METABOLIC, MUSCLE DAMAGE AND HEART RATE RESPONSES IN BRAZILIAN JIU-JITSU MATCHES OF VARIED DURATION

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Abstract:

The aim of this study was to analyze physiological responses in Brazilian jiu-jitsu (BJJ) athletes during matches of varied duration. To this end, 10 athletes (age: 29±5 years, body mass: 77.5±6.3 kg, body fat: 10.0±5.2%, systematic BJJ practice: 10±2 years) were analyzed in matches of varied duration (2-min, 5-min, 8-min and 10-min). Blood collection was performed to determine energetic demands, hormonal responses and muscle damage. The main results showed that a longer duration of combat generated higher lactate ($p<.001$) and glucose ($p=.004$) concentrations. However, when the data were corrected for the effort time, higher lactate concentrations ($p<.001$) and higher heart rates ($p<.001$) were found for shorter combats. No changes were observed regarding insulin ($p=.870$), triglycerides ($p=.219$), total cholesterol ($p=.170$), albumin ($p=.060$) and urea ($p=.772$) values. For markers of muscle damage, no alterations were detected for creatine kinase ($p=.401$). However, evidence of muscle damage was found, as increased lactate desidrogenase ($p=.012$) and creatinine ($p=.002$) concentrations were observed, particularly in longer matches. Thus, it is concluded that different combat times have a direct influence on the physiological, hormonal and metabolic responses.

Key words: *combat sport, energy demands, physiology*

Introduction

Brazilian jiu-jitsu is a grappling combat sport in which the main goal is the submission of the opponent via the application of a stranglehold or joint locks. When there is no submission of the opponent in a match, the bout is decided by specific scores (takedown, guard pass, mount, back mount, back control, knee on belly and sweep), and if a draw persists, then the winner is decided by referees' decision (IBJJF, 2015). The primary physiological characteristic of the sport is intermittence; that is, effort periods are separated by short pause periods (Andreato, et al., 2015b, 2013). Brazilian jiu-jitsu combatants exhibit moderate activation of the glycolytic pathway (Andreato, et al., 2015a, 2014, 2013; Coswig, Neves, & Del Vecchio, 2013; Silva, et al., 2013). However, little is known about the moment when the most relevant physiological changes occur during the combat (Franchini, Bezerra, Oliveira, Souza, & Oliveira, 2005; Franchini, Takito, & Pereira, 2003).

In the match analysis from the 2005 World Cup, it was noted that points in Brazilian jiu-jitsu matches tend to be scored with supremacy in the initial or final minutes (Del Vecchio, Bianchi, Hirata, & Chacon-Mikahili, 2007). This fact suggests that different physiological adjustments may be required during a combat, a fact that should be considered in the design of physical training regimens. However, none of the studies that described the temporal structure of the combat conducted a per-minute description of the time-motion or physiological responses (Andreato, et al., 2015b, 2013; Del Vecchio, et al., 2007).

Some previous studies evaluated heart rate responses in Brazilian jiu-jitsu fragmented combats (Carneiro, et al., 2013; Franchini, et al., 2003, 2005). In a study with practitioners participating in 5-min combats, heart rate was measured every minute and a non-linear increase was observed. Moreover, heart rate decreased in the penultimate minute of the combat, representing a possible sparing effect for the decisive minute of the combat (Franchini, et al., 2003). In a study with black-belt athletes, who participated in 10-min combats and whose heart rate was measured every two minutes, the heart rate during the final minutes (the eighth and tenth minute) was higher than during the initial minutes (Franchini, et al., 2005). Nonetheless, in an investigation that measured heart rate at different times during combats (2.5-min, 5-min, 7.5-min and 10-min) between brown-belts and black-belts and between blue-belts and purple-belts, no differences in the heart rate were observed between combat times; furthermore, the belt rank factor exhibited no influence on the heart rate eithe (Carneiro, et al., 2013).

However, based on the heart rate results of the studies by Franchini et al. (2003, 2005) and on the evaluation by Del Vecchio et al. (2007), combats tend to increase in intensity during the final minutes. If this continues to be a pattern, then the training dynamics should consider this important standard in a training program design.

Nevertheless, considering physiological responses, only heart rate has been assessed to date in fragmented combats. Understanding of other physiological responses (e.g. energy demand and muscle damage markers) would significantly increase our insight into the effects of combat and would assist in the design of training regimens.

The knowledge of sport-specific energy demands can help to prescribe a training program with a greater specificity and to develop nutritional and ergogenic strategies to supply the demands of combats. For this, some markers can be used (e.g. lactate, glucose, lipid profile, purine cycle) (Degoutte, Jouanel, & Filaire, 2003; Andreato, et al., 2015a). The analysis of muscle damage markers may indicate which protocols require recovery strategies (e.g. cryotherapy, hyperbaric oxygen therapy). Therefore, several markers can be used (e.g. creatine kinase – CK, aspartate aminotransferase – AST, alanine aminotransferase – ALT, lactate dehydrogenase – LDH). However, a multiple analysis of damage markers is indicated as the use of a single marker can result in an erroneous interpretation (Bessa, et al., 2008).

