principal versus reserves in national teams [3,10], or young judo athletes and untrained boys [26]. However, these studies used tests much longer than the match duration and utilised mostly lower-body ergometry, while the upper body is more solicited during judo matches. Additionally, little information is available concerning aerobic profiles of different age groups of judo athletes.

The aim of the present study was therefore to compare performance and physiological responses during arm and leg aerobic power tests of combat duration in male child, cadet and senior judo athletes.

MATERIALS AND METHODS

The test protocol, which was the same for all subjects, was adapted from our recent investigation [22] to reproduce match-like physical loads concerning duration and involved muscle groups. Indeed, as absolute power output is influenced by muscle mass and therefore by body mass, body mass-dependent power increments aimed at a similar test duration, i.e. competition duration, for all subjects, independent from their body mass and absolute power. The same incremental protocol was used for arms and legs but, as on the basis of our testing experience [4,22] lower body maximum power was about double than upper body maximum power, values of load increment/min on the arm crank ergometer were half of the values on the cycle ergometer, in order to reach about the same test duration. An ergometry with a continuous incremental load and of duration between 3 and 5 min, depending on fitness status, means that the tests were mainly aerobic.

The choice to adopt body mass-dependent power increments and to relate assessed maximum parameters to body mass was also determined by the necessity to have sport-specific conditions and parameters, taking into account the weight division system present in judo competitions.

Subjects

The test group investigated consisted of 25 injury-free, healthy, male athletes of the two main judo clubs of Tyrol (Austria). Characteristics of male children, U15, male cadets, U17, and male seniors, +20, are reported in Table 1.

All subjects were physically very active. Each judo-training session was of quite high intensity and lasted 1 h 30 min for all age classes. They all had competitive experience in judo tournaments at local, regional, national and some of them also at international level: 3 U15 judokas started to compete at higher level, 3 U17 and 4 +20 athletes also took part in international competitions. The athletes were made familiar with arm cranking before starting the test. All judokas were familiar with cycling even if they performed the proposed test protocol for the first time.

All testing procedures took place at the performance diagnostic laboratory of the Sports Institute of the University of Innsbruck and were conducted in the afternoon, at the end of the competitive period (in June). Athletes were normally hydrated at the time of testing, had a light meal at least 2 hours before, and avoided heavy exercise on the day prior to and day of testing. Written informed consent was provided by all subjects, or the parents if the athletes were minors, prior to their voluntary participation in the testing programme. The study was approved by the Institutional Review Board and conducted in accordance with the guidelines of the Declaration of Helsinki.

Procedures

Anthropometric measurements, body composition and basal measurements

After routine clinical examinations, stature and body mass were assessed using standard techniques. A tetrapolar, multi-frequency bioelectrical impedance analysis (BIA 2000, Data Input GmbH, Germany) was used to determine percentage of body fat (%fat). A capillary blood sample from the ear lobe was collected in order to determine basal concentration of blood lactate (LA) before starting the exercise tests.

Test for the upper body

The upper body test [22] was preceded by a standardized, non-specific warm-up, i.e. 10 min running or cycling followed by 5 min

TABLE 1. JUDOKAS' MAIN CHARACTERISTICS

	U15 (n=7)	U17 (n=10)	+20 (n=8)
Age (yrs)	12.7 ± 1.1 [a]	14.9 ± 0.7 [b]	29.3 ± 9.2 [c]
Height (cm)	160.0 ± 12.1 [a]	175.3 ± 8.6	181.0 ± 5.4 [c]
Body Mass (kg)	46.4 ± 10.3 [a]	65.0 ± 7.5 [b]	87.3 ± 13.5 [c]
BMI ($kg \cdot m^{-2}$)	17.9 ± 1.6 [a]	21.1 ± 0.7 [b]	26.6 ± 3.7 [c]
Body Fat (%)	9.9 ± 3.0	11.1 ± 3.6 [b]	17.3 ± 6.2 [c]
Judo Training Experience (yrs)	6.4 ± 1.5	7.5 ± 1.6 [b]	10.4 ± 3.3 [c]
Weekly Judo Training (hrs:mins)	04:08 ± 00:57	04:57 ± 01:01	04:40 ± 01:51

