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REVIEW

A systematic review on whole-body photobiomodulation for exercise performance and recovery

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Abstract

Purpose Photobiomodulation (PBM) is a non-invasive therapeutic procedure that consists of irradiating a local area of the skin with red and near-infrared lasers or light emitting diodes (LEDs). Local PBM has been studied as a method to improve exercise performance and recovery. This review aims to evaluate the efficacy of whole-body PBM for exercise performance and recovery, comparing its findings to the established effects of localized PBM.

Methods This systematic review was conducted utilising PubMed, The Cochrane Library, EBSCO and Google Scholar, with the search terms (whole-body OR full-body) AND (photobiomodulation OR "light therapy"). We included studies on human participants that used whole-body PBM in the red or near-infrared spectrum, before or after exercise to enhance performance or recovery, and provided a qualitative synthesis of the findings.

Results A total of five studies were identified out of the 193 screened, with a total of 105 physically active participants, representing both sexes, engaging in different exercise modalities. Two studies reported better sleep quality, as determined by a subjective questionnaire and a commercial sleep tracker, including higher serum melatonin and lower nocturnal heart rate in participants using whole-body PBM. However, none of the five studies reported any benefit of whole-body PBM on biomarkers of fatigue and exercise performance.

Conclusion Whole-body PBM may improve sleep quality but shows no evidence of benefits for exercise recovery or performance. Further research is necessary to resolve discrepancies with the benefits observed in localized PBM studies.

Keywords Photobiomodulation · Low-level light therapy · Whole-body · Exercise performance · Exercise recovery

Introduction

Photobiomodulation (PBM), also known as low-level light therapy, is a non-invasive therapeutic procedure in which light emitting diodes (LEDs) or a non-thermal laser irradiate the skin at a red (620–750 nm) or near-infrared (780–1400 nm) wavelength.

A study using live tissue structures from volunteers indicates that red-light (660 nm) at an irradiance of 100 mW/cm^2 (power hitting on the tissue per unit area) penetrates the human tissue up to 50 mm thick, but deeper penetration requires much higher irradiances [1]. A study with a human cadaveric model reported that near-infrared light (830 nm) has greater penetration depth than red light (633 nm), reaching the soft tissue, the skull bone and brain parenchyma [2]. Therefore, PBM can potentially affect various tissues involved in sports performance.

In vitro studies show that light penetrates the skin and photons are absorbed by the cytochrome c oxidase in the mitochondrial respiratory chain, which increases the membrane potential, stimulates ATP production, cAMP, nitric oxide and generates reactive oxygen species. The photons can also activate light sensitive ion channels that modulate membrane permeability. These molecular mechanisms activate signalling pathways and transcription factors that could be translated in health-associated benefits [3].

The use of PBM has several potential medical applications such as accelerating the wound healing process and injury recovery, reducing inflammation in autoimmune diseases and asthma, decreasing pain, regrowing hair, or

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enhancing exercise performance and recovery [4]. However, the exact mechanisms underlying the possible ergogenic or therapeutic effects of PBM are not fully understood.

Several molecular mechanisms may explain the potential benefits of PBM on exercise. In vivo application of PBM with infrared light to rats for 5 days increased mitochondrial respiration in skeletal muscle injuries compared to injured muscles of rats not exposed to PBM [5]. Additionally, rats exposed to PBM with red light showed increased cytochrome oxidase activity compared to control rats, particularly in slow-twitch muscle fibers [6]. These findings suggest that PBM could enhance oxidative exercise capacity.

Red-light PBM has also been shown to increase glucose uptake and glycogen synthesis in skeletal muscle through photoactivation of cytochrome c oxidase, in both mice on a high-fat diet and a diabetic model, compared to sham-treated mice [7]. This effect could potentially translate to improved performance.

Moreover, exercise recovery may be enhanced by PBM, as rats exposed to red-light after resistance swimming had lower creatine kinase (CK) levels than control rats, indicating reduced post-exercise muscle damage [8].

In humans, two systematic reviews and meta-analyses conducted by the same research group concluded that PBM could reduce muscle damage and promote recovery, possibly by minimizing oxidative stress and improving antioxidant activity (increasing superoxide dismutase activity and reducing protein and lipid damage, but not affecting catalase, total antioxidant capacity, or glutathione peroxidase) [9, 10]. Another review concluded that PBM improves endurance performance in single-joint exercises and time to exhaustion during cycling, but it is not effective for strength, running, or swimming [11]. A recent review reported improvements in muscle strength and endurance, primarily measured by maximal voluntary contraction force and the number of repetitions, respectively, as well as a reduction in markers of muscle damage [12].

