Thermal stress and physiological responses in Brazilian jiu-jitsu athletes submitted to simulated fights in a hot environment

Estrés térmico y respuestas fisiológicas en atletas de jiu-jitsu brasileño sometidos a peleas simuladas en un ambiente caluroso

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How to cite in APA

Vieira, D.P., Forte, P., Bernardes Leite, L., Ribeiro, J., Cachada, M., Bolani, W., Pussieldi, G. de A., Rezende, L. M. T., Pimenta, E. M., Cabido, C. E. T., Junior, M. N. S. de O., Mendes, T. T., & Veneroso, C. E. (2025). Estrés térmico y respuestas fisiológicas en atletas de jiu-jitsu brasileño sometidos a peleas simuladas en un ambiente caluroso. *Retos*, *67*, 95–106. https://doi.org/10.47197/retos.v67.111013

Abstract

Objective: Analyze thermal stress and changes in physiological variables in simulated BJJ fights in a hot environment.
Methodology: The study included 12 male athletes, comprising 11 black belts and 1 brown belt. The athletes were divided into pairs according to their categories and there were four 10-minute bouts with 10 minutes of rest between bouts in a covered environment, during the night, with an ambient temperature (TA) of 29.3 ± 0.5ºC and relative air humidity (URA) of 75.9 ± 1.1%. The variables heart rate (HR), lactate, gastrointestinal temperature (T_{gi}) and skin temperature (T_{skin}), hand grip, dehydration rate, total sweating and specific urine density were evaluated. HR, lactate and T_{gi} data were collected before starting the simulated fights (pre 1, 2, 3 and 4), immediately after the end of each fight (post 1, 2, 3, and 4). All other variables were collected during the baseline period, which corresponds to pre 1, and in the post-fight assessments (post-fight 1, 2, 3, and 4).
Results: There was a significant reduction in body mass post-fight compared to pre-simulated fights ($p < 0.001$). Despite ad libitum hydration, athletes transitioned from a euhydrated state to significant-to-severe dehydration by the end of the protocol. HR values were significantly higher post-fight (post 1, 2, 3, 4) compared to rest (pre-1) ($p < 0.001$). Blood lactate levels increased post-fight (post 1, 2, 3, 4) compared to rest (pre-1). T_{gi} increased significantly after the first fight (post 1, 2, 3, 4) compared to rest (pre 1) ($p < 0.001$) and remained stable until the fourth fight. T_{skin} showed a increase post-fight (post 1, 2, 3) compared to rest (pre-1) ($p < 0.001$).
Conclusions: The thermoregulatory mechanisms were sufficient to maintain thermal control during the simulated BJJ fights.

Keywords

Thermoregulation; athletes; physiological; brazilian jiu-jitsu; martial.

Resumen

Objetivo: Analizar el estrés térmico y los cambios en las variables fisiológicas en peleas simuladas de BJJ en un ambiente caluroso.
Metodología: El estudio incluyó a 12 atletas masculinos, que comprendían 11 cinturones negros y 1 cinturón marrón. Los atletas se dividieron en parejas según sus categorías y hubo cuatro combates de 10 minutos con 10 minutos de descanso entre combates en un ambiente cubierto, durante la noche, con una temperatura ambiente (TA) de 29,3 ± 0,5ºC y una humedad relativa del aire (URA) de 75,9 ± 1,1%. Se evaluaron las variables frecuencia cardíaca (FC), lactato, temperatura gastrointestinal (T_{gi}) y temperatura de la piel (T_{skin}), agarre de la mano, tasa de deshidratación, sudoración total y densidad específica de la orina. Los datos de FC, lactato y T_{gi} se recogieron antes de comenzar las peleas simuladas (pre 1, 2, 3 y 4), inmediatamente después del final de cada pelea (post 1, 2, 3 y 4). Todas las demás variables se recopilaron durante el período de referencia, que corresponde al período previo a la pelea 1, y en las evaluaciones posteriores a la pelea (post pelea 1, 2, 3 y 4).
Resultados: Hubo una reducción significativa en la masa corporal después de la pelea en comparación con las peleas pre-simuladas ($p < 0,001$). A pesar de la hidratación ad libitum, los atletas pasaron de un estado euhidratado a una deshidratación significativa a severa al final del protocolo. Los valores de FC fueron significativamente más altos después de la pelea (post 1, 2, 3, 4) en comparación con el descanso (pre-1) ($p < 0,001$). Los niveles de lactato en sangre aumentaron después de la pelea (post 1, 2, 3, 4) en comparación con el descanso (pre-1). T_{gi} aumentó significativamente después de la primera pelea (post 1, 2, 3, 4) en comparación con el descanso (pre 1) ($p < 0,001$) y se mantuvo estable hasta la cuarta pelea. T_{skin} mostró un aumento después de la pelea (post 1, 2, 3) en comparación con el descanso (pre-1) ($p < 0,001$).
Conclusiones: Los mecanismos termorreguladores fueron suficientes para mantener el control térmico durante las peleas simuladas de BJJ.

