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Effect of photobiomodulation therapy on performance and running economy in runners: A randomized double-blinded placebo-controlled trial

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ABSTRACT

The objective of this study was to evaluate effects of photobiomodulation therapy (PBMT) on the 3000 m running performance (primary outcome), running economy (RE), metabolic cost and ratings of perceived exertion during running (secondary outcomes). Twenty male endurance athletes performed 4-min treadmill rectangular test at 12 km.h-1 monitored by a gas analyser. After that, PBMT or placebo in each lower limb was applied, followed performed a maximum test of 3000 m. Immediately after 3000 m test, the athletes repeated the treadmill test. Another application of PBMT/placebo was done after the treadmill test, and athletes went back to the laboratory 24 h later to repeat the treadmill test. After a 72 h interval, athletes repeated all procedures with another treatment intervention (PBMT/placebo). Athletes performed the 3000 m running test ~7s faster when treated with PBMT with similar effort score compared placebo condition. The RE remains unchanged immediately post 3000 m running test, nonetheless RE measured post-24 h improved by 5% with PBMT application without changes in metabolic cost. The PBMT pre- and post-conditioning enhanced the 3000 m running performance and improved RE 24 h following the 3000 m test. However, no changes on ratings of perceived exertion and metabolic cost with the application of PBMT.

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KEYWORDS
Photobiomodulation therapy; distance running; performance; metabolic economy

Introduction

Skeletal muscles of endurance athletes have a high mitochondrial density and size, resulting in an increased energy production capacity through aerobic metabolism (Hoppeler et al., 1973). However, energy production impairment due to neuromuscular fatigue results in reduced performance (Dupuy et al., 2018; Fischer et al., 2015). Although a higher energy intake may delay the onset of fatigue in endurance athletes, such an intake does not avoid the performance decline induced by fatigue. Therefore, strategies that minimize or delay the deleterious fatigue effects contribute to performance increase in these athletes.

Although muscle fatigue is an inevitable multifactorial physiological phenomenon, photobiomodulation therapy (PBMT) has shown promising results in reducing and delaying the fatigue effects (Borsa et al., 2013; Ferraresi et al., 2012; Leal-Junior et al., 2015). The effect of PBMT on muscle fatigue when it is applied previously to an exercise was initially demonstrated by Lopes-Martins et al. (2006) in a protocol involving electrical stimulation of the rat muscle. In humans, pre-exercise PBMT application in studies involving exercises how cycloergometer (Lanferdini et al., 2018a) and maximal running treadmill exercises (De Marchi et al., 2012; Miranda et al., 2016) present promising results (performance increase), suggesting that PBMT may be a potentially effective agent in fighting the deleterious fatigue effects on muscle function.

In general, the findings from running studies applying PBMT before exercise are controversial. The effects of the pre-exercise PBMT application on time to exhaustion and maximum oxygen uptake (VO_{2max}) during treadmill incremental test have been investigated (De Marchi et al., 2012; Miranda et al., 2016). According to the authors, the exhaustion time increase is associated with an increase in the adenosine triphosphate (ATP) availability via the mitochondrial pathway (thus using the aerobic energy production pathway), thereby increasing the energy availability at the muscle tissue, postponing fatigue, and leading to improvements in running performance. Also, these improvements in mitochondrial activity impacting positively on oxygen kinetics (Lanferdini et al., 2018b). Conversely, Malta Ede et al. (2016) have found no differences between PBMT and placebo applied acutely, previous to exercise, on supramaximal running performance. However, the use of PBMT prior to exercise as an effective ergogenic mechanism to improve the endurance performance of runners during a 3000 m test remains unclear (Zouhal et al., 2015).

In addition, PBMT has also been used as a tool capable of assisting in the process of muscle recovery after exercise (Borsa et al., 2013; Leal-Junior et al., 2015). Different studies have

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Abreviation ListATP: Adenosine triphosphate; IAAF: International Association of Athletics Federation; C_{MET}: Metabolic cost; PBMT: Photobiomodulation therapy; RE: Running economy; RNA: Ribonucleic acid; RPE: Rating of perceived exertion; VO_2: Oxygen consumption; VO_{2max}: Maximum oxygen uptake; vVO_{2max}: velocity associated with maximal oxygen uptake

shown that the PBMT application leads to a smaller torque or force loss after muscle microdamage in fatigue protocols (Borges et al., 2014; Fritsch et al., 2016), lower muscle pain (Baroni et al., 2010a; Borges et al., 2014; Fritsch et al., 2016), lower inflammatory markers concentration (De Marchi et al., 2012; Zagatto et al., 2016), and lower echointensity (Fritsch et al., 2016) compared to the placebo effect.

