Energy System Contributions to the Special Judo Fitness Test

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Purpose: This study investigated the energy system contributions of judo athletes to the Special Judo Fitness Test (SJFT). Methods: Fourteen male judo athletes performed the SJFT, which comprised three periods of judo activity (A = 15 s, B and C = 30 s) interspersed with 10 s rest intervals. During this test, one athlete threw two others positioned 6 m from each other using the ippon-seoi-nage technique. The fractions of the aerobic, anaerobic alactic and anaerobic lactic systems were calculated based on oxygen uptake, the fast component of excess postexercise oxygen uptake, and changes in net blood lactate, respectively. The contribution of the three energy systems was compared using a repeated measures analysis of variance and Bonferroni’s multiple comparisons test. Compound symmetry, or sphericity, was determined by Mauchly’s test. A level of significance of 5% (P < .05) was adopted in all analyses. Results: The alactic energy system presented a higher (F = 20.9; P < .001; power observed = 1.0) contribution (86.8 ± 23.6 kJ; 42.3 ± 5.9%) during the test when compared with both aerobic (57.1 ± 11.3 kJ; 28.2 ± 2.9%) and lactic (58.9 ± 12.1 kJ; 29.5 ± 6.2%) energy systems (P < .001 for both comparisons). Conclusions: The higher alactic contribution seems to be a consequence of the high-intensity efforts performed during the test, and its intermittent nature. Thus, when using the SJFT, coaches are evaluating mainly their athletes’ anaerobic alactic system, which can be considered to be the most predominant system contributing to the actions (techniques) performed in the match.

Keywords: combat sports, test, evaluation, high-intensity intermittent exercise

Judo is a dynamic, high-intensity intermittent combat sport that requires complex skills and tactical excellence for success.1–3 As judo athletes have to perform a great number of actions during each match,4 the physical demand of a single match is high as inferred from physiological measurements (eg, blood lactate) conducted just after the matches,1,3,4 and from near maximal heart rate data measured continuously during a 5 min combat test.5 While the techniques that can be used to obtain physiological data in judo combat are restricted by the rules and regulations of the event, a number of specific judo movements have been...
examined to provide a more complete appraisal of the energetic requirements of the activity. In addition, as judo is a sport where training should be directed to different physical abilities (e.g., power, strength, endurance) to allow the athlete to perform his/her technical and tactical actions with better quality, physical conditioning plays an important role in the training and competitive processes. In this way, it is important to have specific tests to evaluate judo players’ physical fitness in order to improve their training routine and contribute to a higher level of performance in competitions.

For this reason some authors have attempted to develop judo specific tests. Among these and other tests proposed, the Special Judo Fitness Test (SJFT) is one of the most widely used tests in judo research and it is used by a number of national teams to evaluate competitors’ judo specific physical capabilities. However, no studies have estimated the energy systems contributions during the SJFT. The knowledge of the energy system contributions during this test would help to improve the evaluation process and direct the training stimulus to the specific physical requirements of each athlete. In addition, this knowledge may help to inform a researcher’s decision to include this test in studies designed to improve the metabolic profile of judo athletes. Thus, the objective of the present study was to estimate the energy system contributions of the SJFT. As the test was created based on the time structure of the judo match and involves specific movements, our hypothesis is that the test is predominantly anaerobic, but has an important aerobic contribution that is likely to play a significant role in the short pauses between high-intensity actions and in the last series of the test.

**Methods**

**Participants**

Fourteen male adult black belt judo athletes (age 19.5 ± 2.4 y, body mass 71.1 ± 7.9 kg, height 174.4 ± 4.4 cm) voluntarily participated in this investigation. Three athletes competed in the –60 kg, three in the –66 kg, six in the –73 kg, one in the –81 kg, and one in the –90 kg weight categories. We explained the testing procedures to the volunteers, each of whom provided written informed consent before participation. As one athlete was 16 years old, his parents also signed the informed consent. All judo athletes had been competing for at least 7–10 y and had previous experience in the execution of the SJFT. The athletes were tested during their preparatory period. The experimental protocol was approved by the Ethics Committee of the Medical University of Silesia, Katowice, Poland (no. NN-013-260/I/01).

**Study Design**

All judo athletes took part in three exercise sessions, with at least 24 to 48 h separating each session. The first two sessions were conducted for characterization purposes and involved a maximal oxygen consumption test (VO2max), and a Wingate test. During the third session a single SJFT was performed. The SJFT was performed on an official judo mat. Athletes were instructed to avoid high-intensity physical training for 24 h before testing to prevent the influence of residual fatigue from interfering with the test performance. During the tests, barometric pressure...
varied from 745 mmHg to 750 mmHg, temperature was between 23 and 25°C, and humidity varied from 50 to 52%.

