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Effect of Photobiomodulation on Critical Swimming Velocity: A Randomized, Crossover, Double-Blind, and Placebo-Controlled Study

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Purpose: To analyze the acute effect of photobiomodulation (PBM) on swimming critical velocity (CV). ***Methods:*** A total of 15 male federated swimmers (20.9 [2.4] y old) participated in this study. Three sets of front crawl were performed at distances of 100, 200, and 400 m to determine the CV under 3 experimental conditions: PBM (420 J), placebo (PLA), and control (C) in this randomized, crossover, double-blind, and placebo-controlled study. One-way analysis of variance for repeated measurements was used for statistical analyses. ***Results:*** The results showed that the prior application of PBM did not have ergogenic effects on CV and front crawl swimming performance: CV (PBM = 1.15 [0.15]; PLA = 1.20 [0.25]; C = 1.15 [0.14] $m \cdot s^{-1}$), swim time (ST) 100 m (PBM = 65.5 [6.3]; PLA = 65.2 [5.6]; C = 66.0 [5.9] s), ST 200 m (PBM = 148.5 [17.9]; PLA = 149.4 [16.4]; C = 150.1 [17.9] s), and ST 400 m (PBM = 327.7 [38.2]; PLA = 321.6 [47.7]; C = 329.5 [41.2] s). ***Conclusions***: A PBM application prior to front crawl swimming test did not significantly modify the CV, ST, physiological factors of metabolic fatigue, perceptual, and front crawl stroke efficiency parameters in competition swimmers covering distances of 100, 200, and 400 m.

Keywords: low-level light therapy, ergogenic, front crawl, endurance test, athletic performance

The photobiomodulation (PBM) is an electromagnetic radiation, nonthermal neither harmful, that utilizes visible or invisible lights through laser or light-emitting diodes (LEDs) sources, and it is being studied as a potential ergogenic resource to improve physical performance and competitive sports activities.[1–3] Studies have shown changes in the mitochondrial size and functionality, increase in the enzymatic activity of the entire mitochondrial respiration complex, and aerobic metabolism-related enzymes after PBM application, ensuring a high rate of adenosine triphosphate (ATP) synthesis via oxidative metabolism during exercise.[4,5]

Another effect of PBM that may be related to aerobic metabolism is the improvement of microcirculation with hyperemia (an increased amount of blood in the vessels of an organ or tissue in the body) at the application site, favoring higher oxygen availability and rate of blood lactate removal, a latent form of energy that can favor the maintenance of muscle function in long-term exercise,[6] if removed earlier. Despite scientific support for PBM as an ergogenic resource to improve aerobic exercise performance, the effects of its application on swimming remain unclear. Prior application of PBM in treadmill tests has shown an ergogenic effect on cardiorespiratory parameter responses, such as increased maximal oxygen uptake, increased peak velocity, decreased maximum heart rate (HR_{max}) that could decrease the values of rating of perceived exertion (RPE), decreased peak lactate (LA_{peak}) after the incremental test, and improved running performance suggesting the use of PBM by running practitioners to optimize muscle recovery and improve aerobic and performance capacity.[7,8]

The few existing studies involving PBM with exercise in an aquatic environment were performed with animal models submitted to swimming training[10,11] and showed that PBM without exercises was unable to improve physical performance of aged rats,[11] and with water polo players[12] without ergogenic effects on swimming test performance. Previous studies on runners and cyclists[1,7,13] have shown that PBM treatment increases fatigue resistance and duration in endurance exercise. Miranda et al[13] applied PBM (270 J on quadriceps, 180 J on hamstrings, and 60 J on calves on each leg) on 20 healthy untrained males who participated in a progressive treadmill test until exhaustion. The distance covered after PBM application was greater (1.96 [0.30] km) than placebo (PLA; 1.84 [0.40] km). Time until exhaustion was also longer after PBM application (780.2 [91.0] s) than placebo (742.1 [94.0] s). Also, Lanferdini et al[1] conducted a study with 20 male competitive cyclists who performed an incremental cycling test to exhaustion. Participants received 3 different doses of PBM on quadriceps (135, 270, or 405 J each leg). The time to exhaustion increased for all PBM doses compared with the placebo. PBM 135 J increased time to exhaustion by ≈15% compared with the placebo and PBM 270 and 405 J increased 9% in time to exhaustion compared with the placebo. They found no differences in time to exhaustion between the 3 doses.

