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Review

A Meta-Analysis of Randomized Controlled Trials on the Effects of Photobiomodulation Therapy on Running Performance

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ABSTRACT

International Journal of Exercise Science 17(4): 327-342, 2024. Objective: To conduct a meta-analysis to investigate the effects of Photobiomodulation (PBM) therapy on running performance. Introduction: PBM has recently been advocated as a valuable non-pharmacological ergogenic strategy, however, the efficacy of PBM on running performance remains unproven. Methods: A computerized literature search was conducted until June 2023. The databases searched were PubMed/Medline, Embase, Scopus, SPORTDiscus, and Web of Science. Inclusion/exclusion criteria were determined through the PICO process. The running variables analyzed were time-trial or time-to-exhaustion. Results were combined with the standardized mean differences (SMD) and the 95% confidence intervals. Results: Twelve studies fulfilled the inclusion criteria. No significant effects in favor of PBM were found (SMD = 0.13; p = 0.11). There was no effect considering the presence (SMD = 0.16; p = 0.38) and absence (SMD = 0.11; p = 0.25) of training, and there was no dose-response effect (p = 0.82). Conclusion: Our findings indicate that PBM alone or combined with a training program does not improve running performance in terms of time-trial and time-to-exhaustion testing. More studies involving PBM plus training and doses higher than 1000 J are needed to determine if PBM is effective in improving running performance.

KEY WORDS: Phototherapy, low-level laser therapy, light-emitting diodes, LED therapy, physical performance, time-to-exhaustion

INTRODUCTION

Ergogenic strategies are generally used in the sports and health context to improve physical performance and body composition (13, 29, 30). Among ergogenic interventions, photobiomodulation (PBM) therapy has recently emerged as a valuable non-pharmacological aid for improving muscle strength and endurance (1, 11, 17). PBM is a non-invasive phototherapy modality that emits light ranging from red to infrared wavelengths (600-1000 nm) through devices containing low-level lasers and/or light-emitting diodes (LEDs). Several mechanisms have been proposed to describe the ergogenic effects of PBM, including i) increased adenosine triphosphate (ATP) synthesis via aerobic metabolism, ii) reduced oxidative stress; and iii) improved muscle regeneration (For more details, see the reviews: (3, 10, 11, 14)). In addition, it has recently been shown that PBM can increase nitric oxide availability (15), a potential vasodilator agent that can improve physical performance (24).

Despite the supposed ergogenic effects, scientific evidence regarding running performance is scarce and contradictory, with some studies reporting positive effects (9, 22, 31) and other null effects (19, 26, 28). For example, Ferraresi, *et al*. (9) showed that pre-exercise PMB with LEDs improved the kinetics of oxygen uptake (VO_2) and increased the time limit of exercise in a high-intense constant workload running test in a single elite runner. In addition, Miranda, *et al*. (22) reported that pre-exercise PBM (combination of lasers and LEDs) increased the time until exhaustion, distance covered, and pulmonary ventilation in a cardiopulmonary test in untrained men. Similarly, Tomazoni, *et al*. (31) observed that pre-exercise PBM with laser therapy increased the VO_{2max} and time until exhaustion in a high-intensity progressive running test in male soccer players. On the other hand, Malta, *et al*. (19) showed no beneficial effect of pre-exercise PBM with LEDs on metabolic energy pathways and time-to-exhaustion during a high-intensity running test in moderately active males. Peserico, et al. (26) also reported no additional effect on 5-km time-trial running performance in previously untrained men after an 8-week running training program combined with PBM with LEDs. In a later study (28), the same authors found no beneficial effect of different doses of PBM with LEDs (30, 120, and 180 J) on running performance parameters in physically active men.

These discrepant findings between studies may be associated with different methodological approaches, including the investigated sample (e.g., trained vs. untrained), type of performance test (e.g., time-trial, and time-to-exhaustion), and PBM parameters (e.g., device type or total irradiation dose), making it difficult to understand the actual effectiveness of PBM on running performance. To compile the existing literature, a meta-analysis study (7), involving twelve randomized clinical trials (RCTs), investigated the effects of PBM on running performance. The authors found no significant effect of PBM on running performance (SMD = 0.17) in terms of time-trial, time-to-exhaustion, and sprint performance. However, this meta-analysis included only crossover-design-based RCTs and did not analyze the possible dose-response effect of PBM (i.e., a meta-regression analysis), or the influence of running training (i.e., as a moderator factor) combined with PBM therapy on physical performance. Given that running performance has beneficial repercussions for both health and sport, understanding the ergogenic effects of PBM on this variable is extremely important for recreational and professional runners and individuals involved in running activities in the context of health (e.g., physically active individuals) or sports performance (e.g., football players).

Therefore, to extend the existing literature, we conducted a meta-analysis to investigate the dose-response effect of PBM therapy alone or associated with a training program on running performance in terms of time-trial and time-to-exhaustion testing. We hypothesized that PBM therapy would be more effective than placebo in improving running performance. We hope that our findings can contribute to decision-making regarding the use of PBM among recreational and professional practitioners of activities involving running performance.

