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Original Research

Effects of Photobiomodulation on High-Intensity Intermittent Anaerobic Performance of Lower Limbs in Brazilian Jiu-Jitsu Athletes: A Randomized, Crossover, Double-Blind Clinical Trial

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ABSTRACT

International Journal of Exercise Science 16(6): 1165-1181, 2023. Photobiomodulation (PBM) has ergogenic effects on aerobic and anaerobic efforts and may improve sports performance. As Brazilian jiu-jitsu (BJJ) fighting requires both aerobic and anaerobic metabolism, so PBM may be effective in increasing the physical performance of BJJ athletes. Thus, this study aimed to verify the effects of PBM with different energy doses (6 or 12 J per point) on high-intensity intermittent anaerobic performance in BJJ athletes. Methods: Eleven male athletes performed three lower limb Wingate testing sessions. At the beginning of each session, in a randomized, crossover, double-blind fashion, the athletes received PBM with a dose of 6 J (4.5 J/cm^2) or 12 J (9.1 J/cm^2), or placebo (PLA) at 17 points in each lower limb. In each session, the squat jump (SJ) and three Wingate test series were performed, with a 3-minute interval between series. Heart rate (HR) was collected immediately before, after each Wingate test, and at 1, 3, and 5 minutes after the last test. The rate of perceived exertion (RPE) was reported after each Wingate test. Differences between Wingate tests and treatment sessions were set at $p<0.05$. Results: No differences were observed between treatments in SJ height, Wingate performance, HR, and RPE ($p>0.05$; for all comparisons). The Wingate test session promoted a reduction in anaerobic capacity in the second and third sets in all conditions, indicating fatigue ($p<0.05$). Conclusion: Treatment with PBM did not produce a dose-dependent ergogenic response in high-intensity intermittent performance in BJJ athletes.

KEY WORDS: Low-intensity light therapy, martial arts, sports performance, stress test

INTRODUCTION

High-intensity intermittent anaerobic efforts were characteristic of combat sports such as Brazilian-jiu jitsu (BJJ), requiring faster recovery between successive efforts and resistance to fatigue to maintain muscle performance during a match (2-5). Clinical trials have shown that Photobiomodulation (PBM) with different doses of energy, administered before exercise, can increase muscle performance in repeated short-duration exercises and delay the onset of muscle fatigue (29, 30, 36, 37). Thus, PBM could be an ergogenic resource in sports that require both aerobic and anaerobic metabolism (5), in high-intensity intermittent actions, such as BJJ. PBM is the irradiation of living tissues with low-intensity light (up to 1000 mW) at wavelengths ranging from red to near infrared (600 to 1100 nm, respectively) (13, 20, 24, 25). PBM ergogenic effect has been associated with stimulation of the cytochrome c-oxidase (CCO) enzyme in the mitochondrial electron transport chain, increasing the production of adenosine triphosphate (ATP) (13, 20, 22, 25). In addition, other ergogenic mechanisms of PBM include a possible effect on motor unit recruitment (26, 44), dissociation of nitric oxide in mitochondrial complex IV, and increased intracellular calcium reuptake (13). Given this, PBM may have the ability to improve both aerobic and anaerobic performance, promote recovery between repeated high-intensity efforts, and could provide an important competitive advantage in intermittent sports.

The Wingate test has a predominantly anaerobic characteristic and is widely used as a method to assess the power and anaerobic capacity of athletes from different combat sports, in response to training or ergogenic methods (12, 15, 17, 33, 38, 42). The effects of PBM on anaerobic, alactic, and lactic capacity were studied in clinical trials using the Wingate test, demonstrating controversial effects (14, 27, 28, 31, 43). Ergogenic effects were not observed on peak and mean power in Wingate tests in volleyball players irradiated (810nm or 660 and 850nm) with 6 J (164.8 J/cm^2) to 41.7 J (6 J/cm^2) (two points on the rectus femoris muscle)(27). Another study also showed no effect on the total work in the Wingate test in volleyball and soccer athletes irradiated with 30 (1071.4 J/cm^2) to 40 J (1428.5 J/cm^2), 830nm, at 5 points on the rectus femoris muscle (28). However, the authors suggested that PBM could affect post-exercise recovery, due to reduced creatine kinase levels and rapid lactate removal in irradiated subjects (27, 28). Another study evaluated the effects of PBM (660 and 930nm; 25.95 J at 4 points on the thigh, 1.8 J/cm^2) on performance recovery in team sports athletes, in the Wingate test, after induction of muscle fatigue (14). There was no effect on lactate removal, peak power, and fatigue index, and the authors concluded that PBM was not efficient for performance recovery after high-intensity efforts (14). However, these studies irradiated small areas of the muscle surface (14, 27, 28) or delivered low doses or energy densities per muscle (14).

The administration of PBM in physically active subjects, in the main muscle groups involved in the Wingate test, at an energy density of 3.9 J/cm^2, also did not show ergogenic effects (43). However, the authors demonstrated that warming up before the test or the combination of a post-activation potentiation maneuver with PBM increased the peak and relative power (43). A recent study demonstrated that PBM (6 J, ~4.5 J/cm^2, 630nm) can improve anaerobic performance (peak and average power) in physically active subjects, when administered in the main muscle groups of lower limbs and associated with a warm-up protocol before the Wingate test (31). The controversial results of these studies may be associated with different areas of irradiation, energy doses, and physical fitness of the volunteers, and to date, do not allow the establishment of whether there is an ergogenic effect of PBM on anaerobic performance and fatigue resistance in athletes.

BJJ is a grappling sport with specific characteristics and significative differences to other similar modalities, as in the match time (e.g., BJJ: 10 min; judo: 4 min; wrestling: 2 rounds of 2 min, with a 30 s rest period between rounds) and effort to rest ratio (time–motion ratio) (e.g., BJJ: 6:1 to 12:1; judo: 2:1 to 3:1; wrestling: 2:1)(1).. Thus, due to match time, athletes also need to develop high levels of aerobic fitness (4). In addition, the anaerobic metabolism plays a decisive role during combat due to its intermittent nature, with motor actions that vary between high and low-intensity efforts, requiring high capacity and anaerobic power from athletes (4). The effort-rest ratio of 6:1, obtained through video analysis, with high- and low-intensity efforts at a ratio of up to 1:11 (2), and the muscular actions of power and maximum strength performed during BJJ fights suggest that the use of ergogenic resources which increase the capacity to produce strength, increase resistance to fatigue, and speed up recovery in moments of pause, could promote a competitive advantage. In this sense, PBM may be an important ergogenic strategy for the performance of high-intensity intermittent actions by BJJ athletes.