However, only one study was found (Dellagrana et al., 2018a), demonstrating promising PBMT effects on running economy (RE), which is one of the fundamental physiological predictors of the runner's performance (McLaughlin et al., 2010). The PBMT action, which occurs mainly through aerobic metabolism, causing an increase in energy release (ATP), especially through the mitochondrial pathway (Ferraresi et al., 2015), can lead to RE improvements, and thus improve the runner's performance. Nevertheless, no study has been found evaluating the PBMT acute effects on the 3000 m of running performance or investigated the metabolic cost (C_{MET}) in submaximal running.

Therefore, the first goal of the present study was to evaluate the PBMT effects on the 3000 m running performance. In addition, we also investigated the PBMT effects on RE and C_{MET} pre-exercise, post-exercise, and post-24 h, and rating of perceived exertion-(RPE) before, during, just after, and after 24 h of a 3000 m test in endurance athletes. Based on the assumption of PBMT being effective as an ergogenic tool when used before different exercises, our first hypothesis was that PBMT would result in a better performance (time reduction) during the 3000 m running test compared to the placebo condition. Moreover, our second hypothesis will be that the PBMT application before and after the test will attenuate the impairment in RE and C_{MET}, consequently reducing the RPE 24 h after the 3000 m running test. The rationale behind this hypothesis was that during and after the maximal running exercise which involve a large eccentric component, differently from cycling, the higher metabolic and inflammatory stress should be attenuated by the PBMT.

Materials and methods

Experimental design

The present study was a randomized, crossover, double-blind, placebo-controlled trial. An alphanumeric code was used to protect the participants' privacy as well as to blind the subjects and researchers involved in the study, thereby characterizing it as a double-blinded study.

The athletes were submitted to five evaluation days with at least 72 h between the first and second day, and between the third and the fourth day. On the first day, athletes performed a maximum incremental test on a treadmill and familiarization with the 3000 m test at the athletic track. From the second to the fifth day, athletes performed: (a) 3000 m test at the athletic track followed by a 5-min submaximal treadmill running test to collect the oxygen uptake (VO_2). The PBMT or placebo was applied immediately before 3000 m test and after submaximal test; (b) a 5-min submaximal treadmill running test to collect the VO_2, 24 h after the 3000 m test; (c) idem to item (a); (d) idem to item (b). The execution order of the four sessions (protocols) with the 3000 m tests was randomized for each participant (Figure 1).

Only one researcher was responsible for the PBMT or placebo application in the volunteers, to ensure that the study was a cross-over, randomized, double-blind clinical trial.

Participants

Twenty male athletes (runners or triathletes), with 34 ± 7.8 years of age. The athletes' training experience was □7.6 years, and a training volume of 5.5 days/wk and □63 ± 31.3 km/wk. Before the selection interview, all procedures were presented to the participants, who signed a consent form to participate in the study that was approved by the local ethics committee (No. 2.437.616), according to the Declaration of Helsinki. Exclusion criteria included chronic disease, smoking, metabolic disorders, using steroids in last five months chronic disease, physical disabilities, smoking, using antibiotic drugs in the previous week, unwilling to participate, and adherence to a specific nutritional plan.

