Short-term low-volume high-intensity intermittent training improves judo-specific performance

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Background & Study Aim:
An important aspect concerning the specificity principle is related to the time structure of the sport. The aim of our study was the effects of short-term low-volume high-intensity intermittent training (HIIT) added to traditional judo training on physiological and performance responses to judo-specific tasks.

Material & Methods:
Thirty-five judo athletes were randomly allocated to a control group (n = 8) and 3 HIIT groups: (1) lower-body cycle-ergometer (n = 9); (2) upper-body cycle-ergometer (n = 9); (3) uchi-komi (technique entrance) (n = 9). All protocols were constituted by 2 blocks of 10 sets of 20 s of all-out effort, with 10 s interval between sets and 5 min between blocks, executed twice per week for 4 weeks. Pre and post-training the athletes performed the Special Judo Fitness Test (SJFT) and a match simulation, with blood lactate, hormones (cortisol, C, and testosterone, T) and muscle damage marker (creatine kinase, CK, lactate dehydrogenase, LDH, aspartate aminotransferase, AST and alanine aminotransferase, ALT) measurements.

Results:
There was an increase (p = 0.031) in the number of throws in the SJFT for the upper-body group, while decreasing the HR immediately after the SJFT and the number of sequences in standing position for the lower-body group (p < 0.001 and p = 0.034, respectively), the index in the SJFT for the uchi-komi group (p = 0.015) and the CK concentration (p = 0.014) in the match simulation for the upper-body group. T/C ratio increased (p = 0.028) after the match simulation in the post-training.

Conclusion:
All training modes improved performance, biochemical and hormonal response to judo-specific performance, but each group adapted in a different way.

Key words: athletes • combat sport • training intensity • training load • uchi-komi

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INTRODUCTION

Training prescription follows some basic principles to improve athletes’ physical conditioning and competitive performance [1]. One of the most important training principles is the specificity of adaptation, which is defined as “the method whereby an athlete is trained in a specific manner to produce a specific adaptation or training response” [2]. Thus, the type of stimulus placed on the athlete dictates the adaptation that will occur [2].

An important aspect concerning the specificity principle is related to the time structure of the sport. Time-motion analysis were conducted to identify precisely what is performed during competition to help coaches to replicate this temporal structure during training sessions [3]. Combat sports are considered high-intensity intermittent sports, and recent studies described the time structure of judo matches [4-6]. Typically, judo matches are composed of ten to twelve 20 s action sequences interspersed by 10 s pauses [5].

In the last two decades high-intensity intermittent exercise has become recommended worldwide for different populations searching for improvement in physical fitness and for athletic groups looking for both aerobic and anaerobic fitness improvement in short periods of time [7]. In combat sports, specific high-intensity intermittent exercise protocols have been investigated [8, 9], but few longitudinal studies were conducted with athletes from combat sports [10-13], despite the intermittent nature of these sports (these and further remarks concern data from the scientific literature, to which we have limited access due to language barriers – see Barczyński et al. [14] and editorial note in article Vacher et al. [15]). Moreover, from all the investigations about high-intensity intermittent training (HIIT) involving athletes from combat sports, none included a sport-specific protocol, i.e., the studies investigated only running as an exercise mode. Although judo athletes frequently engage in non-specific training activities [16], it would be important to verify if a judo-specific high-intensity intermittent training protocol would result in better transferance for judo-specific performance compared to more general approaches.

In fact, longitudinal studies investigating the adaptation of combat sport athletes to different HIIT protocols have also focused on non-specific indicators, such as VO₂max, time limit, performance in four sequential Wingate tests, performance in supramaximal Wingate tests at fixed intensity (e.g., 120% vVO₂max) and maximal accumulated oxygen deficit during running [10-12]. Thus, the type of performance tests used to verify the performance change are not sport-specific and the transference to actual combat performance may be questioned.

Only Bonato et al. [13] used a judo-specific test (the Special Judo Fitness Test, SJFT) to verify the effects of an aerobic training program (consisting of 2 sessions per week of 30 min continuous running at 60% of maximum aerobic speed – MAS – and one session per week of HIIT consisting of 15 x 1 min at 90% MAS with 1 min intervals of active recovery at 60% of MAS) on performance. The authors reported a 12% improvement in the SJFT index after 12 weeks of such a program. However, it is important to note that the interval training program was submaximal.

