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REVIEW ARTICLE

Photobiomodulation therapy for the improvement of muscular performance and reduction of muscular fatigue associated with exercise in healthy people: a systematic review and meta-analysis

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Abstract Researches have been performed to investigate the effects of phototherapy on improving performance and reduction of muscular fatigue. However, a great variability in the light parameters and protocols of the trials are a concern to establish the efficacy of this therapy to be used in sports or clinic. The aim of this study is to investigate the effectiveness, moment of application of phototherapy within an exercise protocol, and which are the parameters optimally effective for the improvement of muscular performance and the reduction of muscular fatigue in healthy people. Systematic searches of PubMed, PEDro, Cochrane Library, EMBASE, and Web of Science databases were conducted for randomized clinical trials to March 2017. Analyses of risk of bias and quality of evidence of the included trials were performed, and authors were contacted to obtain any missing or unclear information. We included 39 trials (861 participants). Data were reported descriptively through tables, and 28 trials were included in meta-analysis comparing outcomes to placebo. Meta-analysis was performed for the variables: time until reach exhaustion, number of repetitions, isometric peak torque, and blood lactate levels showing a very low to moderate quality of evidence and some effect in favor to phototherapy. Further investigation is required due the lack of methodological quality, small sample size, great variability of exercise protocols, and phototherapy parameters. In general, positive results were found using both low-level laser therapy and light-emitting diode therapy or combination of both in a wavelength range from 655 to 950 nm. Most of positive results were observed with an energy dose range from 20 to 60 J for small muscular groups and 60 to 300 J for large muscular groups and maximal power output of 200 mW per diode.

Keywords Phototherapy · Low-level light therapy · Light emitting diode · Performance · Fatigue · Exercise

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Introduction

Strategies to improve performance and reduce muscular fatigue have been investigated in a number of studies in the sports and physical activity fields [1–3]. The aim of these strategies was to provide improvement in muscular performance, decrease muscular fatigue signals, and shorten the recovery process after an activity. Ultimately, these strategies enable the athlete to be better prepared for training or competition. These strategies may also be beneficial for patients in a rehabilitation process while the potential of more efficient exercises may increase the rehabilitation or recovery process.

Various methods to improve muscular performance or slowing down of the signals of muscular fatigue have been studied, such as massage, warm-up, compression garments, and cryotherapy

[4–8]. Scientific evidence regarding the effectiveness of such strategies remains, however, unclear and theoretical [7–9].

Photobiomodulation therapy using low-level laser therapy (LLLT) and light-emitting diode therapy (LEDT) has also been utilized to increase muscular performance and reduce muscular fatigue signals [10, 11]. Photobiomodulation therapy achieving its photobiomodulation effects (i.e., biostimulation or bioinhibition of chemical and physiological functions) when used with optimal parameters inside a specific "therapeutic window" has been well described [12, 13]. Consequently, efforts have been made to establish a range of optimal dose–responses that influence cellular activity [11–14]. Moreover, although the proposed mechanism of photobiostimulation is through increasing cytochrome c-oxidase expression at the mitochondrial level, which leads to an increase in adenosine triphosphate (ATP) production [15, 16], a better muscular response when applied in combination with physical exercise is expected.

Two systematic reviews have been previously published on the effectiveness of photobiostimulation through photobiomodulation therapy on muscular performance [10, 11]. Most studies included in both reviews demonstrated positive outcomes regarding the effectiveness of photobiomodulation therapy on muscle by improving performance and showing ergogenic effects when applied before the exercise. Nonetheless, the results of the published data remained inconclusive, and further research was required to make valid inferences on the estimated effect of photobiomodulation therapy. Since the publication of the last review [11], significant advances have been observed in the literature on the use of photobiomodulation therapy to improve muscle performance [17–20], and the investigation of its effects on this field continues [21]. Therefore, this systematic review aimed to update the current knowledge on the effects of photobiostimulation combined with exercise for muscle performance improvement and muscular fatigue reduction in both athletes and healthy people. Specifically, this systematic review evaluated the effectiveness of the addition of photobiomodulation therapy to an exercise protocol in reducing muscle fatigue and improving muscle performance in healthy individuals between 18 and 40 years; when photobiomodulation therapy should be applied within an exercise protocol to be optimally effective in reducing muscle fatigue and improving muscle performance in healthy individuals; and which photobiomodulation therapy light parameters are optimally effective in reducing muscle fatigue and improving muscle performance in healthy individuals.