Moreover, during a combat, especially in grappling combat sports, it is difficult to continuously measure several variables (Franchini, Del Vecchio, Matsushigue, & Artioli, 2011). Fragmentation of the combat provides the possibility of obtaining measurements at specific time points, thus aiding understanding of what happens during different phases of a combat and potentially improving the preparation of athletes to face demands of the sport.

In view of the mentioned considerations, this study aimed to evaluate metabolic responses, hormonal responses and muscle damage sustained during Brazilian jiu-jitsu matches of varied duration. The present study hypothesized that matches of a longer duration would result in a greater glycolytic activation. Furthermore, increased duration of a combat would not result in extensive increases in muscle damage markers.

Methods

Study design

This study is a descriptive comparison and exploratory study. The study design is presented in Figure 1. The subjects were evaluated during simulated matches of varied duration (two simulations per day), and blood samples were collected pre- and post-matches lasting 2, 5, 8 and 10 minutes in order to investigate significant physiological changes over time. The arrangement of the matches of different durations was counterbalanced with a 60-minute rest interval between matches to allow the measured values to return to baseline.

Between the pre-match test and the beginning of a match, the athletes were allowed a 5-minute recovery interval; this time was also used to warm up. The warm-up protocol was at the athletes' preferences; however, the athletes were requested to maintain the same warm-up protocol before all the matches. The athletes were not informed about the duration prior to a particular match, but were encouraged to engage in fighting as if the total duration was always 10 minutes.

The matches were timed. The time during pauses within a combat was not accounted the match time, thus mimicking official competitions. None match was ended in the event of submission to guarantee that all the athletes would have the same combat time. Similar simulation procedures have been adopted in studies with other grappling combat sports (Andreato, et al., 2015a, 2015b; Barbas, et al., 2011; Kraemer, et al., 2001). Although brown-belt athletes officially compete in 8-minute matches, those from our study were preparing to graduate to the black belt and so adapted to 10-minute matches.

The athletes were divided and matched by body mass to avoid significant weight category differences between the athletes (less than 10% difference in body mass between the athletes) like in official competitions, athletes are classified into weight categories considering the same variation in body mass.

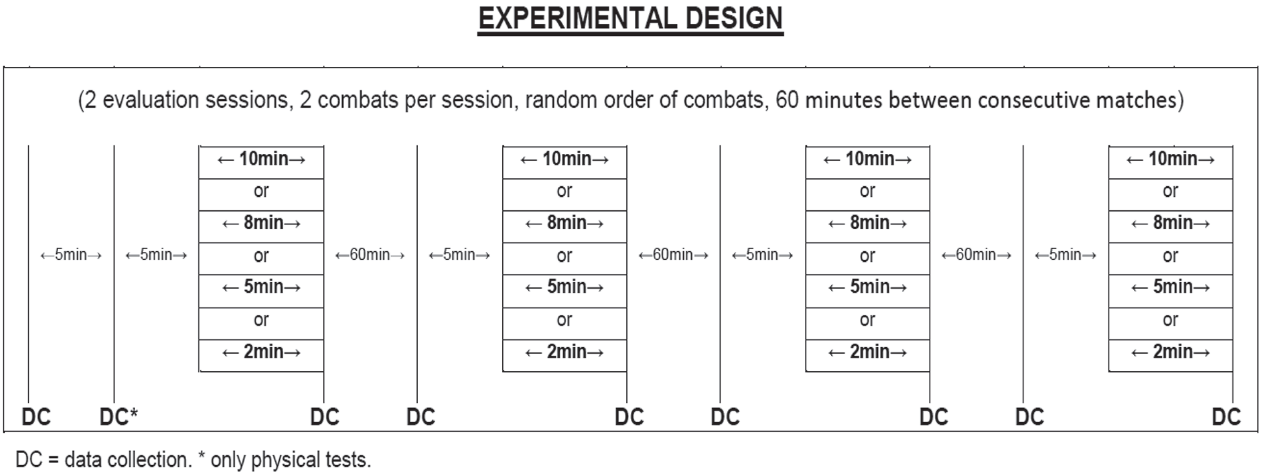

Figure 1. Experimental design – matches of varied duration.

Subjects

The study included 10 male adult Brazilian jiu-jitsu athletes (age: 29±5 years, body mass: 77.5±6.3 kg, body height: 177.1±8.0 cm, body fat: 10.0±5.2%), with 10±2 years of regular and systematic practice (6 brown-belts and 4 black-belts). During the study, an injury occurred during one of the matches; however, the injury occurred at the end of the combat and did not affect the results obtained. Although we did not perform a sample size calculation, due to the lack of baseline measurement, we assumed that this number of subjects was adequate to detect statistical differences if present, as the sample size was similar to the ones in previous studies with Brazilian jiu-jitsu athletes and wrestlers (Andreato, et al., 2015a, 2015b; Barbas, et al., 2011; Kraemer, et al., 2001).