METHODS

Eligibility Criteria

The general guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement (18, 25) were followed. The inclusion criteria in the study were: (1) randomized controlled trials (RCTs) with parallel or crossover designs, (2) in which the primary intervention was PBM therapy with laser and/or light-emitting diodes (LEDs), (3) for healthy adults (no diagnosed pathology), and (4) reporting running performance (time-trials or time-to-exhaustion) for both the PBM therapy and placebo-control conditions. The eligibility criteria for the selection of the studies were determined through the PICO process (Table 1). All procedures were carried out following the ethical issues of the International Journal of Exercise Science (23).

Table 1. Criteria for inclusion and exclusion of studies selected for review.

		Inclusion criteria	Exclusion criteria
P	**Population**	- Healthy adults.	- Elderly, neuromuscular disorders, use of nutritional supplements or steroids, and being engaged in a dietary restriction program.
I	**Intervention**	- PBM therapy.	- Photobiomodulation therapy combined with other therapeutic interventions (e.g., cryotherapy or massage).
C	**Comparison**	- Placebo (PLA).	- Studies without a placebo group or who used another therapy as a placebo.
O	**Outcome**	- Time-trials. - Time-to-exhaustion.	- Indirect performance measures (blood lactate levels, maximum oxygen intake, running economy, etc.

Database Search

An electronic search of the literature was conducted in the online databases: PubMed/Medline, Embase, Scopus, SPORTDiscus, and Web of Science, until June 2023 by one author (A.P.N.) and checked by another author (A.F.A.). Search syntax included terms related to PBM therapy and running performance measures (i.e., time-trial or time-to-exhaustion), as follows: "("photobiomodulation" OR "phototherapy" OR "photobiomodulation therapy" OR "low-level laser therapy" OR "laser therapy" OR "light-emitting diode therapy" OR "LLLT" OR "LEDT" OR "LED irradiation" OR "LED therapy" OR "laser" OR "light-emitting diodes" OR "super-pulsed laser") AND ("runners" OR "running" OR "run" OR "running performance" OR "distance running" OR "running economy" OR "distance running performance" OR "running time" OR "time to exhaustion" OR "5-km running time" OR "endurance running" OR "maximal running speed" OR "3000 m running performance" OR "3000-m running performance")". Search filters were applied to limit the search to randomized clinical trials. No language restrictions were applied during the search. All duplicate studies or those published in the gray literature were excluded. The flow chart illustrating the selection of studies is summarized in Figure 1.

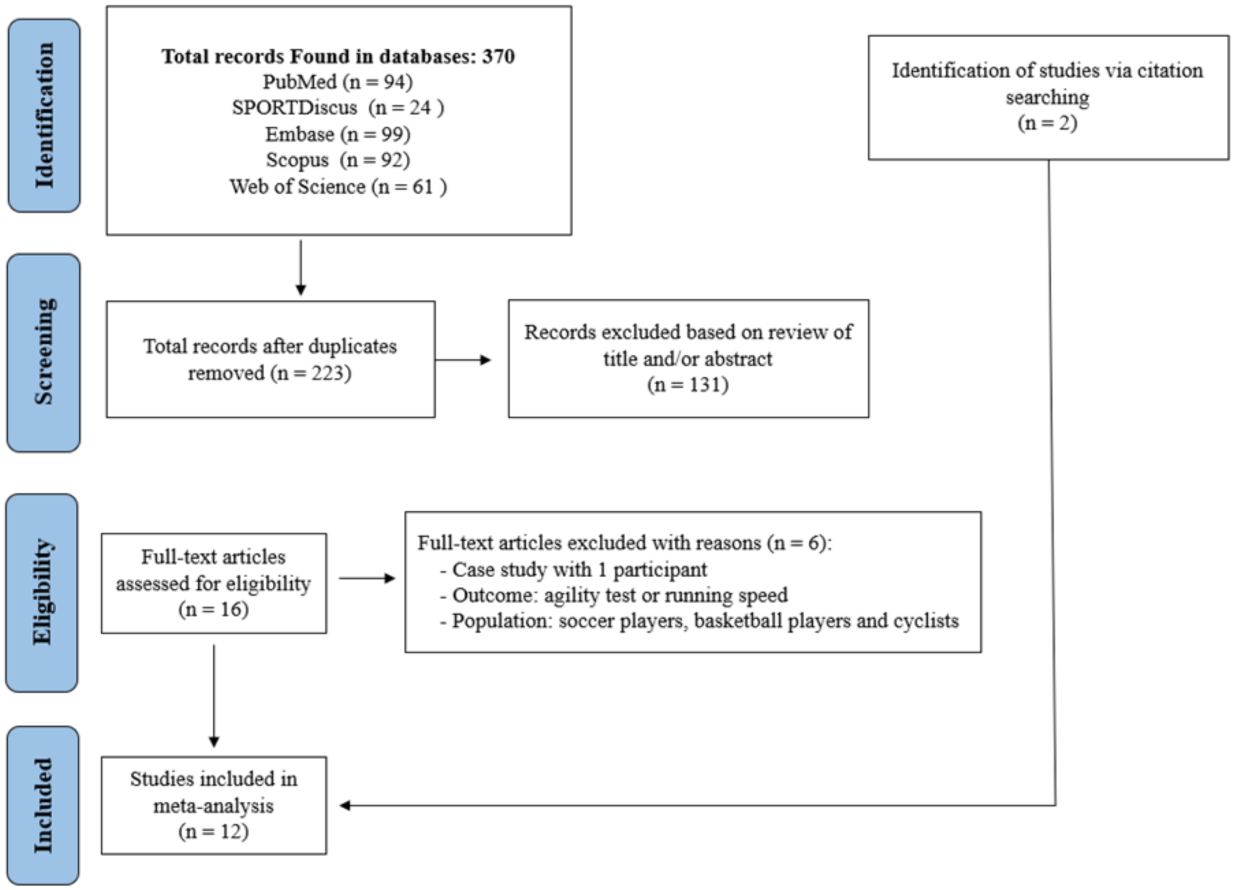

Figure 1. Flow chart from included studies for this meta-analysis.