Methods

Protocol and registration

This systematic review was conducted in accordance with the PRISMA statement. The review protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO – registration #CRD42015024010), and it can be accessed at https://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015024010.

Eligibility criteria

Only randomized controlled trials (RCTs) that tested the effectiveness of photobiomodulation therapy (laser or light-emitting diode [LED] lights) in reducing muscle fatigue signals and/or improving muscular performance in healthy adults, athletes, or physically active individuals, from 18 to 40 years old, against no intervention or placebo group were considered as eligible. The participants should have been enrolled in an exercise session or in a strength or aerobic training protocol with photobiomodulation therapy irradiation applied at any time of the physical exercise proposed.

Search strategy

Systematic electronic searches were conducted on PubMed, Embase, PEDro, Web of Science, and Cochrane Central Register of Controlled Trials. The searches were not limited by date or language of publication, and they were structured following the Cochrane Collaboration recommendations [22]. The last day of the search for articles was March 19, 2017. The reference lists of the full texts screened were searched manually to obtain potentially eligible studies that were not retrieved electronically.

Study selection

One reviewer (AAV) conducted the searches. This reviewer also screened each article based on title information followed by abstract and keyword analysis. After this first step, two independent reviewers (AAV and EV) conducted the inclusion of all full-text articles that remained for inclusion.

Evaluation of the risk of bias

Risk of bias of the eligible studies was evaluated through Cochrane Collaboration's tool for assessing risk of bias of randomized trials [22]. The classification of this tool includes seven items assessing risk of bias: selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting), and other sources of biases [22].

The judgment for each item was classified as "low risk" (+), "high risk" (−), or "unclear risk of bias" (?) [22]. The last was considered when information is lacking or uncertain regarding the potential risk of bias. Two reviewers (AAV and SDB) scored