To verify the possible effects of PBM on performance and aerobic capacity, the critical velocity (CV) test was chosen. The CV derives from the concept of critical power, which has a linear relationship between the total work done at each work rate and its duration during an exercise and defined critical power as the intensity of an exercise in which, in theory, the effort could be maintained without exhaustion.[14,15] Wakayoshi et al[14] tested the CV concept in competition swimmers, demonstrating that CV was correlated with $\dot{V}O_2$, relative to anaerobic threshold (AnT) ($r = .81$) and velocity at AnT ($r = .95$). The authors suggested that CV could be adopted as an endurance index for the performance of competition swimmers. The use of CV as a predictive variable of aerobic performance has been used because it is a noninvasive method and easy to implement.[12]

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Considering swimming has a similar energetic metabolism compared with endurance running and cycling (aerobic metabolism), which has shown potential ergogenic effects on exercise performance, PBM could have the same effects on swimming. The objective of this study was to verify the acute effect of PBM on CV, ST, HR postperformance (HR_{post}), RPE, LA_{peak}, and stroke index (SI). Our hypothesis is that application of PBM prior to a swim test increases CV values and decreases the final ST at distances of 100, 200, and 400 m in front crawl swimming. Also, it decreases the values of HR_{post}, blood lactate concentration ([La]), RPE, and stroke frequency as well as increases the stroke length (SL) and SI.

Method

Participants

The sample size was calculated from a priori analysis for a group by time interaction comparison (*F* test, analysis of variance for repeated measures, and within-between interaction) according to an effect size (ES) of 0.25 (obtained from a pilot studies), power of 80%, and significance level of 5%. We used the software G*Power (version 3.1; Heinrich Heine University Düsseldorf, Düsseldorf, Germany) for the calculation. The priori power analysis revealed a minimal sample of 15 participants.

This study included 15 male swimmers (age 20.9 [2.4] y; height 178.0 [0.1] cm; body mass 76.0 [12.6] kg). The inclusion criteria were a performance ≥60% of the world record of 100, 200, or 400 m and swim at state events. The mean (SD) for the best swimming time of the participants was (100 m = 57.14 [4.35] s, 200 m = 134.69 [15.49] s, and 400 m = 282.13 [35.50] s). The mean (SD) for FINA points of the participants was (100 m = 485 [111.48] s, 200 m = 436.77 [129.06] s, and 400 m = 479.50 [142.33] s). Most swimmers competed at the state-level championships and 2 of them at national. Written informed consent was obtained from all participants, and ethical approval was granted by the Permanent Committee on Ethics in Research with Human Beings, COPEP, State University of Maringá (UEM) (2.554.517/2018).

Study Design

The study had a randomized, crossover, double-blind, and placebo-controlled design, and all participants were following experimental conditions: PBM with LED (420 J total dose applied), placebo (PLA), and control (C). The order of conditions (PBM, PLA, and C) was randomized. To verify the possible effects of PBM on performance and aerobic capacity, the CV test was chosen. The participants completed 9 visits to the swimming pool and each participant performed the tests on different nonconsecutive days under the 3 conditions over 3 weeks with a minimum interval of 48 and a maximum of 72 hours between tests. Participants were instructed to attend for testing well rested, well nourished, and well hydrated. They were also instructed to abstain from caffeine and to refrain from strenuous exercise before the tests.[16] The participants were in the transition of the preparatory period of training periodization.

Procedures

After the PBM or PLA procedure, an individual warm-up of 15 to 20 minutes of self-paced intensity took place following 5 minutes of passive rest. Each performance, in an indoor 25-m swimming pool heated to 28°C, started inside the pool with an impulse from the edge of the pool after a beep, and the time taken to swim each distance was recorded using a manual chronometer. Thereafter, the mean speed of the 100-, 200-, and 400-m maximal performances were calculated in meters per second. CV was determined with a combination of 3 distances (CV = 100, 200, and 400 m) using the slope of the linear regression between swimming distances and time taken to complete each performance.[16] The order in which the participants performed each distance was randomized.

For the application of PBM, we used the LED (THOR-LX2®; THOR Photomedicine Ltd, London, United Kingdom) with 2 clusters of 104 infrared LEDs each. The technical parameters are presented in Table 1. The application was conducted by an assistant researcher who controlled the device on or off (PBM: LED 420 J total dose or PLA). During the application of the PBM, participants used sunglasses and ordinary headphones with standard sound so that the sound and lights emitted by the equipment were not perceived. The application of the PBM had a total duration of approximately 1 minute 45 seconds, 15 seconds per point. The same procedures were used in the PLA and PBM conditions, respecting the presence or absence of light emission for each condition. The irradiation intervention started 15 to 20 minutes before the CV test, in contact mode with the LED cluster held stationary with slight pressure at a 90° angle to the skin at each of the 7 treatment points. PBM was applied to the upper limbs and trunk muscles (region of the pectoral muscle, a region of the dorsal muscle, a middle region of the deltoid, and a region of the triceps muscle) and lower limbs (region of the quadriceps muscle, a region of the biceps muscle femoral, and a region of the gastrocnemic muscle following the axis of distribution of muscle fibers in both legs).