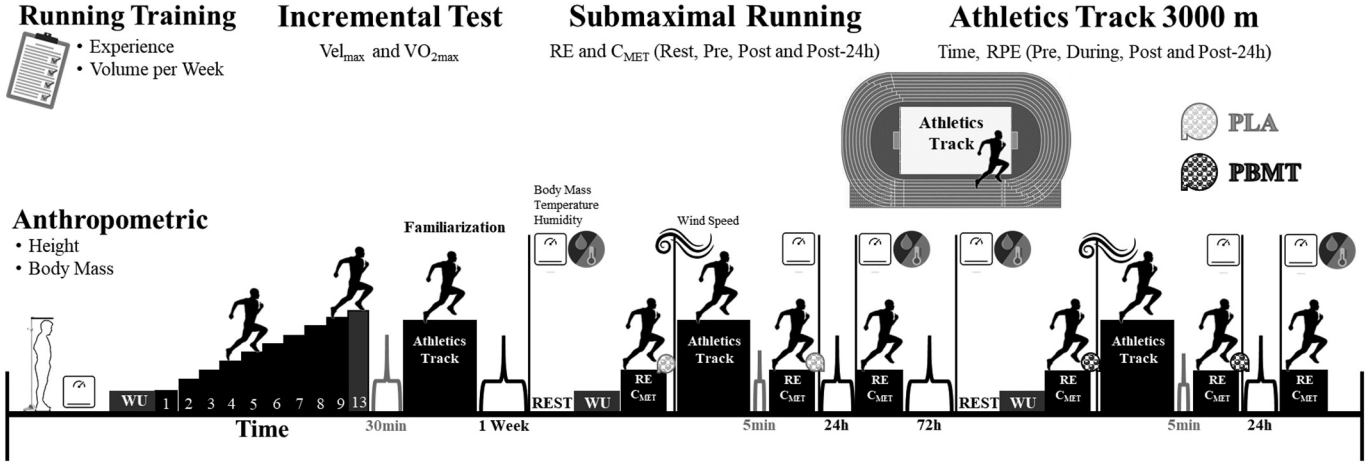

Figure 1. Experimental design: running training [experience (years) and volume per week (days/wk and km/wk)], anthropometric (height and body mass), velocity associated with maximal oxygen uptake (Vel_{max}; maximal oxygen uptake (VO_{2max}); submaximal oxygen uptake (VO_2); Rating of perceived exertion (RPE); Running economy (RE); Metabolic cost (C_{MET}); control variables (body mass, temperature, humidity and wind speed) Warm-up (WU); placebo and photobiomodulation therapy (PBMT).

Data collection and data analysis

Food registry and dietary control

The food registry, aimed to evaluate each athlete's dietary intake, was obtained in the first testing day and encompassed a period of 48 h pre-evaluation. The results of this dietary record were also used to request the athletes to maintain a similar diet in the 48 h prior to the PBMT or placebo conditions testing days. Each participant's food consumption was obtained pre-testing by asking the participant about all food and drink consumed in the last 48 h before the first day of evaluation.

Anthropometric assessment

The athletes' body mass (kg) was measured with a portable electronic scale (Model UP-150, Urano, Brazil) with a 100 g resolution. Their height was measured with a tape measure (Simple Fibre Tread, Sanny, Brazil) with 1 mm of resolution.

PBMT or placebo treatment

The PBMT or placebo treatments were performed before and after the 3000 m tests on the second and fourth testing days. The treatments were applied at five locations in each lower limb on the following muscles: *Quadriceps* (two); *Gluteus Maximus* (one); *Hamstrings* (one) *Gastrocnemius* (one). The treatments were administered using the LEAP Sports Pod (Prototype by Cliffside Group Inc., USA). The placebo treatment was performed in the same manner as the PBMT treatment (30 s per site of application), but with the device switched off. Athletes were blinded for the treatment type by using opaque goggles for eye protection and for blocking the PBMT infrared emission of the device. Treatment randomization was performed by a simple batches design (A or B) in the first exercise session. Therefore, treatments were coded as Placebo-Placebo (A) or PBMT-PBMT (B), and were given to researcher assistance who was responsible for administering the PBMT or placebo dosage before and after the 3000 m tests. This investigator was instructed not to communicate the treatment type to the athletes or the responsible investigator until the end of the data collection (Figure 2).

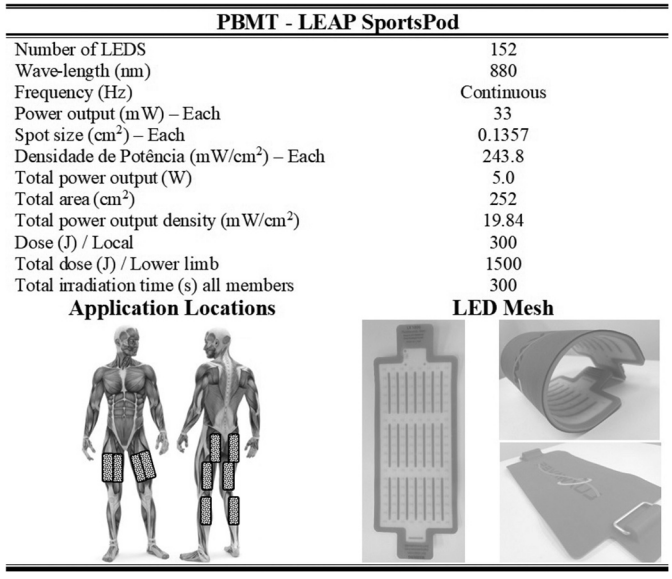

Figure 2. Dose of energy to be applied by the photobiomodulation therapy (PBMT) or placebo application sites before and after the 3000 m tests. Equipment: LEEP sports pod (http://www.leapsportspod.com/leap-store).