Another important characteristic of judo combat is the very high demand placed upon the upper-body due to the constant pushing and pulling actions executed during the grip dispute and technique entrance, while the lower-body segments perform low-intensity actions during feints and approximations interspersed by high-intensity explosive actions during technique entrance [9]. Thus, judo athletes frequently perform high-intensity training for both upper- and lower-body segments [16]. However, little is known about the effects of different modes of HIIT on judo-specific performance and on the physiological response to these tests.

The aim of our study was the effects of short-term low-volume high-intensity intermittent training added to traditional judo training on physiological and performance responses to judo-specific tasks.

The hypothesis of the present study was that judo athletes submitted to the more specific protocol would present better transference to judo-specific performance tests, while groups submitted to general stimulus would present smaller improvement in those tests.

MATERIAL AND METHODS

Design

This study adopted an experimental design. Three groups of judo athletes were randomly formed and
submitted to 4 week HIIT programs directed to the lower-body, upper-body or throwing technique entrance (uchi-komi) added to the regular judo training, while the fourth group (control) performed only the regular judo training. After familiarization with all test procedures, athletes were submitted to the SJFT and to a judo match simulation.

The tests were conducted on the same day, one week before the training protocol started and one week after the ending of the 4 week training. Eighty minute intervals were given between the SJFT and the match simulation. The same test sequence was adopted in the post-test, at the same time of day.

**Participants**

Thirty-five male judo athletes were recruited to take part in the present study after giving their signed consent, as well as that of their guardians for the three athletes aged 17 (who turned 18 years old the year the project was conducted). Athletes were from eight different judo clubs and competed with each other at the state level. All procedures were approved by the Ethics and Research Committee.

To take part in this study the athletes were required to present the following characteristics: (1) to have taken part in official judo competitions during the current year; (2) to be training at least four times per week; (3) to be aged equal to or higher than 17 years old and less than 35 years old; (4) to be competing in the under 100 kg categories; (5) not to be involved with any process of weight loss; (6) not involved with any supplementation or medical treatment. At the time of the experiment athletes were engaged in four 1.5 to 2 h judo sessions per week and in three strength training sessions per week. Groups did not differ (p > 0.05) regarding age, body mass, height and time of judo practice, respectively: **lower-body** (n = 9) 22.3 ±5.2 years old, 76.9 ±10.9 kg, 173.5 ±10.9 cm and 12 ±7 years of practice; **upper-body** (n = 9) 23.6 ±6.7 years old, 84.2 ±13.4 kg, 174.0 ±5.7 cm, and 15 ±7 years of practice; **uchi-komi** (n = 9) 23.4 ±4.2 years old, 78.1 ±13.4 kg, 175.4 ±7.3 cm and 12 ±7 years of practice; **control group** (n = 8) 26.4 ±7.0 years old, 80.2 ±10.3 kg, 175.0 ±7.0 cm, 18 ±7 years of practice.

**Training protocols**

All experimental and control group performed the same judo training sessions. As in the studies of Ravier et al. [10] with karate athletes and Farzad et al. [11] with wrestlers, the experimental groups were submitted to complementary HIIT twice a week. The lower- and upper-body groups performed a 5 min warm-up at 40% of maximal aerobic power (MAP). For the lower-body group the warm-up was conducted at 70 rpm, while for the upper-body group cadence was set at 90 rpm, each on a specific ergometer. The warm-up of the uchi-komi group was 5 min in duration, with movements and entrances of the techniques without throwing the other athlete, who had a similar body mass to the executant (difference set at ± 10% of body mass). After the warm-up the athletes rested 3 min before starting the proposed protocol. The training session was a total of 22 min 40 s, considering the 5 min warm-up, 3 min rest after warm-up, one block of 4 min 50 s of high-intensity intermittent exercise (ten times 20 s effort followed by a 10 s pause), 5 min recovery and the 2nd block of high-intensity intermittent workout.

The only difference in the groups undergoing additional HIIT training was the way the high-intensity intermittent exercise was conducted: (1) the lower-body group performed the HIIT using a lower-body cycle-ergometer. Each effort was an all-out bout using 4.5% of body mass as resistance; (2) the upper-body group underwent exactly the same protocol as used by the lower-body group, except that the ergometer used was an upper-body cycle-ergometer and the load used was 3% of body mass; (3) the specific group was submitted to uchi-komi (technique entrance) with projection at the end of each series.