Stroke parameters were determined during the execution of maximal performances (100, 200, and 400 m). The efforts started in the pool with a push-off from the side of the pool at an audible beep. The total stroke cycles were counted, and the time taken to

Table 1 Parameters of PBM Application

Number of diodes: 104	56 diodes of 660 nm (red light); 48 diodes of 850 nm (infrared)
Wavelength	Mixed—660 and 850 nm
Power output (each diode)	10 mW (660 nm) and 30 mW (850 nm)
Diode area	0.2 cm^2
LED cluster area	46.3 cm^2
Power density (each diode)	50 $mW \cdot cm^{-2}$ (660 nm) and 150 $mW \cdot cm^{-2}$ (850 nm)
Energy density (each diode)	1.5 $J \cdot cm^{-2}$ (660 nm) and 4.5 $J \cdot cm^{-2}$ (850 nm)
Exposure time (per site)	15 s
Total energy irradiated (each diode)	0.3 J (660 nm) and 0.9 J (850 nm)
Total energy irradiated (each site)	30 J
Total energy irradiated on body	420 J
Number of application sites (each body side)	7 sites
Total number of application sites on body	14 sites
Total exposure time	1 min 45 s

Abbreviations: LED, light-emitting diode; PBM, photobiomodulation.

complete each distance was recorded using a manual chronometer. The procedure was performed visually without filming. Thereafter, the average speed of the 100, 200, and 400 m were calculated in meters per second. The stroke parameters were calculated as follows: stroke rate = SC per time, $SL = AS \cdot SR^{-1}$ (in meters), and $SI = SL \times AS$.

At the end of each maximal front crawl performance, HR_{post} was monitored using a cardiac monitor (Polar® FT1; Polar Electro Oy, Kempele, Finland), placed on the swimmer's chest after completing the course and sitting on the edge of the pool. The RPE by the Borg score scale between 6 and 20[9] was checked at the end of the course. Earlobe capillary blood samples (25 µL) were collected into a glass microhematocrit capillary tube before, at the end of each test and at the third and the fifth minutes after tests, during passive recovery sitting on the edge of pool, were subsequently determined by electroenzymatic methods using the Yellow Springs Instrument (YSI) 2300 STAT® (Yellow Springs, OH) automated analyzer. The LA_{peak} was defined for each participant as the highest value among the passive recovery samples.

Statistical Analyses

Data were analyzed using the Statistical Package for the Social Sciences (version 24.0; SPSS® Inc, Chicago, IL). The Shapiro–Wilk test was used to check the normality of the data distribution, and data are presented as mean (SD). One-way analysis of variance was used to assess the main effects of the 3 conditions, and mixed analysis of variance for repeated measures was used to compare stroke parameters between the 3 distances among the 3 experimental conditions. The Mauchly test of sphericity was used to determine data normality, and if necessary, the Epsilon adjustment Greenhouse–Geisser was used to determine main effect. The analyses were completed with the Bonferroni post hoc. Statistical significance was set at $P < .05$. As complementary analysis, the ES (Cohen d)[17] was calculated to determine the magnitude of change in each condition using the following equation:

$$ES = (M1 - M2)/[(SD1 + SD2)/2]$$

where M1 and M2 are the average of each condition and SD1 and SD2 are the respective SDs. The ES was classified according to Cohen[17] as: ≤0.20 (trivial), between 0.21 and 0.50 (small), between 0.51 and 0.80 (moderate), and >0.80 (large).

Results

Figure 1 presents the individual values of the results obtained and the comparisons between the PBM, PLA, and C conditions for the 100-, 200-, and 400-m swimming front crawl distances used to determine the CV and other parameters, and Figure 2 presents the mean (SD) (all group) of the same variables. Table 2 presents mean (SD) for these variables. No statistically significant differences were found for the main variables of interest of the study.

Table 3 shows the absolute and relative values of the difference between the means of the analyzed variables for the group of participants. We can observe that the ST at all distances (100, 200, and 400 m) were shorter in PBM and PLA conditions when compared with the C condition.

