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Rapid weight loss influences the physical, psychological and biological responses during a simulated competition in national judo athletes.

Weight loss in judo: performance implications

Laurie Isacco[1], Fabrice Degoutte[2], Gaël Ennequin[3], Bruno Pereira[4], David Thivel[3], Edith Filaire[5]

1: EA3920 Prognostic Markers and Regulatory Factors of Cardiovascular Diseases and Exercise Performance Health Innovation (EPSI) platform, Univ. Bourgogne Franche-Comte, Besançon, France. Laurie.isacco@univ-fcomte.fr

2: Laboratoire de Biologie Interuniversitaire des Activités Physiques et Sportives, Bat Biologie B, Campus des Cézeaux, Aubière Cedex, France. f.degoutte@live.fr

3: Université Clermont Auvergne, Laboratoire des Adaptations Métaboliques à l'Exercice en conditions Physiologiques et Pathologiques (AME2P, EA 3533), CRNH Auvergne, Clermont-Ferrand, France. Gael.ennequin@uca.fr; david.thivel@uca.fr

4: Clermont-Ferrand University Hospital, Biostatistics Unit (DRCI), Clermont-Ferrand, France. bpereira@chu-clermontferrand.fr

5: University of Clermont-Auvergne, UMR 1019 INRA-UCA, Human Nutrition Unit (UNH), Clermont-Ferrand. + Greentech SA, Biopole Clermont-Limagne, Saint-Beauzire. edithfilaire@gmail.com

Corresponding Author: Laurie Isacco 31, chemin de l'Epitaphe 25000 Besançon, France Email: laurie.isacco@univ-fcomte.fr Phone: +33381666152

Abstract

The effect of rapid energy restriction-induced weight loss on judo-related performance remains unclear, and there is a paucity of information regarding the influence of the fight successions during competition. Thus, the aim of this study was to compare the cumulative effect of judo fights on physical performance, biological and psychological profiles, of national judo competitors with vs without rapid weight loss. After one month of weight maintenance (Baseline), 20 subjects were randomly divided into two groups the week before a simulated competition: i) a Weight Loss group (WL; weight loss ≥ 3% of body mass); ii) a Weight Stable group (WS). The simulated competition was composed of five fights (F1 to F5) separated by 30 min rest. Anthropometric assessments were performed at baseline and on the morning of the simulated competition (T0). Psychological, biological and physical assessments (maximal handgrip strength, upper limb anaerobic capacity) were performed at T0 and after each fight. The variation of body mass between baseline and T0 was significantly different between groups (+1.2% vs -3%; $p<0.01$). The dimensions of the Profile of Mood State questionnaire, the rate of perceived exertion, ammonia, urea and free fatty acid concentrations, maximal strength and time sustained at maximal strength showed a significant group x time interaction at F4 and F5. The study shows that cumulative fights lead to uncoupled responses in physical, psychological and biological parameters in judo competitors who underwent or not rapid weight loss. Specific recovery strategies in terms of nutrition and active recovery should be considered.

Combat sport, performance, energy restriction.

Introduction

Judo is a physically demanding sport with high-intensity intermittent actions requiring excellent overall physical fitness together with fine tactical skills (11, 25, 33, 42). Competitions are characterized by successive 4 min time-limited fights (without "golden score" contests, and from one to five or seven fights for medallists) separated by about 15 to 30 min of recovery (25). Using weight categories, with athletes' body mass measured a few hours before, or the evening before the competition, the optimization of body mass and composition is of prime importance in judo (2, 25).

Although the use of weight classifications should theoretically favour matched anthropometric and physical abilities between competitors (1, 25), athletes usually adopt rapid weight loss strategies before competitions to obtain advantages against smaller, lighter and weaker opponents (21, 36). This rapid weight loss is characterized by food and fluid restriction commonly associated with exercise with plastic suits, diet pills and/or intake of laxatives, vomiting and sauna utilisation, usually one week before the competition (9, 29). While studies have observed a negative effect of successive fights on physical, biological and psychological performance in combat sports, rapid weight reduction prior to the competition may worsen athletes' health and performance (12, 13, 15, 17, 21, 23, 30, 32, 38, 40, 41). Indeed, Filaire et al. (2001) observed that 7 days of food restriction led to reduced physical and psychological performances in judo athletes compared with an equivalent period of weight maintenance (15). According to the authors, the inadequate carbohydrate and micronutrient intake observed during the weight reduction may explain these results. The same research group compared these effects between athletes who underwent a 7-day restrictive diet or not, highlighting altered pre-competition biological, psychological and physical responses in the restrictive diet group (10). Interestingly, energy restriction induced similar changes in biological, psychological and physical parameters compared with a non-restrictive diet following the whole judo competition. Similarly, Artioli et al. did not observe any influence of food restriction-induced rapid weight loss on performance in judo (2). Thus, the influence of energy restriction-induced rapid weight loss on judo-related performance remains unclear (10, 15, 17, 36). The major reasons for these controversial results are the limited number of available studies and their methodological heterogeneity, which preclude drawing firm conclusions. For instance, as opposed to what is currently done in practice, some studies did not allow the athletes to re-feed and rehydrate between the weigh-in and the beginning of the fights (15). Interestingly, in an official competition context, a greater weight regain after weight-in, a surrogate measure for the magnitude of weight loss before weight-in, was associated with competition success (37). Indeed, re-feed and rehydration are common between weigh-in and the first fight in grappling combat athletes leading to body mass regain during this period (31). In addition, some designs did not include a control group and/or exercise protocols did not represent the typical energetic demand and competition format of judo (2, 15, 17). Finally, the performance assessment was done before and after the weight reduction and/or pre and post competition protocols without any information regarding the influence of fight successions (2, 10). It seems important to better understand not only the overall impact of a whole judo competition on such performances, but also on the course of relevant parameters throughout the competition, to develop specific between-fight strategies for judo athletes who underwent weight loss or not. Thus, the aim of the study was to compare the cumulative effect of judo fights on the physical performance, as well as biological and psychological profiles, of national judo competitors with vs without rapid weight loss.

Materials and methods

Subjects

Twenty well-trained male judo competitors (national level, black belt, 24 ± 5 years, 75.5 ± 7.7 kg) volunteered to participate in the study. The average duration of practice was 15 years with a volume of 9 hours of judo training and 3 hours of intense conditioning per week. The conditioning sessions consisted of a high degree of aerobic and anaerobic fitness development along with total body strengthening (maximal strength, speed, endurance and power). The recruited athletes experienced rapid weight reduction of their own volition more than three times in a season. All athletes competed in a category <81kg. The study complied with the Declaration of Helsinki and was approved by the local relevant ethical authorities (CPP Sud Est VI). Consent forms were obtained from all the athletes.

Experimental procedures

The experimental procedures have previously been described elsewhere (10). Briefly, after a period of one month of weight maintenance (Baseline), subjects (n=20) were randomly divided into two groups: i) a Weight Loss group (WL; n=10) asked to lose at least 3% of body mass using the participants' usual restrictive diet within the week before the experimental day; ii) a Weight Stable group (WS; n=10), asked to maintain body mass. Subjects of both groups pursued their usual training during the week before the experimental day.