Similar to the other groups, the athletes in this group were also asked to perform each set in an all-out mode. The technique entrance was conducted on the tatami, and athletes were asked to perform either te-uwaza (arm techniques, such as morote-seoi-nage, ippon seoi-nage) or koshi-uwaza (hip techniques, such as o-goshi, harai-goshi and koshi-guruma). During the execution of uchi-komi, the athletes were also requested to execute the pulling action and the technique execution in its complete form and throw their partner at the end of each 20 s period.

The choice of this temporal structure was due to the following factors: (1) judo fights have an average duration of 3 min, with actions performed in about 10 sequences lasting around 20 s, with 10 s...
interval between them [4]; (2) these protocols can be executed in less than 15 min, including interval periods of rest between sets and between blocks of exercise; (3) in each session, the total exercise time does not exceed 7 min, resulting in only a small addition to the total weekly training volume.

The mean training load for the 8 HIIT sessions, assessed via the method proposed by Foster et al. [17], did not differ (p>0.05) between the experimental groups: lower-body group = 171.7 ± 51.5 a.u.; upper-body training group = 168.6 ± 55.8 a.u.; uchi-komi training group = 190.8 ± 45.0 a.u.

Special Judo Fitness Test
This test was developed by Sterkowicz [18]. Briefly, this test is divided into 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 athlete being tested was required to run to each partner and then throw them as many times as possible using the ippon-seoi-nage technique. Both partners had a similar height and body mass as the athlete performing the test. Just after and 1 min after the test, heart rate was measured by a Polar T-31 device (Polar, Finland). The throws were summed and the following index was calculated:

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

The ICC for the SJFT variables in our laboratory, using a similar sample, was as follows: throws (0.73), heart rate (HR) after the test (0.93), HR 1 min after the test (0.89), and index (0.89) [19].

Blood samples (25 μl) from the ear lobe were taken before, 1-, 3- and 5 min after the SJFT to determine blood lactate concentration using an automated device (YSI 1500, Yellow Springs, OH, USA). The highest value measured after the SJFT was used as a peak blood lactate concentration, and delta of lactate was calculated (peak lactate concentration after the test minus the lactate concentration at rest).

Judo match simulation and technical-tactical analysis
Each athlete performed one 5 min match simulation. Opponents were from the same weight category and technical level and were not involved in any other physical exertion during the experimental conditions. Combat was mediated according to official rules.

All matches were video-recorded (Sony DCR-DVD508) in order to provide information on technical actions and time-motion analysis. Match analysis followed the procedures validated by Miarka et al. [20], using the FRAMI software, to determine the following time structure and technical action variables: (a) time structure: Time-motion measures were composed of combat time, standing combat time, preparation time without contact, gripping time, groundwork combat time and pause time. The frequency of each time-motion indicator was collected per match and expressed by s of fighting time and per sequence (defined as the time between baijime – beginning command – and matte – stop command), following preceding recommendations [4, 6]; (b) technical actions – all techniques were classified and accounted following the Kodokan technical classification, as suggested by previous studies [4, 6]: ashi-waza – leg-technique; te-waza – arm technique; koshi-waza – hip technique; sutemi-waza – sacrifice technique; kansetsu-waza – elbow joint-lock technique; shime-waza – strangle technique; osae-waza – immobilization technique.

During the match simulation the following variables were measured: (a) rating of perceived exertion – registered immediately after the match using the Borg 6-20 scale [21]; (b) blood lactate 25 μl blood ear samples were taken before 1-, 3- and 5 min after the match (blood lactate was measured using an automated device (YSI 1500, Yellow Springs, OH, USA). The highest value measured after the match was used as the peak blood lactate concentration, and delta of lactate was calculated (peak lactate concentration after the test minus the lactate concentration at rest); (c) heart rate (HR) – measured via a HR monitor (Polar T-31, Polar, Finland).

Venous blood sampling and analyses
Venous blood samples were collected by venous puncture from an antecubital vein (15 mL) pre- and post-training period before and after the lower
and upper-body high-intensity intermittent tests. Athletes always performed the tests in the same schedule (afternoon and evening). They reported an adequate hydration status and sleep before the day of each testing protocol. Blood samples were collected at rest in a lying position and room temperature (~20º C) on all days for all athletes to eliminate fluctuations in circulating analyte concentration because of circadian rhythm.