Study Screening, Data Extraction, and Quality Assessment

Articles were screened by title and abstract and then reviewed for eligibility after a full reading. A standardized Excel spreadsheet was created to extract the following data: publication details (authors and year), experimental design (parallel or crossover), sample characteristics (sex, age, and sample size), PBM parameters (light source, dose, treated muscle groups and time) and outcome measures. The risk of bias for the included studies was evaluated by two reviewers (A.P.N and A.F.A) using the Physiotherapy Evidence Database (PEDro) scale (32). The maximum result on the 11-point PEDro scale was 10 (i.e., the first item is not included in the total score) following the ratings: 9–10 = "excellent"; 6-8 = "good"; 4-5 = "moderate"; and, 0–3 = "poor" (2). Inter-rater agreement was assessed using Kappa coefficients. Disagreements were resolved by consensus.

Statistical Analysis
Comprehensive Meta-Analysis software (CMA, version 2.2.064, Biostat, NJ, USA) was used for analysis. The primary outcome measure was running performance (i.e., time-trial and time-to-exhaustion). Data were analyzed using the random-effects model and were expressed as standardized mean difference (SMD) and 95% confidence intervals (95% CI). Inconsistencies were estimated using the I^2 statistic. Two-sided statistical significance was set at $p < 0.05$. Physical training (presence or absence) was included as a moderator factor and analyzed using an analysis of variance (Q-test-based ANOVA). In addition, meta-regression was performed for irradiation dose to identify a possible dose-response relation between dose and running performance. Visual inspection of the asymmetry of funnel plots was used to identify publication bias, and the effect of publication bias on results was estimated using the trim-and-fill method proposed by Duval and Tweedie (8).

RESULTS

Twelve RCTs (4, 6, 12, 16, 19-22, 26-28, 31) were included in the analysis (Fig. 1), involving 19 outcomes in each of the PBM and PLA conditions. The characteristics of the studies are presented in Table 2. The studies were published between 2012 and 2020. Ten studies used a crossover design and two used a parallel design, with a sample size varying between 12-48 subjects in each condition. The age of the participants ranged between ~18-34 years old. Eleven studies included only men, and one study included both sexes.

Table 2. Participant characteristics, intervention, and running performance effect.

Study	Partici pants	N	Study design	PBM light source	Total dose of PBM for both lower limbs	Muscle groups treated for both lower limbs	Timing	Running trial description	Outcome	Perfor mance effect

Dellagrana *et al*. (6)	Recreationally male runners: PBM 420 J (27.0 ± 4.7 years) PBM 840 J (27.1 ± 4.8 years) PBM 1680 J (27.2 ± 4.9 years)	15	C	Cluster with 5 lasers and 28 LEDs: 12 LEDs (670 nm), 8 LEDs (880 nm), and 8 LEDs (950 nm).	3 doses: 420, 840 e 1680 J	Quadriceps: 8 sites, hamstrings: 4 sites, and gastrocnemius: 2 sites.	Immediately before the running trial	Maximum incremental test	Test duration (s)	PBM: 420 J > PLA PBM: 840 J > PLA PBM: 1680 J = PLA
Dellagrana *et al*. (5)	Recreationally trained male runners (27.3 ± 3,3 years)	19	C	Cluster with 5 laser and 28 LEDs (large cluster): 12 red LEDs (670 nm), 5 infrared laser diodes (850 nm), 8 infrared LEDs (880 nm), and 8 infrared LEDs (950 nm).	840 J	Quadriceps: 8 sites; Hamstrings: 4 sites; and Plantar flexors: 2 sites.	Twenty minutes before the running trial	Time-trial performance test in 1500 m.	Test duration (s)	PBM = PLA

De Marchi, *et al.* (4)	Untrained men (22.0 ± 3.0 years)	22	C	5 laser diodes infrared with 810 nm.	720 J	Quadriceps: 6 sites, hamstrings: 4 sites, and gastrocnemius: 2 sites.	Five minutes before the running trial	Incremental Test	Test duration (s)	PBM > PLA
Lanferdini, *et al.* (16)	Male runners or triathletes (34 ± 7.8 years)	20	C	Cluster with 152 LEDs (880 nm).	3000 J	Quadriceps: 2 sites, Gluteus Maximus:1 site, Hamstrings: 1site, Gastrocnemius: 1 site.	Before the running trial	Time-trial performance test in 3000 m.	Test duration (s)	PBM > PLA
Malta, *et al.* (19)	Moderately active men (25.1 ± 4.4 years)	15	C	Cluster with 104 LEDs (56 diodes of 660 nm and 48 diodes of 850 nm).	600 J	Quadriceps: 2 sites, Hamstrings: 2 sites and Plantar flexors: 1 site.	Immediately before the running trial	Time-to-exhaustion	Test duration (s)	PBM = PLA
Mezzaroba *et al.* (20)	Physically active men (27.8 ± 1.7 years)	26	C	Cluster with 104 LEDs infrared (850 nm).	936 J	Quadriceps: 6 sites, hamstrings: 4 sites, and gastrocnemius: 2 sites.	Five minutes before the running trial	Maximum incremental test	Test duration (s)	PBM > PLA

