

1 **Acute physiological and perceptual responses to Brazilian jiu-jitsu**
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3 **sparring: The role of maximal oxygen uptake**
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6 Running title: Physiological and perceptual responses to Brazilian jiu-jitsu sparring
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Acute physiological and perceptual responses to Brazilian jiu-jitsu sparring: The role of maximal oxygen uptake

Sparring is a training form in combat sports designed to simulate fighting. This study sought to assess the relationship between physiological and perceptual responses to Brazilian jiu-jitsu (BJJ) sparring and their relationship with maximal oxygen uptake ($\dot{V}O_{2max}$). Twelve male BJJ athletes (age: 30.6 ± 2.7 (SD) years; height: 182.5 ± 5.9 cm; body mass (m_b): 81.2 ± 6.7 kg; body fat: $9.9 \pm 3.2\%$) with 4.6 ± 2.2 years of BJJ experience and a training volume of 10.3 ± 4.4 hours·week⁻¹ participated in the study. Following a $\dot{V}O_{2max}$ measurement, heart rate (HR), blood lactate concentration ($[La^-]_b$), and rating of perceived exertion (RPE) were obtained during sparring in a regular training session, with each participant sparring 5 consecutive 6-minute rounds separated by 90-second breaks. Mean sparring HR was 164 ± 9 beats·min⁻¹, equivalent to $85 \pm 4\%$ of the maximal HR (HR_{max}). The sparring was perceived as “hard”. Mass-independent $\dot{V}O_{2max}$ correlated negatively with HR, relative HR ($\%HR_{max}$), and $[La^-]_b$ in sparring. The negative relationship between $\dot{V}O_{2max}$ and physiological markers of exertion suggest that $\dot{V}O_{2max}$ affects exercise tolerance in BJJ and could also point to a limited efficacy of sparring for developing aerobic endurance due to insufficient exercise intensity in trained athletes.

Keywords: martial arts; grappling; combat sports; lactate; heart rate; RPE

Introduction

1
2 Brazilian jiu-jitsu (BJJ) is a grappling-based combat sport where the objective is positional control and
3
4 ultimately a submission of the opponent via a chokehold or joint lock. Official matches can span from
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6 a few seconds to hours, but are commonly regulated for durations of 5 to 10 minutes (International
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8 Brazilian Jiu-Jitsu Federation, 2015). Due to the nature of the sport, directly measuring the oxygen
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10 cost of BJJ combat is not feasible. Thus, indirect markers of exertion such as heart rate (HR), blood
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12 lactate concentration ($[La^-]_b$), and rating of perceived exertion (RPE) have been used to investigate
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14 sport-specific demands (Andreato, Follmer, Celidonio, & Honorato, 2016). The latter has become an
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16 increasingly popular approach to intensity assessments in combat sports due to its association with
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18 physiological markers such as HR and $[La^-]_b$ in both training and competition (Slimani, Davis,
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20 Franchini, & Moalla, 2017). In BJJ, however, the relationship between these markers is less clear. HR
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22 and $[La^-]_b$ appears to correlate (Villar, Gillis, Santana, Pinheiro, & Almeida, 2018), while RPE does
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24 not have a consistent relationship with either (Andreato, Follmer, et al., 2016; Andreato et al., 2013;
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26 Andreato et al., 2012).

31 The energy demands of grappling is met by both aerobic and anaerobic processes (Ratamess,
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33 2011). BJJ is characterized by a high volume of low-intensity work interspersed with brief, more
34
35 intense efforts (Andreato, Follmer, et al., 2016). This places considerable demand on aerobic
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37 adenosine triphosphate resynthesis to sustain physiological performance. The degree of aerobic
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39 metabolism in grappling is also apparent from spiroergometer measurements during judo combat
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41 (Julio et al., 2017). The maximal aerobic metabolic rate during exercise is determined by the maximal
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43 oxygen uptake ($\dot{V}O_{2max}$). Recent investigations have reported a $\dot{V}O_{2max}$ of approximately $50 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$
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45 in BJJ athletes (Andreato, Lara, Andrade, & Branco, 2017; Ovreteit, 2018), which is similar to
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47 the age-matched general population (Edvardsen, Hansen, Holme, Dyrstad, & Anderssen, 2013) and
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49 slightly below that of wrestlers (Chaabene et al., 2017) and judokas (Franchini, Del Vecchio,
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51 Matsushigue, & Artioli, 2011). Observations from both simulated (Andreato, Julio, Panissa, et al.,
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53 2015; Andreato, et al., 2012; Da Silva et al., 2013; Villar, et al., 2018) and official (Andreato, et al.,
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55 2013; Andreato et al., 2014; Diaz-Lara, del Coso, García, & Abián-Vicén, 2015) BJJ competition
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57 show that athletes experience significant increases in $[La^-]_b$, with levels often exceeding $10 \text{ mmol} \cdot \text{L}^{-1}$
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1 following a single match, indicating a considerable reliance on anaerobic energy supply. Although this
2 can partly be ascribed to the intermittent nature of BJJ combat, it also implies a limited capacity for
3 aerobic energy yield.
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6 A high aerobic exercise intensity has been shown to be a key component for efficient
7 improvements in $\dot{V}O_{2\max}$ (Bacon, Carter, Ogle, & Joyner, 2013; Helgerud et al., 2007; MacInnis and
8 Gibala, 2017; Storen et al., 2017). A BJJ training session typically consists of warm-ups, technical
9 drills, and sparring (Branco et al., 2016). Sparring is a form of fight simulation, often mirroring
10 official competition rules and performed at a range of different intensities, including maximal effort.
11 Since BJJ does not involve strikes to the head, sparring can be performed at a competition pace with
12 little risk of serious head trauma, assuming a certain level of proficiency. Conversely, intense sparring
13 in striking-based disciplines such as boxing can result in repetitive subconcussive and even concussive
14 blows to the head, increasing the risk for neurological conditions such as chronic traumatic
15 encephalopathy (McKee et al., 2009). Due to the comparably low risk of high-intensity sparring in
16 BJJ, it is often used as a form of endurance training. However, the moderate $\dot{V}O_{2\max}$ in this population
17 warrants investigating its role in BJJ training and whether sparring is an efficient approach to athlete
18 conditioning.
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35 To the best of the author's knowledge, no study to date has explored the relationship between
36 $\dot{V}O_{2\max}$ and training intensity in BJJ. The lacking association between BJJ training volume and $\dot{V}O_{2\max}$
37 suggest that BJJ might have limited utility for developing aerobic endurance (Ovretveit, 2018). Thus,
38 the aim of this study was to determine the association between $\dot{V}O_{2\max}$ and acute physiological
39 responses to unrestricted BJJ sparring, as measured by HR and $[La^-]_b$. Additionally, the relationship
40 between RPE and these physiological measurements was assessed. It was hypothesized that 1) $\dot{V}O_{2\max}$
41 would be negatively associated with HR and $[La^-]_b$, and 2) that there would be a lack of relationship
42 between the physiological markers of exertion and RPE.
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Materials and methods