Maximum incremental test

Athletes were submitted to a maximum incremental test. Initially, they underwent familiarization on a treadmill (Super ATL, Inbrasport-Inbramed, Porto Alegre, Brazil). The maximum incremental test started with an initial velocity of 10 km·h^{-1}, and 1 km·h^{-1} was added per minute until exhaustion (Bentley et al., 2007).

The VO_2 was measured during the incremental test breath by breath using an open circuit gas analyser (Cosmed, Quark CPET, Rome, Italy). After that, the athletes rested for 30 minutes. Immediately after this recovery period, the athletes completed one 3000 m familiarization session on an athletic track.

The VO_2 analysis during the maximal incremental test was performed by visual inspection (breath by breath method). VO_2 values were plotted to exclude values with four standard deviations above or below the average of the movable windows of the whole curve – average of three breaths in each window (Fernandes et al., 2012). During the maximum incremental test, the velocity associated with maximal oxygen uptake (vVO_{2max}) was obtained from the last completed stage, while the VO_{2max} was determined as the highest value observed in the last test stage – higher velocity (Bentley et al., 2007).

Running economy test (RE) and metabolic cost (C_{MET})

The VO_2 obtained during the RE test was evaluated on a treadmill and followed a similar gas analysis as described above. Initially, the VO_2 was collected at rest in the orthostatic position for 6 minutes. Soon after, a 10-minute warm-up was performed on the treadmill at 10 km·h^{-1}, after which the running test was performed for 5 minutes at 12 km·h^{-1}, with a 5-minute interval between each test (Saunders et al., 2004). Before, after, and after 24 h of the 3000 m tests, RE tests were performed again. In addition, parameters including room temperature humidity (Cosmed, Quark CPET, Rome, Italy) and wind speed outdoor (Windy.com) were recorded pre-exercise, immediately post-exercise and, post-24 h in each condition (PBMT or placebo).

The RE tests VO_2 curve was analysed using the software PFT ergo (Cosmed, Quark CPET, Rome, Italy), and the mean VO_2 values were calculated and plotted at the last minute of each stage. RE was defined as the relationship between VO_2 and the running velocity (Daniels, 1985). The metabolic power (W_{MET}) was considered the difference between the VO_2 measured during exercise and the VO_2 at rest. Because the unit of measure used was Watts (W), this difference was multiplied by the energy coefficient (20.9 J·ml^{-1}) and divided by the time in seconds (60 s). The C_{MET} values relative to the speed at 12 km·h^{-1} were calculated by dividing W_{MET} by the speed in m·s^{-1} (Di Prampero et al., 1986).

3000 m running performance

Immediately after the RE test, the athletes performed the familiarization of the 3000 m test at the athletics track, which was 400 m long and was built according to standards of the International Association of Athletics Federation (IAAF).

A digital timer (Vollo Stopwatch, VL-510, USA) was used to measure the test time of 3000 m for each athlete.

Approximately 10 minutes after the PBMT or placebo application (Indoor – Laboratory of Biomechanics), the athletes performed the 3000 m test at the outdoor athletics track (located approximately 100 m from the Laboratory of Biomechanics). A digital timer was used to measure the athletes' time at the 3000 m test. The mean (± SD) values of the 3000 m test time were calculated for each experimental condition.

Rating of perceived exertion (RPE)

Immediately before, during (1000, 2000, 3000 m), 5 minutes after the RE test, and 24 h after the maximum 3000 m tests, the RPE (Borg Scale □ 6–20) was measured by asking the athletes how they rated their effort during each evaluation day (Borg, 1982). In addition, the RPE (6–20) was used to calculate the mean effort at each time point: pre-exercise, during exercise (1000, 2000, 3000 m) post-exercise' and post-24 h of the 3000 m tests (Borg, 1982).

Statistical analysis

Data are reported as means and standard deviation (SD). On the basis of a power analysis (desired power = 0.80, standard deviation of the difference = 6.95 and an alpha error = 0.05) based on the cross-over design using previous data (Zouhal et al., 2015) on repeated measures of the running performance, we determined that a sample size of n = 20 would be sufficient to study the PBMT effect on performance and physiological parameters, resulting in minimal difference detectable of 5.5 s. Data normality was evaluated by a Shapiro-Wilk test and the sphericity by means of the Mauchly test. The t-test for dependent samples was used to compare the differences between the test times of the 3000 m in the PBMT *versus* placebo interventions. Repeated measures two-way ANOVA was used to compare the differences between the conditions (PBMT *versus* placebo) and between the different time instants of the tests for the variables RE, C_{MET} and RPE. The post hoc Bonferroni test was used to identify the main effects. Statistical analysis was performed using an open-source statistical package (JASP 0.11.1 for Windows, Amsterdam, Netherlands), with the significance of α = 0.05. Cohen's effect sizes (ES) were computed for the analysis of magnitude of the differences, and rated as trivial (<0.25), small (0.25–0.49), moderate (0.5–1.0) and large (>1.0) (Rhea, 2004). We chose large ES for discussion of results to ascertain non-overlap between mean scores 55% (Cohen, 1988). All dataset is in Supplementary Material 01 and all statistical output is in Supplementary Material 02.