The blood samples (15 mL) were immediately allocated into two 5 mL vacutainer tubes (Becton Dickinson, BD, Juiz de Fora, MG, Brazil) containing EDTA for plasma separation and into one 5 mL dry vacutainer tube for serum separation. The tubes were centrifuged at 3,500 g for 12 min at 4º C, and plasma and serum samples were stored at ~8º C until analysis. To eliminate inter-assay variance, all samples were analysed in identical runs, resulting in an intra-assay variance of < 5%. Testosterone and cortisol were assessed using ELISA commercial kits (Monobind Inc. 100 North Point Drive, Lake Forest, CA 92630 USA). Creatine kinase (CK) lactate dehydrogenase (LDH), aspartate aminotransferase (AST), and alanine aminotransferase (ALT) were assessed using commercial kits (Labtest®, São Paulo, Brazil). The testosterone and cortisol levels were assessed using plasma, and CK, LDH, AST and ALT levels were assessed using serum. As there was evidence [10, 11] that no change would occur in the control group, the venous blood samples were not taken and, thus, the muscle damage markers and hormonal responses were not measured for this group.

Statistics analyses
All analyses were performed using the Statistica software (version 12). Data was reported as means and standard deviation (±). A Mauchly’s test of sphericity was used to test this assumption, and a Greenhouse–Geisser correction was applied when necessary. A two-way (group and period of training) and three-way (group, period of training and moment of measurement) analysis of variance with repeated measures were applied to compare performance in the variables derived from the physical test and match simulation. Bonferroni’s multiple comparisons test was used when a significant difference was found in the analysis of variance. When only the period of training factor was found, paired Student t tests was conducted for each group to verify the effect of each training protocol. The 95% confidence intervals (CIs) and effect sizes using Cohen’s were calculated and classified as proposed by Rhea [22] following the scale for highly trained individuals for interpretation: < 0.25 [trivial]; 0.25 to < 0.5 [small]; 0.5 to < 1.0 [moderate]; > 1.0 [large]. Statistical significance was set at p < 0.05.

RESULTS

Judo-specific tests
Table 1 presents the judo-specific tests’ performances and delta of lactate in the special Judo fitness test.

For the total number of throws in the SJFT there was a period of training and group interaction effect, with higher values post- compared to pre-training for the upper-body group (p = 0.031, CI —0.84 to —2.93, d = 1.00).

For HR immediately after the SJFT, there was a period of training effect, with higher values pre- than post-training (p = 0.034, CI 0.32 to

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lower-body training group (n = 9)</th>
<th>Upper-body training group (n = 9)</th>
<th>Uchi-komi training group (n = 9)</th>
<th>Control group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Number of throws in the SJFT (rep)</td>
<td>27±3</td>
<td>27±3</td>
<td>25±2*</td>
<td>27±2</td>
</tr>
<tr>
<td>HR after the SJFT (bpm)</td>
<td>181±9*</td>
<td>174±9</td>
<td>175±11</td>
<td>177±13</td>
</tr>
<tr>
<td>HR 1 min after the SJFT (bpm)</td>
<td>152±10</td>
<td>150±13</td>
<td>142±22</td>
<td>144±13</td>
</tr>
<tr>
<td>SJFT index (beats.min−1·throw−1)</td>
<td>13±2</td>
<td>12±2</td>
<td>13±3</td>
<td>12±1</td>
</tr>
<tr>
<td>Delta blood lactate SJFT (mmol.L−1) #</td>
<td>8±1</td>
<td>7±3</td>
<td>10±2</td>
<td>10±2</td>
</tr>
</tbody>
</table>

Note: SJFT Special Judo Fitness Test; HR heart rate; * different from post-training (p < 0.05); *lower-body training group different from control group (p < 0.05).
Isolated t tests for each group revealed lower values in post- than pre-training only in the lower-body group (p = 0.006, CI 2.84 to 12.04, d = 0.87).

For the SJFT index, there was a period of training effect, with higher values pre- than post-training (p = 0.029, CI 0.10 to 0.93, d = 0.27). Isolated t tests indicated lower values post- than pre-training in the uchi-komi group only (p = 0.015, CI 0.29 to 1.93, d = 0.84).

For delta of lactate, only a tendency to lower values in the lower-body group compared to uchi-komi group (p = 0.051, CI 0.49 to 5.36, d = 1.35).