Considering the possible ergogenic effects of PBM, the present study aimed to verify the effect of PBM on the high-intensity intermittent anaerobic performance of BJJ athletes. The main hypothesis of the study was that PBM could improve performance in repeated Wingate tests, in a dose-dependent manner, when compared to the placebo situation. The secondary hypothesis of the study was that PBM could reduce fatigue and accelerate recovery during Wingate test intervals, maintaining higher levels of anaerobic performance in successive efforts, when compared to the placebo condition.

METHODS

Participants

Eleven male BJJ athletes participated in the study (age: 28.7 ± 8.3 years; height: 1.76 ± 0.1 meters; body mass: 84.8 ± 9.96 kg; fat mass: 19.0 ± 8.97 %; lean mass: 46.1 ± 5.0 %; practice time: 7.4 ± 2.9 years), graduated from blue belt to black belt.

The sample size was calculated based on the study by Molina Correa et al. (2021), who analyzed the effect of PBM on performance variables in the Wingate test, using a dose of 6 J applied at the same irradiation points as in the current study, and using the same brand of commercial equipment. The sample size required at least seven participants considering the effect size achieved in relative peak power differences between placebo and PBM session (1.11) (32), a statistical power of 80%, with a maximum alpha error of 5%, in a cross-type test.

The volunteers were previously informed about the study procedures, risks, and benefits, and signed an informed consent form to participate in the research, which was approved by the ethics committee of the Universidade Cesumar (Unicesumar) (CAAE: 44916721.7.0000.5539).

This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (34).

Before the beginning of the evaluations, data related to age, previous experience in the practice of BJJ, training routines, and health conditions were registered. Athletes who had performed at least three weekly sessions of modality-specific training for not less than 3 months were included. Athletes competed and were champions in state (n=3), national (n=2), and international championships (n=6), in 2019 and 2020. Smokers, volunteers with chronic diseases and musculoskeletal injuries, or who were in the process of losing weight to competing were not included in the study. After the anamnesis, participants performed assessments of body composition by electric bioimpedance analysis (InBody model 520, Biospace Co., Ltd., Seul, Korea) and were familiarized with all study procedures. Data collection was carried out between April and June 2021.

Protocol

The present study is a crossover, randomized, double-blind clinical trial to verify the effect of PBM with different doses of energy on the anaerobic performance of BJJ athletes. Participants were instructed not to perform any intense or strenuous physical exercise in the 24 hours preceding the tests. Furthermore, they were instructed not to ingest beverages and foods containing caffeine and food supplements with ergogenic action in the 6 hours before the evaluations. Before the start of the first test session, the athletes were randomized for the type of treatment they would receive per irradiated point in each of the three sessions (Placebo, 6J, or 12J) through a random drawing, using Microsoft Excel software (Microsoft Corporation, Albuquerque, NM, USA). A researcher who was responsible for applying the PBM and who did not participate in any other stage of the study performed randomization.

The PBM was performed before the vertical jumps and Wingate tests for lower limbs. The three test sessions were carried out at the same time of day, with an ambient temperature of ~25°C and a 48-hour interval between sessions (figure 1). This interval between sessions was established to reduce interference in the athletes' training schedules, allow them to recover before the next session, and take into account that PBM does not seem to have lasting cumulative effects on muscle performance (32).

After the PBM, the athletes performed a standardized warm-up and then the squat jump test (SJ). After a 5-minute recovery, the athletes performed a specific warm-up for the Wingate test, and, after a 3-minute rest; they performed three series of Wingate tests for lower limbs with a 3-minute interval between tests (figure 1). The rate of perceived exertion (RPE) and heart rate (HR) were collected (figure 1). In addition, to confirm the effectiveness of blinding procedures, at the end of each assessment session, participants were asked for their perception of which treatment they had received.

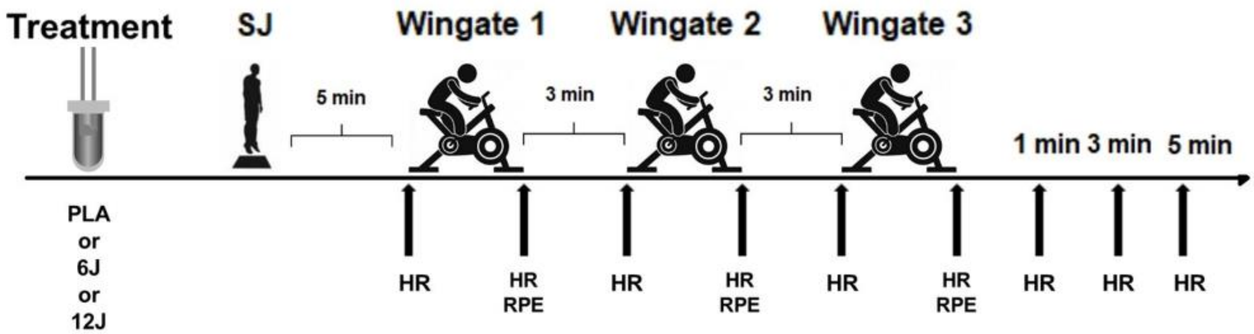

Figure 1. Experimental design of a test session. PLA: placebo treatment; 6 J: photobiomodulation at a dose of 6 Joules per point; 12 J: photobiomodulation at a dose of 12 Joules per point; SJ: Squat Jump; HR: heart rate; RPE: rate of perceived exertion.