Results

The body mass and control variables (wind, temperature and humidity) evaluated during protocols did not show alterations between the two conditions (P > 0.05); Table 1. The athletes presented the following performance in the maximum incremental running test (VO_{2max} of 63.2 ± 6.4 ml·kg^{-1}·min^{-1} and vVO_{2max} of 5.5 ± 0.5 m·s^{-1}.

The PBMT application before the 3000 m test resulted in running performance improvement (~7 seconds) compared to the placebo application (P < 0.007; ES = 0.610; Figure 3).

The RE evaluated in treadmill tests was affected by condition (main effect, P = 0.038), and time (main effect, P = 0.003, Figure 4 and Table 2). However, a significant interaction was not observed (interaction effect of speed × group: P = 0.091). In the placebo condition, RE remains unchanged at pre compared with post and post-24 h (P = 0.152, ES = 0.590; and P = 0.186, ES = 0.573, respectively) as well as at post compared with post-24 h (P = 1.000, ES = 0.017). In the PBMT condition, RE also remains similar at pre compared with post and post-24 h (P = 0.533, ES = 0.479; and P = 1.000, ES = 0.153, respectively, Figure 4 and Table 2). The post hoc tests comparing simple main effects of condition (placebo versus PBMT) shows no differences on RE at pre and post (P = 0.589, ES = 0.111; and P = 0.276, ES = 0.204, respectively), but at post-24 h, the RE was higher for placebo compared with PBMT condition (P = 0.018, ES = 0.717, Figure 4 and Table 2).

The C_{MET} evaluated in treadmill tests was not affected by condition (main effect, P = 0.164); however, it was affected by time (main effect, P = 0.001, Figure 4). Also, a significant interaction was not observed (interaction effect of speed × group: P = 0.095). In the placebo condition, C_{MET} was lower at pre compared with post and post-24 h (P = 0.027, ES = 0.722; and P = 0.029, ES = 0.719, respectively) and similar at post compared with post-24 h (P = 1.000, ES = 0.004). In the PBMT condition, C_{MET} also remains similar at pre compared with post and post-24 h (P = 0.356, ES = 0.516; and P = 1.000, ES = 0.014, respectively, Figure 4). The post hoc tests comparing simple main

Table 1. Results of control variables [anthropometrics, wind speed, temperature and relative humidity in the first evaluation day, and at specific days to evaluate the placebo or photobiomodulation therapy (PBMT) effects on 3000 m test performance] evaluated in instants of time represented in Figure 1 (experimental design) pre, post, and 24-h after the 3000 m test. No significant differences were found between the conditions (p > 0.05).

		Body Mass (kg)	Wind (km/h)	Temperature (°C)	Humidity (%)
	First Day	67.2 ± 6.1	-	-	-
Pre-3000 m	Placebo	67.1 ± 6.3	6.2 ± 5.9	19.2 ± 3.1	71.0 ± 7.1
	PBMT	67.2 ± 6.0	6.2 ± 5.1	18.8 ± 2.7	70.6 ± 5.8
Post-3000 m	Placebo	67.0 ± 6.4	-	-	-
	PBMT	66.8 ± 5.9	-	-	-
Post-24 h	Placebo	66.8 ± 6.1	-	19.3 ± 3.0	70.0 ± 7.2
	PBMT	67.0 ± 5.9	-	19.1 ± 2.6	70.5 ± 6.4

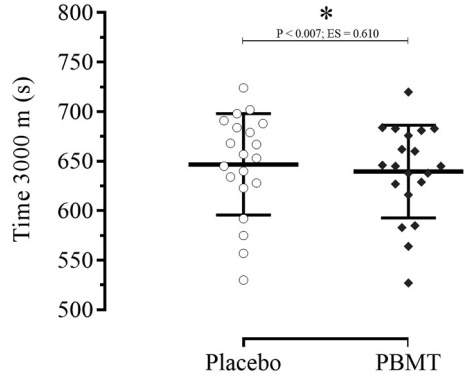

Figure 3. 3000 m test performance at the athletic track, with photobiomodulation therapy (PBMT) or placebo application pre-exercise in runners. * significant difference between PBMT to placebo (P = 0.007; ES = 0.610).