Miranda *et al*. (22)	Healthy men (26 ± 6.0 years)	20	C	Cluster with 12-diode super pulsed lasers and LEDs (4 diodes of 905nm laser, 4 diodes of 875 nm infrared LEDs, 4 diodes of 640 nm red LEDs).	1020 J	Quadriceps: 9 sites, hamstrings: 6 sites, and gastrocnemius: 2 sites.	Five to ten minutes before the running trial	Progressive test	Test duration (s)	PBM > PLA
Miranda, *et al*. (21)	Men and women: PBM (26.1 ± 5.2 years) PLA (25.1 ± 4.6 years)	96	P	Cluster with 12 diodes of super pulsed lasers and LEDs (905 nm - 4 red LEDs 640 nm, 4 infrared LEDs diodes 875 nm).	1020 J	Quadriceps: 9 sites, hamstrings: 6 sites, and gastrocnemius: 2 sites.	Five to ten minutes before the running trial	Progressive test	Test duration (s)	PBM > PLA

Peserico, *et al*. (26)	Untrained men PBM (27.4 ± 3.7 years) PLA (27.3 ± 4.2 years)	30	P	Cluster of LED: 56 diodes of red light (660 nm) and 48 diodes of infrared light (850 nm).	600 J	Quadriceps: 2 sites, hamstrings: 2 sites, and gastrocnemius: 1 site.	Immediately before the running trial	Time-to-exhaustion and time-trial performance test in 5000 m.	Test duration (min.)	PBM = PLA (Time-to-exhaustion) PBM > PLA (5 Km trial)
Peserico, *et al*. (28)	Physically active men 300 J (25.3 ± 3.9 years) 1200 J (25.4 ± 3.10 years) 1800 J (25.5 ± 3.11 years)	15	C	Cluster of LED: 56 diodes of red light (660 nm) and 48 diodes of infrared light (850 nm).	3 doses: 300, 1200 e 1800 J	Quadriceps: 2 sites, hamstrings: 2 sites, and gastrocnemius: 1 site.	Five to ten minutes before the running trial	Incremental Test	Test duration (min.)	PBM = PLA
Tomazoni, *et al*. (31)	High-level football players (18.85 ± 0.6 years)	22	C	Cluster of lasers with 5 diodes of infrared (810 nm).	1700 J	Quadriceps: 9 sites, hamstrings: 6 sites, and gastrocnemius: 2 sites.	Immediately before the running trial	Incremental Test	Test duration (s)	PBM > PLA

Ferreira-Júnior, *et al*. (12)	Physically active men (22.75 ± 1.54 years)	12	C	Cluster with 69 LEDs: 34 red diodes (660 nm) and 35 infrared diodes (850 nm).	417 J	Quadriceps: 2 sites, hamstrings: 2 sites, and gastrocnemius: 1 site.	Five minutes before the running trial	Constant-load test until exhaustion at maximal aerobic speed	Test duration (s)	PBM = PLA

Photobiomodulation, PBM; Placebo, PLA; Light-emitting diodes, LED; Joules, J. C, crossover; P, parallel

Risk off Bias Within Studies

The mean rating of study quality as assessed by the PEDro scale was 7.9, indicating a good-to-excellent level of quality, and no study was rated as poor to moderate quality. The kappa correlation showed good overall agreement between the researchers (k = 0.716 [95% CI, 0.52;0.88], p < 0.001). All studies reported point and variability measures for running performance, and baseline data were similar between the intervention and control conditions.

Risk of Bias Across Studies

Figure 2 shows the funnel plot for the assessment of publication bias. The Duval and Tweedie correction model (8) was applied and no trimmed studies were identified. The I^2 (0.0 [p < 0.001]) was used to analyze the consistency of study results as an assessment of heterogeneity for subgroup analyses.

Main Outcomes

Figure 3 shows the forest plot (SMD and 95% CI) comparing the effects of PBM alone or combined with running training (PBM plus training), and the overall effect including all studies. No significant effect in favor of PBM was observed in the absence ($SMD_{95\%}$= 0.14 [-0.05;0.33]; p = 0.15) or presence ($SMD_{95\%}$ = 0.11 [-0.18;0.39]; p = 0.46) of training, evidencing no global effect of PBM ($SMD_{95\%}$ = 0.13 [-0.03;0.29]; p = 0.11) on running performance. Subgroup analysis indicated a similar effect in the presence or absence of running training (p = 0.797). The meta-regression analysis indicated no dose-response effect for irradiation dose (Slope; p = 0.82) comparing running performance between PBM and PLA conditions, and most studies had a dose ranging around 600 and 1000 J (Figure 4).