Table 2. Time structure of judo combat pre- and post- three different high-intensity intermittent training protocols (values are mean ± standard deviation).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lower-body training group (n = 9)</th>
<th>Upper-body training group (n = 9)</th>
<th>Uchi-komi training group (n = 9)</th>
<th>Control group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Standing sequences (n)</td>
<td>13±2*</td>
<td>10±3</td>
<td>11±3</td>
<td>11±3</td>
</tr>
<tr>
<td>Groundwork sequences (n)</td>
<td>4±3</td>
<td>3±3</td>
<td>5±3</td>
<td>3±2</td>
</tr>
<tr>
<td>Preparation time per sequence (s)</td>
<td>7±8</td>
<td>5±2</td>
<td>5±2</td>
<td>6±2</td>
</tr>
<tr>
<td>Gripping time per sequence (s)</td>
<td>15±5</td>
<td>16±6</td>
<td>16±6</td>
<td>17±6</td>
</tr>
<tr>
<td>Standing combat time per sequence (s)</td>
<td>24±7</td>
<td>26±4</td>
<td>23±5</td>
<td>26±7</td>
</tr>
<tr>
<td>Groundwork time per sequence (s)</td>
<td>6±4</td>
<td>9±6</td>
<td>8±5</td>
<td>7±6</td>
</tr>
<tr>
<td>Pause time per sequence (s)</td>
<td>11±10</td>
<td>9±2</td>
<td>7±2</td>
<td>8±2</td>
</tr>
</tbody>
</table>

Note: Sequence time between beginning (hajime) and interruption (mate) commands; * different from post-training (p < 0.05).

Table 3. Type and quantity of techniques used during the judo combat pre- and post- three different high-intensity intermittent training protocols (values are mean ± standard deviation).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lower-body training group (n = 9)</th>
<th>Upper-body training group (n = 9)</th>
<th>Uchi-komi training group (n = 9)</th>
<th>Control group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attacks performed in standing position (n)</td>
<td>10±6</td>
<td>10±5</td>
<td>12±3</td>
<td>13±4</td>
</tr>
<tr>
<td>Different attacks used (n)</td>
<td>8±3</td>
<td>7±3</td>
<td>5±3</td>
<td>6±1</td>
</tr>
<tr>
<td>Leg techniques per match (n)</td>
<td>6±4</td>
<td>6±4</td>
<td>7±4</td>
<td>9±4</td>
</tr>
<tr>
<td>Hip techniques per match (n)</td>
<td>1±2</td>
<td>1±1</td>
<td>0±1</td>
<td>1±1</td>
</tr>
<tr>
<td>Arm techniques per match (n)</td>
<td>1±1</td>
<td>2±2</td>
<td>3±3</td>
<td>3±3</td>
</tr>
<tr>
<td>Sacrifice techniques per match (n)</td>
<td>2±2</td>
<td>1±1</td>
<td>1±1</td>
<td>0±1</td>
</tr>
<tr>
<td>Immobilizations per match (n)</td>
<td>0±1</td>
<td>0±1</td>
<td>0±1</td>
<td>0±1</td>
</tr>
<tr>
<td>Strangles per match (n)</td>
<td>0±0</td>
<td>0±0</td>
<td>0±0</td>
<td>0±0</td>
</tr>
<tr>
<td>Joint-locks per match (n)</td>
<td>0±0</td>
<td>0±0</td>
<td>0±0</td>
<td>0±0</td>
</tr>
</tbody>
</table>

Time-motion and judo match analysis

Table 2 presents the time-motion analysis of the judo matches before and after three different high-intensity intermittent training protocols.

For the number of standing sequences there was a training period and group interaction effect, but only in lower-body group the values in post- were lower compared to pre-training (p = 0.034, CI 0.19 to 1.67, d = 1.17). For the other variables related to time-motion there were no effects (p > 0.05).

Table 3 presents the technical analysis of the judo matches before and after three different high-intensity intermittent training protocols.
Table 4. Rating of perceived exertion, delta blood lactate, and heart rate responses to the judo matches pre- and post- three different high-intensity intermittent training (values are mean ± standard deviation).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lower-body training (n = 9)</th>
<th>Upper-body training (n = 9)</th>
<th>Uchi-komi training group (n = 9)</th>
<th>Control group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Rating of perceived exertion</td>
<td>15±2</td>
<td>16±2</td>
<td>16±2</td>
<td>15±2</td>
</tr>
<tr>
<td>(a.u.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delta blood lactate (mmol.L⁻¹)</td>
<td>6±3</td>
<td>6±2</td>
<td>6±3</td>
<td>8±2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9±4</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>169±11</td>
<td>156±23</td>
<td>175±5</td>
<td>169±13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>172±11</td>
</tr>
</tbody>
</table>

For the technical variables, there were no effects (p > 0.05). For the delta blood lactate, HR, and RPE in response to the judo match there were no effects of group, training period or interaction (p > 0.05, Table 4).