In all the trials selected in these four reviews [9–12], PBM was performed with a hand-held device or pads in direct contact with the skin irradiating a local area in specific muscles, using red and near-infrared wavelengths between 630 and 980 nm. These reviews compiled trials using lasers, LEDs, or both; the authors did not comment on any possible differences in effects between these two most common light generation methods, though some debate exists in the literature [13]. Another source of methodological heterogeneity can be found in the PBM parameters, such as the irradiance or power density, and the fluence or the dose, which is the total energy per unit of irradiated tissue area.

The growing interest in health and the wide range of applications of light therapy have increased the popularity of the PBM devices. Their use has expanded into areas such as sports performance, with professional athletes using and advocating PBM to enhance exercise outcomes.

Some companies promote the use of whole-body LED panels based on the evidence from local PBM. These organizations primarily pursue profit-driven objectives and do not necessarily represent the stance of the academic community. Nevertheless, coaches and athletes may adopt such new technologies in an effort to enhance exercise performance and recovery. The effects of whole-body PBM on exercise performance and recovery have not been comprehensively investigated. Therefore, the aim of this systematic review is to determine whether there are any effects of whole-body PBM on exercise performance and recovery.

Methods

Search strategy

This review was performed according the updated PRISMA guidelines for systematic reviews [14]. The PRISMA checklist can be found in the supplementary material (Table S1). For the literature search, the databases used in this review were PubMed, The Cochrane Library, EBSCO and Google Scholar. The search terms employed were: (whole-body OR full-body) AND (photobiomodulation OR "light therapy").

Although the focus of this review is exercise performance and recovery, we decided not to narrow our search to exercise only, as there are a limited number of trials using whole-body PBM and we could benefit from finding other potential useful trials for the discussion.

Eligibility criteria

We included all studies published before January 2025. The PICO framework was used to include or exclude studies according to the participants, intervention, comparator and outcome [15]:

We included studies on human participants that used whole-body PBM in the red or near-infrared spectrum, before or after exercise to improve performance or recovery. Controlled studies were preferred, but those using pre-post values were also included. The inclusion criteria consisted of peer-reviewed studies in the English language. The exclusion criteria consisted of studies not peer-reviewed, in a foreign language, those studies using local PBM, using other wavelengths such as ultraviolet or polarised visible light, or without an exercise intervention. Conference abstracts and preclinical studies were also excluded.

Data extraction and synthesis

We screened all titles and abstracts, and full-texts of potential studies were assessed for eligibility. Two researchers (MAM and GB) independently screened the literature and agreed on the study selection. After including studies that met the eligibility criteria, we examined the references of each study and major reviews. A predefined table, which will be displayed in the results section, was used to extract the information of the included studies. Study details such as trial design, sample size, age and characteristics of the participants (including exercise modality), PBM parameters and results reported were extracted. Data extraction was performed by one researcher (MAM) and reviewed by a second researcher (GB). We organized the results as pertaining to exercise performance or recovery, including all measures and time points, and composed a narrative synthesis of the included studies.

Quality assessment

To evaluate the methodological quality of the included studies, we used the PEDro scale [16]. This scale was chosen based on the initial use of PBM in physical therapy interventions and following the previous literature on local PBM [9–11]. The quality assessment was conducted by a single reviewer (MAM). We rated the studies according to the randomization, allocation concealment, baseline similarity, blinding, follow-up and dropouts, and statistical analysis. We did not use the scale to include or exclude any of the trials.

Results

Search results and study characteristics

The literature search was performed on 07 January 2025. Of 193 studies, 140 titles and abstracts were screened after removing duplicates. The full-texts of 18 studies were retrieved for eligibility; 13 studies were excluded for specific reasons, while the remaining 5 studies met the inclusion criteria. Details about the study identification and screening process can be found in the PRISMA flow diagram (Fig. 1).

From the five eligible trials, four studies used randomized control trials [17–20] and one was observational [21], published between 2012 and 2023.

The total number of participants was 105, with a mean sample size per study of 21 ± 15.5, and a mean age of 24.4 ± 8.3 years. Participants were a mix of active and trained males and females of different exercise modalities such as basketball [17], water polo [18], soccer [21], and with experience in resistance [19] and endurance training [20].