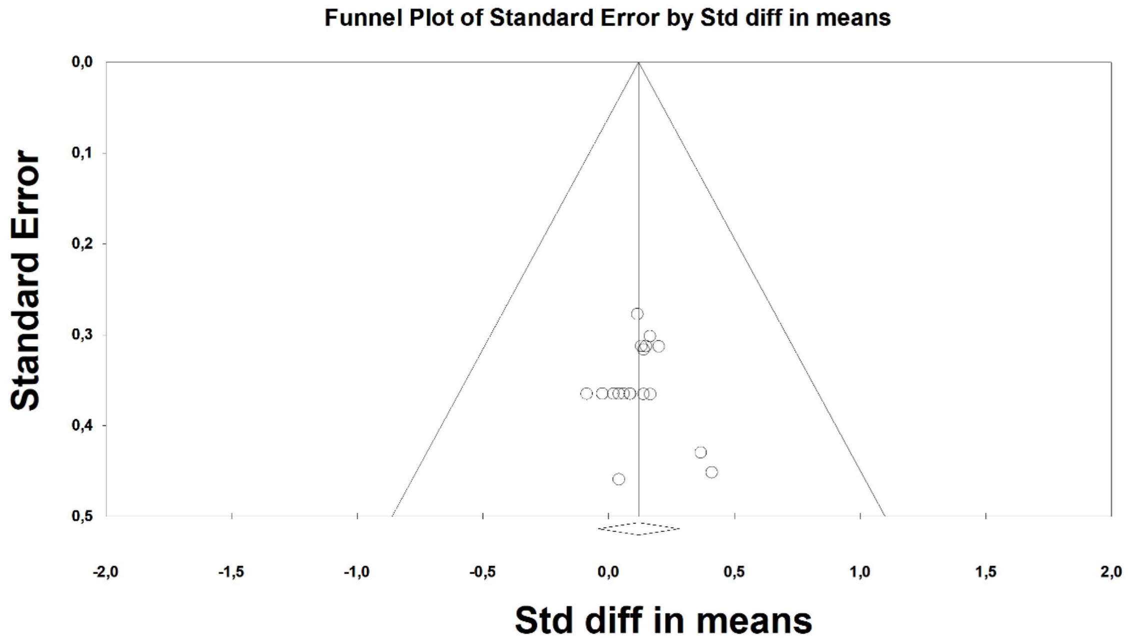

Figure 2. Funnel plot for publication bias

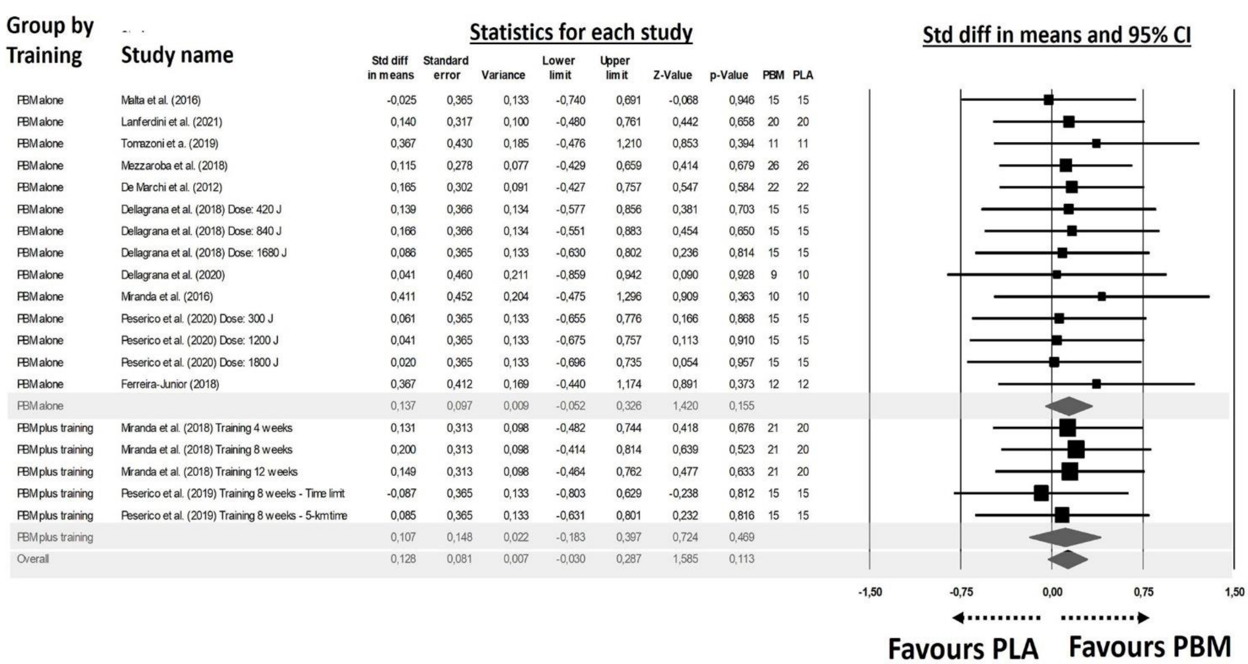

Figure 3. Forest plot comparing running performance between photobiomodulation (PBM) and placebo (PLA) conditions in the absence (PBM alone) or presence (PBM plus training) of running training. Confidence interval, CI.