Study design

Athletes with a consistent volume, frequency, and form of training (≥ 3 sessions \cdot week $^{-1}$ with a sparring component) were recruited from the largest BJJ academy in the region. A questionnaire was used to collect information on rank, experience, and training habits to assess eligibility. The participants underwent cardiopulmonary exercise testing (CPET) to determine their $\dot{V}O_{2\max}$. Subsequently, an upcoming BJJ training session was selected for each athlete for measurements of sparring intensity. No more than one participant was assessed per session to reduce the impact of external factors on the training. The number of sparring rounds was standardized and based on the average training volume of the participating athletes.

Each training session lasted 120 minutes and consisted of 60 minutes of warm-ups and technical drills, followed by 60 minutes of monitored sparring. The curriculum was overlapping from session to session and the physiological impact of any variation in technical content was controlled for with baseline measurements of $[La^-]_b$ (Lactate Scout+, SensLab GmbH, Germany), HR (M400, Polar Electro, Finland), and RPE (Borg, 1970). Then, the participant sparred 5 consecutive 6-minute rounds. Each round was separated by a 90-second break. During the break, measurements of $[La^-]_b$ and RPE were obtained, and HR data for the past round stored. The participants rotated randomly through opponents of different ranks (white through brown) ranging from light to super heavyweight. Partner selection was supervised to assure adequate variation and avoid duplicate pairs. The participants were instructed not to deviate from their normal style and intensity of sparring.

Participants

The study sample comprised 12 active male BJJ athletes (age: 30.6 ± 2.7 years; height: 182.5 ± 5.9 cm; body mass (m_b): 81.2 ± 6.7 kg; body fat: $9.9 \pm 3.2\%$) ranked from white to brown belt, with 4.6 ± 2.2 years of experience and a BJJ training volume of 10.3 ± 4.4 hours \cdot week $^{-1}$. Athletes had to be active competitors with > 1 year of consistent BJJ training or hold the rank of blue belt or higher to be eligible for participation. Additionally, sparring at unrestricted intensities had to be a part of their training and BJJ their main form of aerobic conditioning. Exclusion criteria were low training

1 frequency (< 3 sessions·week⁻¹) and injuries that inhibited training intensity and/or the baseline CPET.
2 The study was approved by the local ethics committee. Written informed consent was obtained from
3 each participant prior to participation.
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8 ***Anthropometry***

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10 Stature was measured to the nearest 0.5 cm with a wall-mounted stadiometer (Seca Corp., Hanover,
11 MD). Segmental multifrequency bioelectrical impedance analysis (MC-980-MA, Tanita Corp., Tokyo,
12 Japan) was used to determine mass and composition of the body. The participants were instructed to
13 avoid same-day exercise prior to testing and be in a euhydrated state with an empty bladder and bowel
14 at the time of the test.
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23 ***Maximal oxygen uptake***