Palabras clave

Termorregulación; atletas; fisiológico; jiu-jitsu brasileño; marcial.

Introduction

In recent decades, Brazilian jiu-jitsu (BJJ) has experienced a surge in global popularity, fueled by the rise of mixed martial arts, where ground fighting proficiency plays a pivotal role in contest outcomes (Andreato et al., 2011; Blomqvist, 2021; Brandt et al., 2021; Carvalho et al., 2022; Dal Bello et al., 2019; Dos Santos et al., 2019; Fernandes et al., 2018). As a martial art, BJJ is distinguished by its repertoire of techniques involving grabbing, throwing, strangling, twisting, and immobilizing/dominating opponents. Physically, BJJ is primarily an intermittent anaerobic sport, necessitating high levels of physical fitness, concentration, and emotional equilibrium (Andreato et al., 2011).

During official tournaments, competitors engage in approximately four to six matches to vie for championship titles, typically lasting five minutes for white belt athletes and ten minutes for black belts. A notable factor that heightens the intensity of participation in these events is the brief time interval between matches, often inadequate for adequate recovery. Studies indicate that during BJJ competitions, the effort-to-recovery ratio ranges from 6:1 to 13:1, with effort phases lasting between 85 and 290 seconds, followed by recovery periods of 5 to 44 seconds. This exceeds the ratios observed in other combat sports. In judo, effort phases last around 20 to 30 seconds with 10-second pauses, resulting in ratios between 2:1 and 3:1, while in wrestling, the ratio is approximately 2:1, with 37 seconds of effort followed by 14 seconds of rest (Andreato et al., 2015; Castarlenas & Solé, 1997; Coswig et al., 2018; Nilsson et al., 2002). These differences highlight the greater physical demands of BJJ, where prolonged exertion phases influence training strategies and conditioning approaches.

In addition to factors such as the frequency and duration of matches and the close quarters combat style inherent in BJJ, the use of the kimono also significantly impedes evaporative heat loss, crucial for regulating body temperature during competitions. This hindrance to heat dissipation can lead to an excessive rise in internal body temperature, stemming from a transient or sustained imbalance between heat production and loss rates, further influenced by physiological alterations induced by the activity, such as reduced hydration levels, heightened lactate concentrations, and increased heart rate (HR) (Cramer & Jay, 2016; Da Silva et al., 2013; Nielsen & Nybo, 2003).

All these alterations induce thermoregulatory stress, which, when compounded with the physiological strain of intense physical activity, may accelerate fatigue. This phenomenon is driven by the competition for cardiac output between two primary demands: active muscles require adequate blood flow to sustain oxygen delivery and energy metabolism, simultaneously, the thermoregulatory system relies on arterial blood to transport metabolic heat to the skin for dissipation. As body temperature rises, skin blood flow increases to facilitate heat loss, potentially reducing central blood volume and cardiac filling, which can impair stroke volume and oxygen supply to the working muscles. This redistribution of blood flow can lead to cardiovascular strain, compromising both aerobic performance and thermal homeostasis, ultimately increasing susceptibility to fatigue (González-Alonso et al., 2008; Lorenzo et al., 2010).