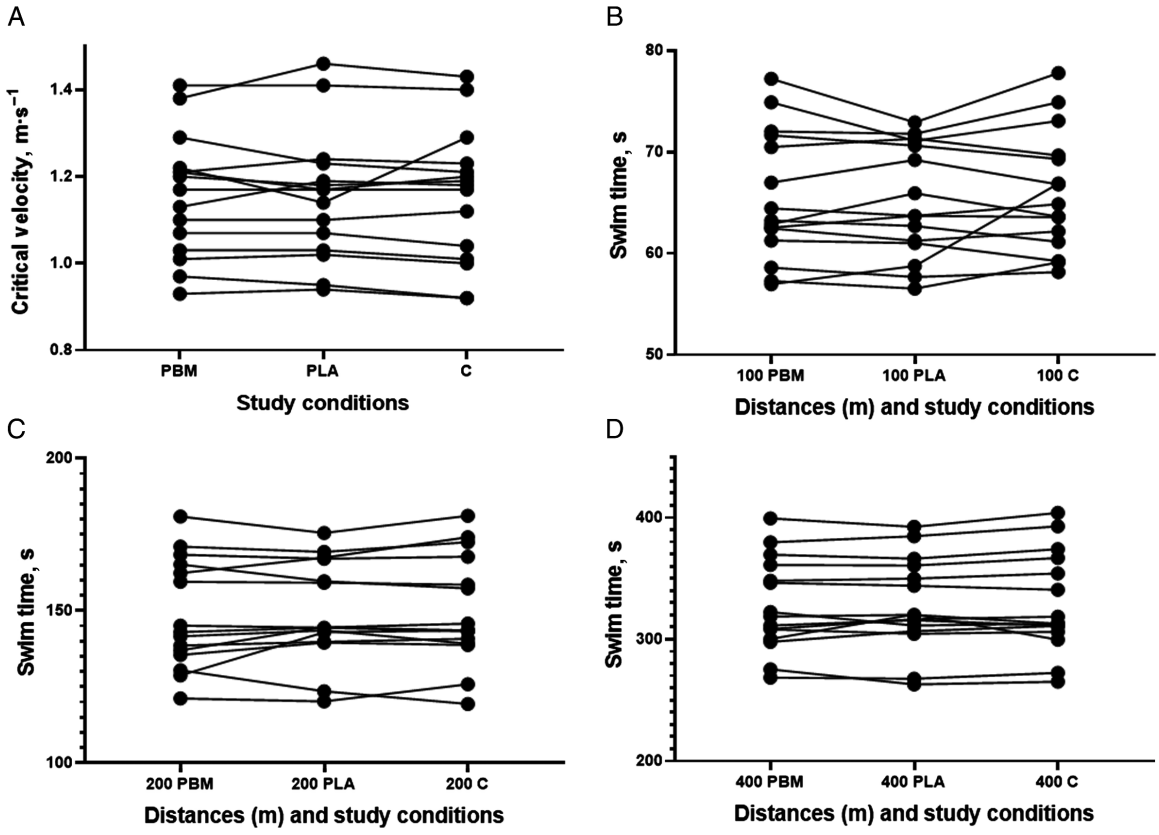

Figure 1 — Individual values of the critical velocity (A) and final swimming time to execution each distance 100-m front crawl (B), 200-m front crawl (C), and 400-m front crawl (D). N = 15. C indicates control; PBM, photobiomodulation; PLA, placebo. $P < .05$.

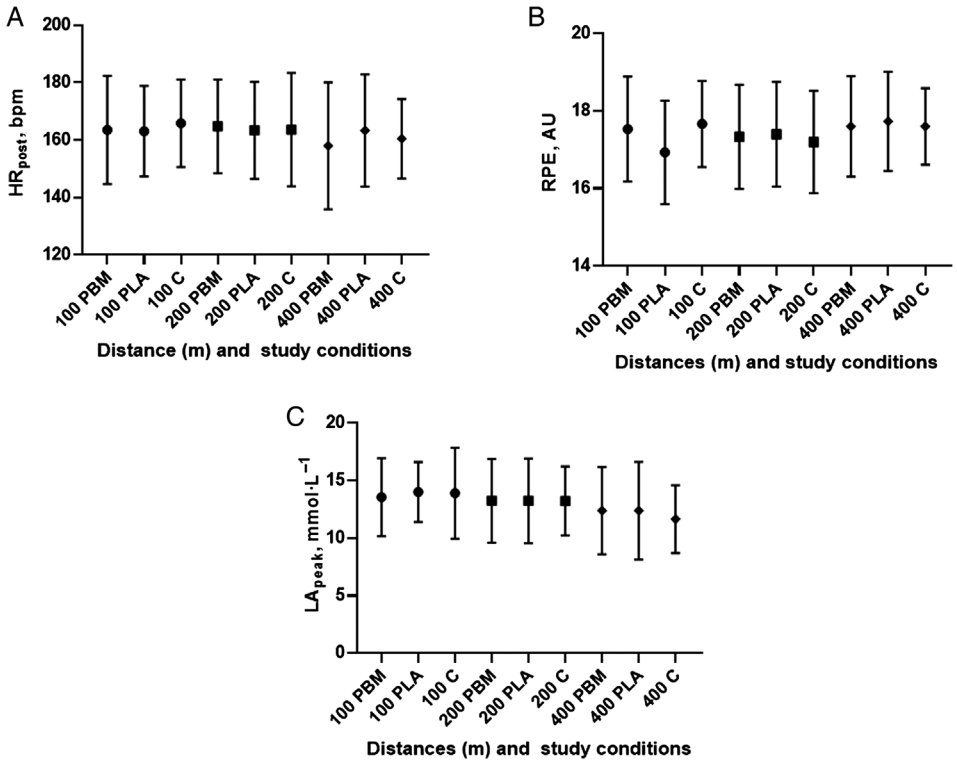

Figure 2 — Mean (SD) of (A) HR_{post}, (B) RPE, and (C) LA_{peak} for the group of participants (N = 15). AU indicates arbitrary units; bpm, beats per minute; C, control; HR_{post}, post exercise heart rate; LA_{peak}, lactate peak; PBM, photobiomodulation; PLA, placebo; RPE, rating of perceived exertion. $P < .05$.