One study used red-light only at a wavelength of 658 nm [17], while the remaining studies used a combination of red and near-infrared light, with wavelengths of 650 and 850 nm [18–21]. Whole-body PBM was performed for a mean duration of 21 ± 10.2 min before and after exercise, in a single session [19, 20], three sessions [18], during 14 days [17] or across the whole season (assumed to be performed after exercise because it was part of the "standard practice for team recovery") [21].

Further details about the study characteristics and results are summarized in Table 1.

In addition, there were three ongoing clinical trials identified in The Cochrane Library. One randomized controlled trial investigating the effect of whole-body PBM on fatigue during a knee flexion and extension test in rugby players [22], a second trial investigating maximal contraction during knee extension in trained individuals [23], and a third trial investigating the effect of whole-body PBM (after a muscle damage protocol, before exercise or a sham PBM intervention) on squat jump and knee extension performance, and on blood CK and delayed onset muscle soreness in professional soccer players [24].

Effects of whole-body PBM on exercise recovery and performance

All five included studies focused on recovery, however three of them also included effects on exercise performance (Table 1).

Sleep

Two studies investigated the effect of PBM on sleep and recovery. Zhao et al. reported better subjective sleep quality, duration and latency in female basketball players following a training period of 14 days in which 30 min of daily whole-body PBM was performed before bedtime compared to the sham intervention; the improved sleep was correlated with higher serum melatonin levels [17]. Rentz et al. observed a reduction in sleep duration in female soccer players the night after 20 min of post-exercise whole-body PBM compared to pre-intervention. The authors hypothesized that PBM might have increased post-exercise waste elimination and that recovery through sleeping was less necessary [21].

Cardiac metrics

Rentz et al. also reported a lower nocturnal heart rate with no effect on average heart rate variability (HRV). Maximal HRV was increased post- vs. pre-treatment, but only during