Maximal Oxygen Consumption Test

During a graded maximal aerobic power test performed on a treadmill (Saturn HP Cosmos W, Germany), oxygen uptake (VO₂), carbon dioxide production (VCO₂), respiratory exchange ratio (RER), and pulmonary ventilation (VE) were measured breath by breath (continuously) using a portable telemetric transmission gas analyzer (K4b², Cosmed, Italy), which validation was previously determined, while heart rate (HR) was measured by the use of a single monitor Polar Team System (Polar Electro Oy, Finland) integrated within the gas analyzer, registering the HR data for each breath. The test started at 8 km·h⁻¹ (treadmill slope: 1.5%), the speed increased by 2 km·h⁻¹ every 3 min while the treadmill slope was kept constant. A 30 s rest interval was implemented between each stage to enable a blood sample to be obtained for the determination of blood lactate. This measurement was obtained using the Biosen C-line lactimeter (Germany), which has a variation lower than 1.5% at 12 mmol·L⁻¹, according to the manufacturer’s manual, and was used to determine the lactate threshold (the intensity resulting in an increase in 0.5 mmol·L⁻¹ in blood lactate concentration). The lactate threshold intensity was used as a reference to prescribe the intensity of the warm up before commencing the SJFT. The test was performed to volitional exhaustion and the criteria identified by Sbriccoli et al was used to determine the successful attainment of maximal oxygen uptake (VO₂max).

Wingate Test

A 30 s lower body Wingate test was performed on a Monark 824 E (Sweden). Load was set at 7.4 N·kg⁻¹ of body mass. Peak power and mean power were expressed relative to body mass as previously suggested. The procedures used by Sbriccoli et al were followed. Briefly, athletes warmed up during 5 min at self-selected pace and performed two 4 to 8 s “all-out” sprints at the end of the fourth and fifth minute. After a 5 min rest they started the Wingate test.

Special Judo Fitness Test Execution

Participants engaged in an active 25 min warm-up consisting of the following: 8 min of running (4 min at 80–100% of lactate threshold intensity, 2.5 min at 110% of lactate threshold intensity, and 1.5 min at 125% of lactate threshold intensity), 6 min of stretching (especially for quadriceps and hamstrings), 2 min of executing judo throwing techniques (three sets of 10 repetitions of the technique used during the test with 30 s interval between the sets), 3 min of stretching, 3 min of performing strength exercise with own body mass (push-ups: three sets of 20 repetitions with 2 min interval between sets, and burpees: two sets of 15 repetitions with 1 min interval between sets), and another 3 min of stretching. Next, the participants performed the SJFT once at the maximal effort they could afford. Briefly, the SJFT was divided in three periods (A = 15 s; B and C = 30 s) with 10 s intervals between them. Each partner was positioned 6 m apart and the participant was required to run to each partner and then throw them as many times as possible using the ippon-seoi-nage technique. Test representation is presented in Figure 1. Both partners had a similar
height and body mass as the athlete performing the test. Just after and 1 min after the test, HR was measured. The throws were added and the following index was calculated via the following equation:

\[
\text{Index} \left( \text{beats} \cdot \text{min}^{-1} \cdot \text{throw}^{-1} \right) = \frac{\text{final HR} \left( \text{beats} \cdot \text{min}^{-1} \right) + \text{HR 1 min after the test} \left( \text{beats} \cdot \text{min}^{-1} \right)}{\text{Number of throws}}
\]

The index is commonly used as an indicator of both aerobic and anaerobic fitness, as it has been correlated to both VO\textsubscript{2}\textmax (Index and VO\textsubscript{2}\textmax, \( r = -0.73 \)) and Wingate performance (Index and total work during the Wingate test, \( r = -0.71 \)).\textsuperscript{14} It is important to emphasize that a higher index indicates a poor SJFT performance, and that this test has been shown to be highly reliable.\textsuperscript{12}

Before the SJFT, immediately after, and 4 and 8 min after the end of the SJFT, blood was collected from their ear lobules to measure lactate concentration. Oxygen uptake and HR were measured continuously 1 min before the test, during the SJFT, and for a 6 min period after completing the test. The same devices used during the treadmill test were used to measure VO\textsubscript{2}, HR and blood lactate.