On the day of the experimentation, which corresponded to a simulated competition, the participants arrived at 7.30 am at the dojo where a standardized and usual breakfast was provided after the weigh-in and the pre-competition assessments (T0). All the participants were instructed to eat the whole breakfast which consisted of two pieces of bread, 10g of jam, 10g of butter, 125g of yoghurt, and a glass of orange juice and water. The simulated competition started at 9.30 am after 20 min of warm-up and 10 min of cool down. The tournament was composed of five fights (F1 to F5) separated by 30 min rest. To create a demanding competitive environment, opponents with similar skills were matched without differentiation between weight loss and weigh stable groups. The subjects were allowed to consume fluids and solids between fights, as currently done in their usual competition practice.

Anthropometric and body composition assessments were performed at baseline and at T0. Psychological, biological and physical assessments were performed on the morning of the simulated competition before the weigh-in and breakfast (T0) and after each fight (F1, F2, F3, F4, F5).

Dietary protocol

To determine the diet ingested, the subjects were instructed to record their food intake for 7 days preceding the simulated competition. All participants received a detailed verbal explanation and written instructions. The participants were asked to indicate as precisely as possible all the details (quantity and nature) regarding the food and fluid ingested at each meal and between meals. Daily energy and nutrient intakes were calculated using Bilnut 4 software (Bilnut 4 software package, SCDA Nutrisoft, France). To ensure the accuracy of the reported information, interviews with each athlete were performed to address any questions or omission during the week (3 times a week).

Anthropometric and body composition data

Body mass (kg) was assessed to the nearest 0.1 kg using a calibrated scales. Height (m) was determined to the nearest 0.01 m using a standing stadiometer. Subjects' weight and height were measured bare-foot while wearing underwear. Body mass index (BMI) was calculated as body mass divided by height in meters squared ($kg.m^{-2}$). Skinfold thickness was measured at the biceps, triceps, subscapular and suprailiac anatomic locations on the left side of the body using a Harpenden skinfold caliper (British Indicators Ltd, West Sussex, UK). Each measurement was performed three times to the nearest millimeter by the same experienced anthropometrist and the mean value was considered for analysis. Fat mass (FM, %) and fat-free mass (FFM, kg) were estimated from measurements of skinfold thickness according to Durnin et Rahaman equation (14).

Psychological parameters

The Profile of Mood States (POMS) questionnaire (34) was used to assess the alteration of mood states among athletes scored on a 5-point Likert-type scale anchored with "Not at all" and "Extremely." The POMS consists of 65 items divided into six subscales: anger, confusion, depression, fatigue, tension and vigour. To ensure accurate evaluation, the French validated version of the POMS questionnaire was used for this study (8). In addition, the Rate of Perceived Exertion (RPE) was measured using the 6 to 20-point Borg scale.

Psychological evaluations were performed at rest (T0) and after each fight (F1, F2, F3, F4, F5). Participants were accustomed to completing the POMS and RPE in their current practice.

Blood samples and biochemical analysis

Blood samples were drawn from an antecubital vein at rest under fasting conditions at 7.30 a.m. (T0) and after each fight (F1, F2, F3, F4, F5), participants were seated quietly and comfortably. Samples were centrifuged at 4000g for 10 min at 4°C to isolate plasma, which was transferred into plastic tubes and kept at −80°C. Also, clotted blood was centrifuged within 1 h at 2500g and serum stored at −80°C. Triglycerides (TG), glucose, uric acid (UA), urea, creatinine concentrations were assessed using an automated and computerized system (HITACHI 911 Roche Diagnostics, Indianapolis, IN, USA). The free fatty acid (FFA) concentrations were determined by enzymatic method using Wako reagents (WAKO Industries Ltd., Higaski-Ku, Osaka, Japan). Measurements of glycerol and ammonia concentrations were conducted using a test kit (Boehringer, Mannheim, Germany). All hormonal markers were determined in serum by direct chemiluminescence according to the manufacturer's protocol. Insulin, Adreno Corticotrophic Hormone (ACTH), cortisol, and testosterone concentrations were analyzed in Immunite 2000 (Diagnostic Products Corporation, Los Angeles, USA), and thyroid hormones concentrations in ACS 180 SE (Bayer Diagnostics, Westwood CA, USA).

Physical parameters

Heart rate. Heart rate (HR) was continuously recorded throughout the experimental day (PE4000 Polar Electro, Oy, Finland). Resting and minimal, maximal and mean HR of each fight were calculated. Relative cardiac cost (RCC) was calculated as followed (10):

RCC (%) = [(HRmean – HRrest) / (HRmax – HRrest)] x 100

The theoretical maximal HR was determined as 205.8-0.685(age) (28).

Maximal isometric handgrip strength and anaerobic capacity of the upper limbs. Two consecutive measurements for maximal isometric handgrip strength (kg) of the right and left hand at rest (T0) and after each fight (F1, F2, F3, F4, F5) were performed with a calibrated dynamometer (Harpenden dynamometer, British Indicators, Ltd., England). The average performance was calculated for each participant. The measurements were conducted under standardized conditions: judo athletes seated comfortably, the shoulder adducted and neutrally rotated, with the forearm and wrist in a neutral position and the elbow at 90° flexion. The participants were verbally encouraged to perform two 3-s maximum voluntary contractions separated by at least 30s of recovery between each trial.

Anaerobic capacity of the upper limbs was determined by using an isometric dynamometer (Globus Ergo Meter®) at rest (T0) and after each fight (F1, F2, F3, F4, F5). The test consisted of 30-s horizontal isometric rowing on a seated chest press machine. The subjects were seated on a vertical bench and performed this test with a 90-degree angle between arms and forearms. Maximal strength (Fmax; kg) and time sustained at Fmax (Time Fmax; s) were recorded (10).

Workload. Workload of each fight was assessed as: duration*RPE (19).

Statistics

Statistical analyses were performed using Stata software version 13 (StataCorp, College Station, TX, US). According to the current literature (15, 23, 40), with 10 participants by group, an effect-size around 1.3 can be highlighted for a two-sided type I error at 5% and a statistical power at 80%. Tests were two-sided with the type-I error set at 5%. Continuous data are expressed as mean ± standard deviation (SD) or as median [interquartile range] according to the statistical distribution. Assumption of normality was assessed with the Shapiro-Wilk test.

The percentages of variation of body mass and body composition data between baseline and T0 were calculated according to the following formula: ((T0-Baseline)/Baseline) x 100.

Comparisons between groups (WL and WS) for non-repeated quantitative parameters (baseline and percentage of variation for anthropometric and body composition data) were performed using the Student *t*-test, or the Mann-Whitney test, when the assumptions for the *t*-test were not met. Homoscedasticity was analysed using the Fisher-Snedecor test. To account for between- and within-participant variability due to several measures being taken for the same subject, random-effects models for correlated data were constructed, rather than the usual statistical tests, which would have been inappropriate due to an unverified assumption of independence. Time-point evaluations, groups and their interactions were considered as fixed effects based on the calculated Area Under the Curve (AUC) using the trapezoid method. The subject was considered a random effect (slope and intercept). A Sidak *post hoc* test was applied to correct the type-I error due to multiple comparisons. The normality of the residuals from these models was studied as described above using the Shapiro-Wilk test. When appropriate, the data were log-transformed to achieve normality of the dependent endpoint. The interaction results were expressed as Hedges'g effect sizes (ES), all the ES being detailed in the Table 4 (supplementary file).