Table 2 Mean (SD) of the Variables From Test to Determine the CV of the Group of Participants (N = 15)

Variables	D, m	PBM	PLA	C	*F*	*P*
CV, $m \cdot s^{-1}$		1.15 (0.15)	1.20 (0.25)	1.15 (0.14)	0.929	.357
	100	65.5 (6.4)	65.2 (5.6)	66.0 (6.0)	0.664	.523
ST, s	200	148.6 (17.9)	149.4 (16.4)	150.1 (17.9)	0.628	.489
	400	327.7 (38.3)	321.6 (47.7)	329.6 (41.2)	1.093	.320
	100	164 (18.8)	163 (15.8)	166 (15.2)	0.290	.750
HR_{post}, bpm	200	165 (16.3)	163 (16.9)	164 (19.7)	0.045	.956
	400	158 (22.1)	163 (19.5)	160 (13.8)	0.986	.386
	100	17.5 (1.46)	16.9 (1.3)	17.7 (1.1)	2.289	.166
RPE, AU	200	17.3 (1.3)	17.4 (1.4)	17.2 (1.3)	0.161	.852
	400	17.6 (1.3)	17.7 (1.3)	17.6 (0.9)	0.127	.087
	100	13.6 (3.4)	14.0 (2.6)	13.9 (3.9)	0.227	.798
LA_{peak}, $mmol \cdot L^{-1}$	200	13.2 (3.6)	13.2 (3.7)	13.2 (2.9)	0.000	1.000
	400	12.4 (3.8)	12.4 (4.2)	11.6 (2.9)	0.769	.473

Abbreviations: AU, arbitrary units; bpm, beats per minute; C, control; CV, critical velocity; D, distance; HR_{post}, post exercise heart rate; LA_{peak}, lactate peak; PBM, photobiomodulation; PLA, placebo; RPE, rating of perceived exertion; ST, swimming time. Note: $P < .05$.

Figure 3 presents the values of the variables related to the swimming index (SI) in the distances of 100-, 200-, and 400-m front crawl swimming of the group of participants. It was observed that there was no statistically significant difference in any of the analyzed variables between the study conditions. No differences were found for SL variables between the distances in each condition of the study. In the comparison for SI, no difference was found between the distances of 100- and 200-m front crawl in the C condition ($P = 1.000$). In the other comparisons, statistically significant differences were found between the distances in each study condition.

Table 3 Absolute and Relative Values of the Difference Between the Mean Values of the Variables in the Group of Participants (N = 15)

Variables	D, m	PBM – PLA	PBM – C	PLA – C
CV, $m \cdot s^{-1}$		–0.04 (–2.96%)	0.01 (0.74%)	0.05 (3.60%)
	100	0.31 (0.47%)	–0.49 (–0.75%)	–0.8 (–1.23%)
ST, s	200	–0.85 (–0.57%)	–1.54 (–1.04%)	–0.69 (–0.46%)
	400	6.1 (1.86%)	–1.85 (–0.56%)	–7.95 (–2.47%)
	100	0.4 (0.24%)	–2.34 (–1.43%)	–2.74 (–1.68%)
HR_{post}, bpm	200	0.4 (0.24%)	1.13 (0.69%)	0.73 (0.44%)
	400	–5.33 (–3.37%)	–2.47 (–1.56%)	2.86 (1.75%)
	100	0.6 (3.42%)	–0.14 (–0.80%)	–0.74 (–4.37%)
RPE, AU	200	–0.07 (–0.40%)	0.13 (0.75%)	0.2 (1.15%)
	400	–0.13 (–0.74%)	0 (0.00%)	0.13 (0.73%)
	100	–0.44 (–3.24%)	–0.34 (–2.51%)	0.1 (0.71%)
LA_{peak}, $mmol \cdot L^{-1}$	200	0.01 (0.08%)	0.02 (0.15%)	0.01 (0.08%)
	400	–0.01 (–0.08%)	0.73 (5.90%)	0.74 (5.97%)

Abbreviations: AU, arbitrary units; bpm, beats per minute; C, control; CV, critical velocity; HR_{post}, post exercise heart rate; LA_{peak}, lactate peak; PBM, photobiomodulation; PLA, placebo; RPE, rating of perceived exertion; ST, swimming time. Note: $P < .05$.