The following inclusion criteria were adopted: athletes graded brown-belts or black-belts (to ensure the subjects were experienced enough); specific modality training at least three times per week (typical duration of one and half hour per session); and uninterrupted training participation for at least three months. Exclusion criteria were the following: athletes with injuries, the ultra-heavyweight (>100 kg) category athletes, athletes in the process of weight loss, and/or those using illicit (e.g. anabolic steroids and recreational drugs) or other drugs (e.g. antibiotics and anti-inflammatory medications). Athletes using dietary supplements were advised to maintain constant use during the study. Additionally, the athletes were instructed not to perform any kind of physical activity 24 hours before data collection.

After being briefed on the procedures and aim of the study, the participants signed a written informed consent form prior to participation. The study was done in accordance with the resolution 196/96 of the Brazilian National Health Council and approved by the Local Ethics Committee (2011/032).

Anthropometry

The measurement of skinfold thickness (chest, midaxillary, triceps, subcapular, abdominal, suprailiac and medial thigh) was performed in triplicate, and the average value was used for the calculation of body density, according to the standardization method of Lohman, Roche, and Martorell (1988). Body density was determined using the equation of Jackson and Pollock (1978), and body fat percentage was estimated using the equation of Siri (1961).

Nutritional intake and water consumption

Before data collection, the athletes were instructed to maintain their normal diet and to arrive fed, with their last light meal eaten at least one hour before the tests. Additionally, athletes were oriented to keep the use of supplements constant during the investigation. The athletes answered a 24-hour dietary recall questionnaire to estimate the intake of macro- and micronutrients (Degoutte, et al., 2003). Nutritional calculations were conducted using Nutrilife 8.1® software. The comparison of dietary intake was based on daily nutritional recommendations for male athletes (Martin, 2001). The athletes had water available *ad libitum* in bottles that were weighed before and after the data collection to quantify water consumption. No ingestion of any food was permitted during the experimental protocol.

Heart rate

Heart rate was measured by specific monitors (Polar Team System®). The measures were obtained before the venipunctures so that the venipuncture did not interfere with the heart rate results.

Blood samples and biochemical analysis

Blood samples (15 ml) were collected from the antecubital veins of the athletes at the predetermined time points (Figure 1). The collections were performed using Injex® 20 ml syringes and ABD® type Scalp 21G disposable needles. After the collection, 4 ml of blood were immediately dispensed into Petrodis® 4 ml tubes with ethylenediamine tetraacetic acid (EDTA) to subsequently obtain blood plasma. The remaining blood content was dispensed in glass tubes without anticoagulant for serum extraction. Both tubes, with and without anticoagulant, were centrifuged at 3000 rpm for 15 minutes at 4°C for the sample separation into blood serum and plasma. The serum and plasma from the blood samples were stored in Eppendorf tubes and frozen at -70°C until the biochemical analysis.

To determine the metabolic responses, the plasma concentrations of glucose, triglycerides, total cholesterol, albumin and urea were measured by a colorimetric method. Analyses were performed using a commercial kit (Gold Analisa®) and a Bioplus® UV-2000 spectrophotometer. The measures of glucose, triglycerides, total cholesterol and urea were analyzed in blood plasma, while albumin was measured in blood serum. To measure the blood lactate concentration [La], blood samples (25 µL) were collected from the earlobe with heparinized capillaries and these were immediately stored in Eppendorfs containing 50 µL of sodium fluoride at 1% for analysis in lactimeter Yellow Springs YSI 1500®.

To measure hormonal concentration in plasma, an enzyme linked immunosorbent assay (ELISA – Enzyme-Linked Immunosorbent Assay) was used to determine insulin concentrations by an Abcam® commercial kit. For cell damage markers, LDH was measured in serum by the kinetic method, and creatinine levels by the colorimetric method. In plasma, CK was measured by the kinetic method and AST and ALT levels by the colorimetric method. Analyses were performed using a commercial kit (Gold Analisa®) and a Bioplus® UV-2000 spectrophotometer.

The average intra-assay reliability, expressed by the coefficients of variation, presented in the kits were 1.2% and 0.9% for glucose, 1.7% and 0.7% for triglycerides, 1.1% and 0.9% for total cholesterol, 0.9% and 1,2% for albumin, 0.5% and 0.8% for urea, 0.5% and 0.6% for CK, 1.4% and 1.5% for AST, 1.8% and 2.8% for ALT, 1.2 and 1.3% for LDH, 2.0 and 4.1% for creatinine and <10% for insulin. The precision of lactate reading was ±2%.

Statistical analysis

The data are presented as means (M), standard deviations (SD), percentage, and delta (final value – initial value). First, the pre-match values were compared using one-way analysis of variance (ANOVA) for repeated measures followed by the Bonferroni *post-hoc* test where indicated. Once that no differences were found among the pre-match values, as was specified in the study design, the mean of the pre-match values at each time point was calculated, and a one-way ANOVA for repeated measures was performed to find differences between the mean of the pre-match values and each post-match value for matches of different durations.