**Figure 1** — Special Judo Fitness Test representation.

### Calculation of the Energy Systems Contribution

Net aerobic energy (\( W_{\text{AER}} \)) was estimated by subtracting resting VO\textsubscript{2} (VO\textsubscript{2}\text{rest measured for a 5 min period before the warm-up, while the athletes were in a stationary standing position}) from the VO\textsubscript{2} area integrated over time during the SJFT time by the trapezoidal method.\textsuperscript{15} The contribution of the anaerobic alactic system (\( W_{\text{PCR}} \)) was considered to be the fast component of excess postexercise oxygen consumption.\textsuperscript{15–18} In the present study, we fitted the kinetics of post-SJFT oxygen consumption to a bi- and monoexponential model and observed that the slow component of the biexponential model was negligible. Thus, the post-SJFT breath-by-breath VO\textsubscript{2} data were fitted to a monoexponential model and \( W_{\text{PCR}} \) was obtained by the integration of the exponential part.

To estimate anaerobic lactic energy, a value of 1 mmol·L\textsuperscript{–1} blood lactate delta (peak blood lactate after the SJFT minus pre-SJFT blood lactate value) was considered to be equivalent to 3 mL O\textsubscript{2}·kg\textsuperscript{–1} body mass.\textsuperscript{19} A caloric equivalent of 20.9 kJ·L O\textsubscript{2}\textsuperscript{–1} was considered for the three energy systems. Total metabolic work was calculated as the sum of the three energy systems. In addition, the contributions of the three energy systems were also expressed as a percentage in relation to total energy expenditure. These analyses were similar to those conducted in studies investigating other sports\textsuperscript{15–18} and were based on the assumptions described by di Prampero and Ferretti.\textsuperscript{19}
Statistical Analysis

All analyses were performed using the SPSS software (version 13.0, Chicago, USA) and Power and Precision 3.2 (Biostat Inc., Nova Jersey, EUA). The descriptive analysis consisted of mean and standard deviation. The distribution of the data was analyzed using the Shapiro–Wilk test and the results showed a normal Gaussian distribution. The contribution of the three energy systems was compared using a repeated measures analysis of variance and Bonferroni’s multiple comparisons test. Compound symmetry, or sphericity, was determined by Mauchly’s test. A level of significance of 5% ($P < .05$) was adopted in all analyses.

Results

Table 1 presents VO2max during the treadmill test, peak and mean power during the Wingate test, and performance and energy systems contributions to the SJFT.

Table 1  Maximal oxygen consumption (VO2max) during the treadmill test, peak and mean power during the Wingate test, and performance and energy system contributions to the Special Judo Fitness Test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treadmill Test</strong></td>
<td></td>
</tr>
<tr>
<td>VO2max (mL·kg⁻¹·min⁻¹)</td>
<td>56.42 ± 3.61</td>
</tr>
<tr>
<td><strong>Wingate Test</strong></td>
<td></td>
</tr>
<tr>
<td>Peak power (W·kg⁻¹)</td>
<td>11.65 ± 2.89</td>
</tr>
<tr>
<td>Mean power (W·kg⁻¹)</td>
<td>10.03 ± 0.20</td>
</tr>
<tr>
<td><strong>Special Judo Fitness Test</strong></td>
<td></td>
</tr>
<tr>
<td>Number of throws during A</td>
<td>6 ± 0</td>
</tr>
<tr>
<td>Number of throws during B</td>
<td>10 ± 1</td>
</tr>
<tr>
<td>Number of throws during C</td>
<td>9 ± 1</td>
</tr>
<tr>
<td>Total number of throws</td>
<td>26 ± 2</td>
</tr>
<tr>
<td>HR immediately after (beats·min⁻¹)</td>
<td>196 ± 12</td>
</tr>
<tr>
<td>HR 1 min after the test (beats·min⁻¹)</td>
<td>169 ± 9</td>
</tr>
<tr>
<td>Index (beats·min⁻¹·throw⁻¹)</td>
<td>14.37 ± 1.33</td>
</tr>
<tr>
<td>Alactic contribution</td>
<td></td>
</tr>
<tr>
<td>Absolute (kJ)***</td>
<td>86.8 ± 23.6</td>
</tr>
<tr>
<td>Relative (%)†††</td>
<td>42.3 ± 5.9</td>
</tr>
<tr>
<td>Lactic contribution</td>
<td></td>
</tr>
<tr>
<td>Absolute (kJ)</td>
<td>58.9 ± 12.1</td>
</tr>
<tr>
<td>Relative (%)</td>
<td>29.5 ± 6.2</td>
</tr>
<tr>
<td>Aerobic contribution</td>
<td></td>
</tr>
<tr>
<td>Absolute (kJ)</td>
<td>57.1 ± 11.3</td>
</tr>
<tr>
<td>Relative (%)</td>
<td>28.2 ± 2.9</td>
</tr>
<tr>
<td>Total Energy Expenditure (kJ)</td>
<td>202.8 ± 35.1</td>
</tr>
</tbody>
</table>

