Sports Science

Effect of photobiomodulation on maximal lactate production rate on swimmers: a randomized, crossover, double-blind and placebo-controlled study

Cesar Luis Teixeira[1,2], Paulo Victor Mezzaroba[3], Cecília Segabinazi Peserico[3], Fabiana Andrade Machado[3,4,5]

[1]Universidade Estadual do Oeste do Paraná, Departamento de Educação Física, Marechal Cândido Rondon, PR, Brazil; [2]Fundação Faculdade de Filosofia, Ciências e Letras de Mandaguari, Departamento de Educação Física, Mandaguari, PR, Brazil; [3]Universidade Estadual de Maringá, Departamento de Educação Física, Maringá, PR, Brazil; [4]Universidade Estadual de Maringá, Programa de Pós-Graduação Associado em Educação Física, Maringá, PR, Brazil; [5]Universidade Estadual de Maringá, Departamento de Ciências Fisiológicas, Programa de Pós-Graduação em Ciências Fisiológicas, Maringá, PR, Brazil.

Associate Editor: Angelina Zanesco. [1]Universidade Metropolitana de Santos, Faculdade de Medicina, Santos, SP, Brazil; [2]Universidade Estadual Paulista "Júlio de Mesquita Filho", Departamento de Educação Física, Instituto de Biociências, Rio Claro, SP, Brazil. E-mail: angelina.zanesco@unesp.br.

Abstract - Aim: This study aimed to verify the acute effect of photobiomodulation (PBM) on maximal lactate production rate (VLa_{max}) in front crawl swimmers. **Methods:** Fifteen male swimmers (20.9 ± 2.4-year-old) participated in this study. Three sets of front crawls were performed at distances of 100-, 200- and 400-m under three experimental conditions: PBM (420 J), placebo (PLA) and control (C) in this randomized, crossover, double-blind and placebo-controlled study. PBM or PLA were applied or simulated before performance tests. One-way Anova for repeated measurements were used for statistical analyses. **Results:** The results showed that the prior PBM application did not affect VLa_{max} in front crawl swimmers: VLa_{max} 100-m (PBM = 0.20 ± 0.05 mmol·L^{-1}·s^{-1}; PLA = 0.20 ± 0.04 mmol·L^{-1}·s^{-1} and C = 0.21 ± 0.04; mmol·L^{-1}·s^{-1}); 200-m (PBM = 0.09 ± 0.03 mmol·L^{-1}·s^{-1}; PLA = 0.08 ± 0.02 mmol·L^{-1}·s^{-1} and C = 0.08 ± 0.02 mmol·L^{-1}·s^{-1}) and 400-m (PBM = 0.04 ± 0.01 mmol·L^{-1}·s^{-1}; PLA = 0.04 ± 0.01 mmol·L^{-1}·s^{-1} and C = 0.03 ± 0.01 mmol·L^{-1}·s^{-1}). Nor effect swim time (ST) performance: ST 100 m (PBM = 65.5 ± 6.3 s; PLA = 65.2 ± 5.6 s; C = 66.0 ± 5.9 s); ST 200 m (PBM = 148.5 ± 17.9 s; PLA = 149.4 ± 16.4 s; C = 150.1 ± 17.9 s); ST 400 m (PBM = 327.7 ± 38.2 s; PLA = 321.6 ± 47.7 s; C = 329.5 ± 41.2 s). **Conclusions:** PBM application prior front crawl swimming tests did not significantly modify the VLa_{max} on swimmers covering distances of 100-, 200- and 400-m.

Keywords: low-level light therapy, ergogenic, front crawl, athletic performance, lactate.

Introduction

The photobiomodulation (PBM) is an electromagnetic radiation, non-thermal neither harmful, that utilizes visible or invisible lights through laser or light emitting diode (LED) sources and it is being studied as a potential ergogenic resource to improve physical performance on competitive sports[1,2]. As long term effects, studies have shown changes in the mitochondrial size and functionality, and acutely, an 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[3,4].

Another effect of PBM that may be related to aerobic metabolism is the improvement of microcirculation with hyperemia at the application site, favoring higher oxygen availability and rate of blood lactate clearance, potentially improving energetic status and the maintenance of muscle function in long-term exercise and at higher intensities[5]. These results suggest potential effect of PBM in the maximal lactate production rate (VLa_{max}) that represents the highest glycolysis demand and predicts anaerobic power[6,7]. However, no study investigated the influence of PBM on VLa_{max} in swimmers or other populations.