The analyses respected the assumption of sphericity assessed by the Mauchly's test and utilized the Greenhouse-Geisser correction when necessary. For the results of food and water consumption, the data were submitted to the Kolmogorov-Smirnov normality test. To compare dependent measures, the *t*-test and the Wilcoxon test was used for normally distributed and non-normally distributed data, respectively. Additionally, to evaluate magnitude of difference, effect size was calculated (eta squared, η^2). The threshold values to effect size were: <0.2 (small), from >0.2 to <0.8 (moderate) and >0.8 (large) (Cohen, 1988). The significance level was set at .05 and observed power was also calculated.

Results

Table 1 presents food intake of the Brazilian jiu-jitsu athletes who participated in matches of varied duration.

No differences were found (p>.05) concerning water intake or any of the food intake variables in the different data collections (Table 1).

First, all the pre-match values were intra-compared and no differences were found for any variable: heart rate – HR ($F_{3,27}$= 2.3, p=.103, η^2=0.20,

Table 1. Food intake of Brazilian jiu-jitsu athletes who participated in matches of varied duration (n=10)

	Intake Day 1	Intake Day 2	Recommended diet
Energy intake (kcal)	1413.8±422.8	1520.9±410.2	-
Water consumption (ml)[a]	838±483	734±409	-
Carbohydrate (g)	430±162	499±147	-
Carbohydrate (%)	51±11	55±7	60
Protein (g)	152±47	164±48	-
Protein (%)	19±6	19±5	15
Fat (g)	115±53	104±49	-
Fat (%)	30±8	27±6	<30
Saturated fat (g)	34±16	33±17	1/3 of total fat
Monounsaturated fat (g)	30±17	25±14	1/3 of total fat
Polyunsaturated fat (g)	27±24	22±12	1/3 of total fat

Data are presented as M±SD. [a]= water intake was measured only during the experimental protocol.

moderate, observed power=.51), glucose ($F_{3,27}$=0.6, p=.606. η^2=0.07, small, observed power=.16), insulin ($F_{3,27}$=0.7, p=.557, η^2=0.07, small, observed power=.18), lactate ($F_{1,3;\ 12,1}$=1.9, p=.196, η^2=0.17, small, observed power=.27), triglycerides ($F_{1,6;\ 14,2}$=0.7, p=.495, η^2=0.07, small, observed power=.13), total cholesterol ($F_{3,27}$=0.9, p=.441, η^2=0.09, small, observed power=.23), albumin ($F_{1,7;\ 15,2}$=2.5, p=.124, η^2=0.22, moderate, observed power=.39), urea ($F_{3,27}$=0.3, p=.834, η^2=0.03, small, observed power=.10), CK ($F_{1,3;\ 12,1}$=0.5, p=.556, η^2=0.05, small, observed power=.10), AST ($F_{1,8;\ 14,5}$=0.2, p=.921, η^2=0.02, small, observed power=.07), ALT ($F_{2,2;17,4}$=3.1, p=.069, η^2=0.28, moderate, observed power=.54), LDH ($F_{3,27}$=0.5, p=.719, η^2=0.05, small, observed power=.13), and creatinine ($F_{3,27}$=0.1, p=.936, η^2= 0.02, small, observed power=.07).

Table 2 illustrates physiological and biochemical responses of the Brazilian jiu-jitsu athletes participating in matches of varied duration.

Heart rate was changed ($F_{4,36}$=167.2, p<.001, η^2=0.95, large, observed power=1.00), with the pre-match values being lower than during 2-, 5-, 8- and 10-min matches (p<.001 for all comparisons). The blood glucose levels changed in response to matches of varied duration ($F_{2,0;\ 17,6}$=8.0, p=.004, η^2=0.47, moderate, observed power=.91); the pre-match values were lower than the post-match values after 8-min (p=.007) and 10-min combat (p=.001). Additionally, the post-match values after 8-min (p=.017) and 10-min combats (p<.001) were higher than the 2-min post-match values.

The insulin levels did not change as a result of the matches (p>.05). The lactate values exhibited temporal differences ($F_{4,36}$=80.7, p<.001, η^2=0.90, large, observed power=1.00), with increases in the blood lactate levels observed for all durations of combats relative to rest (p<.001 for all comparisons). The values after the 10-min match were higher than the values after the 2-min (p<.001), 5-min (p=.001) and 8-min matches (p=.006). Additionally, the lactate concentrations for the 8-min match were higher than that for the 2-min match (p=.013).

No changes (p>.05) were observed for triglycerides, cholesterol, albumin, urea and CK values. However, alterations were observed in the LDH concentrations ($F_{4,36}$=3.8, p=.012, η^2=0.29, moderate, observed power=.84), with an increase in LDH after the 8-min match (p=.015) relative to the pre-match levels. Creatinine levels increased ($F_{4,36}$=5.4, p=.002, η^2=0.38, moderate, observed power=.96) after the 8-min (p=.006) and 10-min matches (p=.010) compared with the pre-match values.