Therefore, in recent years, studies on the effects of environmental heat stress on human performance have acquired considerable scientific relevance, especially due to global climate change (Abi Deivanayagam et al., 2023; Argaud et al., 2007; Ebi et al., 2004; Nybo et al., 2002; World Meteorological Organization, 2021). Rising global temperatures and more frequent heat waves increase the likelihood of athletes competing and training in extreme thermal conditions, which can severely impact performance and physiological responses. In combat sports like BJJ, prolonged physical exertion occurs in close-contact situations and often in indoor environments with limited ventilation. Heat stress may exacerbate fatigue, impair cognitive function, and elevate the risk of heat-related illnesses. Beyond performance impairments, excessive heat exposure significantly raises the likelihood of syncope, muscle cramps, dizziness, and even serious cardiovascular events (Howe & Boden, 2007; Leyk et al., 2019). Hence, implementing strategies to mitigate heat-induced thermoregulatory stress is crucial for optimizing performance and ensuring the health and safety of athletes training and competing in increasingly warmer environments.

Regarding the above-mentioned, no available studies have evaluated thermoregulatory stress during BJJ fights. Given that body temperature control impacts sports performance, knowledge of these variables can be important in preparing for competitions, especially in hot environments. Given this gap, the present study aims to analyze thermal stress and changes in physiological variables in simulated BJJ fights in a hot environment. It was hypothesized that the physiological variables differ in simulated BJJ fights when exposed to hot environments.

Method

Sample

The study included 12 male athletes, comprising 11 black belts and 1 brown belt, with an average age of 28 ± 3 years, an average sports practice duration of 12.9 ± 3.5 years, a body mass of 84.0 ± 10.0 kg, a height of 173.0 ± 6.0 cm, and a body fat percentage (%BF) of 13.5 ± 4.9 (refer to Table 1). All participants were experienced in competing at national and international levels and resided in São Luís, Maranhão, Brazil. The research protocol was submitted to the Federal University of Maranhão Research Ethics Committee and was approved under protocol no. 1.548.709 and CAEE 51908115.6.0000.5087. Before participation, all athletes were fully briefed on the study procedures and provided with a Free and Informed Consent Form (TCLE) to sign. During this process, the potential risks and benefits of the research were thoroughly discussed, ensuring participants the autonomy to decide whether to participate or not, as well as the right to withdraw from the study at any time.

Experimental Procedures

The participants visited the laboratory twice, with both sessions starting at 7:00 PM. They were instructed to abstain from consuming alcohol, caffeine, and thermogenic and engage in intense physical exercise on the day of the experimental sessions. Throughout the experiment, ambient temperature and relative humidity were continuously monitored using an Extech HT30 Heat Stress WBGT Meter psychrometer, model HT30 (FLIR Commercial Systems Inc, Nashua, NH). Ambient temperature was measured with an accuracy of ±1°C, and relative air humidity was measured with an accuracy of ±3%, with readings taken every 30 minutes. All measurements were conducted following the manufacturer's recommendations to ensure the accuracy and reliability of the data.

During the first visit to the laboratory, the participants were introduced to the project and signed the Free and Informed Consent Form (TCLE). Basic demographic data were also collected during this visit to characterize the sample. On the second visit, the main data collection took place, which included the assessment of hydration status, skin temperature (T_{skin}), hand grip strength, Gastrointestinal temperature (T_{gi}), lactate concentration, percentage of weight loss, and sweating rate. Additionally, during this visit, participants engaged in simulated BJJ fights. When at the laboratory, participants provided a urine sample to assess their hydration status using the Urine Specific Gravity (GEU) scale. If they were found to be dehydrated, they were provided with 300 mL of water every 30 minutes. Subsequently, instrumentation was conducted to collect thermoregulatory and physiological data.