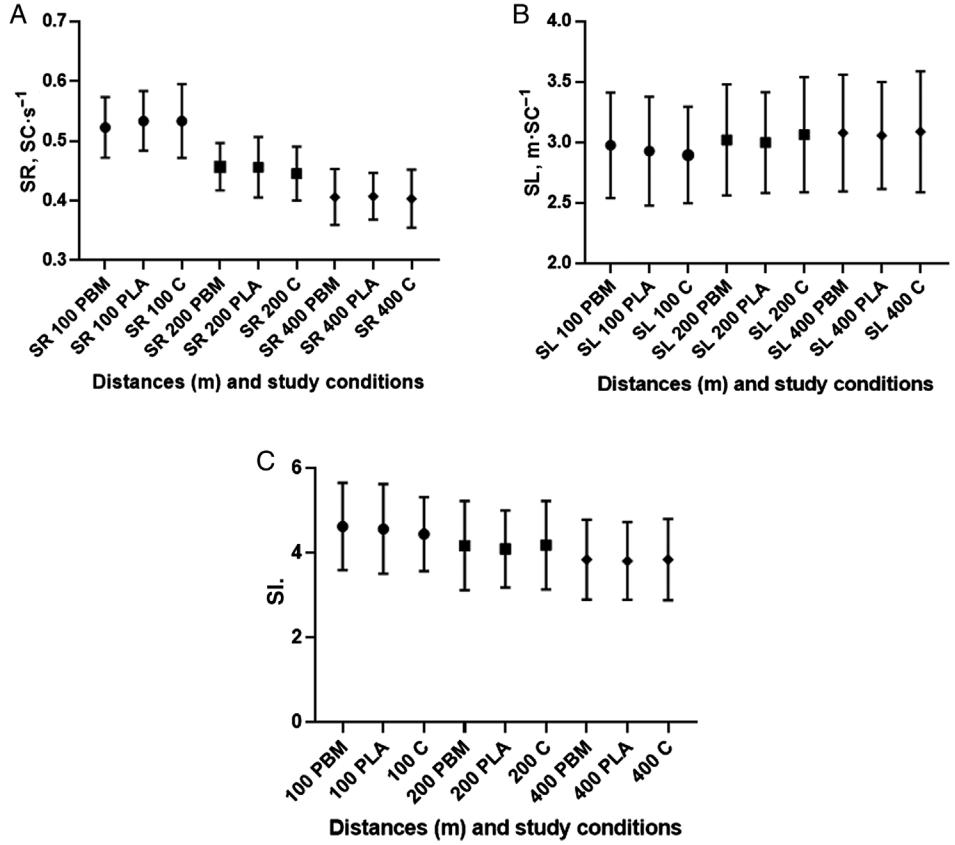

Figure 3 — Mean (SD) of stroke parameters obtained at distances of 100-, 200-, and 400-m front crawl swimming for the group of participants (N = 15): (A) SR, $SC \cdot s^{-1}$, (B) SL, $m \cdot SC^{-1}$; and (C) SI: SL versus AS. C indicates control; $m \cdot SC^{-1}$, swimming distance in meters divided by stroke cycle; PBM, photobiomodulation; PLA, placebo; $SC \cdot s^{-1}$, stroke cycles divided by swimming time in seconds; SI, stroke index; SL, stroke length; SL versus AS; stroke length multiplied by the average speed; SR, stroke rate. $P < .05$.

Discussion

The objective of this study was to verify the acute effect of PBM on CV as well as the swimming performance (ie, ST) and other variables associated with performance in physical exercises, such as HR_{post}, RPE, LA_{peak}, and SI. The main finding was that the application of PBM using LED did not specifically modify the CV or the other variables determined in the same tests, such as ST at

100, 200, and 400 m in front crawl swimming, HR_{post}, RPE, LA_{peak} concentration, SR, SL, and SI, contrary to the initially formulated hypothesis.

To date, no previous studies have indicated a prior application of PBM aimed at examining its potential ergogenic effects on CV or other parameters in swimming performance. Considering that CV is highly related to the AnT,[12,13] the current finds are consistent with studies that verified the effects of PBM on AnT[18,19] that did not indicate results that point to an ergogenic effect. A study[19] that verified the effects of PBM on AnT (using 720 J divided into 180 J on quadriceps, 120 J on hamstrings, and 60 J gastrocnemius of each leg) in an incremental test of running until exhaustion, found no difference between the PBM and PLA conditions for time and absolute $\dot{V}O_{2max}$, respectively (PBM = 457.45 [79.96] s; $\dot{V}O_{max}$ = 2.88[0.40] L · min^{-1}; PLA = 468.82 [85.81] s; $\dot{V}O_{max}$ = 2.90[0.39] L · min^{-1}).

A recent study[18] used 3 different doses of PBM (420 J divided into 120 J on quadriceps, 60 J on hamstrings, and 30 J on gastrocnemius; 840 J divided into 240 J on quadriceps, 120 J on hamstrings, and 60 J on gastrocnemius; 1680 J divided into 480 J on quadriceps, 240 J on hamstrings, and 120 J on gastrocnemius) applied before a submaximal incremental running test, and verified that despite the absence of an ergogenic effect on the individual anaerobic threshold velocity, a high dose of 1680 J was considered possibly harmful.

Although, in both studies[18,19] the doses of PBM meet the recommended parameters of the specialized literature,[20,21] the ideal dose according to the size of muscle groups remains unclear, which can potentially explain the results suggesting no ergogenic effect of PBM on performance in physical exercises. Thus, in this study the lack of an ergogenic effect of PBM on CV may be due to the small dose applied to large muscle groups such as dorsal, pectoral, and quadriceps, as in other studies doses between 60 and 300 J were used for large muscle groups and doses of 20 to 60 J for small muscle groups,[20,21] and in the present study we used 30 J as a fixed parameter for all muscles groups irradiated.