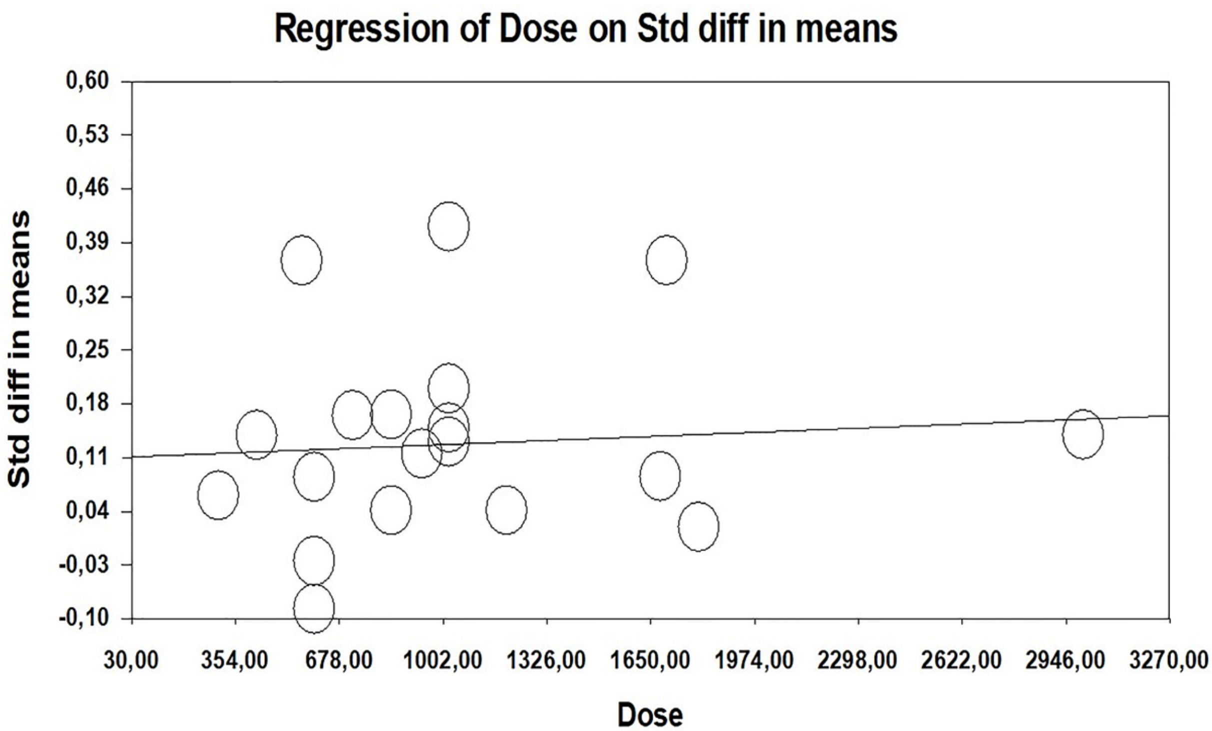

Figure 4. Meta-regression for irradiation dose (in joules) comparing running performance between photobiomodulation (PBM) and placebo (PLA) conditions. Slope analysis indicated no dose-response effect for irradiation dose (p = 0.82).

DISCUSSION

The purpose of this meta-analysis was to investigate the effect of PBM on running performance. In contrast to our hypothesis, the results showed no effect in favor of PBM alone or combined with running training on running performance in terms of time-trial and time-to-exhaustion tests, and no dose-response effect was observed.

All studies included in this meta-analysis have good-to-excellent levels of quality, as indicated by the PEDro scale (mean score = 7.9), and no study had a low-to-moderate quality rating. This indicates that current evidence on the topic is supposedly reliable for determining a possible effect of PBM on running performance. A subgroup analysis was performed to verify the effects of PBM combined with training compared to PBM alone, however, no effect in favor of PBM was identified with PBM alone and associated with running training (p = 0.7). It is worth mentioning that only two studies (21, 26) investigated the effect of PBM associated with a running training program. The study by Miranda, *et al.* (21) investigated the effect of 4, 8, and 12 weeks (3 x/week) of running training plus PBM on time until exhaustion in the progressive running test. The authors showed that the application of PBM before and after the training session was able to increase running endurance, compared with the PLA condition. On the other hand, Peserico, *et al*. (26), when evaluating 30 untrained young adults after 8 weeks of training, found no differences in the total time until exhaustion between the active PBM and placebo groups. Therefore, further studies are needed to confirm the effect of PBM plus exercise training on running performance.

We also performed a meta-regression analysis to investigate a possible dose-response effect of PBM on running performance, and no effect was found when comparing active PBM and PLA conditions. Only two of the studies included in our review tested three different doses of PBM (ranging from 300 to 1800 J) on running performance (6, 28), and contradictory results were observed. The study by Peserico, *et al*. (28) tested doses of 300, 1200, and 1800 J on running performance variables (i.e., peak running velocity, lactate peak, heart rate, and rating of perceived exertion) in physically active men and found no difference between active PBM and placebo conditions. In addition, Dellagrana, *et al.* (6) experimented the total PBM doses of 420, 840, and 1680 J on physiological and performance parameters (i.e., running economy, rate of perceived exertion, velocity at VO_{2max}, peak of velocity, and total time-to-exhaustion) in recreational runners and suggested a possible biphasic response, since there was a beneficial effect only with a dose of 840 J. Therefore, there is no consensus on the optimal dose of PBM for running performance, so additional dose-response studies are needed to determine the effectiveness of PBM on running performance.