Table 5 presents the muscle damage markers and hormonal responses to the judo matches before and after three different HIIT protocols.

For the creatine kinase concentration response to the judo match an effect of moment of measurement was observed, with higher values after combat compared to before (p < 0.001, CI −106.07 to −55.52, d = 0.24). An effect of training period was detected, with lower values post-training compared to pre-training (p = 0.029, CI 21.55 to 476.91, d = 0.72). When each group was analysed isolated this difference was confirmed only for the upper-body training group (p = 0.014, CI 114.41 to 478.16, d = 1.39).

For LDH (p < 0.001, CI −36.60 to −9.01, d = 0.63), AST (p < 0.001, CI −1.36 to −0.66, d = 0.52) and ALT (p < 0.001, CI −1.73 to −0.92, d = 0.67) only an effect of moment was found, with higher values after compared to before the match simulation. For cortisol response to the judo match simulation there were no effects (p > 0.05) of group, moment of measurement, training period or interaction.

For the technical variables, there were no effects (p > 0.05). For the delta blood lactate, HR, and RPE in response to the judo match there were no effects of group, training period or interaction (p > 0.05, Table 4).

Table 5. Muscle damage markers and hormonal responses to the judo matches pre- and post- three different high-intensity intermittent training (values are mean ± standard deviation).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Circumstances</th>
<th>Lower-body training (n = 9)</th>
<th>Upper-body training (n = 9)</th>
<th>Uchi-komi training group (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK (U.L⁻¹)</td>
<td>before the match</td>
<td>303.3±262.1</td>
<td>305.6±210.2</td>
<td>219.8±105.8</td>
</tr>
<tr>
<td></td>
<td>after the match</td>
<td>370.6±256.8</td>
<td>592.4±248.9</td>
<td>291.8±170.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>763.7±780.9</td>
<td>736.7±780.9</td>
<td></td>
</tr>
<tr>
<td>LDH (U.L⁻¹)</td>
<td>before the match</td>
<td>73.1±25.7</td>
<td>71.1±23.4</td>
<td>76.6±19.8</td>
</tr>
<tr>
<td></td>
<td>after the match</td>
<td>81.8±27.3</td>
<td>83.6±14.5</td>
<td>96.8±32.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>102.4±17.2</td>
<td>115.2±12.2</td>
<td></td>
</tr>
<tr>
<td>ST (U.L⁻¹)</td>
<td>before the match</td>
<td>5.0±0.9</td>
<td>4.6±2.8</td>
<td>5.8±2.1</td>
</tr>
<tr>
<td></td>
<td>after the match</td>
<td>5.3±0.9</td>
<td>6.2±3.2</td>
<td>6.4±2.6</td>
</tr>
<tr>
<td>ALT (U.L⁻¹)</td>
<td>before the match</td>
<td>2.95±1.19</td>
<td>4.11±2.17</td>
<td>5.29±2.8</td>
</tr>
<tr>
<td></td>
<td>after the match</td>
<td>4.57±0.67</td>
<td>5.58±3.27</td>
<td>6.48±3.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.04±1.11</td>
<td>6.46±1.68</td>
<td></td>
</tr>
<tr>
<td>Cortisol</td>
<td>before the match</td>
<td>12.22±6.20</td>
<td>11.89±6.70</td>
<td>9.26±5.01</td>
</tr>
<tr>
<td>(ng.mL⁻¹)</td>
<td>after the match</td>
<td>12.96±6.62</td>
<td>10.83±6.45</td>
<td>9.64±6.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.13±6.47</td>
<td>9.08±7.08</td>
<td></td>
</tr>
<tr>
<td>Testosterone</td>
<td>before the match</td>
<td>4.53±1.42</td>
<td>4.55±1.54</td>
<td>5.07±0.15</td>
</tr>
<tr>
<td>(ng.mL⁻¹)</td>
<td>after the match</td>
<td>4.56±1.41</td>
<td>4.61±1.56</td>
<td>5.20±0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.09±0.16</td>
<td>5.09±0.25</td>
<td></td>
</tr>
<tr>
<td>T/C (ng.mL⁻¹)</td>
<td>before the match</td>
<td>0.56±0.48</td>
<td>0.63±0.31</td>
<td>0.68±0.31</td>
</tr>
<tr>
<td></td>
<td>after the match</td>
<td>0.48±0.36</td>
<td>0.49±0.32</td>
<td>0.86±0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.63±0.49</td>
<td>1.00±0.71</td>
<td></td>
</tr>
</tbody>
</table>