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25 Oxygen uptake ($\dot{V}O_2$) was measured (SensorMedics Vmax Spectra 229d, Yorba Linda, CA, USA)
26 during an incremental CPET on a motorized treadmill (PPS 55 Med, Woodway GmbH, Weil am
27 Rhein, Germany) at a 3° gradient. After a standardized warm-up of 10 minutes at 7 km·h⁻¹, treadmill
28 speed was increased by 1 km·h⁻¹ every minute until exhaustion, which generally occurred within 5 to 8
29 minutes. HR was continuously monitored (M400) and the maximal HR achieved was determined as
30 HR_{max}. The highest 30-second average $\dot{V}O_2$ was calculated and accepted as $\dot{V}O_{2max}$ if at least two of
31 the following criteria were met: $\dot{V}O_2$ levelling off despite increasing workload; a proximity of ≤ 5
32 beats·min⁻¹ to HR_{max} if this was known; respiratory exchange ratio ≥ 1.1 ; and/or $[La^-]_b \geq 8$ mmol·L⁻¹.
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34 Following the CPET, the subjective level of exertion was rated on Borg's category scale (Borg, 1970),
35 and blood was sampled from the fingertip and analysed (Biosen C-Line, EKF Diagnostics GmbH,
36 Barleben, Germany) to determine $[La^-]_b$.
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--Insert table 1 here--

Allometric scaling

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2 To account for differences in body size, mass-independent $\dot{V}O_{2\max}$ was calculated with the allometric
3
4 equation $y \cdot x^{-b}$, in which $y = \dot{V}O_{2\max}$, $x = m_b$, and $b =$ the scaling exponent. The theory of similarity
5
6 suggests that $\dot{V}O_2$ is proportional to $m_b^{2/3}$ (Astrand and Rodahl, 1986), but in running performance, $b =$
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8 0.75 has been shown to be more appropriate (Helgerud, 1994). Thus, $\dot{V}O_{2\max}$ was expressed in
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10 absolute ($L \cdot \min^{-1}$), mass-relative ($ml \cdot kg^{-1} \cdot \min^{-1}$), and mass-independent ($ml \cdot kg^{-0.75} \cdot \min^{-1}$) values.
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12 Correlations between the expressions of $\dot{V}O_{2\max}$ and m_b were calculated, with the coefficient size and
13
14 significance being used to estimate the degree of linear independence.
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Statistical analyses

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20 Statistical analyses were performed using IBM SPSS version 24 (Chicago, IL, USA). Figures were
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22 made with GraphPad Prism version 6 (San Diego, CA, USA). Normality was assessed with the
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24 Shapiro-Wilk test and quantile-quantile plots. Repeated measures analysis of variance with Fisher's
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26 Least Significant Difference post hoc test was used to analyse round-by-round changes in markers of
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28 exertion. Mauchly's test was used to assess data sphericity, with the Greenhouse-Geisser correction
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30 being applied when appropriate. Pearson product-moment correlation coefficients were computed to
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32 determine the strength and direction of relationships between variables. Deltas for each round were
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34 calculated as the post-round value – pre-round value. Data are presented as mean \pm standard deviation
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36 in tables and text, and mean \pm standard error in figures. Statistical significance was accepted at $p <$
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Results

All participants achieved $\dot{V}O_{2\max}$ during the CPET without incidence (table 1) and successfully completed the monitored training session with no adverse events. Significant between-round differences were detected for HR ($F(2,22) = 194.22$, $p < 0.001$, $\eta_p^2 = 0.95$), relative HR (%HR_{max}) ($F(2,23) = 193.42$, $p < 0.001$, $\eta_p^2 = 0.94$), $[La^-]_b$ ($F(5,45) = 29.40$, $p < 0.001$, $\eta_p^2 = 0.77$), and RPE ($F(5,55) = 42.70$, $p < 0.001$, $\eta_p^2 = 0.80$). Figure 1 shows the round-by-round physiological and perceptual responses to sparring. Mean and delta responses are presented in table 2 and table 3, respectively. Figure 2 illustrates a typical HR response to a round of sparring.

--Insert figure 1 here--

--Insert table 2 here--

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Body mass correlated with absolute $\dot{V}O_{2\max}$ ($r = 0.660$, $p < 0.05$), while its relationship with mass-relative $\dot{V}O_{2\max}$ was nonsignificant ($r = -0.225$, $p = 0.481$). The correlation coefficient between scaled $\dot{V}O_{2\max}$ and m_b was close to zero ($r = 0.058$, $p = 0.859$), indicating linear independence. Mass-independent $\dot{V}O_{2\max}$ was negatively associated with mean HR ($r = -0.826$, $p < 0.001$), %HR_{max} (figure 3), and $[La^-]_b$ (figure 4). Furthermore, mean HR correlated with mean $[La^-]_b$ ($r = 0.677$, $p < 0.05$). Mean %HR_{max} correlated with mean $[La^-]_b$ ($r = 0.745$, $p < 0.01$), and negatively with m_b ($r = -0.653$, $p < 0.05$). Rank was not associated with any expression of $\dot{V}O_{2\max}$ nor sparring HR ($p > 0.05$), but tended to correlate negatively with mean $[La^-]_b$ ($r = -0.563$, $p = 0.056$). A similar, positive tendency was observed between mean RPE and mean $[La^-]_b$ ($r = 0.568$, $p = 0.054$). RPE and HR were generally independent, but a significant relationship was observed in the last round ($r = 0.642$, $p < 0.05$). No association between RPE and $\dot{V}O_{2\max}$ was detected ($p > 0.05$).