Scientific evidence suggests a possible biphasic response of PBM therapy on physical performance, in which lower doses can result in stimulant effects, while very high doses can promote a potentially inhibitory effect (14). However, another important finding of our meta-analysis concerns the irradiation dose range used in the studies, in which most studies applied doses between 600 and 1000 J and reported divergent results on running performance parameters. Of note, only six studies used total doses greater than 1000 J (ranging from 1020 to 3000 J) (6, 16, 21, 22, 26, 31), indicating that further studies using doses higher than 1000 J are needed to determine a possible dose-response effect of PBM in running performance.

In our review, of the 12 articles included, 5 studies (5, 12, 19, 26, 28) (n = 91 participants) did not demonstrate a superior effect of PBM compared to placebo in terms of running performance, while the remaining (7 articles) (4, 6, 16, 20-22, 31) reported a possible effect of PBM on running test time (221 participants). Our findings are consistent with a recent meta-analysis (7), in which no statistical differences were found in running performance (i.e., time-to-exhaustion, time-trial, and running sprints) between PBM and PLA conditions in 12 analyzed studies. One of the authors' explanations for this result is due to the heterogeneity of the studies, mainly regarding the variety of tests applied (constant load tests, maximum tests, and sprint tests) and PBM parameters. However, it is important to note that almost all the studies included in our review showed a small effect in favor of PBM therapy, compared to PLA, which can be decisive in a competitive context. In addition, the studies published to date on this topic have not yet managed to determine the dose-response effect of PBM on running performance, so it is necessary to investigate other irradiation doses, especially doses greater than 1000 J. Another point is that most of the studies show divergence regarding participants' training status, PBM parameters (i.e., dosage, timing, and muscles irradiated), and type of devices (i.e., laser, LED, or mixed equipment) - factors that should be standardized in future studies.

Our meta-analysis showed that PBM alone or combined with a training program does not improve running performance in terms of time-trial and time-to-exhaustion testing. Even though the current data do not show a statistically significant difference between the PBM and placebo conditions, it is worth highlighting that a trivial effect in favor of PBM can be decisive in a competitive context. Furthermore, we cannot rule out the possibility that the effects of PBM on running performance will become significant when additional high-quality studies determine better settings of irradiation parameters, such as device type, timing, duration, and dosage. Particularly, our meta-analysis highlights the need for more studies involving different parameters of PBM plus training and doses higher than 1000 J.

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REFERENCES

1. Baroni BM, Leal Junior EC, De Marchi T, Lopes AL, Salvador M, Vaz MA. Low level laser therapy before eccentric exercise reduces muscle damage markers in humans. Eur J Appl Physiol 110(4): 789-796, 2010.

2. Cashin AG, McAuley JH. Clinimetrics: Physiotherapy evidence database (PEDRO) scale. J Physiother 66(1): 59, 2020.

3. de Freitas LF, Hamblin MR. Proposed mechanisms of photobiomodulation or low-level light therapy. IEEE J Sel Top Quantum Electron 22(3): 7000417, 2016.

4. De Marchi T, Leal Junior EC, Bortoli C, Tomazoni SS, Lopes-Martins RA, Salvador M. Low-level laser therapy (lllt) in human progressive-intensity running: Effects on exercise performance, skeletal muscle status, and oxidative stress. Lasers Med Sci 27(1): 231-236, 2012.

5. Dellagrana RA, Rossato M, Orssatto LBR, Sakugawa RL, Baroni BM, Diefenthaeler F. Effect of photobiomodulation therapy in the 1500 m run: an analysis of performance and individual responsiveness. Photobiomodul Photomed Laser Surg 38(12): 734-742, 2020.

6. Dellagrana RA, Rossato M, Sakugawa RL, Baroni BM, Diefenthaeler F. Photobiomodulation therapy on physiological and performance parameters during running tests: dose-response effects. J Strength Cond Res 32(10): 2807-2815, 2018.

7. Dutra YM, Malta ES, Elias AS, Broatch JR, Zagatto AM. Deconstructing the ergogenic effects of photobiomodulation: A systematic review and meta-analysis of its efficacy in improving mode-specific exercise performance in humans. Sports Med 52(11): 2733-2757, 2022.

8. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56(2): 455-463, 2000.

9. Ferraresi C, Beltrame T, Fabrizzi F, do Nascimento ES, Karsten M, Francisco Cde O, Borghi-Silva A, Catai AM, Cardoso DR, Ferreira AG, Hamblin MR, Bagnato VS, Parizotto NA. Muscular pre-conditioning using light-emitting diode therapy (LEDT) for high-intensity exercise: A randomized double-blind placebo-controlled trial with a single elite runner. Physiother Theory Pract 31(5): 354-361, 2015.