Results

Dietary restriction

According to the experimental design, the WS group did not experience any change in dietary intake and fluid consumption between baseline and T0. Conversely, the WL group significantly decreased their total energy, carbohydrate, fat and protein intake ($p<0.01$) and the volume of fluid consumption ($p<0.01$) between baseline and T0.

Anthropometric and body composition parameters

While body mass was not significantly different between WS and WL at T0, the variation of body mass between baseline and T0 was significantly different between groups (+1.2% vs -3% respectively; $p<0.01$). Similarly, BMI and FFM showed a significant reduction in the WL group but not in the WS group ($p<0.001$ and $p<0.01$ respectively) with no change over time and difference between groups for FM.

Psychological parameters

While none of the dimensions of the Profile of Mood State questionnaire (Table 1) showed a significant group difference, each of them showed a time effect ($p<0.001$) and significant group x time interactions at F4 and F5.

As illustrated in Figure 1A, the RPE showed a group effect with overall RPE being significantly higher in the WL group compared to the WS group ($p<0.05$), with both groups showing a significant time effect ($p<0.001$). A time x group interaction was observed at F4 ($p<0.05$) and F5 ($p<0.0001$).

Biological parameters

As presented in Table 2, all the biological variables under study showed a significant time effect throughout the competition ($p<0.001$). Only FFA showed a group effect with significantly higher concentrations in the WL compared to the WS group ($p=0.001$). A tendency was observed for a group effect for the urea concentrations ($p=0.078$). Ammonia concentrations showed time x group interaction at F4 ($p=0.072$, tendency) and F5 ($p<0.01$). Urea concentrations showed a time x group interaction at both F4 ($p<0.05$) and F5 ($p<0.01$) while FFA concentrations showed time x group interaction at F3 ($p<0.01$), F4 and F5 ($p<0.001$ for each).

Physical parameters

Table 3 details the results relating to HR and physical performance. While HRmin, HRmean and HRmax did not show a time effect across the successive fights in both groups, significant time x group interactions were observed at F5 ($p=0.05$ for HRmin and HRmean and $p=0.07$ tendency for HRmax). Both WS and WL groups showed a time effect for RCC with a significant increase from F3 to F5 compared with previous fights ($p<0.001$). Relative cardiac cost showed a significant time x group interaction at F4 ($p<0.05$).

Both groups showed a significant time effect ($p<0.001$) with an overall decrease in both handgrip performances (right and left hands); with a time x group interaction at F5 ($p=0.05$ and $p=0.04$ respectively) and a tendency for interaction at F4 ($p=0.08$). The Fmax and the time to Fmax also showed significant time effect throughout the competition ($p<0.001$) with Fmax and time to Fmax showing significant time x group interaction at F4 ($p<0.05$ and $p<0.001$ respectively) and F5 ($p<0.05$ and $p<0.01$ respectively).

As illustrated in Figure 1B, the workload showed a group effect with overall workload being significantly higher in the WL group compared to the WS group ($p<0.05$), with both groups showing a significant time effect ($p<0.001$). A time x group interaction was observed at F5 ($p<0.001$).

Discussion

To the best of our knowledge, this is the first investigation to compare the time course of physical, biological and psychological changes in response to a stimulated competition between national judo athletes who underwent or not rapid weight loss. According to the results, rapid weight loss affects physical performance, psychological and biological profiles during successive fights of a simulated judo competition.

Due to the difficulty of performing experimental procedures during real competitions (i.e., invasiveness, distraction, bias, sport stakes…), the present protocol was performed during a simulated competition. It is legitimate to wonder whether this is truly representative of the typical physiologic demands of judo. We intended to recreate the conditions of an official male judo tournament with five fights on the same day separated by a recovery time of 30 min between bouts. These fights are generally characterised by high-intensity intermittent actions and thus, elicit high metabolic demands. Here, judo competitors exhibited a mean HR of ≈174 bpm and a maximal HR of ≈187 bpm during fights, which represent 92% and 99% of their theoretical maximal HR, respectively. These values are in accordance with previously recorded values during simulated and official competitions (11, 20, 42). Similarly, strength performances were in line with previous observations as Franchini and colleagues indeed reported handgrip strength of ≈ 50 kg in an age-, BMI- and judo level-matched population (20). Altogether, the design of the present study ensured strong validity based on the profiles of the enrolled judo athletes and the representativeness of the simulated competition characteristics to real competitions. Likewise, Franchini and colleagues have emphasised the large reliability of time-motion and physiological responses during judo match simulation (22).

Overall, it is well accepted that competition may alter physical performance and increase perceived exertion. Specifically in judo, previous studies have shown that successive fights induce energy metabolism and inflammatory alteration, cardiovascular stress, a decline in muscle strength power and endurance, neuromuscular responses, and a rise in perceived fatigue (4, 13, 23, 30, 35, 39, 40). In accordance with these results, the present study shows a significant time course of physical, biological and psychological changes in response to the simulated competition. Particularly, while RPE and the relative cardiac cost increase, a decrease in both handgrip strength, as previously observed during wrestling tournament (31), maximal strength and the time sustained at maximal strength was observed, corroborating the physical and psychological fatigue induced by the simulated competition. In addition, the common practice of rapid weight loss in judo may compound the effect of competition on such physical and psychological parameters. Indeed, judo competitions are organized in weight classes, as in other combat sports, to ensure equality between competitors. In common practice, competitors lose a significant amount of weight, mainly through energy restriction, in the few days before the weigh-in. In a large cohort, approximately 90% of judo competitors (excluding those in the heavyweight category) experienced rapid weight loss, with weight loss ranging from 2 to 10% of their body mass over a mean period of seven days (1). In the present work, the participants of the WL group lost 3% of their body mass, which was associated with BMI and FFM reductions with no difference in FM over a 7-day period, which is in accordance with the current literature (2). Although athletes reduce their weight to compete in lower weight categories, to obtain advantages against smaller, lighter and weaker opponents (21), the effect of rapid weight loss on performance remains unclear (2, 10, 15, 17, 36). The limited number of available studies and their methodological heterogeneity are the main reason for such controversial results. In the present study, the simulated competition impaired physical performance in both groups with a specific time course pattern. Indeed, interactions (time x group) for AUC were observed at the fourth and fifth fights for physical performance, psychological profile, ammonia, urea and FFA concentrations. The increase in protein catabolism and lipolysis indicators reflected a rise in the physiological constraint experienced by these judo athletes (11, 27) and completed the findings of Franchini and collaborators highlighting the physiological and inflammatory alterations observed across simulated judo competition (23). Interestingly, these results were associated with interactions at the same times (F4 and F5) for RPE, used to monitor workload in judo (6, 40), and expressing here an increase in the perceived physical effort in the WL compared with the WS group. In a study involving cadet athletes, 14 min of recovery between fight was long enough for blood lactate clearance while RPE remained elevated reflecting the perceived exertion and also the anxiety and stress of the judoka (40). Conversely, the physical performances did not converge in the same direction. Surprisingly, the WL group experienced a smaller decrease in physical performance than their WS counterparts. This might be explained by the fact that chronic weight-cyclers are used to losing weight and may thus be adapted and not become affected by the effect of rapid weight loss on physical performance (7, 16). Moreover, the athletes involved in the present study were all chronic weight-cyclers and the WS group may have been disrupted to change their diet habits before competition. In addition, Artioli and collaborators reported that recovery between weigh-in and the beginning of exercise may prevent the judo-related performance from being affected (2). Similarly, Mendes et al. emphasised that while chronic weight cycling does not preserve from the negative effect of rapid weight loss on performance, the recovery and nature of food and fluid consumption during this period are of prime importance for athletes' performance (32). Accordingly, in the present protocol, the athletes were able to eat and drink before the simulated competition and between fights, as commonly done in current practice (10). Moreover, in the study of Artioli and collaborators, the judo athletes lost 5% vs 3% of body mass here, which is in the lower range of body mass variations reported in the literature. To that extent, ~10% weight loss in 2-week period resulted in decreased judo-specific performance, compared to control group, impairing thus training optimisation (18). Again, this may have favoured the non-deleterious effect of weight loss on physical performance. However, the results must be interpreted with caution mainly due to the small sample size within each group and the important inter-individual variability observed between subjects.