The athletes were divided by body mass to ensure that fights took place without significant differences in weight category (less than 10% difference in body mass between opponents), as in official competitions. The simulated competition was conducted with the same opponents throughout all four fights. Data collection followed a structured timeline. HR, lactate levels, and T_{gi} were measured before each fight (pre 1, 2, 3, and 4) and immediately after (post 1, 2, 3, and 4). T_{skin} and handgrip strength were assessed at baseline (pre 1) and after each fight (post 1, 2, 3, and 4). Before the first fight, the baseline period (pre 1) served as a reference for comparison. Athletes then performed a non-standardized fifteen-minute warm-up, followed by a five-minute rest period before the first fight. Each fight lasted ten minutes, with a ten-minute recovery period between bouts.

Instrument

Body mass index (BMI)

Body mass and height were measured using a digital scale with a portable stadiometer (Welmy, model W300, Brazil). These values were utilized to compute the body mass index (BMI), employing the formula: body mass (kg) divided by height (m2). Bioimpedance analysis (BIODYNAMICS MODEL 450; Seattle, Washington, USA) was employed to assess the volunteers' fat percentage. Body surface area (BSA) was calculated using the equation (Bois, 1989):

$$B\ (m^2) = (0{,}007184\ .\ (height\ in\ cm^{0{,}725}).\ (weight\ in\ kg)^{0{,}425}$$

Skin temperature

T_{skin} was measured utilizing an infrared thermometer (FLUKE, 566) with a laser sight, positioned at a distance of 20 cm, regulated by a ruler attached to the thermometer. All measurements were standardized, marked with a whiteboard brush (PILOT 2 mm), and collected on the right side of the volunteer's body. The measurements took place two minutes before the simulated fights started and immediately after each fight's end. Head temperature was measured at three points: temperature at the top (central point of the head), temperature at the forehead (3 cm above the eyebrow, lateral portion), and temperature at the chin (central part). The average head temperature was calculated using the following equation (Nybo et al., 2002).

$$T_{head} = \frac{(T_{apex} + T_{forehead} + T_{cheek})}{3}$$

To determine the average T_{skin}, the following points were measured: chest temperature (3cm next to the nipple), arm temperature (in the medial portion of the biceps), and thigh temperature (anterior region of the thigh, medial portion). Mean T_{skin} was calculated using the following equation (Roberts et al., 1977):

$$T_{skin} = (T_{chest} x\ 0{,}43) + (T_{arm}\ x\ 0{,}25) + (T_{thigh}\ x\ 0{,}32)$$

Gastrointestinal temperature

The T_{gi} was monitored throughout the experiment using a telemetric system (CorTemp® HQ Inc, Florida, USA), consisting of ingestible capsules that transmit low-frequency radio waves, with wavelengths varying according to temperature. These radio waves were received and converted into digital format by a data recorder (CorTemp® HQ Inc, Florida, USA). To ensure measurement accuracy and considering the capsules' sensitivity to temperature variations in the gastrointestinal tract, participants ingested the capsules one day before data collection, following instructions to ingest them between 7 and 8 hours before the start of data collection. All the procedures adhered to previously established recommendations (Byrne & Lim, 2007).

Lactate concentration and heart rate

Blood samples were collected by puncturing the participants' digital pulp to evaluate lactate concentrations after cleaning the area with 70% ethyl alcohol. We use a lancing device with disposable microlancets for this purpose. A drop of blood was then placed in the center of the dipstick test zone. We use the Roche Accutrend Plus portable lactate analyzer, which uses dry chemistry to analyze the lactate present in the blood. This device evaluates lactate concentrations in the range of 0.8 to 21.7 mmol·L-1 (blood value) and 0.7 to 26 mmol·L-1 (plasma value).

The HR during simulated fights was recorded using a HR monitor (Team Pod@ Heart Monitor-Firstbeat, Finland). This device includes a sensor positioned next to the athlete's chest and secured with an elastic strap. The real-time telemetry receiver is directly connected to the Firstbeat SPORTS Individual® software, enabling precise and real-time monitoring of participants' HR.