Table 1 Methods, participants, interventions, and outcomes

Authors	Year	Setting	Design	Sample size (n)	Participants	Outcome assessment condition	Placebo	Main outcomes
Almeida et al. [24]	2012	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial.	10	Untrained healthy male students (22.30 ± 2.26 years)	Isometric contraction of elbow flexors (nondominant arm) on the Scott bench for 60 s.	Not specified.	Peak force (kgf) Average force (kgf)
Alves et al. [25]	2014	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial.	18	Untrained healthy male and female (22 ± 1 years)	Cardiopulmonary exercise testing in electromagnetic cycle ergometer (70 rpm).	Device turned off.	Total exercise time (s) Heart rate (HR, bpm) Absolute VO2 max (mL/min) Relative VO2 max (mL/kg min) Work load RPE Systolic blood pressure (mmHg) Blood lactate concentration (mmol/L) Electromyography fatigue threshold (s)
Antonialli et al. [14]	2014	Laboratory	Randomized, double-blinded, placebo-controlled trial.	40	Untrained healthy male (24.10 ± 1.52 years).	Eccentric isokinetic exercise protocol (knee extensor musculature of the nondominant leg—five sets of 15 reps, velocity of 60°/seg).	Device turned on but without laser irradiation.	Isometric peak torque (MVC-Nm) DOMS (VAS - mm) CK activity (U/L) DOMS–algometry (kgf)
Baroni et al. [26]	2010a	Laboratory	Randomized double-blind placebo-controlled trial.	36	Untrained healthy male (25.35 ± 3.41 years LLLT group, 24.28 ± 5.48 years placebo group)	Eccentric isokinetic exercise protocol (knee extensor musculature of the nondominant leg—five sets of 15 reps, velocity of 60°/seg).	Device turned off.	Isometric peak torque (MVC-Nm) DOMS CK activity (IU/L) LDH (IU/L)
Baroni et al. [27]	2010b	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial.	17	Untrained, healthy and physically active subjects (26.29 ± 4.33 years).	30 maximal isokinetic concentric repetitions of knee flexion–extension performed at an angular velocity of 180°/seg with a 90-degree ROM (knee extensor musculature of the dominant leg).	Device turned off.	Isometric peak torque (MVC-Nm) AVG peak torque (Nm) AVG power (W) Total work (J) Work fatigue index (%)
Baroni et al. [66]	2015	Laboratory	Randomized clinical trial	30	Untrained, healthy male (23.20 ± 2.15 years control group, 24.50 ± 3.53 years training group, and 21.60 ± 2.63 years training + LLLT)	8-week knee extensor isokinetic eccentric training program (eccentric isokinetic exercise protocol - knee extensor musculature of the nondominant leg—3-4 sets of 10 reps, velocity of 60°/seg).	No placebo group.	Isometric peak torque (MVC-Nm) Concentric peak torque (Nm) Eccentric peak torque (Nm) Muscle thickness (cm)
Borges et al. [28]	2014	Laboratory	Randomized double-blinded placebo-controlled trial.	17	Untrained healthy male (22 ± 1 years LEDT and 21 ± 1 years placebo)	30 eccentric contractions with a load of 100% of maximal voluntary isometric contraction strength of the elbow flexors of the nondominant arm (weighted dumbbells).	A small protective shield was placed over the tip of the probe LEDT blocking the irradiation.	Isometric muscle strength (N) Muscle soreness (cm) Elbow range of motion (ROM-deg)
De Marchi et al. [29]	2012	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial.	22	Untrained healthy male (22.02 ± 3.02 years).	Progressive running protocol on a motor-driven treadmill	Not specified.	Time to exhaustion (s) Absolute VO2 max (L/min) Relative VO2 max (mL/kg min) Aerobic threshold (s and L/min) Anaerobic threshold (s and L/min) TBARS (nmol/mL)

Table 1 (continued)