Zagatto et al[12] conducted a study with 20 young male water polo players applying PBM (810 nm and 48 J) before a 200-m front crawl swim test. To date, it is the only study investigating the effect of PBM on swimming considering the final ST as a performance indicator. In the PBM group, the participants swam the 200-m distance around 1.1% faster comparing to PLA group (PBM vs PLA, ES = 0.23 [0.32], considered small). In the present study, the results of 200-m front crawl, presented the ES: PLA versus PBM (0.14, trivial, –0.57%); C versus PBM (–0.05, trivial, –1.04%); C versus PLA (–0.18, trivial, –0.69%). Although we did not observe statistically significant differences in the present study, a final ST of almost half a second shorter (0.49 s) in the 100-m front crawl, 1.54 second in the 200 m, and 1.85 second in the 400 m, compared with C condition, can compromise the presence on the podium in high level competitive events.

In the same study, Zagatto et al[12] applied the PBM (24 J) in the muscles of the adductor longus of each participants' legs. When applying PBM to the latissimus dorsi, pectoral, triceps, and shoulder muscles, we expected to find different results from the study by Zagatto et al,[12] as these muscle groups are the main drivers for crawl swimming, and so far, this study has been the only one to apply PBM to these muscle groups. However, the results do not point to a possible ergogenic effect on ST that is statistically significant, indicating no stimulatory effects in biological tissue by PBM at doses between 24 and 30 J.[4]

Regarding HR_{post}, no differences were found between study conditions. It is possible to observe a small decrease in the average HR_{post} in the PBM condition in the 100-m front crawl: PBM versus C –2 beats per minute (bpm), 400-m front crawl: PBM versus C –2 bpm and 400-m front crawl: PBM versus PLA –5 bpm. The results were similar to those of the study conducted by Peserico et al,[22] who tested 3 different doses of PBM (300 J divided into 60 J on quadriceps, 60 J on hamstrings, and 30 J on gastrocnemius; 1200 J divided into 240 J on quadriceps, 240 J on hamstrings, and 120 J on gastrocnemius and 1800 J divided into 360 J on quadriceps, 360 J on hamstrings, and 180 J on gastrocnemius). The authors found no statistically significant differences in HR_{max} and submaximal heart rate, in a progressive treadmill test, between the 3 different doses of PBM and the C and PLA conditions. HR_{max} (bpm) (C = 186 [8.6] bpm; PLA = 181 [5.4] bpm; PBM 300 J = 182 [4.1] bpm; PBM 1200 J = 181 [8.2] bpm; and PBM 1800 J = 182 [7.1] bpm).

On a study carried out with on a treadmill incremental test, Mezzaroba et al[8] found a moderate ES of the PBM application on HR_{max} (193 [3.9] bpm) compared with PLA (195 [3.4] bpm), $P = .018$; ES = 0.53. The authors attribute this decrease in HR_{max} to a possible influence of the biological mechanism of light, promoting a better recovery of cardiac parameters values after exercise as well as a possible improvement in the extraction of oxygen by the peripheral muscles.

On the other hand, the aquatic environment used for swimming can lead to changes in cardiovascular parameters due to the hydrostatic pressure, as the main physiological effect in the immersed human body is the reduction of heart rate.[23,24] While swimming, the heart rate is significantly reduced as a compensation for the high stroke volume caused by the body position in decubitus, water temperature, and the body weight discharge caused by hydrostatics. When the athletes exercised in water (ie, training or swimming competition), the basic characteristics of circulatory functions are altered with increased cardiac output, stroke volume, and perfusion in nonmuscular tissues. During physical exercise, maximum cardiac output, heart rate, blood flow, oxygen transport, anaerobic threshold, and potency were 15% lower in water than in exercise on land, even in water at 25°C to 29°C.[25,26]

Besides that, in the present study, no evidence was found that a prior application of PBM produced an ergogenic effect on RPE, unlike studies of Dellagrana et al[18] and Mezzaroba et al,[8] which presented results that can be considered as ergogenic in treadmill tests. Mezzaroba et al[8] observed a reduction in RPE between stages 8 to 14 km·h^{-1} in the PBM condition compared with the PLA condition. Dellagrana et al[18] compared different doses of PBM (420, 840, and 1680 J), and found a reduction in RPE values during the tests (8 km·h^{-1} and in the 9 km·h^{-1}) in the PBM condition when compared with the C condition. At the speed of 8 km·h^{-1}, the RPE values were 7.2 (1.5) arbitrary unit (AU), PBM 420 J; 7.0 (1.5) AU, PBM 840 J; 7.3 (1.4) AU, PBM 1680 J; and 8.7 (1.8) AU, C conditions. At the speed of 9 km·h^{-1}, the RPE values found were 8.7 (1.9) AU, PBM 420 J; 8.5 (1.6) AU, PBM 840 J; 8.7 (2.1) AU, PBM 1680 J; and 10.0 (2.5) AU, C conditions.