Table 3 presents variation in the physiological and biochemical responses of the athletes during matches of varied duration.

The delta analysis revealed differences only for glucose ($F_{2,1;\ 19,0}$=3.6, p=.044, η^2=0.29, moderate, observed power=.61) and lactate ($F_{3,27}$=9.1, p<.001, η^2=0.50, moderate, observed power=.99) measurements. Blood glucose exhibited higher variation in the 10-min matches than in the 2-min match (p=.004). The lactate levels exhibited higher variation in the 10-min match than in the 2-min (p=.002) and 5-min matches (p=.025). No alterations (p>.05) were observed in the deltas of heart rate, insulin, triglycerides, total cholesterol, albumin, urea, creatinine, CK or LDH.

Table 2. Physiological and biochemical responses of Brazilian jiu-jitsu athletes participating in matches of varied duration (n=10)

	Pre-match	Post-match			
	Mean	2 min	5 min	8 min	10 min
Heart rate (bpm)	79±12	159±12^{a}	159±11^{a}	166±8^{a}	167±15^{a}
Glucose (mg/dL)	102±13	103±18	136±43	146±28^{a,b}	154±31^{a,b}
Insulin (ng/ml)	4.0±1.4	3.9±2.2	4.2±3.1	4.5±2.4	4.6±2.6
Lactate (mmol/L)	1.1±0.3	6.2±1.2^{a}	7.4±1.9^{a}	8.1±2.3$^{a\ b}$	10.1±1.4^{a,b,c,d}
Triglycerides (mg/dL)	152±73	176±104	163±75	180±91	207±137
Total cholesterol (mg/dL)	190±35	204±40	210±34	198±38	195±40
Albumin (g/dL)	3.6±0.2	3.8±0.3	3.9±0.3	3.9±0.4	4.0±0.3
Urea (mg/dL)	33±4	35±5	34±6	34±8	36±7
CK (U/L)	228±85	284±184	272±119	311±145	252±112
AST (U/L)	19±9	24±10	26±9	20±11	24±10
ALT (U/L)	11±3	12±3	12±3	11±3	14±2
LDH (U/L)	342±59	361±78	373±53	398±75^{a}	389±47
Creatinine (mg/dL)	1.1±0.1	1.2±0.3	1.3±0.2	1.4±0.1^{a}	1.3±0.3^{a}

Data are presented as M±SD. CK= creatine kinase, LDH= lactate dehydrogenase. [a] Significantly different from the pre-match values (p<.05), [b] Significantly different from the 2-min values (p<.05), [c] Significantly different from the 5-min values (p<.05), [d] Significantly different from the 8-min values (p<.05).

Table 3. Variation (Δ) in the physiological and biochemical responses in the athletes during the matches of varied duration (n=10)

	Match 2 min	Match 5 min	Match 8 min	Match 10 min
Δ Heart rate (bpm)	82±8	82±8	89±16	81±14
Δ Glucose (mg/dL)	1±15	33±44	49±35	47±35 [a]
Δ Insulin (ng/ml)	-0.9±3.3	0.2±2.9	0.8±3.0	1.3±1.9
Δ Lactate (mmol/L)	5.4±1.2	6.4±1.8	7.2±2.2	8.7±1.6 [a, b]
Δ Triglycerides (mg/dL)	13±15	22±28	37±43	45±57
Δ Total cholesterol (mg/dL)	9±18	25±13	12±26	3±19
Δ Albumin (g/dL)	0.2±0.3	0.2±0.3	0.5±0.4	0.3±0.3
Δ Urea (mg/dL)	1±6	0±5	1±5	1±4
Δ CK (U/L)	56±55	44±39	58±56	49±34
Δ AST (U/L)	5±6	7±10	3±9	4±9
Δ ALT (U/L)	1±2	1±2	2±2	2±3
Δ LDH (U/L)	5±89	31±44	65±46	55±23
Δ Creatinine (mg/dL)	0.1±0.2	0.2±0.1	0.3±0.2	0.2±0.2

Data are presented as M±SD. CK = creatine kinase, LDH = lactate dehydrogenase. [a] Significantly different from 2-min matches (p<.05), [b] Significantly different from 5-min matches (p<.05).

Table 4. Variation per minute in the physiological and biochemical responses of Brazilian jiu-jitsu athletes during matches of varied duration (n=10)