Authors	Year	Setting	Design	Sample size (*n*)	Participants	Outcome assessment condition	Placebo	Main outcomes
								Carbonylated proteins (nmol) SOD activity (U SOD/g of protein) CAT activity (U CAT/mg of protein) CK activity (U/L) LDH (U/L)
De Marchi et al. [17]	2017	Laboratory	Randomized, double-blinded, placebo-controlled trial	40	Healthy physically active male volunteers (25.30 ± 3.32)	Fatigue-induced protocol by performing 5 sets of 10 eccentric/concentric contractions of the elbow flexors (isokinetic dynamometer)	Device turned on but without laser irradiation.	Isometric Peak torque (MVC-Nm) DOMS TBARS (nmol/mL) Carbonylated proteins (nmol) CK activity (U/L)
De Paiva et al. [18]	2016	Laboratory	Randomized, double-blind, placebo-controlled clinical trial	50	Untrained healthy male (24.98 ± 5.9 years).	Eccentric isokinetic exercise protocol (knee extensor musculature of the nondominant leg—five sets of 15 reps, velocity of 60°/seg).	Device turned on but without laser irradiation.	MVC DOMS CK activity (U/L)
De Souza et al. [19]	2016	Laboratory	Randomized, blinded controlled clinical trial	60	Young and physically active volunteers of both genders (22.6 ± 2.7)	Fatigue-induced protocol by performing 100 isokinetic concentric contractions of ankle plantar flexors at a speed of 90°/s.	Second pen of the laser device which was disconnected and did not effectively irradiate energy.	Dynamometric fatigue index Median frequency
Denis et al. [30]	2013	Laboratory	Randomized, single-blinded, placebo-controlled, crossover trial.	18	Athletes healthy male (soccer, hockey, and rugby union) (22.1 ± 4.1 years).	Wingate anaerobic test Yoyo intermittent recovery test	Not specified.	Work (kJ) Blood lactate levels (mmol/L) Peak power (W) Fatigue index (%)
Felismino et al. [31]	2014	Laboratory	Randomized double-blind placebo-controlled study.	22	Physically active healthy males (25.09 ± 4.6 years placebo group and 26.1 ± 4.1 years LLLT group).	Biceps curl exercise—10 sets of 10 repetitions with a load of 50% of 1RM	Device turned off	CK activity (%) 1-RM
Ferraresi et al. [32]	2011	Laboratory	Randomized controlled clinical trial.	36	Healthy male (19.7 ± 0.8 years training + laser group, 21.2 ± 2.5 years training group, and 21.8 ± 2.1 years control group).	Dynamic strength training program involving the leg-press exercise twice a week for 12 consecutive weeks.	No placebo group.	1-RM leg test (%), MPID test Thigh perimetry (%)
Ferraresi et al. [56]	2015	Field	Randomized, double-blind, and placebo-controlled trial.	12	Athletes (male volleyball players) (25.5 ± 5.3 years).	4 matches during a national championship.	Device turned on but without laser irradiation.	CK activity (U/L)
Fritsch et al. [33]	2016	Laboratory	Randomized, double-blinded, placebo-controlled trial	24	healthy male volunteers (24 ± 2.58)	Plyometric exercises	Device turned off	Isometric Peak torque (MVC-Nm) Echo intensity (ultrasonography) Muscle soreness (VAS)
Gorgey et al. [34]	2008	Laboratory	Randomized, crossover trials (pilot study)	5	Untrained healthy male students (19 ± 0.7 years).	NMES protocol was delivered for 3 min to induce fatigue in the knee extensor muscle group (two test trials (LLLT 3 e 7 J + NMES) and a control trial (NMES only)).	No placebo group.	MVC (Nm)
Hemmings et al. [35]	2017	Laboratory	Randomized, blind placebo-controlled cross-over trial	34	recreational resistance-trained athletes (both genders) (21.1 ± 2.0)	Eccentric leg extension with 120% of MVC until fatigue (isokinetic dynamometer).	Device turned off and the beep sound was simulated from another laser probe.	Number of repetitions Isometric Peak torque (MVC-Nm) Blood lactate

Table 1 (continued)