Handgrip strength

The athletes performed the handgrip test with a Jamar dynamometer model J00105 (Lafayette Instrument, Lafayette, LA, USA) adjusted to hand size to measure maximal isometric handgrip strength. The average of three measurements obtained the ICC > 0.97.

Hydration status, % weight loss and sweating rate

The participant's hydration status was assessed by considering the percentage of dehydration and body mass loss, total sweating rate, and quantity of water consumed (Popowski et al., 2001). Each participant was weighed before and after the fights while wearing only swim trunks or shorts. During ten-minute rest intervals, participants were allowed to drink water ad libitum. To calculate the percentage of dehydration, the following equation was utilized.

$$\%dehydratation = \frac{(initial\ weight - final\ weight)}{final\ weight}\ x100$$

The % of body weight loss was calculated by the difference between body mass before and after the simulated fights, this difference being corrected by the amount of water consumed.

$$\%weight\ loss = \left(\Delta body\ mass - \frac{water\ consumed}{initial\ weight}\right) x\ 100$$

The total sweating rate was calculated by the difference in body mass, relativized by the body surface area and divided by the exercise time. The volunteers were properly dried with paper towels and sweating was corrected by drinking water during the fights.

$$sweat\ rate = \frac{(\ \Delta body\ mass - \text{water consumed})}{(\frac{ASC}{time\ in\ min})}$$

Statistical analysis

The data were presented as mean ± standard deviation and minimum and maximum values. The normality of the data was assessed using the Shapiro-Wilk test. Comparisons between measurements before and during the simulated fight protocol were conducted using one-way repeated measures (RM) ANOVA, followed by Tukey's multiple comparisons test with a single pooled variance. A significance level of $p < 0.05$ was considered statistically significant. All analyses were performed using GraphPad Prism 10.4.1.

Results

The ambient temperature and relative humidity were monitored every fifteen minutes, remaining constant at 29.3 ± 0.5 ºC and 75.9 ± 1.1% relative humidity (RH). Table 1 presents the participants' baseline data and hydration status after the simulated fight protocol. There was a significant reduction in body mass post-fights compared to pre-simulated fights (pre: 84.4 ± 10.2 kg; post: 83.2 ± 10.0 kg; $p < 0.001$, $\eta^2 = 0.822$). Throughout the protocol, participants were able to hydrate ad libitum. The athletes began the protocol in a euhydrated state and ended the simulated fights in a state of significant to severe dehydration, as indicated in Table 1.

Table 1. Sample characterization and dehydration status after a simulated fight protocol.

Variables	Mean ± SD	Minimum	Maximum
Age (years)	28,0 ± 3,0	24,0	33,0
Practice time (years)	12,9 ± 3,5	9,0	20,0
Pre body mass (kg)	84,4 ± 10,2	64,5	111,0
Height (cm)	173,2 ± 5,7	165,0	183,0
BMI (kg/m^2)	27,6 ± 3,7	22,4	37,5
ASC (m^2)	1,9 ± 0,1	1,7	2,2
% Fat mass	13,5 ± 4,9	7,9	27,4
% Dehydration	1,6 ± 0,9	-0,1	3,3
% Body loss	1,3 ± 0,6	- 0,1	2,1
Total sweat rate (L)	2,2 ± 0,6	0,9	3,2
Water consumed (ml)	952,3 ± 380,5	322	1500

Values presented as mean ± SD, Minimum and Maximum

Figure 1 displays the participants' HR and lactate concentration measurements in the pre-and post-simulated fights. In panel A, higher HR values are observed in the post-fight moments compared to rest and pre-fight values (pre 1: 65.83 ± 10.80 bpm; post 1: 168.80 ± 8.48 bpm; pre 2: 124.60 ± 11.89 bpm; post 2: 169.30 ± 10.85 bpm; pre 3: 130.30 ± 13.26 bpm; post 3: 165.40 ± 9.60; pre 4: 127.10 ± 14.64 bpm; post 4: 159.90 ± 12.51 bpm; $p < 0.001$, $\eta^2 = 0.918$). Regarding the analysis of blood lactate levels (Panel