	Match 2 min	Match 5 min	Match 8 min	Match 10 min
Heart rate ($bpm \cdot min^{-1}$)	41±4	16±2[a]	11±2[a,b]	8±1[a,b,c]
Glucose ($mg \cdot dL^{-1} \cdot min^{-1}$)	0±7	7±9	6±4	5±4
Insulin ($ng \cdot ml^{-1} \cdot min^{-1}$)	-0.5±1.7	0.0±0.6	0.1±0.4	0.1±0.2
Lactate ($mmol \cdot L^{-1} \cdot min^{-1}$)	2.7±0.6	1.3±0.4[a]	0.9±0.3[a,b]	0.9±0.2[a,b]
Triglycerides ($mg \cdot dL^{-1} \cdot min^{-1}$)	7±7	4±6	5±5	5±6
Total cholesterol ($mg \cdot dL^{-1} \cdot min^{-1}$)	4±9	5±3	2±3	0±2
Albumin ($g \cdot dL^{-1} \cdot min^{-1}$)	0.1±0.1	0.0±0.1	0.1±0.1	0.0±0.0
Urea ($mg \cdot dL^{-1} \cdot min^{-1}$)	0.7±2.9	0.1±1.0	0.2±0.7	0.1±0.4
CK ($U \cdot L^{-1} \cdot min^{-1}$)	28±27	9±8	7±7	5±3
AST($U \cdot L^{-1} \cdot min^{-1}$)	2.3±3.0	1.5±1.9	0.3±1.1	0.4±0.9
ALT ($U \cdot L^{-1} \cdot min^{-1}$)	0.3±1.0	0.2±0.3	0.3±0.3	0.2±0.3
LDH ($U \cdot L^{-1} \cdot min^{-1}$)	3±45	6±9	8±6	6±2
Creatinine ($mg \cdot dL^{-1} \cdot min^{-1}$)	0.1±0.1	0.0±0.0	0.0±0.0	0.0±0.0

Data are presented as M±SD. CK = creatine kinase, LDH = lactate dehydrogenase. [a] Significantly different from the 2-min matches (p<.05), [b] Significantly different from the 5-min matches (p<.05), [c] Significantly different from the 8-min matches (p<.05).

Table 4 presents the variation per minute in the physiological and biochemical responses of the Brazilian jiu-jitsu athletes during matches of varied duration.

The variation per minute demonstrated differences between the matches for heart rate ($F_{1,5;\ 13,2}$=411.7, p<.001, η^2=0.98, large, observed power=1.00), with a greater variation per minute for the 2-min match than for the 5-min, 8-min and 10-min matches (p<.001 for all comparisons). The variation per minute was higher in the 5-min match than in the 8-min and 10-min matches (p<.001 for the two comparisons). The variation in the 8-min match was higher than in the 10-min match (p=.003). The variation per minute in the lactate levels also exhibited differences ($F_{3,27}$=62.5, p<.001, η^2=0.87, large, observed power=1.00), with a greater variation in the 2-min match than in the 5-min, 8-min and 10-min matches (p<.001 for all comparisons). The variation per minute in the 5-min match was higher than the variations in the 8-min (p=.005) and 10-min matches (p=.034).

No changes (p>.05) were observed in the variation per minute for glucose, insulin, triglycerides, total cholesterol, albumin, urea, CK, creatinine, and LDH levels.

Discussion and conclusions

This study aimed to evaluate physiological responses to Brazilian jiu-jitsu matches of varied duration. For this, two matches were performed per day, with a long rest interval between matches to guarantee that each match was initiated without the influence of residual fatigue. This design was successful, as there was no difference between the pre-match measurements for any variable. The present study demonstrates that matches of varied duration result in higher lactate and glucose concentrations over matches of greater duration. Nevertheless, the results are reversed when the values are normalized by the effort time, with a higher glycolytic activation in the shorter matches.

All matches (2-min, 5-min, 8-min and 10-min match) resulted in increases in HR. The mean post-match HR was similar to that previously observed in 5-min (Franchini, et al., 2003), 7-min (Andreato, et al., 2012) and 10-min (Franchini, et al., 2005) combat simulations. Although there was an increase in the post-match values vs. pre-match values for all durations of combat, the HR values after combat did not differ among the matches of different durations. These results are similar to a previous study of 10-min matches (HR measured every 2.5 min) in which no differences were observed in HR over the course of the match (Carneiro, et al., 2013). However, in 5-min matches (HR measured every minute), HR increased nonlinearly, with a decrease in the penultimate minute of the match as a possible sparing effect for the final minute (Franchini, et al., 2003). In 10-min matches (HR measured every two minutes) between black-belts, HR in the final phase of the combat (the eighth and tenth minute) was higher than in the initial phase (Franchini, et al., 2005). In the studies of Franchini et al. (2003, 2005), there were breaks (30 seconds and one minute) during the combat for the measurement of other variables, which may have allowed athletes to recover, thus probably altering the results.

Nonetheless, when the HR values were normalized by the effort time (Table 4), a higher cardiovascular demand was observed in the first minutes of the match. This phenomenon occurs due to an adrenergic discharge resulting in a chronotropic response of the heart aiming to quickly increase cardiac output to maintain an adequate supply of nutrients and oxygen to active tissues concomitant with the removal of the metabolites produced during cellular respiration (Borresen & Lambert, 2008).

The lactate concentrations [LAC] increased after combats of all durations; however, glucose increased only in the matches of a longer duration (8-min and 10-min matches). The [LAC] increase was expected, as increases have previously been reported in various samples and situations. Increases in [LAC] have been reported in 7-min simulations (Andreato, et al., 2012), 10-min simulations (Franchini, et al., 2005), and in two regional competitions (Andreato, et al., 2013, 2014) and after official combats during the 2013 European Open Jiu-Jitsu Championship (Diaz-Lara, Coso, García, & Vicén, 2015).