--Insert table 3 here--

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--Insert figure 4 here--

Discussion

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2 Despite an increasing number of studies investigating physiological and perceptual responses to
3 competitive BJJ combat, little attention has been devoted to these responses in regular training.

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5 Exploring the interaction between sparring intensity and $\dot{V}O_{2max}$ may help discern the role of this
6 attribute in BJJ combat, as well as the utility of sparring as an approach to athlete conditioning. Thus,
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8 this study sought to investigate the relationships between physiological and perceptual markers of
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10 exertion and $\dot{V}O_{2max}$ during unrestricted BJJ sparring. The main findings were that the athletes worked
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12 up to a high intensity during the first two rounds of sparring, which was maintained for the rest of the
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14 session, with an average HR of 85% of HR_{max} ; accumulated significant amounts of lactate during the
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16 initial round of sparring with no meaningful reduction in subsequent rounds; and rated their average
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18 level of exertion as “hard”, equivalent to 74% of the maximal perceived exertion. $\dot{V}O_{2max}$ was
19
20 negatively associated with sparring HR, % HR_{max} , and $[La^-]_b$, indicating that $\dot{V}O_{2max}$ might have an
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22 important impact on physiological performance in BJJ combat by delaying the fatigue process.
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28 Furthermore, given the importance of exercise intensity for improvements in $\dot{V}O_{2max}$, these
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30 observations could imply that sparring does not effectively target this attribute, particularly in trained
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32 (> 55 ml·kg⁻¹ (De Pauw et al., 2013)) athletes.

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35 An increased $\dot{V}O_{2max}$ will improve intracellular oxygen availability during exercise, thus
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37 reducing the reliance on anaerobic processes and consequently the metabolite response to a given
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39 exercise intensity, enhancing the ability to maintain muscle pH and contractile capacity at higher
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41 intensities (Astrand and Rodahl, 1986; Ratamess, 2011). In addition to the potential effects on exercise
42
43 tolerance in BJJ combat, this has relevance for tournaments, where progressing through a bracket is
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45 akin to an interval training session, with between-match rest periods of similar duration as the match
46
47 regulation time (International Brazilian Jiu-Jitsu Federation, 2015). Shifting from anaerobic to aerobic
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49 energy yield could result in a considerable physiological performance advantage, particularly in large
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51 brackets. Interestingly, $[La^-]_b$ has been observed to decrease with consecutive matches (Andreato,
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53 Julio, Panissa, et al., 2015), which could reflect an inability to maintain work output due to a depletion
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55 of phosphocreatine, proton accumulation, and reduced pH (Gastin, 2001). Although the present
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57 findings do not establish a causal link between $\dot{V}O_{2max}$ and sparring intensity, the strong negative
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1 correlation between $\dot{V}O_{2\max}$ and the physiological markers of exertion indicate that this attribute can
2 have considerable impact on BJJ performance.
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4 The nature of the relationship between $\dot{V}O_{2\max}$ and $\%HR_{\max}$ also offers support to the
5 previously proposed ceiling effect of BJJ on developing this attribute significantly beyond the
6 population average (Ovretveit, 2018). The average sparring HR suggests that the athletes performed at
7 an intensity conducive to cardiovascular improvements (Storen, et al., 2017). This, however, was not
8 reflected in their $\dot{V}O_{2\max}$, which was moderate compared to other athlete populations (Saltin and
9 Astrand, 1967), despite regularly engaging in high-intensity sparring. Similar limitations have been
10 observed in soccer, albeit in athletes with a higher $\dot{V}O_{2\max}$. In a study on soccer-specific aerobic
11 endurance training, Hoff and colleagues (2002) observed that, while sport-specific training can be a
12 useful approach to improvements in aerobic endurance, players with the highest $\dot{V}O_{2\max}$ performed at
13 the lowest fraction of $\dot{V}O_{2\max}$ during small group play. This highlights the importance of careful
14 considerations when applying sport-specific training to improve physiological functions. In the current
15 BJJ literature, a $\dot{V}O_{2\max}$ considerably above $50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ is rarely observed (Andreato, et al., 2017;
16 Ovretveit, 2018). In fact, the present athletes were in the higher range of what is typically found in this
17 population, and thus might be in proximity of the upper limit of $\dot{V}O_{2\max}$ achievable through BJJ
18 training alone.
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37 The effort pattern of BJJ combat has been thoroughly analysed (Andreato, Follmer, et al.,
38 2016), with several investigations providing physiological context to these observations (Andreato, et
39 al., 2013; Andreato, Julio, Panissa, et al., 2015; Andreato, et al., 2014; Andreato, et al., 2012; Da
40 Silva, et al., 2013; Diaz-Lara, et al., 2015; Villar, et al., 2018). Yet, there is a dearth of continuous HR
41 measurements and consequently a knowledge gap regarding this marker of intensity in BJJ. The high
42 variation in metabolic demand necessitates constant monitoring of HR during combat to obtain a
43 representative measurement. This was evident from the individual HR curves observed in the present
44 study, which revealed considerable fluctuations during rounds. Although some practical concerns
45 regarding the use of a HR monitor in combat sports have been raised (Slimani, et al., 2017), results
46 from the present study suggest that it can be a feasible instrument for intensity measurements in BJJ.
47 In similar studies, HR has been obtained pre- and post-combat (Andreato, Julio, Panissa, et al., 2015;
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Andreato, et al., 2012; Villar, et al., 2018). While this data can be indicative of effort, continuous measurements of HR expressed relative to the individual HR_{max} provides a more accurate description of intensity.