The lack of ergogenic effect of the previous application of PBM on RPE in this study can be possibly explained by the linear relationship of RPE with the increase in the intensity and duration of exercises as well as with heart rate and [La].[9,22] Since the Borg scale (6–20)[9] has numerical references with respective descriptors that provide responses that increase linearly as a function of aerobic demand: intensity, time of effort, and heart rate and the amplitude of numerical responses between 6 and 20 strongly correspond to

the HR_{max} amplitude of a healthy young adult, between 60 and 200 bpm. Given that, the PBM did not modify the HR_{post}; it was expected that the RPE also did not present different values between the conditions of the present study.

Analysis of the LA_{peak} showed no difference between the conditions of the present study. Likewise, no differences were found in the results of studies with incremental running test[8] with 26 healthy and physically active men, PBM (9.8 [1.7] mmol·L^{-1}) versus PLA (10.0 [1.8] mmol·L^{-1}), and Dellagrana et al[18] also found no difference in the concentrations of LA_{peak} between PBM 420 J (10.9 [2.5] mmol·L^{-1}), PBM 840 J (10.8 [2.9] mmol·L^{-1}), and PBM 1680 J (10.7 [2.42] mmol·L^{-1}) versus C condition (11.8 [3.1] mmol·L^{-1}) versus PLA (10.9 [3.1] mmol·L^{-1}). However, in a study with 10 professional volleyball players,[27] PBM 41.7 J was applied, and immediately afterward, the participants were submitted to a test of maximum voluntary contraction of the biceps brachii muscle until exhaustion. The LA_{peak} was significantly lower in the PBM group (8.20 [3.99] mmol·L^{-1}) than in the PLA (11.50 [3.21] mmol·L^{-1}). It is believed that the low blood [La] after exercise in the PBM condition may have been caused by several factors, such as improved microcirculation, reduced muscle fatigue, or improved lactate removal, which occurs more prolonged after the end of the exercise.[8,27]

The absence of PBM ergogenic effect on physiological and performance variables also affected the technical parameters, such as SI that represents an indicator of propulsive efficiency, improvement of technical skill, and an excellent technical parameter to predict performance.[28] However, it is important to highlight that even without statistical difference, the stroke rate was higher in the PBM condition when compared with the other conditions in the 100-m front crawl distance. Comparing the variables SR, SL, and SI between swimming distances in the same condition of the study, it was observed that there was a statistically significant difference for stroke rate that differs between the 3 distances (100, 200, and 400 m) in each condition (PBM, PLA, and C). Possible effects of PBM on the energy production system, such as an increase in ATP production, lower concentration, and increased rate of metabolite removal,[6,29] could be observed on SR, SL, and SI variables, because changes in technical variables such as SL can be connected to simultaneous changes in physiological variables, such as blood [La]. This suggests that there is a close relationship between physiological factors of metabolic fatigue and a worsened swimming ability.[30,31]

A few limitations of this study must be mentioned. First, we did not analyze HR_{max} during the test execution, but in order to enable free maximal performance, and reduce the impact of external factor (eg, the chest compression, or even the sensation of displacement of the HR sensor during start and turns), we adopted the heart rate measurement from the placement of the strap belt at the time of completing the swim course. Although no differences were observed in the results obtained, and the variations in the HR_{post} values were within the expected for exercises performed at maximum effort, the procedure needs studies that confirm its reliability.

Second, we believe that choosing the scale (6–20) proposed by Borg[9] used in this study may not be ideal for the evaluation of RPE in maximum single efforts of short duration as in swimming. That scale was designed to be used during aerobic tests of incremental load on a cycle ergometer, with load increments of 4 to 6 minutes, which differs strongly from the protocol of the test used in this study of a single maximum effort that varied between 1.05 and 5.30 minutes in duration.

Practical Applications

This investigation revealed that application of low dose of PBM before exercise did not have an ergogenic effect on swimming CV but may improve the final ST for each distance as on 200-m front crawl in PBM condition when compared with the C condition and an improvement in the 400 m in the front crawl when compared with the PLA and C condition. Swimmers and coaches should be aware of the potential effects of PBM on swimming performance parameters. Future studies should use a better way to verify HR and RPE during performance and can experience PBM prior to exercise, with different application parameters, higher doses, and over greater distances (400 m above), therefore the ergogenic effects of PBM on aerobic capacity and swimming performance can be verified.

Conclusions

Based on the results of the present study regarding the acute effects of PBM on CV and front crawl swimming performance, it can be concluded that a prior application with low dose of PBM, using LED, did not significantly change CV, nor HR_{post}, RPE, and LA_{peak}, the performance variables ST, SR, SL, and SI, determined by the maximum front crawl performance at distances of 100, 200, and 400 m in competitive swimmers.

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