Note: Values are means ± SD for age, height, body mass, body mass index (BMI), percentage of body fat, judo training experience, and weekly judo training. Significant differences ($p < 0.05$) between U15 and U17 (a), U17 and +20 (b), U15 and +20 (c) judo athletes.

of stretching exercises, and a specific warm-up, i.e. 3 min cranking on the test ergometer at a power corresponding to 0.5 $W \cdot kg^{-1}$ of body mass, immediately before starting the assessment programme at the same power of 0.5 $W \cdot kg^{-1}$. The protocol consisted of a continuous incremental test using an arm crank ergometer (Ergometrics er800SH, Ergoline, Germany) [22]. The increment of power per min was 0.5 $W \cdot kg^{-1} \cdot min^{-1}$, with gradual increment units of 5 W at regular time intervals, intending to reach a test duration of between 3 and 5 min. As an example, an athlete of 60 kg started the test cranking at a power of 30 W and had 5 W increments every 10 s (i.e. 30 $W \cdot min^{-1}$). The test ended when, due to physical or psychological exhaustion, a cranking frequency above 40 revolutions per minute could no longer be maintained. Maximum power at the end of the test (Pmax) and total crank time to exhaustion (Time) were recorded. Oxygen uptake ($\dot{V}O_2$) and minute ventilation (VE) were determined as the averages of 30 s by breath-by-breath measurements (Oxycon Mobile, Jaeger, Germany) in order to have peak values of oxygen uptake ($\dot{V}O_2$peak) and minute ventilation (VEpeak). Heart rate was monitored continuously during the exercise test (Polar 810, Finland). The highest heart rate observed was defined as peak heart rate (HRpeak). At the end of the test, athletes expressed their rate of perceived exertion (RPE) for breathing effort (RPE-Br) as well as for muscle pain (RPE-Mm) indicated on the Borg scale [2]. Then athletes continued to crank against a low resistance for about half a minute in order to cool down. Three minutes after the end of the test, a blood sample was collected from the ear lobe for the measurement of LA.

Test for the lower body

The lower body test was performed after at least a 1-hour break following the upper body test. Considering that this test involves a larger muscle mass than the test with the arm crank ergometer, to reduce the negative effect of fatigue on performance, the sequence of the two tests was always the same. The protocol consisted of a continuous incremental test on an electrodynamically braked cycle ergometer (Ergoselect 100, Ergoline, Germany). The handle bar and saddle of the cycle were individually adjusted. The specific warm-up consisted of pedalling at a self-selected pace for 3 min at a power of 1 $W \cdot kg^{-1}$ of body mass. Then the test started immediately at the same power of 1 $W \cdot kg^{-1}$, with gradual increment units of 5 W at regular time intervals, corresponding to 1 $W \cdot kg^{-1} \cdot min^{-1}$, intending to reach a test duration of between 3 and 5 min. Subjects were free to choose the optimal pedalling rate; when the value sank below 50 revolutions per minute the test ended. Pmax and total cycling time to exhaustion (Time) were recorded. $\dot{V}O_2$ and VE were measured breath-by-breath during the test in order to determine peak values ($\dot{V}O_2$peak and VEpeak, respectively) using an open spirometric system (Oxycon Mobile, Jaeger, Germany). The highest heart rate registered during the test (Polar 810, Finland) was defined as HRpeak. RPE-Br and RPE-Mm were assessed with the Borg scale [2]. After this test, athletes continued pedalling for another minute at a low resistance. LA 3 min post-exercise was measured from ear lobe capillary blood.