Despite being a practical tool for intensity assessments, HR data obtained in combat sports comes with several important caveats (Slimani, Znazen, Sellami, & Davis, 2018). When a given rate of continuous work is performed for > 2 minutes, HR can be used as an indicator of $\dot{V}O_2$ (Swain, Abernathy, Smith, Lee, & Bunn, 1994). However, HR during intermittent work of < 2 minutes can overestimate $\dot{V}O_2$ (Hoff and Helgerud, 2004). Thus, since BJJ combat typically consists of short work periods with frequent changes in intensity (Andreato, Follmer, et al., 2016), sparring HR is likely not an accurate representation of sparring $\dot{V}O_2$. Moreover, HR is elevated in arm compared to leg exercise at a given workload (Vokac, Bell, Bautz-Holter, & Rodahl, 1975), which is relevant to BJJ, where the arms are heavily involved. This can be exacerbated by isometric muscle contractions, which increases blood pressure and consequently HR. Additionally, both simulated and official BJJ competition have been shown to induce a stress hormone response (Moreira et al., 2012), possibly leading to further increases in HR. Conversely, circulatory alterations related to supine exercise can reduce both submaximal and maximal HR (Cotsamire, Sullivan, Bashore, & Leier, 1987), which might counteract some of the factors causing an overestimation. However, the notion that sparring HR was overestimated in the present study is supported by the disagreement between RPE and HR, with the average relative HR being 15% higher than the relative RPE.

The discrepancy between RPE and HR suggests that RPE should be used with caution in BJJ, as previously expressed by others (Andreato, Follmer, et al., 2016; Andreato, Julio, Goncalves Panissa, et al., 2015). Yet, interestingly, mean RPE and $[La^-]_b$ tended to correlate. Thus, RPE might provide some indication of physical exertion during sparring. However, as the literature contains conflicting findings (Andreato, et al., 2013; Andreato, et al., 2012; Villar, et al., 2018), the applicability of RPE in BJJ is still debatable. Notably, the observed RPE and lactate responses in the present study were comparable to those found in athletes continuously encouraged by coaches and instructed to perform at the highest possible intensity (Branco, et al., 2016). This suggest a high voluntary effort, as the athletes were specifically instructed not to deviate from their normal training

1 intensity. The short 90-second breaks might have increased perceived and actual exertion, but
2 underestimated $[La^-]_b$ due to a lag in lactate diffusion from the working muscles to systemic
3 circulation. Generally, round-by-round variations in the physiological responses were low compared to
4 similar experiments with longer breaks (Andreato et al., 2016; Andreato, Julio, Panissa, et al., 2015).
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6 Interestingly, RPE peaked after the last round, which could reflect a lack of recovery between rounds
7 and the cumulative effects of periodic work above the anaerobic threshold.
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11 Consistent with past findings (Andreato, et al., 2017; Ovretveit, 2018), rank was not associated
12 with $\dot{V}O_{2max}$, nor did it correlate with sparring HR. However, it tended to have a negative relationship
13 with $[La^-]_b$. Previously, it has been suggested that differences in BJJ-specific endurance can in part be
14 attributed to work economy (Ovretveit, 2018). A more advanced athlete might be able to perform
15 techniques at a lower energy cost and rely less on prolonged isometric muscle contractions during
16 sparring, thus improving local blood flow. Aspects related to work economy can likely be modified
17 substantially by sport-specific training. Important to note, however, is that $\dot{V}O_{2max}$ and work economy
18 are separate determinants of aerobic endurance performance and should be trained accordingly (Pate
19 and Kriska, 1984).
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33 The impact of m_b on athletic performance is related to the extent gravity is counteracted by the
34 athlete (Hoff, Kemi, & Helgerud, 2005). The importance of allometric scaling in size-heterogeneous
35 samples is well-established (Astrand and Rodahl, 1986; Bergh, Sjodin, Forsberg, & Svedenhag, 1991;
36 Hoff, et al., 2005; Lolli, Batterham, Weston, & Atkinson, 2017). In the present study, there was a \leq
37 29% weight difference among the participants, and normalisation using the exponent 0.75 resulted in a
38 mass-independent $\dot{V}O_{2max}$. Ideally, the scaling exponent should be based on how the oxygen demand
39 relates to m_b in the specific activity. However, the influence of m_b on $\dot{V}O_2$ during grappling is difficult
40 to gauge due to the high positional variation and unfeasibility of sport-specific spiroergometry.
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42 Standing combat, similar to wrestling and judo, requires full support of m_b , while groundwork presents
43 numerous ways of which m_b is carried. Parenthetically, m_b likely affects pass- and guard-focused
44 grapplers differently. Regardless of grappling style, m_b will inevitably have some impact on
45 performance; the lack of a sport-specific scaling exponent does not negate the principles of allometry.
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47 A negative association was observed between m_b and $\%HR_{max}$, which could be related to a greater
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1 absolute capacity for oxygen consumption combined with a grappling style that minimizes the impact
2 of m_b in the bigger athletes. However, m_b did not significantly relate to $[La^-]_b$, which suggest a limited
3 impact of the ostensibly lower sparring intensity in these athletes. The reduced relative HR could have
4 been caused by factors such as fewer and/or shorter isometric contractions, techniques that replaced
5 muscular work with mechanical advantages, pressure rather than speed when passing the guard, and/or
6 less scrambling. It could also simply have been a result of the size advantage held by the bigger athlete
7 as the sample was not separated into weight classes. In official competition facing size-matched
8 opponents, the intensity profile might be different. Thus, m_b is likely not intrinsically linked to lower
9 combat intensity, but rather more dependent on the size relationship between the combating athletes.