Photobiomodulation (PBM): PBM was applied immediately before the initial warm-up, with the light-emitting diodes positioned perpendicular to the selected musculature, while the participants were lying on a stretcher. The irradiation points are shown in figure 2 and applied using two PBM devices (Bios Therapy II, Bios Equipamentos Médicos, São José dos Campos, São Paulo, Brazil). The optical output of the PBM apparatus was measured before treatments with a power meter (PD 300 Sensor Fotodiodo; Ophir Optronics, Jerusalem, Israel) to ensure calibration and the correct dose of energy prescribed in the treatment protocol. The treatment prescriptions are shown in table 1.

Figure 2. Irradiation points.

For the blinding of volunteers, they were asked to wear opaque glasses, which blindfolded their eyes, and headphones emitting music during the application of PBM so as not to perceive any beep or light emission from the device. The equipment was kept in a stationary position, as close as possible to the skin surface, so that the participant would not notice the irradiation points or any vibration of the device in operation.

Table 1. PBM prescription.

Parameters	Description
Wavelength	630 nm
Frequency output	Continuous
Optical power output	300 mW
Spot area	1.32 cm^2
Power density	230 mW/cm^2
Energy per point	
Placebo	0
6 J	6 J
12 J	12 J
Energy density per point	
Placebo	0
6 J	~4.5 J/cm^2
12 J	~9.1 J/cm^2
Time ON/OFF per point	
Placebo	0/40 s
6 J	20/20 s
12 J	40/0 s
Number of irradiated points per limb	17 points 7 cm apart
Total direct probe irradiation area	24.4 cm^2
Estimated total irradiated area*	334 cm^2
Total energy per limb	
Placebo	0 J
6 J	102 J
12 J	204 J
Application mode	Stationary: ~ 0.5 cm above the skin surface

* based on manufacturer's datasheet

Squat jump (SJ): After a standardized warm-up for the lower limbs (two sets of 30-s of low-intensity stationary running and vertical jumps exercises interspersed by 10s of passive recovery), athletes performed three SJs, with an interval of 10 seconds between each attempt (11). The SJ height was assessed with a contact mat connected to computer software (Jump System Pro, CEFISE, Nova Odessa, Brazil). The best height of the three SJ was recorded for statistical purposes.

Lower limb Wingate test: The Wingate tests were performed on a cycle ergometer (CEFISE, Biotec 2100, Nova Odessa, Brazil), starting with a specific warm-up [five series of 30 seconds (20-s at 70 rpm and 10-s at 100 rpm), at 100 W]. The first Wingate test started 3 minutes after the specific warm-up. Three Wingate tests were performed for the lower limbs, with a load of 7.5% relative to the subject's body mass and starting from zero speed. Between each test, a passive rest interval of three minutes was allowed. The protocol was chosen to take into account the ratio of high and low-intensity actions in a BJJ combat (~1:11) (2), and the influence of recovery time on performance in Wingate tests (21). The peak power (P_{peak}) absolute (W) and relative (W/kg), average power (P_{mean}) absolute (W) and relative (W/kg), maximum speed (V_{max}) and average speed (V_{mean}), maximum rotations per minute (RPM_{max}) and average RPM (RPM_{mean}), and fatigue index (FI) were recorded. In addition, the time (s) to P_{peak} (TP_{peak}), Explosive Force (F_{exp}) (F_{exp} = P_{peak} divided by TP_{peak}), and Power Drop (P_{drop} = difference between P_{peak} and power at the end of the test) were calculated.

Heart rate (HR) and rate of perceived exertion (RPE): HR measurements were performed immediately before and after each Wingate test and at 1, 3, and 5 minutes after the last test in the session. For HR analysis, a heart rate monitor (Polar FT1, Polar Electro, Kempele, Finland) was used.

RPE was collected immediately after each Wingate test, using the Borg 15-point perceived exertion scale (10).

Statistical Analysis
Data normality was verified with the Shapiro-Wilk test. Data are expressed as mean and standard deviation. The sphericity of the data was analyzed by the Mauchly test and when the sphericity assumption was violated, a Greenhouse-Geisser correction was applied. One-way analysis of variance (ANOVA one-way) was used to verify the effect of treatments on performance in the SJ. Two-way analysis of variance (two-way ANOVA) was used to identify effects (treatment x moment) on performance in the Wingate tests (1st, 2nd, and 3rd), HR, and RPE. Bonferroni's post hoc test was used in comparisons between treatments in the SJ and in the Wingate tests when the significance of the variables was detected in the one-way and two-way ANOVA tests. Differences were considered statistically significant if $p<0.05$. Data analysis was performed using Prisma GraphPad software, version 8.0.1 (GraphPad Software, La Jolla, CA).

The percentage performance reduction between sets (Δ) was determined for the performance and fatigue indices. The Cohen effect size (<0.19= trivial effect; >0.2=small effect; >0.5=medium effect; >0.8=large effect) was used in comparisons between jump tests and the Δ between Wingate tests.

RESULTS

No significant differences were identified ($p=0.75$, $F (1.74; 17.46) = 0.24$) in SJ height between PLA (36.8 ± 8.7 cm), 6 J (37.1 ± 8.9 cm), and 12 J (36.9 ± 9.0 cm) sessions.

The absolute P_{peak} in the three series of the repeated Wingate test presented no effect of treatment ($p=0.98$, $F (2, 30) = 0.016$, $\eta^2 = 0.06$) or interaction with series ($p=0.99$; $F (4, 60) = 0.04$, $\eta^2 = 0.04$), only an effect of series ($p<0, 0001$; $F (1.106, 33.17) = 56.91$, $\eta^2 = 0.284$). Absolute P_{peak} significantly reduced in the 2nd series in PLA and 6 J sessions and all treatments in the 3rd series (figure 3a). The series of the Wingate test showed an effect on the relative P_{peak} ($p<0.001$; $F (1.562, 46.86)$ =

38.98, η^2= 0.28), with no effect of the interaction between series and treatment (p=0.99; F (4, 60) = 0.04, η^2= 0.04) or treatment effect (p=0.98; F (2, 30) = 0.016, η^2= 0.06). The relative P_{peak} was reduced in the 6 J group in the 2nd series and all groups in the 3rd effort (figure 3b).