Olbrecht[8] considers VLa_{max} one of the most important physiological parameters to describe the conditioning profile in swimming, once the aerobic and anaerobic capacities determining the swimmer's maximal competition performance and the way the aerobic and anaerobic systems contribute to the metabolic energy supply during exercise.

Although no study has associated PBM and VLa_{max}, some authors examined the effect of PBM on other lactate parameters (*e.g.*, LA_{peak}) determined after maximal tests[9-11]. Peserico et al.[9] conducted a study in which 15 physically active men were submitted to five maximal running performance conditions: control (C), three different PBM doses (30, 120 and 180 J per area) and placebo (PLA); they found no difference among the outcomes from PBM conditions and PLA for LA_{peak}. Similarly, Dellagrana et al.[10] compared the effects of three different PBM doses (15, 30 and 60 J per site) on LA_{peak} in 15 recreational males' runners after maximal incremental treadmill tests, with no differences found between conditions.

On the other hand, Mezzaroba et al.[11] in a study with 26 healthy, physically active, young men aimed to investigate the effect of prior PBM application on the responses of blood lactate clearance during the running incremental test; it was demonstrated positive responses of the prior LED (936 J) application in the blood lactate clearance compared to PLA. The main results were found mainly at 13th and 15th min post-exercise ($LA_{13\text{-}min}$ and $LA_{15\text{-}min}$ respectively). Authors believed these effects could be due to the improvement in microcirculation. Thus, these findings suggest that PBM application could improve peripheral blood lactate removal rate.

Concerning swimming, the only study found so far by Teixeira et al.[12] investigated the effect of PBM on front crawl performances and showed that PBM was unable to improve physical performance or generate an ergogenic effect on maximal swimming tests, however no blood metabolic parameters were verified.

The objective of this study was to verify the acute effect of PBM on VLa_{max} in front crawl swimmers. Our hypothesis is that application of PBM prior to swimming tests can increase VLa_{max}.

Method

Participants

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

Took place on this study 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 compete at state events. Swimming best time of the participants were: 100-m = 57.1 ± 4.3 s; 200-m = 134.6 ± 15.45 s and 400-m = 282.1 ± 35.5 s. FINA (*Fédération Internacionale de Natation*) points of the participants were: 100-m = 485 ± 111.4 s; 200-m = 436.7 ± 129.1 s and 400-m = 479.5 ± 142.3 s. All swimmers compete at state level championships and two of them at national. Written, informed consent was obtained from participants, and ethical approval was granted by the local research ethics committee (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 light emitted diodes (LED - 420 J total doses applied), placebo (PLA) and control (C). The order of conditions (PBM, PLA and C) was randomized. The participants completed nine visits to the swimming pool and each participant performed the tests on different non-consecutive days under the three conditions over three weeks with a minimum interval of 48 h and a maximum of 72 h between tests. In each visit the participants performed just one distance in one condition. 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[13]. The participants were in the transition of the preparatory period of training periodization.

Procedures

After the PBM or PLA application the participants had an individual warm-up of 15-20 min of self-paced intensity following 5 min of passive rest. In the C condition the participants performed the same warm-up as soon as they arrived at the test site. Three sets of front crawl were performed at distances of 100-, 200- and 400-m under three experimental conditions: PBM, PLA or control (C). 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. The order in which the participants performed each distance was randomized.

For the PBM application it was used the LED equipment (THOR-LX2®, Thor Photomedicine Ltd, London, UK) with two clusters of 104 infrared LED diodes each. The application was conducted by an assistant researcher who controlled the device on or off (PBM: LED 420 J total dose or PLA, respectively). The application of the PBM had a total duration of approximately 1 min and 45 s, 15 s per point (30 J per point[10]), as shown in Table 1. 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 15-20 min before the swimming test, in contact mode with the

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/cm^2 (660 nm) and 150 mW/cm^2 (850 nm)
Energy density (each diode):	0.75 J/cm^2 (660 nm) and 2.25 J/cm^2 (850 nm)
Exposure time (per site):	15 s
Total energy irradiated (each diode):	0.15 J (660 nm) and 0.45 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

LED cluster held stationary with slight pressure at a 90° angle to the skin at each of the seven treatment points. PBM was applied to the upper limbs and trunk muscles (clavicular portion of pectoralis major; latissimus dorsi; lateral deltoid and triceps brachii - long and lateral head) and lower limbs (recto femoris on the quadriceps muscle, middle portion of biceps femoris, and a region of the gastrocnemii muscle) following the axis of distribution of muscle fibers in both legs (seven points each side, total of 14 points on body).