10
11 Two distinct intensity components of a typical BJJ training session emerged from this study.
12 Warm-up and skill training represented low-intensity work, with a mean $[La^-]_b < 2$ mM and HR <
13 50% of HR_{max} after an hour of drilling techniques. The participants rated their level of exertion as
14 “very, very light” pre-sparring. Notably, 12 separate training sessions with overlapping, but slightly
15 varying content were monitored and all elicited similar HR, lactate, and RPE responses, indicating that
16 physical exertion when performing BJJ drills is largely independent of the specific technique being
17 emphasized. Contrasting the low-intensity skill component was the sparring, which represented high-
18 intensity work, perceived by the athletes as “hard”, with a mean $[La^-]_b$ of ~9 mM and mean HR of
19 85% of HR_{max} .

20
21 As opposed to similar investigations, where markers of exertion have been assessed during
22 official competitions (Andreato, et al., 2013; Andreato, et al., 2014; Diaz-Lara, et al., 2015) or in study
23 designs simulating them (Andreato, Julio, Panissa, et al., 2015; Andreato, et al., 2012; Da Silva, et al.,
24 2013; Villar, et al., 2018), this study did not attempt to recreate a competition setting. Rather, acute
25 physiological and perceptual responses to BJJ sparring was assessed during a regular training session.
26 The additional cardiorespiratory information provided by $\dot{V}O_{2max}$ and continuous HR measurements
27 represents a novel approach to understanding the type and degree of exercise stimulus in BJJ. The
28 generalizability of the present findings is limited by the sample size and the cross-sectional study
29 design, which cannot establish causality. Studies involving more participants and repeated
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2 measurements of physical capacities and physiological responses to sparring may provide further
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4 insight into the acute and chronic effects of BJJ training.
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6 **Conclusions**

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8 The negative relationship observed between $\dot{V}O_{2max}$ and physiological markers of exertion suggest that
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10 $\dot{V}O_{2max}$ affects exercise tolerance in BJJ. This could also imply a limited efficacy of sparring for the
11
12 development of $\dot{V}O_{2max}$ due to insufficient exercise intensity in trained athletes. Although the athletes
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14 appeared to self-select a high sparring intensity, HR data obtained during BJJ combat should be
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16 interpreted with caution, as it might overestimate actual exercise intensity and energy expenditure. An
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18 increased $\dot{V}O_{2max}$ appears to be associated with a reduced reliance on anaerobic processes during
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20 sparring, which could have implications for the sustainability of both match and tournament
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22 performance. Considering that BJJ is a skill-based sport, BJJ training should represent the bulk of the
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24 athletes' training volume. Although this training likely induces improvements in some aspects of
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26 aerobic endurance, like work economy, it might have a limited effect on others, such as $\dot{V}O_{2max}$,
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28 possibly related to effort characteristics and body position (Ovretveit, 2018). Thus, alternative
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30 approaches to aerobic conditioning should be considered by athletes who seek improvements in
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34 $\dot{V}O_{2max}$.
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38 **Acknowledgements**

39
40 The author would like to thank the athletes that participated in this study.
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44 **Declaration of interest statement**

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46 None apply.
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Tables

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4 Table 1. Maximal oxygen uptake
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9 Table 2. Mean physiological and perceptual responses to Brazilian jiu-jitsu sparring (n = 60 rounds)
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13 Table 3. Variations (Δ) in physiological and perceptual responses to Brazilian jiu-jitsu sparring
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Table 1. Maximal oxygen uptake

	Mean \pm SD	Range
$\dot{V}O_{2max}$		
(L \cdot min $^{-1}$)	4.3 \pm 0.4	3.8 – 5.4
(ml \cdot kg $^{-1}$ \cdot min $^{-1}$)	53.6 \pm 4.1	48.1 – 60.5
(ml \cdot kg $^{-0.75}$ \cdot min $^{-1}$)	160.7 \pm 12.0	148.3 – 185.9
HR $_{max}$ (beats \cdot min $^{-1}$)	193 \pm 6	181 – 204
[La $^{-}$] $_b$ (mmol \cdot L $^{-1}$)	14.4 \pm 1.4	12.3 – 16.5
RPE (6 – 20)	18 \pm 1	17 – 20

Data are presented as mean \pm SD. $\dot{V}O_{2max}$, maximal oxygen uptake; HR $_{max}$, maximal heart rate; [La $^{-}$] $_b$, blood lactate concentration; RPE, rating of perceived exertion.