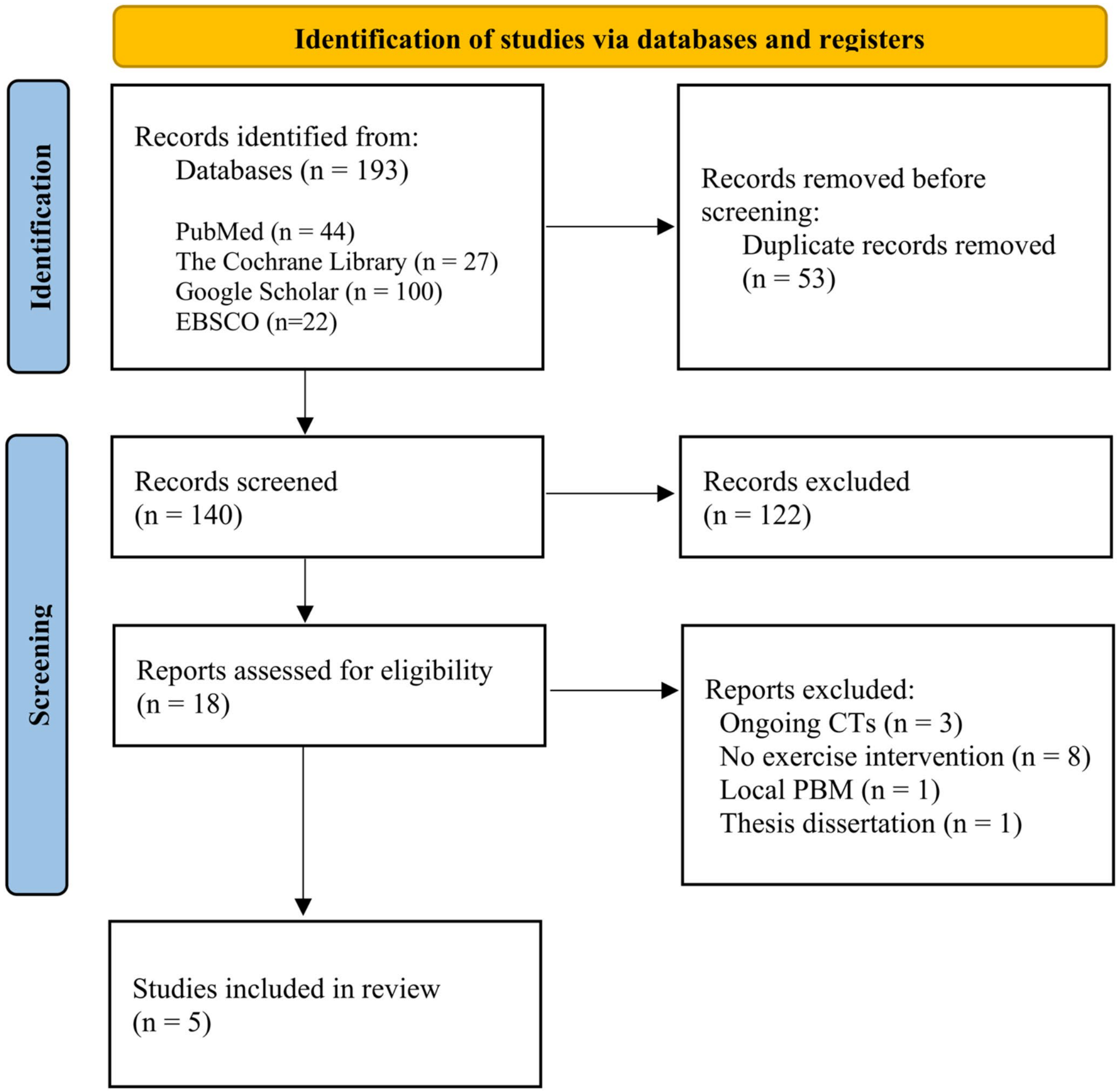

Fig. 1 Flow diagram of the literature search according to the preferred reporting items for systematic reviews and meta-analyses [14]

the first half of the night [21]. A randomized controlled trial in active males and females reported a higher heart rate during exercise and an improved HRV the following morning after a single 20-minute session of whole-body PBM performed before a four-times repeated Wingate test compared to the sham intervention; HRV immediately following exercise was not changed [20]. Another randomized controlled trial did not find any effect of 5 min whole-body PBM after each of three water polo games (within 5 days) on HRV [18]. A crossover trial reported that HRV of trained males was not affected during the recovery from a single session of high-intensity resistance exercise when PBM was applied 15 min before and 15 min after training [19].

Exercise performance

While some meta-analyses have reported positive effects on performance from local PBM [11, 12], the three studies included herein did not. Zhao et al. elicited no significant improvement on a 12-minute running performance test [17]. Forsey et al. indicated no effect of PBM on cycling performance and the rate of perceived exertion [20]. In Zagatto et

Table 1 Study characteristics and results. Approximated values in the PBM parameters indicate that they were calculated based on the relation between irradiance, fluence and time of exposure, and represent the total values per PBM session

Ref.	Design	*n*	Age	Population	PBM parameters	Duration	Timing	Performance outcome	Recovery outcome
Zhao et al. (2012) [17]	Parallel SB-RCT	20	18.6	Female basketball players	658 nm Irradiance ~ 16.6 mW/cm^2 Fluence 30 J/cm^2 Dayou PDT Technology	30 min/day during 14 days	After exercise (at night)	↔ running (Cooper test)	↑ sleep ↑ melatonin
Zagatto et al. (2020) [18]	Parallel DB-RCT	13	18.0	Water polo male players	660 and 850 nm Irradiance 46.17 mW/cm^2 Fluence ~ 13.8 J/cm^2 Joovv Elite system	5 min/day during 3 sessions (within 5 days)	After exercise	↔ MVC during knee extension ↔ squat jump	↔ IL-6 & TNF-α ↔ CK & LDH ↔ testosterone to cortisol ratio
Ghigiarelli et al. (2020) [19]	Crossover RCT	12	31.0	Trained males (resistance training)	660 and 850 nm Irradiance 17 mW/cm^2 Fluence 25 J/cm^2 NovoTHOR	Two 15-minute sessions on a single day	Before and after exercise	NR	↔ IL-6 ↔ CK ↔ HRV
Rentz et al. (2022) [21]	Observational	12	NR	Soccer female players	660 and 850 nm Irradiance ~ 24 mW/cm^2 Fluence ~ 28.8 J/cm^2 NovoTHOR	20 min in 1–2 sessions/week across the season	After exercise	NR	↑ sleep ↓ nocturnal HR ↔ HRV
Forsey et al. (2023) [20]	SB-RCT	48	~ 34	Females and males from running and triathlon groups	660 and 850 nm Irradiance 28 mW/cm^2 Fluence ~ 33.6 J/cm^2 NovoTHOR	20 min in a single session	Before exercise	↔ cycling (Wingate test) ↔ blood lactate ↑ peak HR ↔ RPE	↔ post-exercise HRV ↑ morning HRV