***Different from lactic and aerobic energy systems ($P < .001$).
†††Different from lactic and aerobic energy systems ($P < .001$).
The alactic energy system presented a higher absolute (kilojoules) energy contribution ($F = 18.5; P = .0000$; observed power = 1.0) when compared with both aerobic and lactic energy systems ($P = .0002$ and $P = .006$, respectively). The same was found when the relative (%) participation was considered; ie, the alactic energy system presented a higher contribution ($F = 20.9; P = .000$; observed power = 1.0) when compared with both aerobic and lactic energy systems ($P = .0001$ and 0.004, respectively).

Figure 2 presents the oxygen uptake during both the SJFT and recovery. When each period during the test was considered the VO$_2$ values were as follows: A = 16.03 ± 2.43 mL·kg$^{-1}$·min$^{-1}$; first 10 s rest interval = 31.42 ± 0.86 mL·kg$^{-1}$·min$^{-1}$; B = 45.95 ± 1.17 mL·kg$^{-1}$·min$^{-1}$; second 10 s rest interval = 45.87 ± 0.69 mL·kg$^{-1}$·min$^{-1}$; C = 47.29 ± 0.75 mL·kg$^{-1}$·min$^{-1}$. When these values were compared, a significant difference was found ($F = 153.4; P = .0000$; observed power = 1.0). Oxygen uptake values achieved during part A of the test were lower than those achieved during all other moments of the test ($P = .0001$ for all comparisons). In addition, values achieved during the first 10 s rest interval were lower than those achieved in all other moments of the test ($P = .0001$). Oxygen uptake achieved during the C part of the SJFT represented 83.8 ± 1.3% of the VO$_2$max of the treadmill test.

Blood lactate also differed between moments of measurement ($F = 313.3; P = .0000$; observed power = 1.0). Blood lactate was lower pre-SJFT (2.54 ± 0.84 mmol·L$^{-1}$) compared with all other moments (immediately after = 10.80 ± 1.78 mmol·L$^{-1}$).
mmol·L⁻¹; 4 min after = 15.31 ± 1.93 mmol·L⁻¹; 8 min after = 15.69 ± 2.51 mmol·L⁻¹; P = .0002 for all comparisons). Values immediately after the SJFT were also lower than those found in subsequent measurements (P = .0002 for all comparisons). Peak blood lactate was achieved in the 4th minute for five athletes and in the 8th minute for all others, resulting in 15.85 ± 2.51 mmol·L⁻¹.

Discussion

To our knowledge, this is the first study to estimate the energy systems contributions during a specific judo fitness test. The results of the present study indicate that there was a higher alactic contribution compared with both aerobic and lactic contributions during the SJFT. The higher alactic contribution seems to be a consequence of the high-intensity efforts performed during the test, and of its intermittent nature. In fact, a predominance of the alactic energy system has been reported during short duration high-intensity intermittent exercise.20 Furthermore, during high-intensity intermittent exercise different investigations21–23 have reported an inhibition of the glycolytic energy system and an increase in the oxidative system contribution. It is possible that similar processes occurred during the SJFT.

The performance of this group during the SJFT is classified12 as poor when the index is considered. This result is attributed especially to a “poor/very poor” and “poor” result in HR immediately after and HR 1 min after the SJFT. The VO₂max of this group was also slightly below the values presented by both elite (58.1 ± 10.8 mL·kg⁻¹·min⁻¹) and nonelite (63.3 ± 10.6 mL·kg⁻¹·min⁻¹) judo athletes,24 but similar to that measured (52.9 ± 4.4 mL·kg⁻¹·min⁻¹) in Olympic-level judo athletes.5 Peak and mean power during Wingate test was lower than previously reported in explosive (16.2 ± 1.1 W·kg⁻¹), and endurance classified judo athletes (14.6 ± 0.9 W·kg⁻¹),25 but similar to that presented in Olympic-level judo athletes (12.1 ± 2.4 W·kg⁻¹).5 Mean power was slightly lower than presented by explosive (12.0 ± 0.9 W·kg⁻¹) and endurance classified judo athletes (12.0 ± 1.0 W·kg⁻¹),25 but higher than that presented in Olympic-level judo athletes (5.4 ± 1.1 W·kg⁻¹).5 Taken together, the poor performance during the SJFT, the slightly lower values of VO₂max, and peak and mean power presented by the athletes in the present study may be a consequence of the periodization phase that they were engaged in. As fitness status may influence the energetic contributions during the SJFT, this may limit the ability to generalize the present findings to other groups of judo athletes involved in different periodization phases and/or demonstrating divergent levels of fitness.