Statistics

Standard descriptive statistical procedures were used to determine mean ± standard deviation (SD) values for each of the 3 groups of judo athletes. MANOVA was used to evaluate differences between means of the most relevant parameters. Simple correlation coefficients by Pearson were calculated to determine relationships between variables. Statistical significance was set at $p < 0.05$. The program used for statistical analyses was SPSS (version 15.0.1; SPSS Inc., Chicago, USA, 2006).

RESULTS

Table 2 shows the results of ergometric testing of upper and lower body (arms and legs). The test on the arm crank ergometer lasted about 3 min for children, corresponding to the 3 min of U15 official fighting time, and about 4 min for seniors and cadets, which is a bit less than the regular duration of a judo combat in seniors (lasting 5 min) but coincides with the match length of the U17 age class (Table 2). The cycling test lasted about 4 min for children, i.e. one min more than regular combat duration for this age class, and about 4 and half min in cadet and senior judokas, being in between fighting time of U17 (4 min) and +20 (5 min) age classes (Table 2).

Children ($p < 0.031$) as well as cadets ($p < 0.002$) had higher upper body relative $\dot{V}O_2$peak than seniors. Moreover, when compared to seniors, children showed lower blood lactate concentrations after cranking ($p < 0.013$) as well as after cycling ($p < 0.024$).

With increasing age upper and lower body relative $\dot{V}O_2$peak decreased ($r = -0.575$, $p < 0.003$ and $r = -0.580$, $p < 0.002$, respectively), LA after cranking increased ($r = 0.473$, $p < 0.017$), and rest and post-exercise HR decreased or tended to decrease (basal heart rate: U15: 83 bpm, U17: 70 bpm, +20: 64 bpm, $r = -0.473$, $p < 0.017$; $r = -0.387$, $p < 0.056$ after cranking and $r = -0.568$, $p < 0.003$ after cycling).

DISCUSSION

The objective of the present study was to compare performance and physiological responses during arm and leg aerobic power tests of combat duration in male child, cadet and senior judo athletes. The main results obtained showed that children as well as cadets had higher upper body relative $\dot{V}O_2$peak than seniors. Furthermore, with increasing age, upper and lower body $\dot{V}O_2$peak decreased. On the other hand, differences in relative $\dot{V}O_2$peak during lower body work between judo athletes of the three age classes did not reach significance. These results are in agreement with Pocecco et al. [22] and partially in accordance with Little [19], but in disagreement with Franchini et al. [12], concerning cadet and senior judokas. No data related to U15 judo athletes were found. To explain the present results, it could be speculated that more years of judo practice of seniors compared to cadets and children (10.4 ± 3.3 years vs. 7.5 ± 1.6 years and 6.4 ± 1.5 years, respectively) and of strength training, with more emphasis on the upper body compared to the lower body, could have led to specific muscle adaptations. This