Maximal lactate production rate (VLa_{max}*)*

VLa_{max} was calculated, as shown below, by the difference between maximal interpolated post-exercise La ($La_{maxPost}$) and resting *La* (La_{pre}) that was divided by the difference between swimming test time (t_{test}) and the period at the beginning of exercise for which no lactate formation is assumed t_{alac}. The time considered to determined t_{alac} were 4 s for 100-m front crawl swimming and 8 s for 200- and 400-m front crawl swimming[14,15]. This swim-specific calculation (Equation (1)) enables to estimate glycolytic capacity for exercises until 600 s[16].

$$VLa_{max}\left[\mathrm{mmol{\cdot}L^{-1}\cdot s^{-1}}\right] = \frac{La_{maxPost}\left(\mathrm{mmol{\cdot}L^{-1}}\right) - La_{pre}\left(\mathrm{mmol{\cdot}L^{-1}}\right)}{t_{test}(\mathrm{s}) - t_{alac}(\mathrm{s})} \quad (1)$$

To determine the lactate concentrations, earlobe capillary blood samples (25 µL) were collected into a capillary tube. The samples were subsequently determined by electro-enzymatic methods using the YSI 2300 STAT® (Yellow Springs, OH) automated analyzer.

Statistical analyses

Data were analyzed using the Statistical Package for the Social Sciences v.24.0 (SPSS® Inc., USA). The Shapiro-Wilk test was used to check the normality of the data distribution and data are presented as mean ± standard deviation (SD). Anova for repeated measures was used to compare the three conditions (PBM, PLA and C). It was used the Mauchly's test of sphericity to determine data normality, and if necessary, the Epsilon adjustment Greenhouse-Geisser to determine main effect. The analyses were completed with the Bonferroni *post hoc*. Statistical significance was set at $p < 0.05$. As complementary analysis the effect size (*ES*), (Cohen's *d*)[17] was calculated to determine the magnitude of change in each condition using the following equation:

$$ES = (M1 - M2) \div ((SD1 + SD2) \div 2) \quad (2)$$

Note that $M1$ and $M2$ the average of each condition, $SD1$ and $SD2$ the respective standard deviations. The *ES* was classified according to Cohen[17] as: ≤ 0.20 (trivial), between 0.21 and 0.50 (small), between 0.51 e 0.80 (moderate) and > 0.80 (large).

Results

The values for time at 100-, 200- and 400-m front crawl swimming are presented in Table 2. The mixed Anova for repeated measures didn't indicate statistically significant differences between conditions.

The values for VLa_{max} at 100-, 200- and 400-m front crawl swimming are demonstrated in Table 3. The mixed Anova for repeated measures didn't show statistically significant differences between conditions. Qualitative analysis showed a large ES for PBM *vs*. C (1.00), PLA *vs*. C

Table 2 - Mean ± SD of time to complete distances of 100-, 200- and 400-m front crawl all out on the three different conditions.

	D (m)	**PBM**	**PLA**	**C**	**F**	**p**
Time (s)	100	65.5 ± 6.4	65.2 ± 5.6	66.0 ± 6.0	0.664	0.523
	200	148.6 ± 17.9	149.4 ± 16.4	150.1 ± 17.9	0.628	0.489
	400	327.7 ± 38.3	321.6 ± 47.7	329.6 ± 41.2	1.093	0.320

Note: n = 15; Time (s), swim time to perform the distances; D (m), distances of tests; PBM, photobiomodulation; PLA, placebo; C, control.
$p < 0.05$.

Table 3 - Comparison of maximal lactate production rate accumulation rate for distances of 100-, 200- and 400-m in front crawl swimming in three different conditions.