Table 2. Mean physiological and perceptual responses to Brazilian jiu-jitsu sparring (n = 60 rounds)

	Mean \pm SD	Range
HR (beats \cdot min $^{-1}$)	164 \pm 9	149 – 183
Relative HR (%HR $_{max}$)	85 \pm 4	76 – 90
RPE (6 – 20)	15 \pm 1	13 – 17
Relative RPE (%RPE $_{max}$)	74 \pm 7	65 – 85
[La $^{-}$] $_b$ (mmol \cdot L $^{-1}$)	8.83 \pm 2.26	3.60 – 11.22

Data are presented as mean \pm SD. HR, heart rate; HR $_{max}$, maximal heart rate; RPE, rating of perceived exertion; RPE $_{max}$, maximal rating of perceived exertion; [La $^{-}$] $_b$, blood lactate concentration.

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Table 3. Variations (Δ) in physiological and perceptual responses to Brazilian jiu-jitsu sparring

	Round 1	Round 2	Round 3	Round 4	Round 5
Δ HR (beats·min ⁻¹)	63 ± 13 ^{b,c,d,e}	9 ± 5 ^{a,c,d}	3 ± 6 ^{a,b}	-3 ± 9 ^{a,b}	3 ± 9 ^a
Δ Relative HR (%HR _{max})	32 ± 6 ^{b,c,d,e}	5 ± 3 ^{a,c,d}	1 ± 3 ^{a,b}	-2 ± 5 ^{a,b}	2 ± 5 ^a
Δ RPE	6 ± 2 ^{b,c,d,e}	2 ± 2 ^a	1 ± 2 ^a	0 ± 3 ^a	1 ± 2 ^a
Δ Relative RPE (%RPE _{max})	28 ± 9 ^{b,c,d,e}	8 ± 9 ^a	4 ± 11 ^a	0 ± 15 ^a	7 ± 11 ^a
Δ [La ⁻] _b (mmol·L ⁻¹)	5.74 ± 2.05 ^{b,c,d,e}	1.59 ± 2.38 ^{a,d}	1.2 ± 2.90 ^a	-1.02 ± 2.47 ^{a,b}	0.4 ± 1.76 ^a

Data are presented as mean ± SD. HR, heart rate; HR_{max}, maximal heart rate; RPE, rating of perceived exertion; RPE_{max}, maximal rating of perceived exertion; [La⁻]_b, blood lactate concentration; ^{a,b,c,d,e} significant difference ($p < 0.05$) compared to round 1 (a), 2 (b) 3 (c), 4 (d), and 5 (e), respectively.

1 **Figures**
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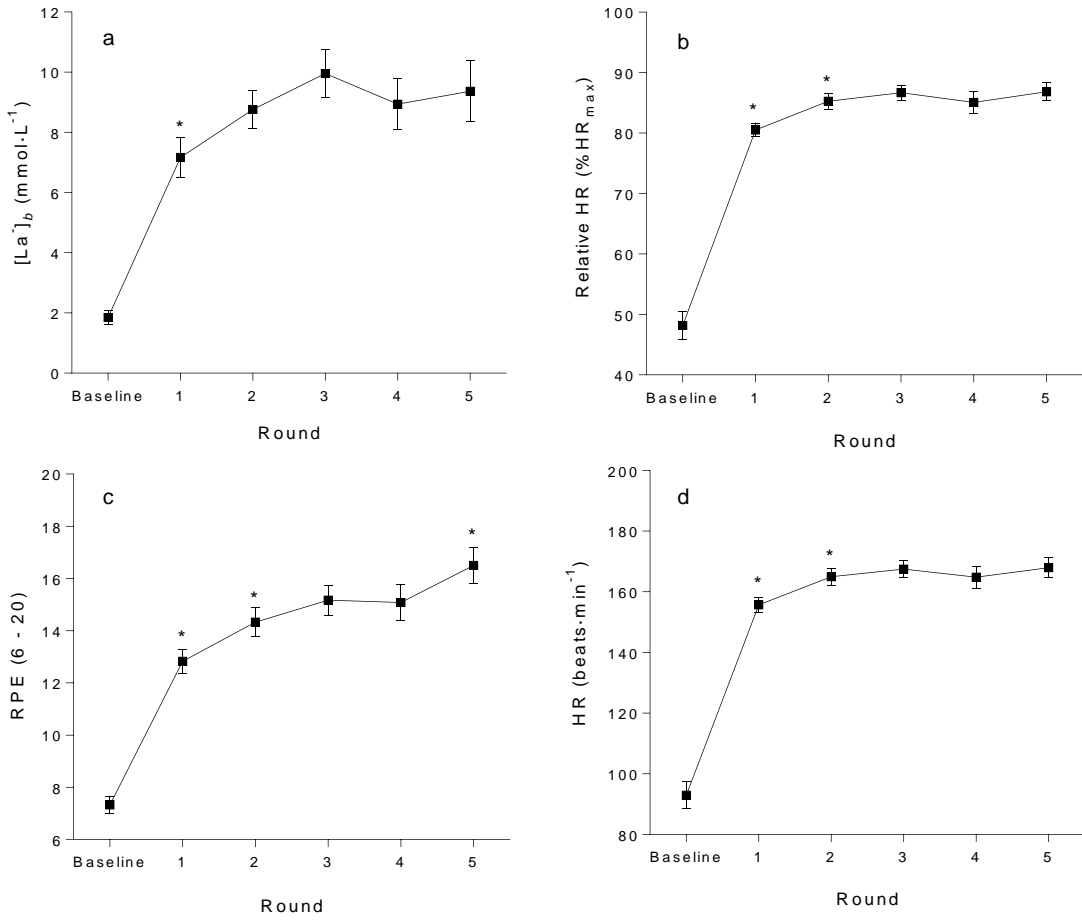
6 Figure 1. Blood lactate concentration ($[La^-]_b$), heart rate (HR), and rating of perceived exertion
7 (RPE) in Brazilian jiu-jitsu sparring
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12 Figure 2. Individual heart rate (HR) response to a 6-minute Brazilian jiu-jitsu sparring round
13 (average of ~85% of HR_{max})
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19 Figure 3. The association between maximal oxygen uptake ($\dot{V}O_{2max}$) and relative heart rate
20 ($\%HR_{max}$) in Brazilian jiu-jitsu sparring
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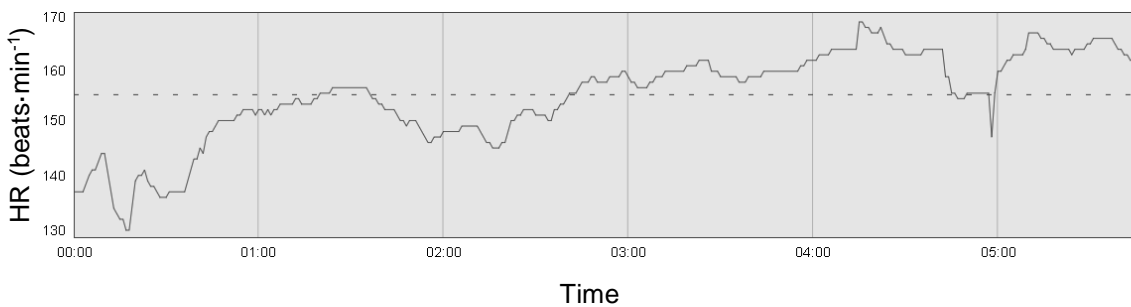
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26 Figure 4. The association between maximal oxygen uptake ($\dot{V}O_{2max}$) and blood lactate
27 concentration ($[La^-]_b$) in Brazilian jiu-jitsu sparring
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Figure 1. Blood lactate concentration ($[La^-]_b$), heart rate (HR), and rating of perceived exertion (RPE) in Brazilian jiu-jitsu sparring