TABLE 2. JUDOKAS' PERFORMANCE PARAMETERS ASSESSED DURING UPPER AND LOWER BODY ERGOMETRY

	U15 (n=7)	U17 (n=10)	+20 (n=8)
Upper Body			
Pmax (W)	106 ± 27 [a]	169 ± 24 [b]	223 ± 35 [c]
Pmax ($W \cdot kg^{-1}$)	2.3 ± 0.3	2.6 ± 0.3	2.6 ± 0.2
Time (s)	187 ± 49 [a]	248 ± 41	246 ± 29 [c]
$\dot{V}O_2$peak ($l \cdot min^{-1}$)	1.72 ± 0.39 [a]	2.54 ± 0.39	2.70 ± 0.41 [c]
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	37.3 ± 4.9	39.2 ± 5.0 [b]	31.0 ± 2.1 [c]
VEpeak ($l \cdot min^{-1}$)	70.9 ± 17.5 [a]	104.4 ± 24.6	132.4 ± 29.1 [c]
VEpeak ($l \cdot kg^{-1} \cdot min^{-1}$)	1.6 ± 0.3	1.6 ± 0.3	1.5 ± 0.3
HRpeak ($b \cdot min^{-1}$)	185 ± 17	186 ± 12	177 ± 13
RPE-Br	15 ± 2	13 ± 2	14 ± 1
RPE-Mm	17 ± 1	17 ± 2	17 ± 1
LA ($mmol \cdot l^{-1}$)	7.8 ± 2.4	10.4 ± 2.0	11.4 ± 2.1 [c]
Lower Body			
Pmax (W)	236 ± 57 [a]	348 ± 52 [b]	481 ± 98 [c]
Pmax($W \cdot kg^{-1}$)	5.1 ± 0.6	5.4 ± 0.7	5.5 ± 0.7
Time (s)	246 ± 36	265 ± 42	270 ± 45
$\dot{V}O_2$peak ($l \cdot min^{-1}$)	2.43 ± 0.57 [a]	3.31 ± 0.46	3.98 ± 0.70 [c]
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.6 ± 5.7	51.2 ± 6.5	45.9 ± 6.6
VEpeak ($l \cdot min^{-1}$)	88.9 ± 32.2	126.9 ± 24.7 [b]	172.6 ± 43.3 [c]
VEpeak ($l \cdot kg^{-1} \cdot min^{-1}$)	1.9 ± 0.5	2.0 ± 0.4	2.0 ± 0.4
HRpeak ($b \cdot min-^{-1}$)	189 ± 6	189 ± 12	179 ± 15
RPE-Br	16 ± 2	17 ± 2	16 ± 2
RPE-Mm	17 ± 2	17 ± 1	18 ± 1
LA ($mmol \cdot l^{-1}$)	7.9 ± 3.0	11.1 ± 2.9	12.0 ± 1.9 [c]
Ratios			
PmaxUB/PmaxLB (%)	45.6 ± 7.2	48.9 ± 6.6	47.0 ± 5.7
$\dot{V}O_2$peakUB/$\dot{V}O_2$peakLB (%)	71.3 ± 9.0	76.9 ± 8.2	68.4 ± 8.2

Note: Values are means ± SD for maximum power (Pmax), test duration (Time), peak oxygen uptake ($\dot{V}O_2$peak), peak ventilation (VEpeak), peak heart rate (HRpeak), rate of perceived exertion for breathing effort (RPE-Br) and for muscle pain (RPE-Mm), blood lactate concentration 3 min post-exercise (LA), ratio between upper and lower body maximum power (PmaxUB/PmaxLB) and $\dot{V}O_2$peak ($\dot{V}O_2$peakUB/$\dot{V}O_2$peakLB).
Significant differences ($p < 0.05$) between U15 and U17 (a), U17 and +20 (b), U15 and +20 (c) judo athletes.

theory is also supported by other authors discussing results of physiological testing of adult male judo athletes and wrestlers [15, 28], who furthermore suggest the possibility of differences in the fibre type distribution in the upper and lower body of adult combat sport athletes [15]. Indeed, resistance exercise may induce lower sympathetic [1] and hormonal responses (blood testosterone) in young men than in their adult counterparts; the latter are therefore likely to have a more anabolic response for adaptation [6]. This may have led to increased arm muscle mass in senior judokas without an adequate increase in aerobic capacity of the arms [27]. Further results from the literature [30] confirm these training adaptations, reporting an increase in muscle strength and cross-sectional area without an increase in capillary density and muscular microcirculation parameters following resistance training in adult non-athletic subjects. On the other hand, Karagounis et al. [17] reported significant upper and lower body arterial adaptation, i.e., limb arteries' diameter and blood mean flow velocity, in adult elite judo athletes compared to sedentary persons. However, neither cross-sectional nor longitudinal research on judokas seems to have studied capillary density.

When compared to seniors, children had lower blood lactate after cranking as well as after cycling. Moreover, LA after cranking increased with age. This trend is in accordance with Franchini et al. [12] as well as with Sterkowicz et al. [26] and is well known in the literature. For example, Boisseau and Delamarche [1, p. 410] stated that "the compromised ability to generate energy from glycolysis during exercise induces lower maximal muscle lactate levels in young individuals", and Eriksson and Saltin [7] reported that muscle lactate production increased with age.