Authors	Year	Setting	Design	Sample size (n)	Participants	Outcome assessment condition	Placebo	Main outcomes
Higashi et al. [36]	2013	Laboratory	Randomized, triple-blind, placebo-controlled, crossover trial.	20	Active healthy females (21.9 ± 1.1 years).	Elbow flexion-extension movement as possible with 75% of weight of 1-RM.	Not specified	Blood lactate (p value/graphs), EMG fatigue (p value/graphs), Number of elbow flexion-extension repetitions
Kelencz et al. [37]	2010	Laboratory	Randomized clinical trial.	30	Healthy males and females (7 men, 23 women) (23 ± 3 years).	MVC lasted 60 s.	Device turned off	Activity of the right masseter (μV) Activity of the left masseter (μV) Maximal force (kgf) Mean force (kgf) Time to exhaustion (s)
Leal-Junior et al. [38]	2008	Laboratory	Randomized double-blind placebo-controlled trial.	12	Athletes (male volleyball players) (22 ± 3 years)	Voluntary biceps contractions - load of 75% of the MVC	a small protective shield was placed over the tip of the probe blocking the laser energy	Blood lactate (mmol/L) Time to exhaustion (s) Number of repetitions
Leal-Junior et al. [39]	2009a	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial.	8	Athletes (male volleyball players) (18.50 ± 0.93 years)	Wingate test (cycling at maximal speed for 30 s with a load of 7.5% of the athlete's body weight)	Not specified	Blood lactate (mmol/L) CK activity (U/L) Peak power output (W/kg) Mean power output (W/kg)
Leal-Junior et al. [40]	2009b	Laboratory	Randomized double-blinded placebo-controlled cross-over trial.	10	Athletes (male volleyball players) (23.6 ± 5.6 years).	Voluntary biceps humeri contractions with a workload of 75% of their maximal voluntary contraction force.	Not specified	Number of repetitions Time to exhaustion (s) CK activity (U/L) Blood lactate (mmol/L) CRP levels (mg/dL)
Leal-Junior et al. [41]	2009c	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial	20	Athletes (male volleyball and soccer players). Volleyball n = 9 (20.67 ± 2.96 years) Soccer n = 11 (16.18 ± 0.75 years)	Wingate test (cycling at maximum speed for 30 s against a load of 7.5% of the athlete's body weight).	Not specified	Muscle Work (J) Blood lactate (mmol/L) CK activity (U/L)
Leal-Junior et al. [42]	2009d	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial	10	Athletes (male volleyball players) (22.30 ± 6.09 years).	Voluntary biceps humeri contractions with a workload of 75% of their maximal voluntary contraction force.	Not specified	Number of repetitions Blood lactate (mmol/L) Time to exhaustion (s)
Leal-Junior et al. [43]	2010	Laboratory	Randomized double-blind placebo-controlled cross-over trial.	9	Athletes (male volleyball players) (18.6 ± 1 years).	Voluntary biceps humeri contractions with a workload of 75% of their maximal voluntary contraction force until exhaustion.	Not specified.	Number of repetitions Time to exhaustion (s) Blood lactate (mmol/L) CK activity (U/L) C-reactive protein (mg/dL)
Leal-Junior et al. [44]	2011a	Laboratory	Randomized double-blind placebo-controlled cross-over trial	6	Athletes (male young futsal athletes) (20.67 ± 2.96).	Wingate test (cycling at maximum speed for 30 s against a load of 7.5% of the athlete's body weight).	Not specified.	Peak Power (W/kg) Mean Power (W/kg) Blood lactate levels (mmol/L) CK activity (U/L) CRP levels (mg/dL).
Leal-Junior et al. [45]	2011b	Laboratory	Randomized double-blind placebo-controlled cross-over trial.	6	Athletes (male volleyball players) (18.57 ± 0.98 years).	Wingate test (cycling at maximum speed for 30 s against a load of 7.5% of the athlete's body weight).	Equipment on placebo mode (without active irradiation)	Peak power (W/kg) Mean power (W/kg) Fatigue index (%) TBARS levels (nmol/mL)
Maciel et al. [46]	2013	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial	7	Athletes (female volleyball players) (22.57 ± 3.82 years).	Jumps and isometric plantiflexion exercise	Not specified.	Peak force (N) Horizontal jump (cm) Vertical jump (cm) Time to fatigue (s)

Table 1 (continued)