Abbreviations: SB, single-blinded; DB, double-blinded; RCT, randomized controlled trial; NR, not reported; MVC, maximal voluntary contraction; IL-6, interleukin-6; TNF-α, tumour necrosis factor-alpha; CK, creatine kinase; LDH, lactate dehydrogenase; HR, heart rate; HRV, hear rate variability; RPE, rate of perceived exertion

Table 2 Rating of the PEDro scale: (1) eligibility criteria is not used to calculate the PEDro score. (2) Random allocation. (3) concealed allocation. (4) baseline comparability. (5) blinding of participants. (6) blinding of therapists. (7) blinding of outcome evaluators. (8) key outcomes on >85% follow-up. (9) subjects allocated to treatment or control had results reported; or "intention to treat" analysis. (10) between-group comparisons. 11. Point of measures and variability. A final score of 9–10 is considered excellent, 6–8 is good, 4–5 is fair, and 0–3 is poor

	Zhao et al. (2012)	Zagatto et al. (2020)	Ghigiarelli et al. (2020)	Rentz et al. (2022)	Forsey et al. (2023)
1	✓	✓	✓	✓	✓
2	✓	✓	✓	✗	✓
3	✗	✓	✓	✗	✗
4	✓	✓	✓	✗	✓
5	✓	✓	✗	✗	✓
6	✗	✓	✗	✗	✗
7	✗	✓	✗	✗	✗
8	✗	✓	✓	✗	✗
9	✗	✓	✓	✓	✗
10	✓	✓	✓	✗	✓
11	✓	✓	✓	✓	✓
Score	5/10 fair	10/10 excellent	7/10 good	2/10 poor	5/10 fair

al., neuromuscular exercise performance, assessed by maximal voluntary contraction and squat jump before the games, did not improve in the PBM group compared to the sham intervention [18].

Recovery

Three trials measured blood markers of recovery, each recording no change: Zagatto et al. investigated interleukin-6 (IL-6), tumour necrosis factor-alpha (TNF-α), CK, lactate dehydrogenase (LDH) and testosterone/cortisol ratio [18], while null results were similarly reported for salivary IL-6 and blood CK [20], and blood lactate [19] by Ghigiarelli et al. and Forsey et al., respectively.

Risk of bias

Following the PEDro scale for quality assessment of the included studies (Table 2), only one study was rated as poor because it is observational [21] and some items of the scale do not apply. From the rest of studies, all of them were randomized and single-blinded, except one trial that was double-blinded and obtained a score assigned as excellent [18]. Another trial was rated as good [19] and the other two as fair [17, 20]. For further information, see the supplementary material with the individual score for all the items and the explanation of each score (Table S2).

Discussion

The aim of this systematic review was to assess the existing literature on whole-body PBM and exercise. Based on the current evidence, there is no benefit of whole-body PBM on exercise performance or recovery.

However, improved sleep is a potential benefit. Two of the selected studies suggest that whole-body PBM performed after exercise could enhance sleeping quality mediated by elevations in melatonin [17] and an improvement in nocturnal heart rate [21] in female team sports players. It is important to note that the latter study is observational, applying whole-body PBM across the season and comparing outcomes to pre-intervention baselines. This design introduces confounding factors that preclude establishing a causal relationship between PBM and improved sleep.

This potential improvement in sleep may be reflected in better recovery after exercise. However, biomarkers such as salivary IL-6 or blood CK were not affected during the 24–72 h following whole-body PBM before and after an exercise-induced muscle damage protocol in individuals experienced in resistance training [19]. Other biomarkers of inflammation, muscle damage and general recovery such as IL-6, TNF-α, CK and testosterone/cortisol ratio were not affected by whole-body PBM performed after exercise in male water polo players; LDH was modestly reduced in the treatment group, but for only the second of three time points [18].

A systematic review by Leal-Junior et al. (2015) did not include CK levels in their meta-analysis due to high heterogeneity. Nevertheless, they reported that all included studies observed a significant effect of local PBM in reducing CK levels after exercise [9]. Additionally, a recent meta-analysis reported a reduction in CK and LDH levels, suggesting a reduction in muscle damage [12], which contrasts with our findings on whole-body PBM.

Regarding exercise performance, an improvement in a 12-minute running test during 14 days of whole-body PBM was reported only when comparing pre- to post-intervention values in the treated group. However, no effect was observed when PBM was compared to the placebo group [17]. This finding aligns with the meta-analysis conducted by Dutra et al. (2022), which reported no significant impact of local PBM on running performance, including measures such as time to exhaustion, time-trial, or repeated-sprint performance [11].