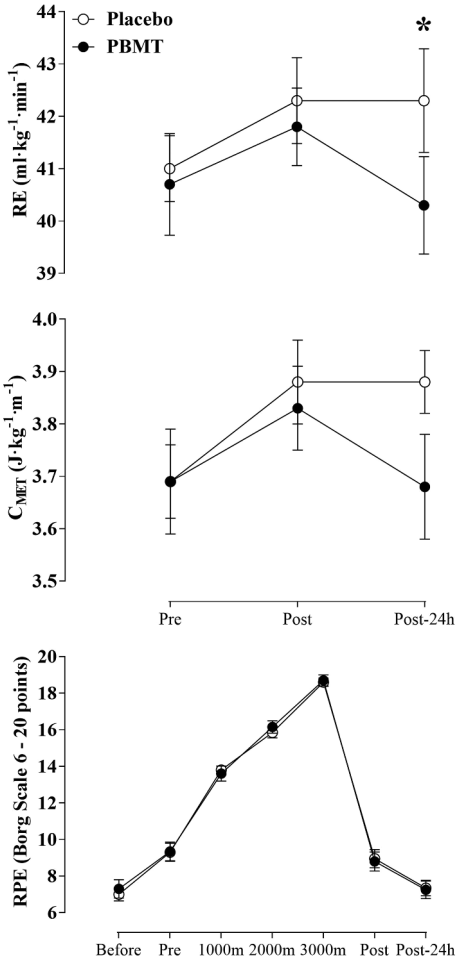

Figure 4. Results of running economy (RE) and metabolic cost (C_{MET}) pre-, post- and post-24 h of the 3000 m test between the two conditions [placebo and photobiomodulation therapy (PBMT)]. Results for the ratings of perceived exertion (RPE) before, pre, 1000 m, 2000 m, 3000 m, post and 24-h after the 3000 m test. * significant difference between the conditions (P = 0.018, ES = 0.717).

Table 2. Results of running economy (RE pre-, post- and post-24 h of the 3000 m test between the two conditions [placebo and photobiomodulation therapy (PBMT)]). Absolute and relative oxygen consumption during running economy test.

		RE ($ml.kg^{-1}.min^{-1}$)	RE (% of VO_{2max})
Pre-3000 m	Placebo	41.0 ± 2.8	65.3 ± 5.9
	PBMT	40.7 ± 4.3	64.8 ± 7.7
Post-3000 m	Placebo	42.3 ± 3.7	67.5 ± 6.9
	PBMT	41.8 ± 3.3	66.7 ± 8.2
Post-24 h*	Placebo	42.3 ± 4.4	67.3 ± 6.8
	PBMT	40.3 ± 4.2	64.2 ± 7.0

*Significant difference between placebo and PBMT ($p < 0.05$), Percentage of maximal oxygen uptake (% of VO_{2max})

effects of condition (placebo versus PBMT) shows no differences on RE at pre, post and post-24 (P = 0.989, ES = 0.003; and P = 0.345, ES = 0.162; P = 0.060, ES = 0.570, respectively).

The RPE evaluated before and pre-track test, at 1000 m, 2000 m and 3000 m during the track test, and just after and post-24 h the track test, was not affected by condition (main effect, P = 0.837); however, it was affected by time (main effect, P = 0.001, Figure 4). Also, a significant interaction was not observed (interaction effect of speed × group: P = 0.813). As observed in Figure 4, the RPE increased linearly from pre to 3000 m time point (P < 0.001, ES > 2.200), then reducing significantly from 3000 m to post (P < 0.001, ES = 3.554) and from post to post-24 (P = 0.041, ES = 0.803; Figure 4 and Supplementary material 03).

Discussion

To the best of our knowledge, this is the first study to investigate the possible beneficial PBMT effects on the runner's performance in a 3000 m athletics track. According to our results, PBMT, applied to lower limb muscles (quadriceps, hamstrings, gluteus maximus and triceps sural) prior to the 3000 m test, was able to reduce the time required to complete the test in 7 s [15 athletes showed improvement (from 3 to 40 s), while another 5 showed worsening performance (from −1 to −10 s) with the PBMT application]. In addition, the pre- and post-exercise PBMT applications promoted specific changes in the VO_2 response evaluated at a specific speed (12 $km{\cdot}h^{-1}$), thus improving the runners the metabolic economy 24 h after the 3000 m test, without altering metabolic economy just after the 3000 m test. Also, the RPE was not affected by PBMT applications. These results endorse the idea that PBMT application was responsible for the performance improvement of 3000 m and RE 24 h after test.