The P_{mean} presented an effect of series (p<0.001, F (1.336, 40.07) = 246.3, η^2 = 0.676), but without a treatment effect (p=0.93, F (2, 30) = 0.065, η^2= 0.10) or series X treatment interaction (p=0.97, F (4, 60) = 0.12, η^2= 0.07). The reduction in P_{mean} occurred between series in all treatments (figure 3c). The series had an effect on the relative P_{mean} (p<0.001; F (1.562, 46.85) = 141.7, η^2 = 0.05). However, no effect of treatment (p=0.96; F (2, 30) = 0.03, η^2 = 0.58) or interaction of the treatment with the series was observed (p=0.74, F (4, 60) = 0.49, η^2 = 0.40) (figure 3d).

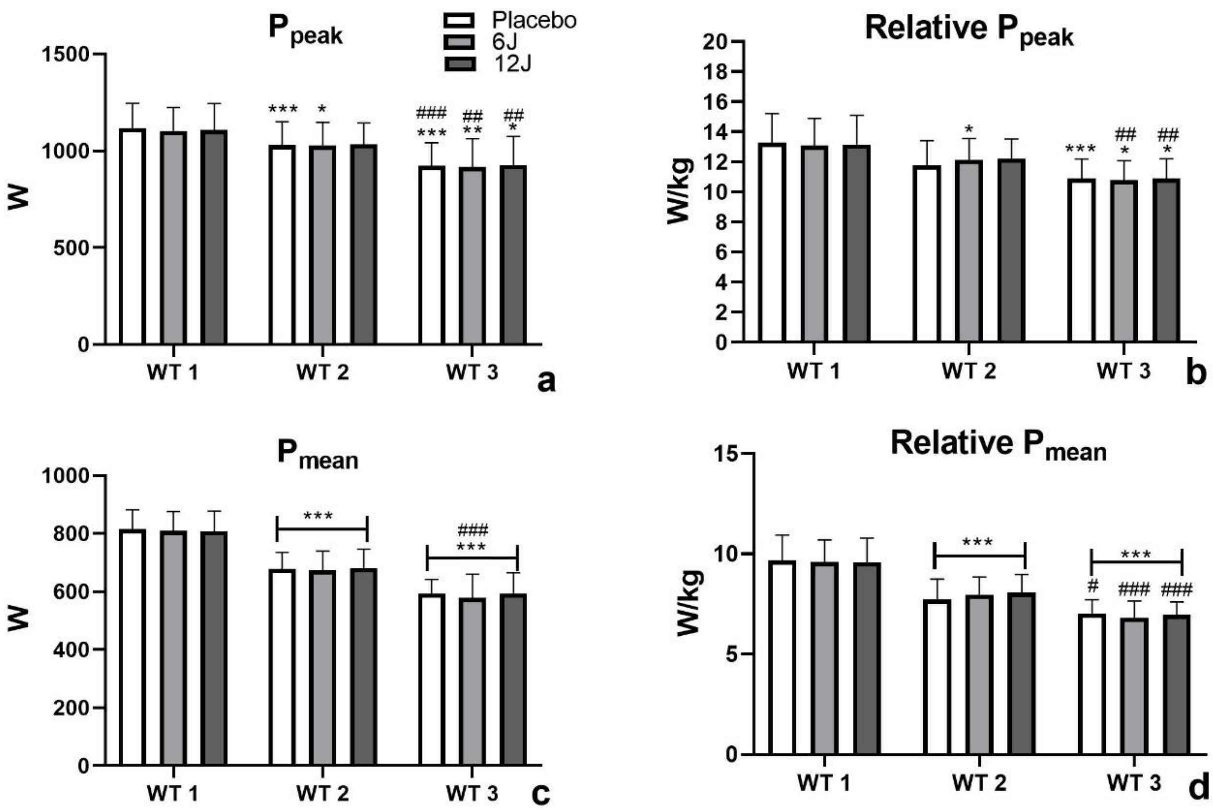

Figure 3. Mean (SD) anaerobic performance in the three sets of Wingate tests (WT) in BJJ athletes submitted to photobiomodulation with 6J, 12J, and placebo. * p<0.05, ** p<0.01, and *** p<0.005 compared to Wingate test 1; # p<0.05, ## p<0.01, and ### p<0.005 compared to Wingate test 2. Bonferroni test.

The V_{max} (p<0.0001, F (1.191, 35.74) = 47.24, η^2 = 0.286) and the V_{mean} (p<0.001; F (1.29, 38.83) = 180.7; η^2 = 0.583) showed an effect of the Wingate series. V_{max} and V_{mean} were significantly reduced in the 2nd and 3rd test series (figure 4a and 4b). There was no effect of treatment on V_{max} (p=0.97, F (2, 30) = 0.029, η^2 = 0.10) or interaction of treatment and series (p=0.99, F (4, 60) = 0.042, η^2 = 0.10). V_{mean} were also not significantly influenced by treatment (p=0.92, F (2, 30) = 0.082, η^2 = 0.17) and there was no interaction of treatment and Wingate tests (p=0.99, F (4, 60) = 0.06, η^2 = 0.03).

The Wingate test series promoted a progressive reduction in the performance of RPM_{max} ($p<0.001$; $F(1.084, 32.53) = 50.75$; $\eta^2 = 0.285$) and RPM_{mean} ($p<0.001$; $F(1.267, 38.01) = 183 .9$; $\eta^2 = 0.585$). RPM_{max} reduced in the 2nd Wingate test series in PLA and 6 J sessions, and in all treatments in 3rd series (figure 4c). For the RPM_{mean}, a significant performance reduction was observed in all treatments in the 2nd and 3rd series of Wingate tests (figure 4d). No effects of treatment were detected in RPM_{max} ($p=0.98$, $F(2, 30) = 0.015$, $\eta^2 = 0.05$) and RPM_{mean} ($p=0.94$, $F(3, 30) = 0.058$, $\eta^2 = 0.12$). In addition, no significant interaction between treatment and Wingate tests was observed for RPM_{max} ($p=0.99$, $F(4, 60) = 0.022$, $\eta^2 = 0.02$) and RPM_{mean} ($p=0.98$, $F(4, 60) = 0.078$, $\eta^2 = 0.05$).