B) before and after the simulated fights, higher blood lactate values were observed at all times after the first fight compared to the rest measurement (pre 1: 2.46 ± 1.07 mmol·L^{-1}; post 1: 10.40 ± 3.86 mmol·L^{-1}; pre 2: 8.63 ± 2.91 mmol·L^{-1}; post 2: 10.56 ± 4.09 mmol·L^{-1}; pre 3: 8.63 ± 2.44 mmol·L^{-1}; post 3: 9.46 ± 3.22 mmol·L^{-1}; pre 4: 7.03 ± 3.32 mmol·L^{-1}; post 4: 9.88 ± 3.99 mmol·L^{-1}; $p < 0.001$, η^2 = 0.6184). In the isolated comparison between pre- and post-fight moments, a difference was observed only for fight 4 (pre-4: 7.03 ± 3.3 mmol·L^{-1} vs. post-4: 9.8 ± 3.9 mmol·L^{-1}; $p < 0.001$, η^2 = 0.6184).

Figure 1. Heart rate (A) and blood lactate concentration (B) during a simulated fight protocol. Data are presented as mean ± standard deviation. *P < 0.001 vs. Pre 1; #P < 0.001 between pre-and post-exercise.

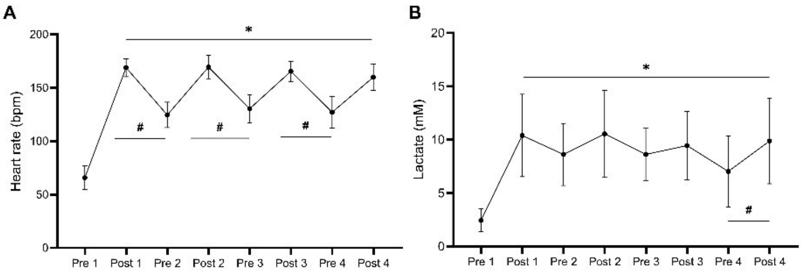
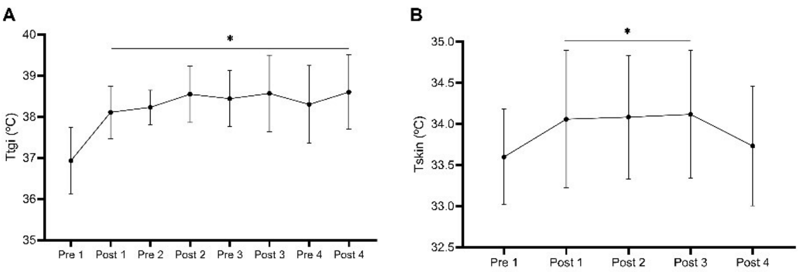


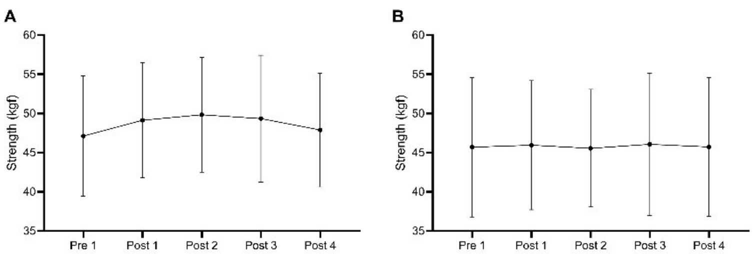
Figure 2 illustrates T_{gi} and T_{skin} throughout the simulated fight protocol. Regarding the data on T_{gi} (Panel A), a significant increase was observed after the first fight compared to the resting value (pre 1: 36.93 ± 0.81 °C; post 1: 38.11 ± 0.64°C; $p < 0.001$, η^2 = 0.5622) and then maintained a stable trend until the conclusion of the fourth fight (pre 2: 38.23 ± 0.42 °C; post 2: 38.55 ± 0.69 °C; pre 3: 38.44 ± 0.68 °C; post 3: 38.60 ± 0.93 °C; pre 4: 38.30 ± 0.95 °C; post 4: 38.60 ± 0.90 °C). As for T_{skin} (Panel B), a significant increase was observed in the immediate post-fight moments 1, 2, and 3 compared to the resting value (pre 1: 33.60 ± 0.60 °C; post 1: 34.06 ± 0.83 °C; post 2: 34.08 ± 0.75 °C; post 3: 34.12 ± 0.78 °C; post 4: 33.73 ± 0.73 °C; $p < 0.001$, η^2 = 0.2985).