10. Ferraresi C, Hamblin MR, Parizotto NA. Low-level laser (light) therapy (LLLT) on muscle tissue: Performance, fatigue, and repair benefited by the power of light. Photonics Lasers Med 1(4): 267-286, 2012.

11. Ferraresi C, Huang YY, Hamblin MR. Photobiomodulation in human muscle tissue: An advantage in sports performance? J Biophotonics 9(11-12): 1273-1299, 2016.

12. Ferreira-Junior A, Kaspchak LAM, Bertuzzi R, Okuno NM. Effects of light-emitting diode irradiation on time to exhaustion at maximal aerobic speed. Lasers Med Sci 33(4): 935-939, 2018.

13. Goston JL, Correia MI. Intake of nutritional supplements among people exercising in gyms and influencing factors. Nutrition 26(6): 604-611, 2010.

14. Hamblin MR. Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. AIMS Biophys 4(3): 337-361, 2017.

15. Kashiwagi S, Morita A, Yokomizo S, Ogawa E, Komai E, Huang PL, Bragin DE, Atochin DN. Photobiomodulation and nitric oxide signaling. Nitric Oxide 130: 58-68, 2023.

16. Lanferdini FJ, Silva ES, Boeno FP, Sonda FC, Rosa RG. Effect of photobiomodulation therapy on performance and running economy in runners: A randomized double-blinded placebo-controlled trial. J Sports Sci 39(12): 1348-1355, 2021.

17. Leal-Junior EC, Vanin AA, Miranda EF, de Carvalho Pde T, Dal Corso S, Bjordal JM. Effect of phototherapy (low-level laser therapy and light-emitting diode therapy) on exercise performance and markers of exercise recovery: A systematic review with meta-analysis. Lasers in medical science 30(2): 925-939, 2015.

18. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. BMJ 339: b2700, 2009.

19. Malta EDS, De Poli RAB, Brisola GMP, Milioni F, Miyagi WE, Machado FA, Zagatto AM. Acute led irradiation does not change the anaerobic capacity and time to exhaustion during a high-intensity running effort: a double-blind, crossover, and placebo-controlled study. Lasers Med Sci 31(7): 1473-1480, 2016.

20. Mezzaroba PV, Pessôa Filho DM, Zagatto AM, Machado FA. Led session prior incremental step test enhance VO(2max) in running. Lasers Med Sci 33(6): 1263-1270, 2018.

21. Miranda EF, Tomazoni SS, de Paiva PRV, Pinto HD, Smith D, Santos LA, de Tarso Camillo de Carvalho P, Leal-Junior ECP. When is the best moment to apply photobiomodulation therapy (PBMT) when associated to a treadmill endurance-training program? A randomized, triple-blinded, placebo-controlled clinical trial. Lasers Med Sci 33(4): 719-727, 2018.

22. Miranda EF, Vanin AA, Tomazoni SS, Grandinetti Vdos S, de Paiva PR, Machado Cdos S, Monteiro KK, Casalechi HL, de Tarso P, de Carvalho C, Leal-Junior EC. Using pre-exercise photobiomodulation therapy

combining super-pulsed lasers and light-emitting diodes to improve performance in progressive cardiopulmonary exercise tests. J Athl Train 51(2): 129-135, 2016.

23. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

24. Oral O. Nitric oxide and its role in exercise physiology. J Sports Med Phys Fitness 61(9): 1208-1211, 2021.

25. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 372: n71, 2021.

26. Peserico CS, Zagatto AM, Machado FA. Effects of endurance running training associated with photobiomodulation on 5-km performance and muscle soreness: A randomized placebo-controlled trial. Front Physiol 10: 211, 2019.

27. Rossato M, Dellagrana RA, Sakugawa RL, Baroni BM, Diefenthaeler F. Dose-response effect of photobiomodulation therapy on muscle performance and fatigue during a multiple-set knee extension exercise: A randomized, crossover, double-blind placebo-controlled trial. Photobiomodul Photomed Laser Surg 38(12): 758-765, 2020.

28. Peserico CS, Garozi L, Zagatto AM, Machado FA. Does previous application of photobiomodulation using light-emitting diodes at different energy doses modify the peak running velocity and physiological parameters? A randomized, crossover, double-blind, and placebo-controlled study. Photobiomodul Photomed Laser Surg 38(12): 727-733, 2020.

29. Senekal M, Meltzer S, Horne A, Abrey NCG, Papenfus L, van der Merwe S, Temple NJ. Dietary supplement use in younger and older men exercising at gyms in Cape Town. South Afr J Clin Nutr 34(1): 1-8, 2019.

30. Silver MD. Use of ergogenic aids by athletes. J Am Acad Orthop Surg 9(1): 61-70, 2001.

31. Tomazoni SS, Machado C, De Marchi T. Infrared low-level laser therapy (photobiomodulation therapy) before intense progressive running test of high-level soccer players: Effects on functional, muscle damage, inflammatory, and oxidative stress markers-a randomized controlled trial. Oxid Med Cell Longev 2019: 6239058, 2019.

32. Yamato TP, Maher C, Koes B, Moseley A. The PEDRO scale had acceptably high convergent validity, construct validity, and interrater reliability in evaluating methodological quality of pharmaceutical trials. J Clin Epidemiol 86: 176-181, 2017.