The first hypothesis of the present study was that the PBMT would cause an improvement in the 3000 m test performance. Therefore, our results confirm this hypothesis, since a trivial minimum reduction of 7 s (1.1%) in the 3000 m test time was found compared to the placebo application. Additionally, these results corroborate with other results reported in the literature, where positive effects were observed with PBMT for the fatigue processes reduction and performance improvement in strength exercises (De Almeida et al., 2012; Baroni et al., 2010b), and 9–15% increased time of maximum exhaustion of cycling test (Lanferdini et al., 2018a). Also, some studies have shown that PBMT application pre-exercise was able to increase (2.0–3.4%) exercise time-out in maximum incremental treadmill running (Dellagrana et al., 2018a; De Marchi et al., 2012). However, other studies found no changes in cycling or running performance with application of PBMT pre-exercise (Dutra et al., 2020; Malta Ede et al., 2016). Our results demonstrate that at relatively lower intensities [average speed as a percentage of maximal oxygen uptake velocity of 82% (Lanferdini et al., 2020)] close to the second ventilatory threshold, the running performance is increased, but the improvement is not accompanied by acute improvements in metabolic economy. Our results, despite being of small magnitudes of improvement performance in outdoor 3000 m of running time trial, compared previous studies (Dellagrana et al., 2018a; De Marchi et al., 2012) who also performed a maximal running test, but indoors. Moreover, the participants included in our study were submitted to a familiarization session with the 3000 m test without any type of time control, thus avoiding the effect of any learning between the PBMT *versus* placebo situations. Our results support evidence from previous studies evaluating cyclists (Lanferdini et al., 2018a), and runners (Dellagrana et al., 2018a;

De Marchi et al., 2012). Furthermore, the current report describes the first outcomes demonstrating positive responses after the use of PBMT on running performance at ecological conditions in endurance athletes.

The most widely accepted possible mechanism for increasing performance caused by the action of PBMT action on muscle cells still requires further clarification, it has been suggested that the primary mechanism of PBMT action is the increase in ATP synthesis via mitochondrial pathway [using oxidative metabolism (Ferraresi et al., 2015)]. According to this hypothesis, light energy is absorbed by some molecular photoreceptors or chromophores, such as cytochrome C-oxidase in the mitochondria, which leads to an increase in the rate of ATP, RNA and protein synthesis, as well as a change in redox potential and greater release of nitric oxide (Huang et al., 2011). Thus, a cell signalling induced by the PBMT application could lead to improvements in muscle function and, consequently, in performance during exercise. Assuming that this hypothesis holds true, it confirms that PBMT is useful for improving performance in aerobic activities, such as running. However, future well-designed experimental models are required to confirm this hypothesis.

The second hypothesis was that the PBMT application before and after the 3000 m test should improve RE, C_{MET} and RPE compared to the placebo effect just after the 3000 m test and 24 h after the 3000 m test. From the results of this study, the hypothesis was partially refuted, as the PBMT application caused an improvement in metabolic economy 24 h after the 3000 m test, however, without changes in the metabolic economy just after the 3000 m, and in the RPE during all evaluations.

These results corroborate with those of Dellagrana et al. (2018a) who also found ~3% improvement in RE for the velocities evaluated from 8 and 9 $km{\cdot}h^{-1}$, while in the present investigation, the observed increase was of 5% at a running speed of 12 $km{\cdot}h^{-1}$. RE improvement in the present study may be related to the fact that the evaluation was performed 24 h after the 3000 m test, which could have maximized the PBMT tissue repair effects compared to placebo (Huang et al., 2011). In addition, in the abovementioned study, the RE evaluation was performed separately from the maximum test. In another study by Dellagrana et al. (2018b) which investigated the PBMT effects on the neuromuscular economy, they demonstrated a neuromuscular economy improvement after PBMT application that supports the present study findings.

One possible explanation for RE improvement with PBMT application is its protective effect, which possibly resulted in less muscle damage caused by exercise when compared to placebo application (De Marchi et al., 2017). In this sense, the oxidative muscle fibres would have the enzymatic apparatus preserved, which would lead to better oxidative capacity, better VO_2, and consequently better RE (Jones et al., 2017). Fast muscle recovery is critical for athletes, especially during competition, since athletes commonly return to training approximately 24–48 h following competition (Dupuy et al., 2018). The ability to train consistently at high levels is a determinant factor for athletes, and the potential advantage offered by PBMT for muscle performance recovery (e.g., improvement of RE) after exercise-induced muscle damage should be considered (Assumpcao Cde et al., 2013).