Figure 2. Gastrointestinal temperature (A) Skin temperature (B) during a simulated fight protocol. Data are presented as mean ± standard deviation. *P < 0.001 vs. Pre 1.



No differences were observed in handgrip measurements before and after the simulated fights, either for the right hand (p = 0.3617, η^2 = 0.0920) or for the left hand (p = 0.9983, η^2 = 0.0027).

Figure 3. Handgrip strength during a simulated fight protocol. (A) Right hand and (B) left hand. Data are presented as mean ± standard deviation.



Discussion

The present study aimed to analyze thermal stress and changes in physiological variables in simulated BJJ fights in a hot environment. The main result of the study is that after the first fight, all variables analyzed - except head temperature - showed an increase that persisted until the end of the protocol; that is, the time interval between fights was not enough to return physiological variables to baseline levels. This scenario indicates that BJJ athletes perform a large part of their official fights in conditions that are unfavorable to performance and thermoregulatory comfort.

Initially, a reduction in body mass was observed after the matches (~1.2 kg on average), suggesting a state of acute dehydration, even with ad libitum fluid intake. Additionally, the athletes began the protocol in a euhydrated state and finished the simulated matches in a state of significant to severe dehydration. This finding is consistent with previous studies on high-intensity sports, in which intense efforts, especially in hot environments, result in substantial fluid losses (Duffield et al., 2012; McCubbin et al., 2020; Rollo et al., 2021; Sabou et al., 2020). This reduction in body fluid volume may impair thermoregulatory mechanisms and cardiovascular stability (González-Alonso et al., 1997; Watso & Farquhar, 2019). Such a condition may have contributed to increased physiological stress experienced by the athletes during the bouts. Consequently, maintaining performance throughout the matches may have been compromised, particularly in situations requiring a high recovery capacity between efforts. Furthermore, the increase in HR after the matches, observed in the present study, reinforces the high cardiovascular demand imposed by BJJ, a pattern similar to that reported in other combat sports (Da Silva et al., 2020; Slimani et al., 2018).

This progressive physiological stress was also reflected in changes in blood lactate levels throughout the matches. After the first bout, lactate values increased compared to the resting condition and remained elevated until the end of the protocol. However, despite this sustained elevation, a difference between pre- and post-match moments was only observed in the final bout, suggesting a progressive accumulation of metabolic stress throughout the combats. This pattern reinforces the high anaerobic demand of BJJ, supporting previous studies that indicate anaerobic glycolysis as a determining factor in the performance of high-intensity sports (Beneke et al., 2011; Mastalerz et al., 2024).

Post-match lactate concentrations exceeded 9 mmol·L^{-1}, reinforcing the predominance of the lactic anaerobic pathway in BJJ, an intermittent sport with high metabolic demand (Andreato et al., 2015; Jones & Ledford, 2012). This pattern is similar to that observed by Franchini et al., 2005, who identified elevated blood lactate concentrations after matches 3 and 4, suggesting a significant demand on the glycolytic pathway. It is well known that lactate concentration is directly associated with increased heart rate. Therefore, the cumulative stimuli imposed by consecutive matches may have led to sustained heart rate levels above resting values, prominently increasing lactate concentration after the final event. Additionally, lactate removal mechanisms may lose efficiency following intermittent high-intensity stimuli (Da Silva et al., 2013; Villar et al., 2018).