In judo, athletes of a higher technical level have presented a lower glycolytic activation during the combat (Franchini, Artioli, & Brito, 2013). However, in Brazilian jiu-jitsu, the technical factor seems to exert direct influence on this variable, as advanced athletes (brown-belts and black-belts) did not differ from non-advanced athletes (blue-belts and purple-belts) (Silva, et al., 2013). However, there is no consensus on the glycemic response in Brazilian jiu-jitsu combats. In 7-min simulations, no glycemic alterations were observed (Andreato, et al., 2012), although increased blood glucose was observed in simulations of two subsequent 10-min matches (Coswig, et al., 2013) and in two studies involving regional competitions (Andreato, et al., 2013, 2014). Nonetheless, the glucose and lactate concentrations were influenced by time, as the largest increases occurred after the matches of longer duration. Despite the increases in the glucose and lactate concentrations, the insulin did not differ over time.

The obtained *moderate* activation (in 2-min, 5-min and 8-min matches) and *high* activation (10-min matches) of the glycolytic pathway can be explained by the temporality of the combat, which is characterized by shorter pause times (Andreato, et al., 2013), which is insufficient for the complete restoration of phosphagenic stores depleted during the actions performed (Glaister, 2005), thereby resulting in glycolytic activation with a subsequent production of lactate.

However, when the results were normalized by the effort time (Table 4), the pattern was reversed; a greater activation was observed in shorter matches. These results are interesting because the results of a higher activation in the longer matches may reflect a cumulative effect during a combat; lactate production rate during a combat was greater than the removal rate, especially in the initial minutes. Considering the classification proposed by Buchheit and Laursen (2013) to analyze the final values of the matches (Table 2), the lactate values may be considered *moderate* for the 2-min, 5-min and 8-min matches and *high* for the 10-min match. Nevertheless, considering the lactate accumulation rate (Table 4), the values may be considered *strongly anaerobic* for the 2-min and 5-min matches and *mildly anaerobic* for the 8-min and 10-min matches.

The triglycerides and cholesterol concentrations did not change as a result of the matches of varied duration. Nonetheless, the plasma albumin levels rose after the 10-min match. In analysis of the total variations (Table 3) and variations per minute of combats (Table 4), no alterations were observed concerning the lipid profile. Thus, the results of the present study confirm those from previous studies that reported no changes in triglycerides or total cholesterol in the 7-min simulations (Andreato, et al., 2012) as well as triglycerides and total cholesterol and its fractions in the 10-min simulations (Coswig, et al., 2013). However, the results of the present study did not confirm the results observed during judo combats, in which lipid metabolism was significantly activated after the match, resulting in increases in triglycerides, free fatty acids, glycerol, total cholesterol and HDL cholesterol (Degoutte, et al., 2003). However, it should be noted that there is a difference in the total combat time, the temporal structure and characteristics of the Brazilian jiu-jitsu matches (stand up fight vs. ground fight) (Del Vecchio, et al., 2007) and judo (Franchini, et al., 2013).

Thus, some factors may explain the obtained low activation of the fat metabolism in the present study. During exercise, especially a high-intensity one, there is an increase in the catecholamines release, which stimulates both glycogen breakdown and lipolysis. The increase in the glycogen breakdown rate and the glycolysis rate results in lactate formation, which inhibits lipolysis induced by catecholamines (Brouns & Van Der Vusse, 1998; Jeukendrup, Saris, & Wagenmakers, 1998b). Moreover, the ATP production rate per minute via fat is smaller than the production via carbohydrates because the fat oxidation process requires higher levels of oxygen (Brouns & Van Der Vusse, 1998). Moreover, some enzymatic processes limit the flow of fatty acids from blood to mitochondria (Brouns & Van Der Vusse, 1998; Jeukendrup, Saris, & Wagenmakers, 1998a). This fact may be related to a decreased blood flow in adipose tissue, causing a smaller amount of free albumin to reach the local circulation, resulting in less release of fatty acids (Hawley, 2002).

Carbohydrate availability and the level of physical fitness are fundamental to determine the use of lipid in metabolism (Ranallo & Rhodes, 1998). It should be noted that carbohydrate intake was lower than recommended for male athletes (51±11 and 55±7%) and that protein intake was above recommended levels (19±6 and 19±5%) in our sample. Overall, the recommended carbohydrate intake is approximately 60% of the dietary energy intake, whereas protein and fat recommendations are 15 and <30%, respectively (Martin, 2001). Thus, adjustments of the diets of athletes are necessary, especially for Brazilian jiu-jitsu athletes to generate a moderate activation of the glycolytic pathway during the match (Andreato, et al., 2015a; Coswig, et al., 2013; Silva, et al., 2013).