However, regarding the results on the athletes' RPE during and after the 3000 m tests, no changes were found in the comparison between the PBMT and placebo applications. These results disagree with those found by Dellagrana et al. (2018a) who found a reduction of ~8% in RPE during the running test performed at 8 $km{\cdot}h^{-1}$. Indeed, as the aforementioned authors did not evaluate the RPE during the maximal test, we cannot conclude that in fact there is an RPE reduction (global perception effort) with the action of PBMT (local action) during maximum ecological tests, that is, that simulate the training or race reality. An additional explanation to the improvement in 3000 m test performance is related to effects of PBMT on ratings of perceived pain probably felt by runners during the 3000 m test. Previous findings have shown that PBMT has potential to alleviate the sensation of pain on extreme exercise after 24 h (Baroni et al., 2010a). Modern approaches modelling the determinants of exercise fatigue and exhaustion have determined that the exertion perceived as a different component of muscle pain sensation (Staiano et al., 2018). While at supramaximal intensities the exertion perceived is the cardinal exercise stopper, in our study at lower intensity than maximal, probably the unpleasant muscle pain might be mediating the exercise limits. Indeed, it has been stablished that pain neuronal pathways triggers feedback through group III/IV afferent nerves, the same nerves mediated by metabolites like lactate during intense exercise (Pollak et al., 2014). Probably, better performance found out applying the PBMT is due to neuro-psychological factors related to muscle pain sensation. Likewise, this factor seems to have affected the inflammatory process and delayed-onset muscle soreness. However, differently from acute response (just after 3000 m test), the mitochondrial restorative mechanism affected positively metabolic economy 24 h after 3000 m.

The RE represents an integrative parameter of aerobic metabolic during endurance events (Peyre-Tartaruga & Coertjens, 2018; Di Prampero et al., 1986). In this study, the RE was deteriorated from pre- to post-3000 m running test at similar degree between PBMT and placebo conditions, though the performance have improved in the PBMT. Consequently, the physiological mechanism related to the improved performance here seems not to be represented in the RE. It turns that the maximal aerobic power or the metabolic threshold should be optimized after the acute application of PBMT in endurance athletes. Future studies will be needed to clarify the impact of these critical physiological determinants (Bassett & Howley, 2000) on enhanced performance after PBMT intervention.

Therefore, our results suggest that PBMT is an effective ergogenic agent for increasing performance and RE (after 24 h) in runners. Previous PBMT application can then improve muscle performance, reducing signs of muscle fatigue and speeding up the muscle recovery process. Despite the promising results of the present study, they should be viewed with caution because of the low amount of evidence on the subject currently. In addition, studies investigating PBMT action on performance in different athletic events may help to strengthen the present study results.

Another important aspect is the chronicle PBMT application to ascertain if there are indeed repairing effects of this technique on muscle recovery and performance improvement in runners.

Limitations

This study had some limitations. We were unable to conduct biochemical muscle damage evaluations (e.g., creatine kinase, c-reactive protein), or echo intensity muscle quality to determine the PBMT effects on muscle structure and function. Another limitation is that we were unable to locally measure muscle oxygenation (concentration of oxyhaemoglobin, deoxyhemoglobin and total haemoglobin) to investigate the PBMT effect on muscular oxygenation changes compared to the placebo effect, which would help us to better determine some of the possible mechanisms of action of PBMT.

Practical application

Our results suggest that PBMT is a useful ergogenic method to improve endurance performance in an ecological test of running (3000 m on the athletics track) and optimization of the metabolic economy 24 h after the 3000 m, without changes metabolic economy just after the 3000 m test and the RPE before, during and 24-h after the 3000 m test. However, it is still necessary to investigate the effects of PBMT on performance in other athletics events (short, medium and long), as well as the effects of applying PBMT on a RE and muscle oxygenation during tests or races, as well as muscle recovery. Also, considering the positive results in RE 24 h after 3000 m test, we suggest verifying the influence of a long-term and continuous PBMT intervention on running performance and physiological parameters as an essential step towards unveiling the role of PBMT on stimulus-recovery-adaptation process ultimately enhancing performance in endurance athletes.

Conclusion

In summary, the results of the present study demonstrated that the PBMT application, previous to a running exercise, improved the 3000 m test performance when compared to the placebo application pre-exercise. In addition, the pre- and post-exercise PBMT application caused a 5% of improvement in metabolic economy post-24 h compared to the placebo application. The PBMT application was not able to attenuate the impaired metabolic economy just after the 3000 m running test. Finally, we did not observe alteration in RPE between the two conditions before, during or after the 3000 m test.

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation (Supplementary Material 01).

Disclosure statement

The authors declare that they have no conflict of interest. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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