This study has some limitations that deserve to be underlined. While it would have been more robust to perform a crossover design study, the complexity of the protocol, the sport level of the athletes and thus their training and competition commitments and busy schedule did not allow to conduct it. Additionally, information are missing regarding fight/competition success of the athletes, and whether these data are associated with the physical, psychological and biological responses during competition in judo warrants further study. While only fluid/flood restriction was manipulated to lose weight in the present study, it is worth nothing that other methods are commonly used in judo practice (e.g. 96.7% increased exercise, 44% sauna or plastic clothing, 13.2% diuretics or laxatives) and may specifically affect performance, psychological and biological responses and health (3, 5).

In conclusion, the present study shows for the first time that cumulative fights lead to uncoupled responses in physical, psychological and biological parameters in judo competitors who underwent rapid weight loss vs those who did not. It may be hypothesised that the relation between rapid weight loss and a decline in judo-related performance may be dependent on the magnitude of weight loss, the athletes' usual practice (chronic weight-cyclers vs not chronic weight-cyclers), recovery between weigh-in and the beginning of the competition, and between fights.

The interactions observed at the fourth and fifth fights for physical, psychological and some biological variables should prompt us to consider individual recovery strategies between fights (nutrition, active recovery) (24, 26), especially for potential medallists, according to the subjects' characteristics and usual practice before competitions.

It is relevant to note that rapid weight loss is not free of health risks, and coaches, medical staff and federations should favour optimal and safe practices for the athletes' health in short and long-term perspectives.

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Declaration of interest

The authors declare no conflict of interest.

References

1. **Artioli GG**, **Gualano B**, **Franchini E**, **Scagliusi FB**, **Takesian M**, **Fuchs M**, **Lancha AH**. Prevalence, magnitude, and methods of rapid weight loss among judo competitors. *Med Sci Sports Exerc* 42: 436–442, 2010.

2. **Artioli GG**, **Iglesias RT**, **Franchini E**, **Gualano B**, **Kashiwagura DB**, **Solis MY**, **Benatti FB**, **Fuchs M**, **Lancha Junior AH**. Rapid weight loss followed by recovery time does not affect judo-related performance. *J Sports Sci* 28: 21–32, 2010.

3. **Barley OR**, **Chapman DW**, **Abbiss CR**. Weight loss strategies in combat sports and concerning habits in mixed martial arts. *Int J Sports Physiol Perform* 13, 2018.

4. **Bonitch-Góngora JG**, **Bonitch-Domínguez JG**, **Padial P**, **Feriche B**. The Effect of Lactate Concentration on the Handgrip Strength During Judo Bouts. *J Strength Cond Res* 26: 1863–1871, 2012.

5. **Brito CJ**, **Roas A FCM**, **Brito I SS**, **Marins J CB**, **Córdova C**, **Franchini E**. Methods of body mass reduction by combat sport athletes. [Online]. *Int J Sport Nutr Exerc Metab* 22: 89–97, 2012. http://www.ncbi.nlm.nih.gov/pubmed/22349031 [30 Jul. 2019].

6. **Bromley SJ**, **Drew MK**, **McIntosh A**, **Talpey S**. Rating of perceived exertion is a stable and appropriate measure of workload in judo. *J Sci Med Sport* 21: 1008–1012, 2018.

7. **Buford TW**, **Rossi SJ**, **Smith DB**, **O'Brien MS**, **Pickering C**. The effect of a

competitive wrestling season on body weight, hydration, and muscular performance in collegiate wrestlers. *J strength Cond Res* 20: 689–92, 2006.

8. **Cayrou, S, Dickes, P, Gauvain-Piquard, A, Dolbeault, S, Callahan, S, & Rogé B**. Validation de la traduction française du POMS (Profile of Mood States). *Psychol Psychométri* 21: 5–22, 2000.

9. **Davis SE**, **Dwyer GB**, **Reed K**, **Bopp C**, **Stosic J**, **Shepanski M**. Preliminary investigation: The impact of the NCAA Wrestling Weight Certification Program on weight cutting. *J Strength Cond Res* 16: 305–307, 2002.

10. **Degoutte F**, **Jouanel P**, **Bègue RJ**, **Colombier M**, **Lac G**, **Pequignot JM**, **Filaire E**. Food restriction, performance, biochemical, psychological, and endocrine changes in judo athletes. *Int J Sports Med* 27: 9–18, 2006.

11. **Degoutte F**, **Jouanel P**, **Filaire E**. Energy demands during a judo match and recovery. *Br J Sports Med* 37: 245–9, 2003.

12. **Detanico D**, **Dellagrana RA**, **Athayde MS da S**, **Kons RL**, **Góes A**. Effect of a Brazilian Jiu-jitsu-simulated tournament on strength parameters and perceptual responses. *Sport Biomech* 16: 115–126, 2017.

13. **Detanico D**, **Pupo JD**, **Franchini E**, **dos Santos SG**. Effects of Successive Judo Matches on Fatigue and Muscle Damage Markers. *J Strength Cond Res* 29: 1010–1016, 2015.

14. **Durnin JVGA**, **Rahaman MM**. The assessment of the amount of fat in the human body from measurements of skinfold thickness. *Br J Nutr* 21: 681, 2005.

15. **Filaire E**, **Maso F**, **Degoutte F**, **Jouanel P**, **Lac G**. Food restriction, performance, psychological state and lipid values in judo athletes. *Int J Sports Med* 22: 454–9, 2001.

16. **Finn KJ**, **Dolgener FA**, **Williams RB**. Effects of carbohydrate refeeding on physiological responses and psychological and physical performance following acute

weight reduction in collegiate wrestlers. *J strength Cond Res* 18: 328–33, 2004.

17. **Fogelholm GM**, **Koskinen R**, **Laakso J**, **Rankinen T**, **Ruokonen I**. Gradual and rapid weight loss: effects on nutrition and performance in male athletes. *Med Sci Sports Exerc* 25: 371–7, 1993.