* Significant difference ($p < 0.05$) compared to previous round

Figure 2. Individual heart rate (HR) response to a 6-minute Brazilian jiu-jitsu sparring round (average of ~85% of HR_{max})



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Figure 3. The association between maximal oxygen uptake ($\dot{V}O_{2max}$) and relative heart rate ($\%HR_{max}$) in Brazilian jiu-jitsu sparring

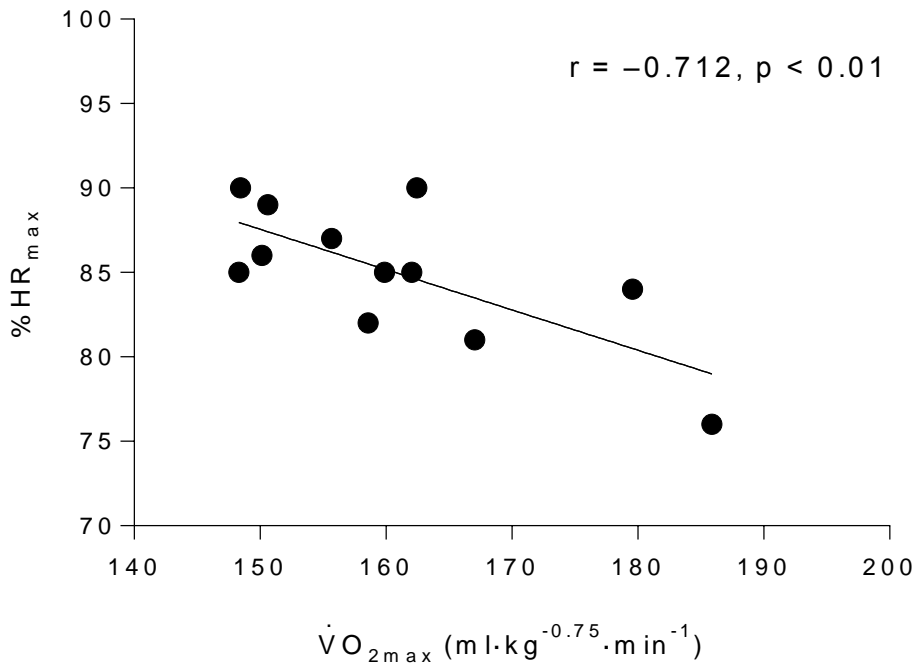


Figure 4. The association between maximal oxygen uptake ($\dot{V}O_{2max}$) and blood lactate concentration ($[La^-]_b$) in Brazilian jiu-jitsu sparring