Regarding thermal responses to exertion, T_{gi} increased at the onset of activity and stabilized after the second match. This increase is consistent with the rise in metabolic activity required to sustain muscle contractions and energy production for the activity (Bradbury et al., 1964; Mündel, 2020). However, the magnitude of this response may vary depending on the athletes' training level, as mechanical efficiency and movement economy influence heat generation (Akerman et al., 2016). The stabilization of T_{gi} suggests that thermoregulatory mechanisms were effective in limiting further increases in core temperature, considering that the sample consisted of experienced athletes (black and brown belts). However, the short recovery intervals were insufficient to fully dissipate the accumulated heat, causing the athletes to begin subsequent matches with residual thermal load. It is worth noting that this accumulation may impair performance by intensifying fatigue and perceived exertion, as previously observed in sports performed under adverse environmental conditions (Bergeron et al., 2012; Gasparetto & Nesseler, 2020; Plakias et al., 2024).

Additionally, T_{skin} provides important insights into thermal regulation (Jessen, 2001; Schlader et al., 2018). After the first match, T_{skin} increased and remained elevated throughout the protocol, which may have contributed to preventing T_{gi} from exceeding physiological limits. However, since this study did not directly assess specific thermoregulatory mechanisms, such as cutaneous blood flow or heat loss through convection, further research is needed to clarify the relative contribution of these factors to temperature regulation in BJJ athletes.

Finally, despite the evident physiological stress throughout the matches, handgrip strength remained unchanged throughout the protocol. This finding is particularly relevant, as grip strength plays a fundamental role in BJJ, being essential for executing and maintaining grips during combat (Jones & Ledford, 2012; Silva et al., 2014). Thus, the observed strength preservation suggests that short-term neuromuscular fatigue may not be a primary limiting factor in successive matches. A possible explanation for this finding is the neuromuscular adaptation of athletes to intermittent efforts, allowing them to maintain performance even under high physiological demand. However, the literature indicates that dehydration may impair strength performance in prolonged efforts (Judelson et al., 2007; Rodrigues et al., 2014), suggesting that future studies should assess grip endurance over multiple matches to understand its impact on competitive performance better.

This study presents some limitations. The absence of a control group prevents comparisons with non-practitioners, beginner athletes, or athletes from other sports, making it difficult to confirm whether the findings are specific to BJJ athletes. Additionally, a time-motion analysis was not conducted, which could provide a more detailed insight into technical-tactical performance and the effort-to-rest ratio during matches. The matches were also simulated in a controlled environment, which may not fully reflect competitive demands. Finally, the sample consisted predominantly of high-level athletes (11 black belts and 1 brown belt), without an analysis of the impact of technical level on the results.

From a practical perspective, the maintenance of grip strength suggests that short-term neuromuscular fatigue may not be a primary limiting factor, directing attention toward thermal recovery and hydration strategies between matches. The stabilization of T_{gi} reinforces the importance of cooling methods, such as cold-water immersion or active ventilation, to minimize the impact of accumulated thermal load. Additionally, elevated lactate levels highlight the need for training focused not only on anaerobic capacity but also on metabolic recovery from intense efforts. Finally, individualized hydration strategies are recommended to mitigate the potential negative effects of dehydration in prolonged competitions.

Conclusions

The thermoregulatory mechanisms were sufficient to maintain a stable internal temperature during BJJ simulated fights in a hot environment, despite the restrictive nature of the attire, which is thick and heavy and limits heat dissipation. However, athletes completed the protocol dehydrated, highlighting the physiological strain imposed by prolonged exertion under these conditions. Since dehydration can impair performance, delay recovery, and increase the risk of heat-related illnesses, proper hydration strategies should be prioritized during training and competitions. Additionally, considering the increasing prevalence of high-temperature environments due to climate change, further research should explore interventions to optimize thermoregulation in BJJ athletes, such as cooling strategies and hydration protocols tailored to the specific demands of the sport.

Acknowledgements

L. B. Leite is thankful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brazil (CAPES) for the scholarship.

Financing

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Finance Code 001.

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