Note: CK creatine kinase; LDH lactate dehydrogenase; AST aspartato transaminase; ALT alanine transaminase; different from after the match (p < 0.05); * pre-different from post-training in upper-body training group (p < 0.05); § after the match pre-training different from after the match post-training (p < 0.05).
Testosterone concentration response to the judo match simulation was affected only by moment of measurement, with higher values after the match compared to before the match simulation (p = 0.010, CI –0.36 to –0.03, d = 0.196). For the testosterone-cortisol ratio response to the match training period and moment of measurement interaction was detected. Values after the match at pre-training were lower than after the match at post-training (p = 0.028, CI –0.32 to –0.02, d = 0.334).

**Discussion**

The main findings of the present study were that the addition of a short-term, low-volume, HIIT program to the typical judo training program increased the number of throws in the SJFT for the upper-body training group, while decreasing the HR immediately after the SJFT and the number of sequences in standing position for the lower-body training group, the index in the SJFT for the uchi-komi training group, and the CK concentration the match simulation for the upper-body training group. Moreover, the T/C ratio increased after the match simulation in the post-training period. LDH, AST and ALT and testosterone concentrations were increased only by the execution of the match simulation, with no differences between groups or training periods. Additionally, no changes in delta blood lactate in the SJFT and match simulation, HR and RPE in response to match simulation. Thus, the hypothesis that judo athletes submitted to the more specific protocol would present better transference to judo-specific performance tests was not confirmed, as all training modes were able to improve performance, biochemical and hormonal response to judo-specific performance.

Both aerobic and anaerobic energy systems contributed to the SJFT performance [23] and HIIT has been reported to improve both aerobic and anaerobic fitness [7]. Thus, it is probable that the improvement in energy release through these pathways have contributed to an increased number of throws in the SJFT for the upper-body training group, decreased HR immediately the SJFT for the lower-body training group and improved index for the uchi-komi training group. These results suggest that each group adapted in a different way to the SJFT due to the different HIIT protocols. Furthermore, although the SJFT includes displacements using running as exercise mode, the ippon-seoi-nage is classified as an arm technique [9] and a higher transference may have occurred for the upper-body training group.

The decreased HR immediately the SJFT for the lower-body training group seems to indicated that the adaptations for this groups were mainly related to an improved aerobic fitness, which can be a consequence of the higher muscle mass involvement in this exercise mode, resulting in lower cardiovascular demand during the test execution. The uchi-komi training group had the most desirable improvement in this test, as a lower index is considered a mixture of aerobic and anaerobic improvements [24], and was probably generated due to both high muscle mass engagement in the technique entrance and to a positive transference of the technique execution to the ippon-seoi-nage performance during the test. A recent study [25] demonstrated that both undulating and linear strength 8 week training programs were able to increase the numbers of throws in the B and C sets of the SJFT and decreased the SJFT index without changing the HR response to this test. These results suggest that HIIT should be applied when SJFT aerobic-related adaptation is desired, while the SJFT anaerobic-related variables can be improved using either strength training or HIIT.

The lower-body HIIT protocol used in the present study decreased standing combat time per sequence during the match simulation. Most of the combat time in judo is spent in the standing position [4], more scores are obtained in this combat phase and judo matches are considered to have a high physiological demand [5]. Thus, the decrease in the standing combat time can be associated to the improved aerobic and anaerobic fitness generated by the HIIT protocols, which probably allowed the athletes to perform techniques in higher intensity despite spending less time in this preferrable condition where more scores are achieved. No change was observed concerning technical actions. Another study [25] investigating 8 weeks of linear and undulating strength training protocols also did not result in changes in technical actions during a simulated combat, despite changes in strength-related and in the SJFT performances. Thus, it seems that changes in physical fitness generated by short-term training protocols (4 to 8 weeks) do not affect technical-tactical actions during simulated judo combats.
Increased values of blood lactate were observed both in the SJFT and in the match simulation. Blood lactate is a common biochemical marker used to infer glycolytic activation during judo combat and a recent review [5] reported similar values as found in the present study. Farzad et al. [11] also did not find any changes in peak blood lactate after a high-intensity intermittent test (four Wingate bouts) after a 4 week HIIT protocol in wrestlers. Conversely, Ravier et al. [10] reported increased blood lactate after a supramaximal test to determine MAOD in karate athletes submitted to 7 week HIIT protocols. A possible explanation for this difference can be associated to the training period applied. Studies reporting higher blood lactate after supramaximal tests following HIIT protocols were typically longer than 6 weeks [26]. RPE, as expected, increased when the match simulation was conducted, but no change was found with HIIT protocols, probably because the athletes regulated themselves to perform a similar effort during the match, which was elevated after the match both pre- and post-training.