In agreement with this previous meta-analysis, which reported no effect of local PBM on muscle strength [11], Zagatto et al. (2020) found no effect of whole-body PBM on maximal voluntary contraction and squat jump in male water polo players receiving PBM after three water polo games compared to the sham intervention [18]. However, the meta-analysis by Li et al. (2024) did report an improvement in muscle strength, particularly in physically inactive individuals, though also in athletes [12]. All three meta-analyses observed improvements in single-joint endurance exercises (time to exhaustion and number of repetitions) [9, 11, 12].

Similar to the study by Forsey et al. (2023), which reported no effect on Wingate test performance in active males and females receiving whole-body PBM before a cycling test compared to the sham intervention [20], the meta-analysis by Dutra et al. (2022) found no effect of local PBM in all-out sprint cycling performance, but did observe an improvement in time to exhaustion [11].

However, these meta-analyses are not without limitations. Methodological errors such as double-counting participants from a single study can inflate sample sizes and increase the likelihood of finding positive results. Furthermore, including multiple studies from the same research groups can introduce bias due to shared methodologies or similar research approaches, further skewing the results.

There is an additional study, which did not meet our eligibility criteria but it is worth mentioning. A conference abstract described a crossover study of agility in ten healthy, young (22.60 ± 3.27 years) trained participants following 10 min of whole-body PBM (13.85 J/cm^2, 46.17 mW/cm^2) or sham irradiation. The study concluded that the treatment had no effect on the Illinois Agility Test [25].

In the field of sports injury, a systematic review and meta-analysis compiled results from six studies to investigate the effect of PBM on pain and return to play in injured athletes. The authors concluded that, while there is evidence that PBM reduces pain considerably (a standardized mean difference of 1.03 was calculated), the time elapsed before the injured athletes could resume full sports participation was apparently not altered [26]. However, as only two studies in the review reported return to play time, the authors could not perform a meta-analysis on this outcome.

Four studies on whole-body PBM have been identified on non-exercise related topics but with potential applications to sports injury management. A clinical improvement and anti-inflammatory effect in children with recurrent respiratory disease was reported by Falus, et al. [27], and an improvement in cognitive tests in patients with COVID-19 brain fog was reported by Bowen and Arany [28], both after 4–5 weeks of whole-body PBM therapy. The other two studies reported a reduction in pain and better quality of life in patients with fibromyalgia after 4–6 weeks of whole-body PBM therapy, with these benefits maintained at their respective 6-month follow-ups [29–32].

These studies could have potential applications in sports injuries, such as during the inflammatory process, pain modulation, and support for cognitive recovery after traumatic brain injuries. Currently, there are no studies performed on these topics using whole-body PBM.

A major limitation of this systematic review is that there is a small number of studies on whole-body PBM including a total of only 105 participants, with heterogeneous study outcomes, which prevented us from performing a meta-analysis. Additionally, in our discussion, we compared our findings with those of previous meta-analyses focused on local PBM studies, but the differing findings with this current review cannot be fully explained. Another obstacle to the derivation of strong conclusions from the available literature is the variation in irradiance, light source distance, and exposure duration between studies. For example, while two studies comprised several treatment sessions over a period of weeks or months [17, 21], two others confined treatment to a single day [19, 20].

One of the differences between whole-body and local PBM is the distance between the light source and the skin. If the light source is further away as is the case during whole-body PBM, the penetration of light into the skin decreases and the intensity required is higher. The lack of positive results observed in this review could be due to the PBM parameters such as power density and fluence. In order to understand the discrepancy with results from studies on local PBM, further research on whole-body PBM is needed, ideally enrolling larger study cohorts and adhering to standardized treatment parameters.

Nevertheless, the practicality of whole-body PBM in sports is constrained by the substantial size and limited portability of these devices, making them challenging to transport and utilize during away competitions. Additionally, their high cost further limits widespread adoption.

Conclusion

High-performance athletes and coaches are continuously seeking new ways to improve exercise performance and recovery. In the recent years, it has been suggested that PBM may have performance-enhancing effects. Several companies are using the evidence behind local PBM to support their whole-body devices, but a comprehensive review of the current literature has been lacking.

This systematic review does not support the use of whole-body PBM for exercise performance and recovery. The only suggested benefit observed in this review is better sleep after the use of whole-body PBM, although the evidence is limited.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10103-025-04318-w.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Human Ethics and Consent to participate Not applicable.

Competing interests The authors declare no competing interests.

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