18. **Fortes LS**, **Costa BDV**, **Paes PP**, **Cyrino ES**, **Vianna JM**, **Franchini E**. Effect of rapid weight loss on physical performance in judo athletes: is rapid weight loss a help for judokas with weight problems?*. *Int. J. Perform. Anal. Sport* (2017). doi: 10.1080/24748668.2017.1399323.

19. **Foster C**. Monitoring training in athletes with reference to overtraining syndrome. [Online]. *Med Sci Sports Exerc* 30: 1164–8, 1998. http://www.ncbi.nlm.nih.gov/pubmed/9662690 [30 Jul. 2019].

20. **Franchini E**, **Branco BM**, **Agostinho MF**, **Calmet M**, **Candau R**. Influence of linear and undulating strength periodization on physical fitness, physiological, and performance responses to simulated judo matches. *J strength Cond Res* 29: 358–67, 2015.

21. **Franchini E**, **Brito CJ**, **Artioli GG**. Weight loss in combat sports: physiological, psychological and performance effects. *J Int Soc Sports Nutr* 9: 52, 2012.

22. **Franchini E**, **Dunn E**, **Takito MY**. Reliability and Usefulness of Time-Motion and Physiological Responses in Simulated Judo Matches. *J. Strength Cond. Res.* (July 4, 2018). doi: 10.1519/JSC.0000000000002727.

23. **Franchini E**, **Lira FS**, **Julio UF**, **Antunes BM**, **Agostinho MF**, **Shiroma SA**, **Gonçalves Panissa VL**. Cytokine, physiological, technical–tactical and time structure responses in simulated judo competition. *Int. J. Perform. Anal. Sport* (2018). doi: 10.1080/24748668.2018.1501993.

24. **Franchini E**, **de Moraes Bertuzzi RC**, **Takito MY**, **Kiss MAPDM**. Effects of

recovery type after a judo match on blood lactate and performance in specific and non-specific judo tasks. *Eur J Appl Physiol* 107: 377–383, 2009.

25. **Franchini E**, **Del Vecchio FB**, **Matsushigue KA**, **Artioli GG**. Physiological Profiles of Elite Judo Athletes. *Sport Med* 41: 147–166, 2011.

26. **Franchini E**, **Yuri Takito M**, **Yuzo Nakamura F**, **Ayumi Matsushigue K**, **Peduti Dal'Molin Kiss MA**. Effects of recovery type after a judo combat on blood lactate removal and on performance in an intermittent anaerobic task. [Online]. *J Sports Med Phys Fitness* 43: 424–31, 2003. http://www.ncbi.nlm.nih.gov/pubmed/14767401 [29 Jul. 2019].

27. **Hellsten Y**, **Sjödin B**, **Richter EA**, **Bangsbo J**. Urate uptake and lowered ATP levels in human muscle after high-intensity intermittent exercise. *Am J Physiol* 274: E600-6, 1998.

28. **Inbar O**, **Oren A**, **Scheinowitz M**, **Rotstein A**, **Dlin R**, **Casaburi R**. Normal cardiopulmonary responses during incremental exercise in 20- to 70-yr-old men. [Online]. *Med Sci Sports Exerc* 26: 538–46, 1994. http://www.ncbi.nlm.nih.gov/pubmed/8007799 [6 Aug. 2019].

29. **Kiningham RB**, **Gorenflo DW**. Weight loss methods of high school wrestlers. *Med Sci Sports Exerc* 33: 810–3, 2001.

30. **Kons RL**, **Dal Pupo J**, **Ache-Dias J**, **Garcia T**, **Rodrigues da Silva R**, **Katicips LFG**, **Detanico D**. Effect of official judo matches on handgrip strength and perceptual responses. *J Exerc Rehabil* 14: 93–99, 2018.

31. **Kraemer WJ**, **Fry AC**, **Rubin MR**, **Triplett-McBride T**, **Gordon SE**, **Koziris LP**, **Lynch JM**, **Volek JS**, **Meuffels DE**, **Newton RU**, **Fleck SJ**. Physiological and performance responses to tournament wrestling. [Online]. *Med Sci Sports Exerc* 33: 1367–78, 2001. http://www.ncbi.nlm.nih.gov/pubmed/11474340 [29 Jul. 2019].

32. **Mendes SH**, **Tritto AC**, **Guilherme JPLF**, **Solis MY**, **Vieira DE**, **Franchini E**, **Lancha AH**, **Artioli GG**. Effect of rapid weight loss on performance in combat sport male athletes: does adaptation to chronic weight cycling play a role? *Br J Sports Med* 47: 1155–60, 2013.

33. **Miarka B**, **Del Vecchio FB**, **Julianetti R**, **Cury R**, **Camey S**, **Franchini E**. Time-motion and tactical analysis of Olympic judo fighters. *Int J Perform Anal Sport* 16: 133–142, 2016.

34. **Morgan WP**, **Brown DR**, **Raglin JS**, **O'Connor PJ**, **Ellickson KA**. Psychological monitoring of overtraining and staleness. *Br J Sports Med* 21: 107–114, 1987.

35. **Norrelund H**. The metabolic role of growth hormone in humans with particular reference to fasting. *Growth Horm IGF Res* 15: 95–122, 2005.

36. **Oppliger RA**, **Steen SAN**, **Scott JR**. Weight loss practices of college wrestlers. *Int J Sport Nutr Exerc Metab* 13: 29–46, 2003.

37. **Reale R**, **Cox GR**, **Slater G**, **Burke LM**. Regain in Body Mass After Weigh-In is Linked to Success in Real Life Judo Competition. *Int J Sport Nutr Exerc Metab* 26: 525–530, 2016.

38. **Roemmich JN**, **Sinning WE**. Weight loss and wrestling training: effects on growth-related hormones. *J Appl Physiol* 82: 1760–4, 1997.

39. **Serrano-Huete V**, **Latorre-Román PA**, **García-Pinillos F**, **Morcillo Losa JA**, **Moreno-Del Castillo R**, **Párraga-Montilla JA**. Acute Effect of A Judo Contest on Muscular Performance Parameters And Physiological Response. *Int J Kinesiol Sport Sci* 4, 2016.

40. **Stavrinou PS**, **Argyrou M**, **Hadjicharalambous M**. Physiological and metabolic responses during a simulated judo competition among cadet athletes. *Int. J. Perform. Anal. Sport* (2016). doi: 10.1080/24748668.2016.11868933.

41. **Too D**, **Wakayama EJ**, **Locati LL**, **Landwer GE**. Effect of a precompetition bodybuilding diet and training regimen on body composition and blood chemistry. *J Sports Med Phys Fitness* 38: 245–52, 1998.

42. **Torres-Luque G**, **Hernández-García R**, **Escobar-Molina R**, **Garatachea N**, **Nikolaidis P**. Physical and Physiological Characteristics of Judo Athletes: An Update. *Sports* 4: 20, 2016.

Table 1. Course of Profile of Mood State dimensions during the simulated competition.