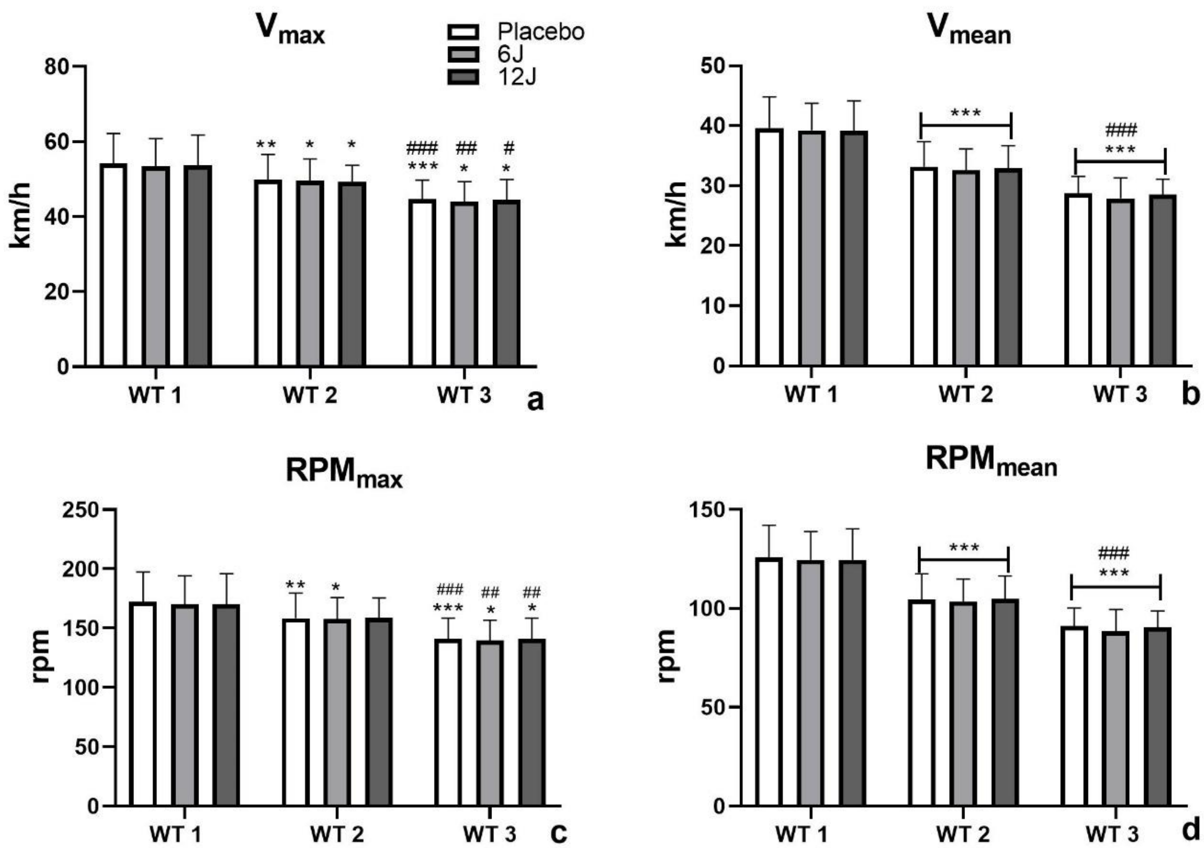

Figure 4. Performance in maximum speed (V_{max}), average speed (V_{mean}), and maximum RPM (RPM_{max}) and average RPM (RPM_{mean}) during the three sets of Wingate tests (WT) in BJJ athletes submitted to photobiomodulation with 6J, 12J, and placebo. * $P < 0.05$, ** $p < 0.01$, and *** $p < 0.005$ compared to Wingate test 1; # $p <0.05$, ## $p <0.01$ and ### $p <0.005$ compared to Wingate test 2. Bonferroni test.

Regarding fatigue parameters, the FI increased in successive series of the Wingate test ($p < 0.001$, $F(1.577, 47.30) = 25.36$, $\eta^2 = 0.15$), without treatment effects ($p=0.91$, $F(2, 30) = 0.086$, $\eta^2 = 0.38$) and interaction between sets and treatment ($p=0.75$, $F(4, 60) = 0.47$, $\eta 2 = 0.56$). The FI showed an increase in the second Wingate series in all treatments (figure 5a).

The P_{drop} was reduced in the 3rd Wingate test series ($p< 0.01$; $F (1.321, 39.62) = 6.449$; $\eta^2 = 2.60$) only in the placebo session (figure 5b). There was no significant effect of treatment ($p= 0.96$, $F (2, 30) = 0.037$, $\eta^2 = 0.21$) or interaction with series ($p=0.92$, $F (4, 60) = 0.23$, $\eta^2 = 0.18$).

The TP_{peak} ($p<0.001$; $F (1.672, 50.17) = 16.69$; $\eta^2 = 0.236$) increased over the Wingate tests series, but without treatment effect ($p= 0.71$, $F (2, 30) = 0.33$, $\eta^2 = 0.69$) and interaction between series and treatment ($p=048$, $F (4, 60) = 0.87$, $\eta^2 = 2.47$). The 6 J session promoted an increase in time until the athletes reached P_{peak} in the 3rd series (figure 5c).

F_{exp} was significantly reduced over the Wingate sets ($p<0.0001$; $F (1.829, 54.86) = 34.86$; $\eta^2 = 0.34$), without the influence of treatment ($p= 0.90$, $F (2, 30) = 0.10$; $\eta^2 = 0.23$) or treatment and series interaction ($p=0.78$, $F (4, 60) = 0.42$, $\eta^2 = 0.84$). F_{exp} was reduced in the 3re series in all treatments, and the 6 J group also showed a reduction in relation to the 2nd serie (figure 5d).