The urea concentrations did not change during matches of varied duration. Urea was measured in this study as a parameter to determine whether protein degradation took place (Hartmann & Mester, 2000). The evaluation of protein degradation is important because when glycogen stores are depleted, the contribution of protein breakdown providing ATP during exercise is increased (Grandjean & Ruud, 1994). Other studies involving Brazilian jiu-jitsu also found no alterations in the urea concentrations after a single 7-min simulation (Andreato, et al., 2012) or after two simulations of 10-min each (Coswig, et al., 2013).

The muscle damage markers (CK, AST, ALT, LDH and creatinine) revealed evidence of muscle damage in the longer matches; LDH levels increased in the 8-min match, and creatinine increased in the 8-min and 10-min matches. However, CK, AST and ALT levels were unchanged. Previous studies involving Brazilian jiu-jitsu reported that matches generated muscle damage. In the 7-min match simulations, although increases were not observed in the CK, AST and creatinine concentrations, increased ALT and LDH levels were reported (Andreato, et al., 2012). Coswig et al. (2013) evaluated the effects of two matches of 10-min each, and upon analyzing only the first combat, no increase was observed in CK and LDH levels. However, an increase in AST and ALT enzymes did occur after the first match, indicating muscle damage. When the effects of a simulated competition on muscle damage markers were evaluated, the authors observed increases in creatinine and AST in the first match, increased ALT in the third match and increased CK in the fourth match, although LDH levels were unchanged. These results demonstrate the importance of analyzing multiple muscle damage markers (Andreato, et al., 2015a). In another study involving a simulated competition it was observed that after the competition (five 10-minute matches separated by 5-minute rests) there was an increase of some muscle damage markers (CK, creatinine and uric acid) (Brandão, Fernandes, Alves, Fonseca, & Reis, 2014).

In wrestling, when evaluating the effect of only one combat, no alterations in CK were reported by two studies (Barbas, et al., 2011; Kraemer, et al., 2001). Nevertheless, one study reported an increase in C reactive protein, which can also be used as a marker of damage/inflammation (Barbas, et al., 2011). In judo, when athletes performed three bouts of combat (lasting 1.5, 3 and 5 minutes), decreased LDH was observed in the 1.5-min matches, increased CK was observed in the 5-minute matches, and AST and ALT were increased in all matches (Ribeiro, Tierra-Criollo, & Martins, 2006). Indicatives of muscle damage were also observed after three judo matches (5-minute matches separated by 15-minute rests), with an increase of CK and LDH levels (Detanico, Dal Pupo, Franchini, & Santos, 2015).

An important fact that directly influences the identification of muscle damage is the training status. A long-term judo training induces adjustments that generate lower elevations in CK, AST, ALT and LDH in judokas (Miura, et al., 2005). Additionally, when assessing the muscle damage response, studies must take into consideration the peak of detection of the markers used. The peak of CK does not occur immediately after the damage; this increase may be identified as late as 48 hours after damage (Smith, et al., 1994). Thus, one of the limitations of the present study was failing to evaluate the muscle damage several hours after the matches.

Consequently, although there is divergence among studies concerning which markers increase after the Brazilian jiu-jitsu matches, there seems to be a consensus that the matches result in muscle damage. These increases in plasma levels of damage markers may be the result of alterations of the muscle cell membrane, possibly due to hypoxia reactions and muscle ischemia resulting from exhaustive exercise, as well as the result of the action of increased intracellular calcium incurring the activation of calcium-dependent proteases (Moreau, Dubots, & Boggio, 1995). Another factor that may influence cellular damage is a high number of eccentric actions (Proske & Allen, 2005). These results may promote studies evaluating different recovery strategies after the Brazilian jiu-jitsu matches, similar to a recent study that evaluated the effect of cryotherapy on the recovery of athletes (Pinho-Júnior, et al., 2014).

In summary, the duration of Brazilian jiu-jitsu matches influences the participants' physiological responses. Longer matches resulted in higher blood lactate and increased muscle damage markers. Nonetheless, the lipid metabolism was unchanged for all matches. When the physiological responses were normalized by effort time, higher glycolytic activation and heart rate were observed during shorter matches.

The findings of the present study demonstrated metabolism rated as *strongly anaerobic* considering the classification proposed by Buchheit and Laursen (2013) in the 2- and 5-min matches, with a decrease in this pathway activation thereafter. Thus, athletes must be trained to sustain a high anaerobic release in the first five minutes of any match and to be able to keep the pace thereafter, relying more on the oxidative system, despite the metabolite accumulation resulting from the anaerobic solicitation in the beginning of the match. Thus, athletes should be exposed to high-intensity intermittent exercises relying heavily on anaerobic energy systems to be able to execute sport-specific technical actions under conditions of fatigue. High-intensity matches similar in length to official competitions should be prioritized, with intervals between fights similar to those established in competitions or long enough to provide full recovery for athletes.

In addition, due to the glycolytic pathway activation characteristics during the match, nutritional strategies that meet the supply of glucose during activity could be used to ensure adequate intake of carbohydrates before training sessions and competitions. Moreover, the use of buffering ergogenic aids can be a valid strategy for this modality.

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Conflict of interest

The authors do not have any conflicts of interest to report.

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