Although some previous studies have measured oxygen uptake during judo specific activities,6,26–29 other aspects related to the total energy expenditure and to the energy system contributions were not considered. In fact, only one study was found that considered the energy expenditure from sources other than the aerobic contribution.6 However, this is the first study to calculate the energy expenditure and the energy systems contributions in the SJFT.

Using a different protocol (one throw every 5 s during 4 min) and a small number of athletes (n = 4), Sugiyama and Kajitani28 found a slightly higher oxygen uptake during seoi-nage (46.57 ± 2.96 mL·kg⁻¹·min⁻¹) compared with that observed in our study (mean value during the SJFT: 43.90 ± 5.64 mL·kg⁻¹·min⁻¹). However, our values were much higher than that observed by Franchini et al6
using one seoi-nage throw every 15 s during 5 min (33.71 ± 5.68 mL·kg⁻¹·min⁻¹). These differences are possibly associated with the running exercise mode during the throws in the SJFT, which requires the involvement of more muscle mass performing high-intensity movements when compared with the displacement used in the previous studies that employed the seoi-nage during nage-komi (repetitive throwing practice exercise). In addition, the different fitness levels (eg, VO₂max) of the athletes, and the structure of the test (eg, work:rest intervals) may also have contributed to this difference. The total energy expenditure found by Sugiyama and Kajitani using the seoi-nage (8.12 ± 0.33 kJ/throw) was slightly above the values found in our study (7.81 ± 1.4 kJ/throw), but did not consider the anaerobic contribution of the effort. Franchini et al. also using the seoi-nage, reported an energy expenditure of 13.65 ± 4.30 kJ/throw. As the frequency of throws were much higher in our experiment (one throw every 0.35 s) compared with others, but the exercise duration was much lower (only 1 min 15 s compared with 4–5 min) it is possible that fatigue mechanisms could affect the efficiency resulting in higher energy expenditure per throw as the exercise becomes longer. The VO₂ measured during our experiment was higher than that observed during a 40 min match simulation (randori) in five male judo players who fought against 10 opponents (one every 4 min) and achieved a mean VO₂ of 28–31 mL·kg⁻¹·min⁻¹ with a VO₂peak of 39 mL·kg⁻¹·min⁻¹. In fact, using only one 3 min simulated judo match as reference, Ahmaidi et al. reported mean VO₂ values of 40.73 ± 4.05 mL·kg⁻¹·min⁻¹, which is similar to the mean VO₂ values achieved during the SJFT. Thus, it is possible that the SJFT may provide a reasonable approximation of the aerobic demand of authentic judo combat, as this situation often imposes higher physiological requirements than both training and simulated combat settings. In addition, the blood lactate after the SJFT was quite similar to that reported after match simulation (randori; 12.3 ± 0.8 mmol·L⁻¹) and after real competition (shiai; 13.2 ± 1.6 mmol·L⁻¹). This finding has been highlighted previously and may suggest that the SJFT induces similar glycolytic demands as these judo settings. During the SJFT, however, most of the lactate accumulated in the blood may reflect the predominance of lower body actions, whereas during the match simulation and competition this may represent the higher incidence of upper body actions required to maintain a strong grip (kumi-kata) on an opponent.

Conclusions and Practical Applications

In conclusion, the results of the present study demonstrate that the energy systems contribution during the SJFT is predominantly alactic, with significant contributions from both lactic and aerobic energy systems. In this way, when using the SJFT coaches are evaluating mainly their athletes’ anaerobic alactic system, which can be considered to be the most predominant system contributing to the actions (techniques) performed in the match, as the judo techniques are performed within a few seconds. These actions require a short, quick, all-out burst of maximal power which is mainly obtained from the alactic anaerobic system. In addition, this test also appears to provide a close approximation of the lactate response (eg, lactic energy system) and cardiorespiratory demand in authentic and simulated judo combat. Taken together these data indicate that the SJFT is valid in relation to the physiological demands imposed by judo combat.
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References