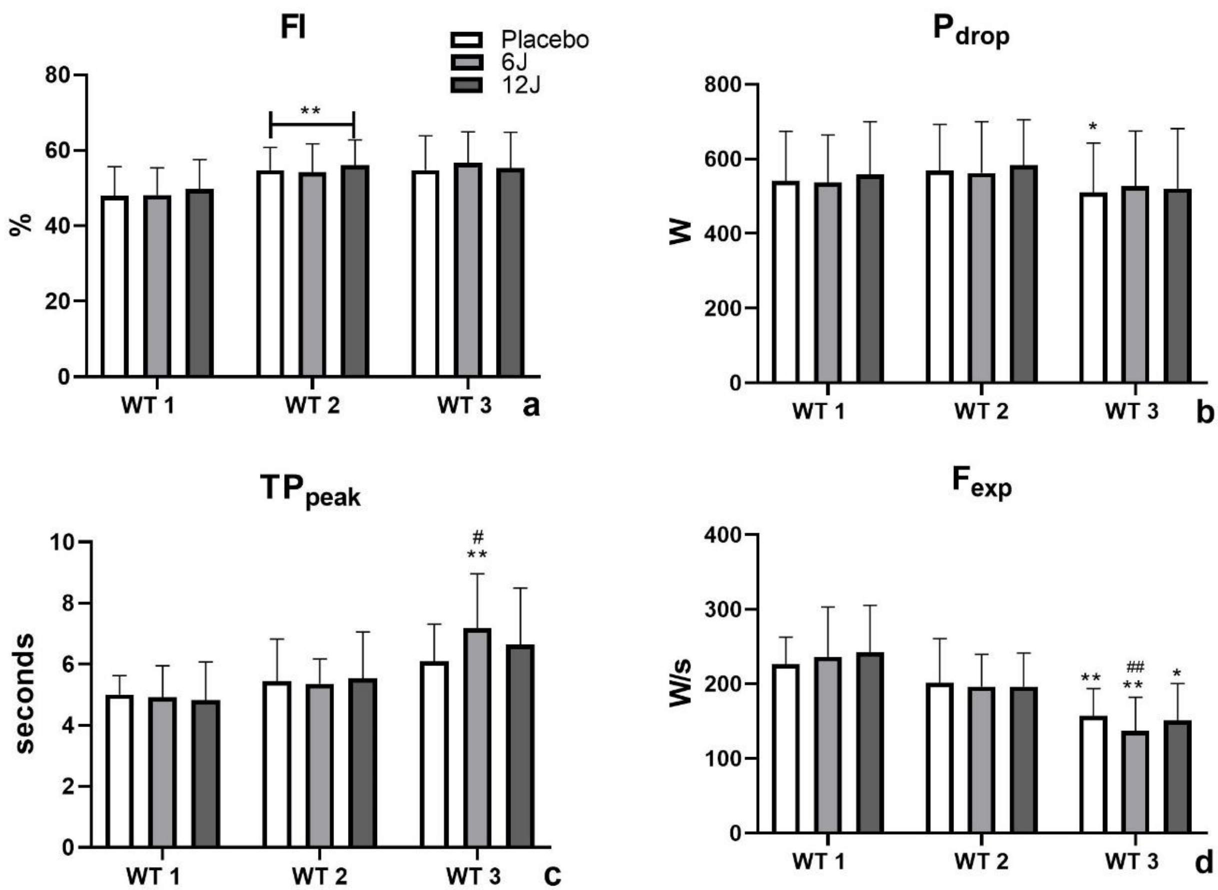

Figure 5. Fatigue markers in three Wingate tests (WT) in BJJ athletes submitted to photobiomodulation with 6J, 12J, and placebo. * p<0.05 and ** p<0.01 compared to Wingate test 1; # p<0.05 and ## p<0.01 compared to Wingate test 2.

Table 2. Percentage variation (Δ) in relation to Wingate test 1 and Cohen´s effect size differences in relation to Placebo session.