		F1	**F2**	**F3**	**F4**	**F5**	**Time Effect**	**Group Effect**	**Interaction**			
		Mean ± SD	***Mean*** ± SD	***Mean*** ± SD	***Mean*** ± SD	***Mean*** ± SD			***F2***	***F3***	***F4***	***F5***
Tension	WL	39 ± 6	35 ± 3c	36 ± 5c,C	35 ± 5c,C,#	36 ± 5c,C,#,***	<0.001	0.28	0.66	0.28	0.08	0.015
	WS	40 ± 9	39 ± 8a	38 ± 7c	38 ± 7c,C	36 ± 5c,C,#	<0.001					
Depression	WL	37 ± 3	37 ± 3c	37 ± 3c,C	38 ± 5c,C,#	38 ± 4c,C,#,***	<0.001	0.13	0.55	0.14	0.01	0.001
	WS	36 ± 1	37 ± 2a	36 ± 2c	36 ± 2c,C	36 ± 2c,C,#,*	<0.001					
Anger	WL	42 ± 4	42 ± 2c	44 ± 4c,C	43 ± 7c,C,#	44 ± 4c,C,#,***	<0.001	0.2	0.61	0.21	0.04	0.004
	WS	42 ± 3	45 ± 9a	44 ± 7c	44 ± 7c,C	43 ± 4c,C,#	<0.001					
Vigour	WL	53 ± 11	52 ± 8c	50 ± 10c,C	47 ± 9c,C,#	49 ± 12c,C,#,***	<0.001	0.18	0.56	0.16	0.034	0.005
	WS	54 ± 4	51 ± 5a	51 ± 6c	49 ± 5c,C	53 ± 9c,C,#,*	<0.001					
Fatigue	WL	47 ± 5	47 ± 9c	48 ± 7c,C	50 ± 9c,C,#	53 ± 9c,C,#,***	<0.001	0.13	0.56	0.16	0.02	0.001
	WS	46 ± 6	47 ± 7	47 ± 6c,A	47 ± 6c,C	50 ± 5c,C,#,*	<0.001					
Confusion	WL	41 ± 5	40 ± 4c	39 ± 4c,C	41 ± 6c,C,#	40 ± 7c,C,#,***	<0.001	0.16	0.55	0.16	0.02	0.001
	WS	39 ± 6	40 ± 6a	39 ± 7c	38 ± 3c,C	37 ± 3c,C,#	<0.001					

F1 : Fight 1 ; F2 : Fight 2 ; F3 : Fight 3 ; F4 : Fight 4 ; F5 : Fight 5 ; SD : Standard Deviation. a. b and c respectively stand for p<0.05; p<0.01 and p<0.001 versus F1; A. B and C respectively stand for p<0.05; p<0.01 and p<0.001 versus F2; +. $ and # respectively stand for p<0.05; p<0.01 and p<0.001 versus F3. *. ** and * respectively stand for p<0.05; p<0.01 and p<0.001 versus F4.**

Table 2. Course of the biological variables during the simulated competition.

		F1	F2	F3	F4	F5	Time Effect	Group Effect	Interaction			
		Mean ± SD	***Mean*** ± SD	***Mean*** ± SD	***Mean*** ± SD	***Mean*** ± SD			***F2***	***F3***	***F4***	***F5***
Cortisol (mmol.L^{-1})	WL	603.2 ± 146.8	604.1 ± 170.5a	540.7 ± 146.5a,B	497.2 ± 160.4a,C,$	505.8 ± 118.4a,C,#,**	<0.001	0.17	0.49	0.22	0.1	0.07
	WS	535.6 ± 101.2	564.6 ± 86.9b	548.8 ± 130.9c,B	509.3 ± 143.4c,C,$	510.1 ± 140.5c,C,#,**	<0.001					
Testosterone (nmol/ L^{-1})	WL	12.3 ± 3.2	11 ± 3.2a	10.1 ± 3.9a,A	10 ± 3.9a,C,$	9.5 ± 2.1a,C.#.**	<0.001	0.5	0.74	0.56	0.41	0.18
	WS	17.9 ± 3.7	16.8 ± 3.7b	14.1 ± 2.1c,A	15.2 ± 4.1c,C,+	14 ± 4.9c,C.#.*	<0.001					
Testosterone/Cortisol	WL	21.6 ± 9.4	19.6 ± 8.9b	19.7 ± 7.8c,B	21.1 ± 10.1c,C,+	19.8 ± 8.2c,C,#,**	<0.001	0.39	0.73	0.59	0.34	0.14
	WS	35.4 ± 12.2	30.6 ± 13a	26.8 ± 11.1c	34.4 ± 23.2c,C	32.9 ± 32.6c,C,#,*	<0.001					
ACTH (pg mL^{-1})	WL	46.2 ± 22.4	38.9 ± 25.9c	29 ± 16.4c,B	17.9 ± 5.5c,C	31.6 ± 20.4c,C,$	<0.001	0.19	0.38	0.15	0.15	0.14
	WS	37.8 ± 8.1	36.1 ± 14.8c	29.1 ± 11.3c	20.9 ± 5.4c,C	22.4 ± 8.6c,C,#,*	<0.001					
TSH (mUI L^{-1})	WL	1.7 ± 0.5	1.9 ± 0.5b	1.9 ± 0.5c,A	1.9 ± 0.5c,C,+	2 ± 0.6c,C,#,*	<0.001	0.53	0.76	0.57	0.4	0.29
	WS	2.5 ± 1.3	2.6 ± 1.4a	2.6 ± 1.3c	1.6 ± 1.2c,C	2.5 ± 1.3c,C,#,*	<0.001					
T3 (pmol L^{-1})	WL	4.8 ± 0.3	5 ± 0.4c	5 ± 0.4c,C	5 ± 0.3c,C,#	5.1 ± 0.3c,C,#,***	<0.001	0.35	0.65	0.38	0.21	0.18
	WS	5 ± 0.4	5.1 ± 0.4b	5.2 ± 0.4c,A	5.4 ± 0.5c,C,$	5.4 ± 0.5c,C,#,**	<0.001					
T4 (pmol L^{-1})	WL	15.3 ± 1.3	15.3 ± 1.3c	15.4 ± 1.1c,C	15.5 ± 1.4c,C,#	15.3 ± 1.5c,C,#,**	<0.001	0.47	0.78	0.41	0.18	0.21
	WS	14.8 ± 1.6	14.9 ±	15.2 ±	15.5 ±	15.7 ±	<0.0					