	PBM	PLA	C	*F*	p
VLa_{max} 100 m [mmol·L^{-1}·s^{-1}]	0.20 ± 0.05	0.20 ± 0.04	0.21 ± 0.04	0.091	0.913
VLa_{max} 200 m [mmol·L^{-1}·s^{-1}]	0.09 ± 0.03	0.08 ± 0.02	0.08 ± 0.02	0.137	0.872
VLa_{max} 400 m [mmol·L^{-1}·s^{-1}]	0.04 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.221	0.802

Note: n = 15; VLa_{max}, maximal lactate production rate; PBM, photobiomodulation; PLA, placebo; C, control.
$p < 0.05$.

(1.00) at 400-m front crawl swimming and small ES for PBM *vs*. PLA (0.40) and PBM *vs*. C (0.40) at 200-m front crawl swimming. For the other comparisons ES were trivial on the three distances.

Discussion

The objective of this study was to verify the acute effect of PBM on VLa_{max} in front crawl swimmers. The main findings showed that prior PBM application using LED did not modify the VLa_{max} at 100-, 200- and 400-m in front crawl swimming, contrary to the initially formulated hypothesis.

Concerning the effect of PBM on VLa_{max}, no previous study examined this assumption. However, it was already investigated the effect of prior PBM application on other lactate parameters obtained after maximal tests[9-11,17].

For example, Peserico et al.[9] found no significant difference among PBM conditions and PLA for LA_{peak} values (PLA = 8.9 ± 1.8 mmol·L^{-1}; PBM 30 J = 9.4 ± 2.3 mmol·L^{-1}; PBM 120 J = 9.4 ± 2.1 mmol·L^{-1}; PBM 180 J = 8.7 ± 2.7 mmol·L^{-1}). Dellagrana et al.[10] also found no difference in the LA_{peak} concentration 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}) and PLA (10.9 ± 3.1 mmol·L^{-1}).

Nevertheless, Mezzaroba et al.[11] investigated the blood lactate concentration after two incremental running tests with previous PLA or PBM application and found a positive response at PBM condition in the blood lactate clearance, especially at 13th and 15th min after the test ($LA_{13\text{-min}}$: PLA = 7.7 ± 1.9; PBM = 7.2 ± 1.3 mmol·L^{-1}; $LA_{15\text{-min}}$; PLA = 7.3 ± 2.8; PBM = 6.6 ± 1.3 mmol·L^{-1}).

In addition, Machado et al.[17] aimed to examine the recovery effects of PBM applied between two running time trials on blood lactate in 11 physically active males' recreational runners. LA concentrations were verified before and after each test, 24-h, and 48-h after. The results from 24-h later showed that the effect size between PBM and PLA condition was moderate (the concentrations for PBM condition were lower than for PLA condition; ES: -0.62).

Considering the present study and the absence of PBM effects on VLa_{max}, it may be due the use of lower doses of PBM (30 J) per point on large muscles. Beyond that, there are peculiarities of the aquatic environment that must be considered, the hydrostatic pressure for example, lead to changes in cardiovascular parameters, 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 buoyancy[18].

These events can generate an increase in cardiac output, stroke volume, and perfusion in non-muscular tissues of swimmers, in addition to facilitating the venous return and consequently the removal of blood lactate[19,20]. Considering that, water sports could minimize the effect of PBM application therapy due to the physical properties that are already acting on the body.

As main limitation of our study, we point out the low dose (30 J)[21] used and the application at only one point in the large muscle groups, which was based on previous studies with results that pointed to a possible effect of PBM on performance variables and indicators of aerobic metabolism[22,23].

Conclusion

We conclude that PBM applied prior swimming tests did not affect the VLa_{max} values at the distances of 100-, 200- and 400-m front crawl in competitive swimmers. In terms of practical application, based on these results, there were not enough evidence to recommend the use of PBM as an ergogenic resource by coaches and swimmers with the intention of improving performance in crawl swimming events.

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Corresponding author

Fabiana Andrade Machado. Universidade Estadual de Maringá, Departamento de Educação Física, Centro de Ciências da Saúde, Maringá, PR, Brazil.
E-mail: famachado_uem@hotmail.com, famachado@uem.br.

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