	Percentage change compared to 1rs WT (Δ)			Cohen´s effect size (95% CI)	
	Placebo	6 J	12 J	6J x Placebo	12 J x Placebo
Absolute ΔP_{peak}					
2nd WT	-7.8 ± 4.2%	-6.7 ± 6.7%	-6.3 ± 6.8%	Small: -0.20 (-1.03 to 0.65)	Small: -0.28 (-1.09 to 0.58)
3rd WT	-17.3 ± 7.1%	-16.3 ± 13.1%	-15.7 ± 12.7%	Trivial: 0.09 (-0.74 to 0.93)	Trivial: 0.16 (-0.69 to 0.99)
Relative ΔP_{peak}					
2nd WT	-10.3 ± 11.5%	-6.7 ± 6.7%	-6.2 ± 6.8%	Small: 0.38 (-0.48 to 1.21)	Small: 0.44 (-0.42 to 1.27)
3rd WT	-17.3 ± 7.1 %	-16.3 ± 13.1%	-15.8 ± 12.7%	Trivial: 0.09 (-0.74 to 0.93)	Trivial: 0.16 (-0.69 to 0.99)
Absolute ΔP_{mean}					
2nd WT	-16.6 ± 2.9%	-16.6 ± 7.3%	-15.5 ± 6.6%	Trivial: 0.03 (-0.80 to 0.87)	Trivial: -0.24 (-1.06 to 0.61)
3rd WT	-27 ± 5.9%	-28.4 ± 9%	-26.3% ± 9.2%	Trivial: 0.19 (-0.65 to 1.03)	Trivial: -0.09 (-0.92 to 0.75)
Relative ΔP_{mean}					
2nd WT	-19.4 ± 10.2%	-16.5 ± 7.3%	-15.5 ± 6.6%	Small: 0.32 (-0.53 to 1.15)	Small: 0.45 (- 0.41 to 1.28)
3rd WT	-27 ± 5.9%	-28.4 ± 8.9%	-26.3 ± 9.2%	Trivial: -0.19 (-1.02 to 0.65)	Trivial: 0.09 (-0.75 to 0.92)
ΔV_{max}					
2nd WT	-7.8 ± 4.2%	-6.7 ± 6.7%	-7.4 ± 7.6%	Small: 0.20 (-0.65 to 1.03)	Trivial: 0.09 (-0.77 to 0.90)
3rd WT	-17.1 ± 7.3%	-16.3 ± 13.1%	-15.7 ± 12.7%	Trivial: 0.08 (-0.76 to 0.91)	Trivial: 0.14 (-0.71 to 0.97)
ΔV_{mean}					
2nd WT	-7.8 ± 4.2%	-6.7 ± 6.7%	-7.4 ± 7.6%	Trivial: -0.08 (-0.92 to 0.76)	Trivial: 0.09 (-0.75 to 0.92)
3rd WT	-27.1 ± 5.9%	-28.4 ± 8.9%	-26.3 ± 9.2%	Trivial: -0.17 (-1.00 to 0.67)	Trivial: -0.17 (-1.00 to 0.67)
ΔRPM_{max}					
2nd WT	-7.8 ± 4.2%	-7.1 ± 6.9%	-6.2 ± 6.8%	Trivial: -0.12 (-0.72 to 0.95)	Small: 0.28 (-0.57 to 1.11)
3rd WT	-17.3 ± 7.1%	-16.7 ± 13.4%	-15.7 ± 12.7%	Trivial: 0.08 (-0.78 to 0.89)	Trivial: 0.16 (-0.69 to 0.99)
ΔRPM_{mean}					
2nd WT	-16.6 ± 4.9%	-16.5 ± 7.3%	-15.5 ± 6.8%	Trivial: -0.02 (-0.82 to 0.85)	Small: 0.22 (-0.63 to 1.05)
3rd WT	-27 ± 5.9%	-28.4 ± 9%	-26.3 ± 9.2%	Trivial: -0.18 (-1.01 to 0.66)	Trivial: 0.09 (-0.75 to 0.92)
ΔFI					
2nd WT	15.8 ± 12.5%	13.2 ± 10.3%	13.8 ± 13.3%	Small: -0.23 (-1.06 to 0.62)	Trivial: -0.14 (-0.97 to 0.70)
3rd WT	19.9 ± 14.7%	18.6 ± 16%	11.5 ± 14.5%	Trivial: -0.08 (-0.92 to 0.75)	Medium: -0.58 (-1.40 to 0.30)
ΔP_{drop}					
2nd WT	6.9 ± 14.3%	5.7 ± 13.5%	6.6 ± 15%	Trivial: -0.09 (-0.92 to 0.75)	Trivial: -0.02 (-0.86 to 0.82)
3rd WT	-4.0 ± 18.4%	0.2 ± 25.3%	-0.5 ± 21%;	Trivial: -0.19 (-0.65 to 1.02)	Trivial: -0.17 (-0.67 to 1.01)
ΔTP_{peak}					
2nd WT	10.3 ± 31.8%	13.4 ± 27.6%	17.8 ± 27.3%	Trivial: 0.10 (-0.74 to 0.94)	Small: 0.25 (-0.60 to 1.08)
3rd WT	23.6 ± 32%	50.6 ± 39.1%	46.4 ± 56 %	Medium: 0.76 (-0.14 to 1.59)	Medium: 0.50 (-0.37 to 1.32)
ΔF_{exp}					
2nd WT	10.3 ± 23.9%	-12.6 ± 25.7%	-16.4 ± 20.3%	Trivial: -0.09 (-0.93 to 0.75)	Small: -0.28 (-1.10 to 0.57)
3rd WT	-29.2 ± 17.5%	-38.8 ± 26.5%	-33.7 ± 26.5%	Small: -0.43 (-1.26 to 0.43)	Small: 0.20 (-1.03 to 0.64)

WT: Wingate test. CI: confidence interval

The percentage decay in performance (Δ) in the 2nd and 3rd sets of the Wingate tests in different sessions of treatment is shown in table 2. For the majority of variables, the effect size is considered trivial to small. The medium effect size was detected for ΔIF in the 3rd series of Wingate tests in the 12 J session in relation to Placebo. Medium effect sizes were observed for increased ΔTP_{peak} in 6 J and 12 J sessions in the 3rd set of Wingate tests compared to the placebo session (Table 2).

The HR before (Pre) and after (Post) each series of the Wingate test and at 1, 3, and 5 minutes of recovery after the last test of the session (figure 6a) did not show differences in relation to the treatment ($p=0.87$, $F(2, 30) = 0.13$, $\eta^2 = 0.05$), but did show changes in the function of the time (p

< 0.001; F (4130, 123.9) = 572.5, $\eta^2 = 0.89$). The RPE increased during the Wingate test series ($p < 0.0001$; F (1.244, 37.32) = 72.29; $\eta^2 = 0.391$) in all treatments in the second and third series of the test (figure 6b). Treatments did not significantly alter RPE (p=0.74, F (2, 30) = 0.29, $\eta^2 = 0.84$).

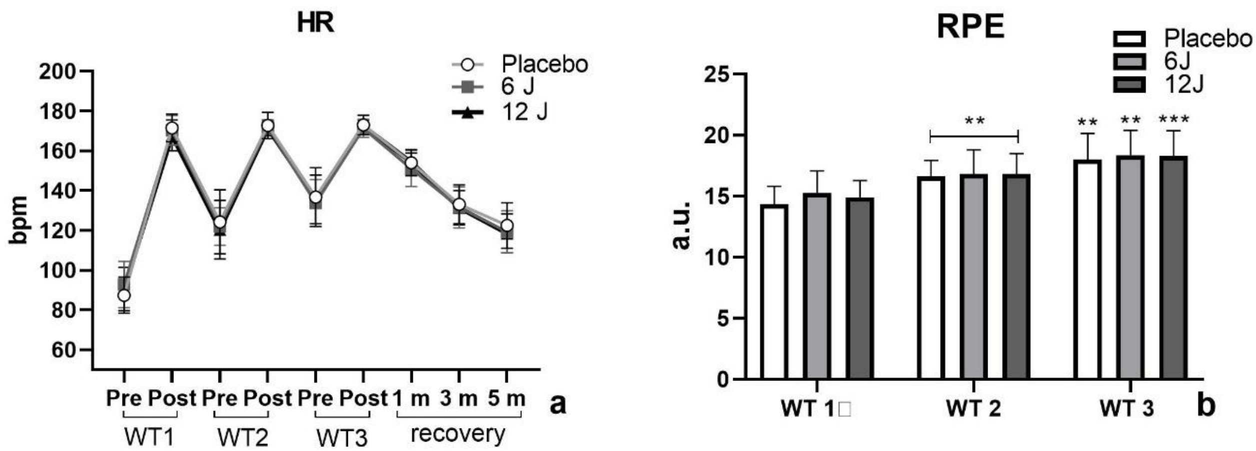

Figure 6. Internal load measurements in BJJ athletes during the session of three Wingate tests submitted to photobiomodulation with 6 J, 12 J, and placebo. HR: Heart rate in beats per minute (bpm). RPE: rate of perceived exertion in arbitrary units (a.u.) ** p<0.01 and *** p<0.005 compared to Wingate test 1.