	S		1.5b	1.6c,B	1.6c,C,+	1.4c,C,#,**	01					
	W	0.33 ±	0.33 ±	0.33 ±	0.33 ±	0.34 ±	<0.0					
t3/t4	L	0.05	0.04c	0.04c,C	0.04c,C,#	0.05c,C,#,**	01	0.58	0.8	0.5	0.3	0.3
	W	0.34 ±	0.34 ±	0.34 ±	0.35 ±	0.35±	<0.0		5	4	3	7
	S	0.04	0.03b	0.04c,A	0.04c,C,$	0.04c,C,#,**	01					
	W	264.7 ±	263.6 ±	262.1	263.7 ±	266.2 ±	<0.0					
IGF-1 (pg mL^{-1})	L	84.2	79.7b	80.9c,B	86.2c,C,$	89.6c,C,#,**	01	0.32	0.6	0.3	0.1	0.1
	W	260.5 ±	258.6 ±		260.1±	261.7 ±	<0.0		4	6	7	1
	S	74.1	80b	259 ± 80.2c	84.2c,C,+	75.6c,C,#,*	01					
	W		6.5 ±			6.6 ±	<0.0					
DHEA-s (µmol L-	L	6.3 ± 0.9	1.1c.C	6.6 ± 0.7c,C	6.4 ± 1c,C,#	0.8c,C,#,***	01	0.8	0.9	0.8	0.7	0.4
1)	W						<0.0		4	5		3
	S	8.1 ± 2.1	8.7 ± 2.1a	8.9 ± 2.4c,A	9.3 ±2.6c,C,$	9.1 ± 2.1c,C,#,*	01					
	W		16.9 ±	17.1 ±	12.7 ±		<0.0					
Insulin (mUI L^{-1})	L	14.6 ± 7.1	8.2b	7.6c,B	4.4c,C,+	8.9 ± 3.6c,C,#	01	0.88	0.9	0.8	0.7	0.5
	W			24.7 ±	18.7 ±		<0.0		7	9	2	5
	S	16.4 ± 8.2	22.4 ± 8.8a	10.9c,A	9.1c,C,+	12 ± 4.9c,C,#	01					
	W						<0.0					
Glucose (mmol L-	L	6.7 ± 1.1	7.4 ± 1.1c	6.9 ± 1.5c,C	5.8 ± 0.9c,C,#	5.7 ± 0.9c,C,#,**	01	0.33	0.6	0.3	0.2	0.1
1)	W						<0.0		2	6		5
	S	6.3 ± 0.9	7.8 ± 0.6b	7.1 ± 1.5c,B	6.2 ± 0.9c,C,$	5.6 ± 1.3c,C,#,*	01					
	W	61.9 ±	68.2 ±	60.9 ±	69.8 ±	84.1 ±	<0.0					
NH3 (µmol L^{-1})	L	34.1	34.4b	14.7c,B	32.9c,C,$	30.1c,C,#,**	01	0.18	0.5	0.2	0.0	0.0
	W	62.9 ±	58.2 ±		55.7 ±	57.2 ±	<0.0		7	4	72	1
	S	34.4	22.9b	58.8 ± 28.5c	21.9c,C,+	18.9c,C,#,*	01					
	W	6.22 ±	6.53 ±	6.6 ±	6.66 ±	6.91 ±	<0.0					
Urea (mmol L^{-1})	L	1.64	1.71c	1.66c,B	1.8c,C,$	2.01c,C,#,**	01	0.07	0.4	0.1	0.0	0.0
	W	5.34 ±	5.44 ±	5.73 ±	5.75 ±	5.88 ±	<0.0	8	2	11	18	04
	S	0.62	0.62b	0.67c,B	0.69c,C,+	0.73c,C,#,**	01					
	W	423.7 ±	476.2 ±	518.8 ±	548 ±	580.1 ±	<0.0					
UA (µmol L^{-1})	L	111.3	111.1b	109.3c,B	121.1c,C,$	131.6c,C,#,**	01	0.52	0.8	0.7	0.5	0.4
	W	418.7 ±	489 ±	541.3 ±	583.1 ±	613 ±	<0.0		6	6	1	3
	S	73.1	110.6b	133.8c,A	151.1c,C,+	158c,C,#,**	01					
	W	119.6 ±	128.5 ±	130.5 ±	130.5 ±	134.7 ±	<0.0					
Creatine (µmol L-	L	19.8	17.3c	16.7c,C	18c,C,#	22.3c,C,#,***	01	0.26	0.6	0.2	0.1	0.0
1)	W	117.9 ±	124.3 ±	130.3 ±	131.9 ±	131.9 ±	<0.0			9	2	74
	S	9.3	13.2a	11.2c,A	13.6c,C,+	11.7c,C,#,**	01					
TG (mmol L^{-1})	W	0.67 ±	0.59 ±	0.57 ±	0.58 ±	0.61 ±	<0.0	0.45	0.7	0.4	0.1	0.0

	L	0.34	0.2b	0.19c,C	0.26c,A,+	0.23c,C,#,*	01		5	5	9	9
	W	1.01 ±	0.96 ±		1.08 ±	0.99 ±	<0.0					
	S	0.45	0.48a	1.04 ± 0.49c	0.45c,C,+	0.34c,C,#,*	01					
	W	0.46 ±	0.44 ±	0.41 ±	0.39 ±	0.53 ±	<0.0					
FFA (mmol L^{-1})	L	0.18	0.21b	0.25c,A	0.21c,C,+	0.31c,C,#,*	01	0.00	0.1	0.0	0.0	0.0
	W	0.24 ±	0.25 ±			0.26 ±	<0.0	1	6	08	00	00
	S	0.15	0.13b	0.24 ± 0.08c	0.22 ± 0.1c,C	0.15c,C,#,*	01					
	W	172.8 ±	171.8 ±	195.2 ±	169.8 ±	194.8 ±	<0.0					
Glycerol (µmol L^{-1})	L	50.4	49.1b	48.7c,B	62.5c,C,$	90.5c,C.#,**	01	0.66	0.9	0.8	0.6	0.5
	W	207.4 ±	230.2 ±	187.5 ±	195.3 ±	183.5 ±	<0.0		8	5		1
	S	51.5	59.2b	58.1c,B	55.7c,C,+	57.8c,C,#,*	01					
	W	0.011 ±	0.011 ±	0.012 ±	0.013 ±	0.013 ±	<0.0					
DHEA/cortisol	L	0.003	0.003c	0.002c,B	0.003c,C,#	0.002c,C,#,***	01	0.66	0.8	0.8	0.6	0.4
	W	0.156 ±	0.015 ±	0.016 ±	0.019 ±	0.018 ±	<0.0		7		8	1
	S	0.005	0.003b	0.005c	0.008c,C,+	0.004c,C,#,**	01					

F1 : Fight 1 ; F2 : Fight 2 ; F3 : Fight 3 ; F4 : Fight 4 ; F5 : Fight 5 ; SD : Standard Deviation. a. b and c respectively stand for p<0.05; p<0.01 and p<0.001 versus F1; A. B and C respectively stand for p<0.05; p<0.01 and p<0.001 versus F2; +. $ and # respectively stand for p<0.05; p<0.01 and p<0.001 versus F3. *. ** and * respectively stand for p<0.05; p<0.01 and p<0.001 versus F4.**

ACTH: Adreno Cortico Trophic Hormone; DHEA-s: dehydroepiandrosterone sulfate; FFA: free fatty acids; IGF-1: insulin-like growth factor-1; NH3: ammonia; TSH : thyroid stimulating hormone; TG: triglycerides; T3: triiodothyronine; T4: thyroxine; UA: uric acid;

Table 3. Course of cardiac variables and physical performance during the simulated competition.