Thus, we can conclude that judokas of different age classes reach similar relative Pmax values, but utilizing different proportions of the various energy systems. It could be speculated that a different volume and quality of training, in addition to a dissimilar response to it, could have contributed to the age-related differences in the present results.

Assessed post-exercise lactate values of senior judokas (11.4 ± 2.1 $mmol \cdot l^{-1}$ after cranking and 12.0 ± 1.9 $mmol \cdot l^{-1}$ after cycling) were very similar to data of adult male judo athletes after a competition match: 11.8 ± 3.9 mmol · l^{-1} [12] and 11.6 ± 4.8 mmol · l^{-1} to 12.7 ± 5.0 mmol · l^{-1} [8]. Also blood lactate values of tested cadet athletes (10.4 ± 2.0 mmol · l^{-1} after cranking and 11.1 ± 2.9 mmol · l^{-1} after cycling) were comparable to post-combat values of judokas of the same age: 10.2 ± 2.5 mmol · l^{-1} [12]. Moreover, there is also a certain similarity between present scores for RPE of +20 judokas, ranging from 14 ± 1 to 18 ± 1 (Table 2), and RPE values of male adult athletes after the last fight of a judo competition: 14.6 ± 0.7 [23]. The slightly lower value from the literature could be due to the deleted moment of assessment: retrospectively in a recall of 10 min after the match. These observations give an additional justification to our testing protocol. On the other hand, male cadets' RPE values after 3 judo combats reported in the literature (13 ± 2)[12] were somewhat lower than the present values, which ranged between 13 ± 2 and 17 ± 2. Unfortunately, no data concerning blood lactate concentration and RPE after judo fights seem to be available for child judokas.

The selected test protocols, even if of match duration and quite easy to reproduce, do not reflect exactly the intermittent nature of a judo match and of the whole judo competition. As a matter of fact, the tests were performed progressively, being mainly aerobic, while in judo the effort is supramaximal in the determinant actions used to score or defend, and is intermittent in nature considering the single match as well as the whole competition. However, it should be mentioned that the minimal recovery time of 15 min typically reported in judo competitions [13] seems to be long enough for a full performance recovery of highly trained judokas [8]. So the present tests seem to be a compromise between sport specificity and the possibility to assess maximum performance parameters with quite simple and reproducible laboratory tests. In future research, a higher number of subjects possibly representing all weight divisions among each age class would be advantageous, even if we are aware that in judo it is not easy to recruit such a high number of test participants. Also the male U20 as well as all female age classes should be represented. In the present study, unfortunately, a too low number of subjects in this age class and of this sex participated in the research to be of statistical relevance and could not therefore be included in the results. Moreover, the use of the RPE scale for young athletes, in order to have comparable data to those of cadets and seniors, instead of a child-specific Children's Effort Perception Table (CERT), remains questionable [18]. However, this research confirms some previous results concerning age differences in ergometric performance [22] and seems to be one of the first studies to research the aerobic profile of different age groups of judo athletes, including children, using specific upper and lower body ergometric tests.

CONCLUSIONS

Children and cadets presented higher upper body relative $\dot{V}O_2$peak compared to senior judo athletes. Moreover, when compared to seniors, children showed lower blood lactate concentrations after cranking as well as after cycling. Age was negatively related to $\dot{V}O_2$peak and positively related to LA after arm cranking. From these results we can conclude that there are differences in the upper and lower body physiological responses to specific arm and leg aerobic power tests of combat duration in male child, cadet and senior judo athletes. These differences should be considered in planning the training for judo athletes of different age classes.

Acknowledgements

The authors would like to acknowledge all the judo athletes who volunteered for this study as well as their trainers for the kind collaboration and the Tiroler Wissenschaftsfonds for the financial support.

This study has been published as an abstract.

Conflict of interest: none.

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