Regarding the athlete´s blinding to treatment, in the 1st and 2nd series, none of the athletes correctly identified the treatment received. In the 3rd session, only two athletes correctly identified the treatment received.

DISCUSSION

The results did not confirm the alternative hypotheses that treatment with PBM would promote an increase in anaerobic performance. Regardless of the applied dose, when compared to the PLA treatment, no significant differences were found between PLA and PBM (6 J and 12 J) in successive series of the Wingate test. Additionally, PBM (6 J and 12 J) also did not significantly influence physiological and perceptual responses throughout the test session, compared to PLA. Of concern, a percentage increase in fatigue responses suggests that PBM could have a medium but detrimental effect on acceleration (time to reach peak power) in the third series of the Wingate test.

The SJ was included in this study to verify whether the PBM (6J and 12J) would promote potentization in the lower limbs, which could be a prior indicator of performance improvement. However, PBM did not promote potentiation effects in the irradiated muscles, since no differences were found in SJ height between treatments. Our results also show that there was no residual fatigue between test sessions since no differences in SJ were detected.

To assess the effect of PBM on anaerobic performance, as well as the effect on recovery between Wingate series, the performance of athletes was evaluated in three Wingate tests for lower limbs, with passive recovery intervals of 3 minutes, as recommended in studies with judo athletes (17) and BJJ athletes (5). Previous studies using the Wingate test to assess PBM responses performed a single test in each session, so it was not possible to evaluate fatigue accumulation or recovery over successive efforts (14, 27, 28, 32, 43).

During the Wingate test, the main source of energy for exercise comes from anaerobic metabolism (ATP and phosphocreatine degradation and anaerobic glycolysis) (9, 23, 41). Although the mechanism by which PBM under the same conditions could increase test performance has not yet been established, it is suggested that a possible ergogenic effect in the first test would be associated with the release of nitric oxide (NO) (32). However, no ergogenic effects were observed in the first series of the test, in agreement with findings by other authors (32, 43). As observed for NO-inducing supplements, which have effects in untrained and moderately trained subjects, but have no significant ergogenic effects in trained subjects (7), the effect of NO release induced by PBM may also have little impact on the physical performance of BJJ athletes with high physical fitness.

Another mechanism that could contribute to the ergogenic effect and reduction in accumulated fatigue between series is the ability of PBM to promote an increase in ATP synthesis via mitochondrial oxidative metabolism. Thus, after the initial warm-up, it was expected that performance in the first Wingate test, in the 6 J and 12 J sessions, would be greater than in the PLA session. However, there was no difference in performance between conditions. Moreover, no significant effect was observed on recovery between series, and fatigue and drop in performance occurred in the 2nd and 3rd series in all study sessions. Contrary to the study hypothesis, the increase in TP_{peak} and the reduction in F_{exp} suggest a possible negative effect of the 6 J dose on the acceleration capacity in the third serie of the Wingate test.

The parameters P_{peak} (W and W/kg), V_{max}, and RPM_{max} are directly related to anaerobic power, while P_{mean} (W and W/kg), V_{mean}, and RPM_{mean}, are related to the anaerobic capacity to produce high performance with the lactic and alactic energy systems recruiting a great number of motor units (35, 40). Therefore, the greater the areas of the muscles involved in the exercise irradiated with PBM, the greater the effects on performance could be. However, despite radiating the same muscle areas and with doses similar or higher to those used by Molina Correa et al. (32), PBM was not able to produce better performances than the placebo condition. It suggests that the training level of the subject may interfere with the clinical results, which could explain the difference in the results found in this study, evaluating athletes, compared to those of Molina Correa et al. (32), who evaluated healthy adults.

It is noteworthy that, as more Wingate tests are performed in the same exercise session, in the moments of pause between the subsequent tests, the energy resynthesis predominantly comes from the aerobic metabolism (18, 19). In addition, the contribution of aerobic metabolism in providing energy for the performance of exercise is greater when more tests with anaerobic characteristics are performed (8, 9, 41). Since PBM promotes greater activation of the electron transport chain and an increase in the ATP synthesis (20, 25), it was expected that PBM would contribute to greater ATP resynthesis and, consequently, to better recovery between subsequent Wingate tests. On the contrary, PBM was not effective in promoting better recovery responses between the Wingate tests, because the test performance in the 6J and 12J sessions did not differ from those found in the PLA session.

Wingate tests promoted an increase in physiological and perceptual responses throughout the three sets in different treatments. However, PBM seems not to affect the internal load, as the HR and RPE values did not differ between treatments. These results are in line with those of previous studies that did not identify a positive effect of PBM on internal load variables (31, 39).

Despite we found no ergogenic effect of PMB on the anaerobic performance of BJJ athletes, previous studies suggested that PBM may have some ergogenic effect in BJJ athletes on reducing fatigue and improving maximal isometric voluntary contraction in elbow flexion and handgrip strength (6, 16). However, pre-exercise treatment with PBM, at doses of 6 J and 12 J per point, did not contribute to increases in high-intensity intermittent performance in BJJ athletes. Lastly, new studies, to advance the understanding of photobiomodulation applied to combat sports athletes, should seek to comprehend the effect of photobiomodulation used chronically and, its effects on female athletes.

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