CK, LDH, AST and ALT increased after match simulations. Recent studies using grappling combat sports match simulations (e.g., judo and jiu-jitsu) also reported increased values post-compared to pre-match [27-31], although in some of these studies the increased concentration was significant only after 2 or 3 matches [30, 31]. Among the muscle damage markers used in the present study, only the CK response to the match simulation was decreased after the HIIT and only for the upper-body training group, which can be a consequence of the lower total muscle mass involved in this protocol compared to the others.

When HIIT studies using combat sports athletes are considered, only Farzad et al. [11] measured CK after a 4 week training protocol in wrestlers and observed increased values after the training period. However, as wrestlers were submitted to HIIT using running as an exercise mode, these athletes were submitted to a higher eccentric overload than the judo athletes from the present study, who executed 2 cycle-ergometer-type exercises and uchi-komi protocols. The cycle-ergometer protocols have minimal eccentric actions, while the uchi-komi is a very common judo exercise to which judo athletes are adapted. Taken together, these aspects may explain the difference observed between our study (maintenance of CK concentrations for the lower-body and uchi-komi training groups and decreased CK values for the upper-body training group) and the results reported by Farzad et al. [11]. No HIIT studies using combat sport athletes measured other muscle injury markers. In the present study, no evidence of changes in LDH, AST and ALT in response to the match simulation were found, suggesting that the HIIT protocols did not induce extra muscle damage.

Cortisol was not changed in the match simulation, while testosterone increased in response to match simulation execution. However, no training period or group effects were found for these variables. The T/C ratio increased in response to the match simulation, suggesting that this condition induced a more anabolic state in these judo athletes. The increase in T to the match and T/C ratio in response to the match simulation can be explained by a behavioural adaptation to the confrontation and by the high-intensity generated by the combat, as observed in studies investigating the hormonal response to match simulation [32, 33] and randori [34]. Additionally, a testosterone increase was reported to be positively correlated to offensive actions (e.g., grip disputes and attacks) during the judo match simulation [32], and to the motivation to win the match [33].

Accordingly, there was an increase in the T/C response to the match simulation post-training compared to pre-training, suggesting that the HIIT protocols induced a more anabolic response to the judo-specific action. Only one study investigated the T/C ratio response to HIIT in grappling combat sport athletes [11]. Wrestlers submitted to a 4 week HIIT presented a significant increase in resting T/C ratio post-training compared to pre-training [11], but no measurement was conducted in response to a wrestling-specific test or match simulation.

Monitoring exercises intensity (regardless of applied indicators) not only during the judo training but any physical activity in sport [15] and during health-related training [35] is only one of the elements of training load. Literature review concerning especially a sports training is confirming that the large number of publications is concerning effects, however few papers the causes, that is just precise evaluation of training load. Therefore very valuable publications announcing among others that it is possible to get identical
or higher training effects in the short time at the lower number of repetitions of specific exercises [36], at lower body exploitation. Very important are articles concerning the evaluation of means (exercises) [36, 37]. Since the concept of training load is not limited to the physical sphere (energy) [35], therefore it is important also to analyze training means (causes) in psychological and pedagogical terms [38].

CONCLUSIONS

In conclusion, short-term, low-volume HIIT added to regular judo training was able to increase the number of throws in the SJFT for the upper-body training group, while decreasing the HR immediately after the SJFT and the number of sequences in standing position for the lower-body training group, the index in the SJFT for the uchi-komi training group and the CK concentration in the match simulation for the upper-body training group. Moreover, the T/C ratio increased after the match simulation in the post-training period. Thus, all training modes improved performance, biochemical and hormonal response to judo-specific performance, but each group adapted in a different way.

HIGHLIGHTS

High-intensity intermittent training (HIIT) was able to improve performance in SJFT for upper, lower-body and uchi-komi groups. HIIT was able to decrease number of sequences in standing position for the lower-body training group. HIIT was able to decrease CK in a match simulation for the upper-body group. HIIT increased T/C in all training groups in a match simulation.

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