		F1 *Mean* ± SD	F2 *Mean* ± SD	F3 *Mean* ± SD	F4 *Mean* ± SD	F5 *Mean* ± SD	Time Effect	Group Effect	Interaction *F2*	*F3*	*F4*	*F5*
	W											
HRmin (bpm)	L	155 ± 24	161 ± 8	158 ± 11	154 ±14	160 ± 9	0.23	0.46	0.1	0.06	0.12	0.05
	W								8			
	S	163 ± 11	163 ± 8	144 ± 52	156 ± 11	158 ± 14	0.15					
	W											
HRmean (bpm)	L	17 ± 12	174 ± 5	173 ± 9	170 ± 10	174 ± 6	0.32	0.21	0.2	0.3	0.59	0.05
	W								5			
	S	178 ± 6	177 ± 3	176 ± 5	175 ± 7	174 ± 9	0.42					
HRmax (bpm)	W	184 ± 10	184 ± 6	184 ± 10	184 ± 9	185 ± 6	0.89	0.3	0.5	0.56	0.78	0.07

	L								2			
	WS	189 ± 8	187 ± 3	187 ± 5	187 ± 6	185 ± 9	0.47					
RCC (%)	WL	82 ± 8	84 ± 3	83 ± 5C	82 ± 6C,#	85 ± 3C,#,***	<0.001	0.12	0.35	0.11	0.04	0.09
	WS	86 ± 5	85 ± 2	84 ± 4A	84 ± 6C,+	83 ± 7C,#,*	<0.001					
HG right (kg)	WL	53 ± 6	54 ± 7c	52 ± 7c,C	51 ± 7c,C	49 ± 7c,C	<0.001	0.26	0.58	0.25	0.08	0.05
	WS	54 ± 9	52 ± 9c	50 ± 8c,A	50 ± 8c,C,+	49 ± 9c,C,#,*	<0.001					
HG left (kg)	WL	51 ± 7	50 ± 7c	50 ± 8c,C	50 ± 8c,C,#	48 ± 8c,C,#,***	<0.001	0.23	0.57	0.26	0.08	0.04
	WS	50 ± 8	50 ± 9c	48 ± 6c,A	46 ± 8c,C,+	46 ± 7c,C,#,*	<0.001					
Fmax (kg)	WL	80 ± 8	83 ± 14c	85 ± 13c,C	78 ± 13c,C,$	79 ± 13c,C,#,***	<0.001	0.16	0.55	0.18	0.042	0.013
	WS	80 ± 16	76 ± 17c	76 ± 14c,B	70 ± 13c,C,+	67 ± 15c,C,#,*	<0.001					
Time to Fmax (s)	WL	11.5 ± 8.6	7.1 ± 5.9a	9.6 ± 7.1c	10.4 ± 9c,C	9.8 ± 7.4c,C,#	<0.001	0.001	0.14	0.007	0.00	0.00
	WS	3.5 ± 3.5	2.8 ± 2.5	4.3 ± 3.4b	4.4 ± 5.7c,B	3.6 ± 2.7c,C,#	<0.001					

F1 : Fight 1 ; F2 : Fight 2 ; F3 : Fight 3 ; F4 : Fight 4 ; F5 : Fight 5 ; SD : Standard Deviation. a. b and c respectively stand for p<0.05; p<0.01 and p<0.001 versus F1; A. B and C respectively stand for p<0.05; p<0.01 and p<0.001 versus F2; +. $ and # respectively stand for p<0.05; p<0.01 and p<0.001 versus F3. *. ** and * respectively stand for p<0.05; p<0.01 and p<0.001 versus F4.**

Fmax: maximal strength; HG; handgrip; HR: heart rate; RCC: relative cardiac cost; Time to Fmax: time sustained at maximal strength

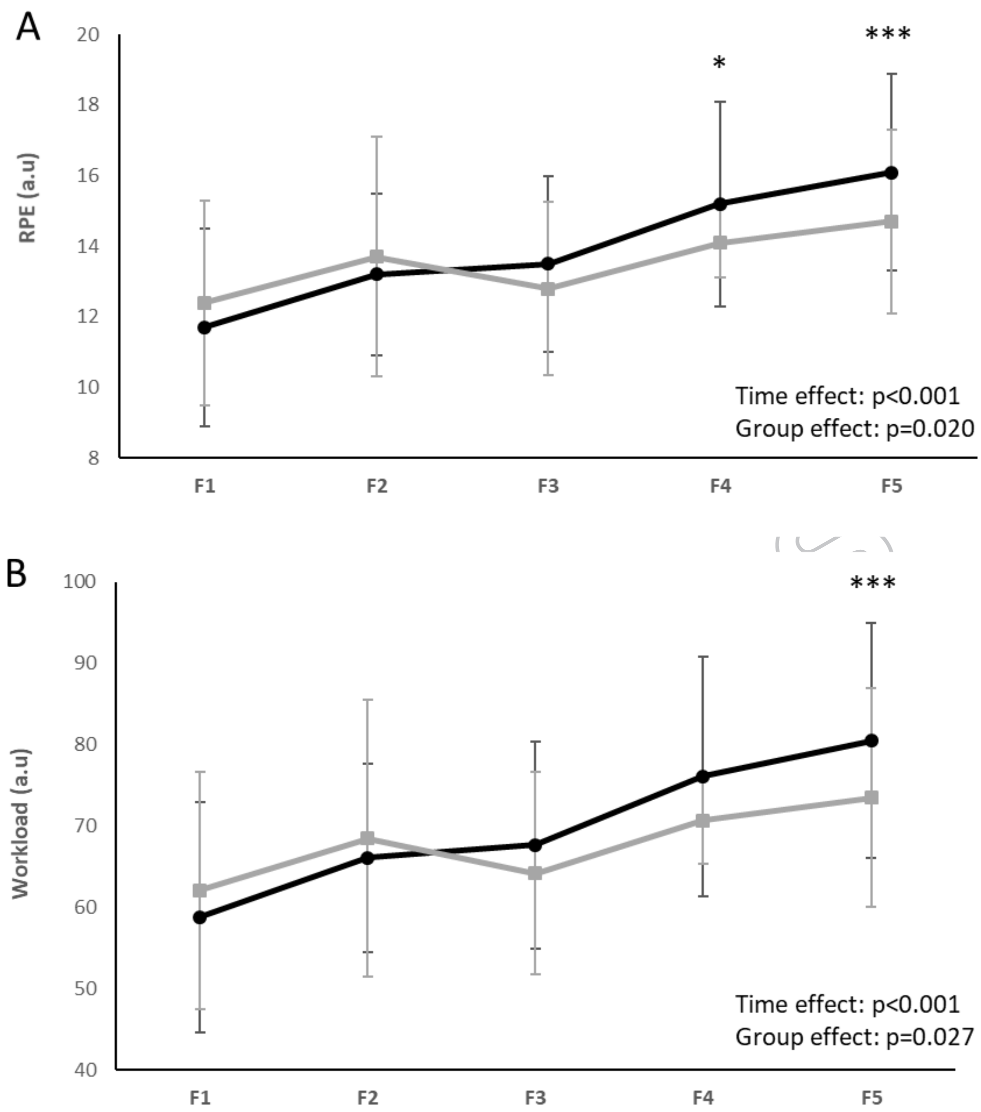

Figure 1A. Rate of perceived exertion (A) and workload (B) evolution during the simulated competition.

F1 : Fight 1 ; F2 : Fight 2 ; F3 : Fight 3 ; F4 : Fight 4 ; F5 : Fight 5 ; RPE: rate of perceived exertion; *p<0.05 for time*group interaction; *** p<0.001 for time*group interaction.

Grey line: weight stable group; black line: weight loss group