Authors	Year	Setting	Design	Sample size (*n*)	Participants	Outcome assessment condition	Placebo	Main outcomes
								RMS lateral gastrocnemius (µV) RMS medial gastrocnemius (µV)
Malta et al. [47]	2016	Laboratory	Randomized, crossover, double-blind, placebo-controlled clinical trial	15	Caucasian males moderately active and healthy males (25.1 ± 4.4 years)	Graded exercise test and two supramaximal efforts at 115% of the intensity associated with maximal oxygen uptake.	Device turned off and subjects using blindfolds and wearing headphones to avoid perceiving light and sound signals during the LEDT session.	Alternative maximal accumulated oxygen deficit ($MAOD_{ALT}$) Time to exhaustion Respiratory exchange ratio RPE
Miranda et al. [20]	2016	Laboratory	Randomized, double-blind, placebo-controlled, crossover trial	20	Untrained healthy male (26.0 ± 6.0 years).	Progressive cardiopulmonary test on a treadmill.	Device turned on but without laser irradiation.	Distance covered (km) Time until exhaustion (s) Pulmonary ventilation (L/min) Oxygen uptake (mL/kg/min Carbon dioxide production (mL/kg/min) Dyspnea score
Pinto et al. [48]	2016	Field	Randomized, double-blind, placebo controlled, crossover trial.	12	Athletes (male rugby players) (23.50 ± 2.32 years)	Bangsboo Sprint Test (BST) (field test)	Device turned on but without laser irradiation.	Blood lactate (mmol/L) Fatigue Perception (questionnaire) ST-Mean (from BST) ST-Best (from BST) Fatigue index (from BST)
Reis et al. [49]	2014	Laboratory	Randomized, double blind, and placebo controlled	27	Athletes (male soccer players) (22.62 ± 8.03 years)	Leg extension exercise with a load at 75% of 1RM.	Not specified	Blood lactate (mmol/L) CK activity (U/L) Time to fatigue (s) Number of repetitions 75% of maximum load (RM)
Rossato et al. [50]	2016	Laboratory	Randomized, crossover, double-blind, placebo-controlled trial	10	Physically active healthy male (29 ± 6.0 years)	Isometric contraction at 60% of MVC.	Device turned off	Time to exhaustion Isometric Peak torque (MVC-Nm) EMG
Vanin et al. [51]	2016a	Laboratory	Randomized, double-blind, placebo-controlled trial	28	High-level soccer athletes	Eccentric isokinetic exercise protocol (knee extensor musculature of the nondominant leg—five sets of 15 reps, velocity of 60°/seg).	Device turned off	Isometric Peak torque (MVC-Nm) DOMS CK activity IL-6 expression
Vanin et al. [52]	2016b	Laboratory	Randomized, double-blind, placebo-controlled trial	48	Physically active healthy males (26 ± 5.24 years)	Leg Press and Leg Extension exercises twice a week—5 series of 10 repetitions with 80% of 1 RM.	Device turned on but without laser irradiation.	Isometric Peak torque (MVC-Nm) 1-RM Perimetry
Vieira et al. [53]	2012	Laboratory	Randomized controlled clinical trial.	45	Physically active healthy female students (21.2 ± 2.1 years control group, 20.5 ± 1.3 years training group, and 21.2 ± 1.7 years training with LLLT group)	Cycle ergometer exercise with load applied to the ventilatory threshold (VT) for three times a week for 9 consecutive weeks–-endurance training.	No placebo group	Fatigue index (FIext - %?) Total work (TWext – J?) Ventilatory threshold Body mass (kg) BMI (kg/m^2)
Vieira et al. [54]	2014	Laboratory	Randomized, double-blind, placebo controlled, crossover trial.	7	young men (21 ± 3 years of age) who were clinically healthy	Three sets of 20 RM of knee flexion-extensions using an isokinetic dynamometer at 60°/s (workout)	Device probe turned off.	RM EMG fatigue index

Table 1 (continued)

Authors	Year	Setting	Design	Sample size (*n*)	Participants	Outcome assessment condition	Placebo	Main outcomes
Zagatto et al. [55]	2016	Field	Randomized, double-blinded, placebo-controlled trial.	20	Athletes (male water polo players) (15.4 ± 1.2 years)	Five training days	Device turned on but without laser irradiation.	Time to cover 200-m maximal swimming (P200) 30-s crossbar jump test (30CJ) RPE (a.u.) IL-1β (pg/mL) IL-10 (pg/mL) TNF-alpha (pg/mL) Creatine kinase activity (U/L) LDH

LEDT light-emitting diode therapy, *LLLT* low-level laser therapy, *NMES* neuromuscular electrical stimulation, *CK* creatine kinase, *MVC* maximal voluntary contraction, *IL* interleukin, *LDH* lactate dehydrogenase, *RPE* rating of perceived exertion, *BMI* body mass index, *RM* repetition maximum, *EMG* electromyography, *DOMS* delayed onset muscle soreness, *VAS* visual analogic scale, *MPDI* isokinetic muscle performance in isokinetic dynamometry, *ST-mean* mean sprint time, *ST-Best* best sprint time, *BST* Bangsbo test, *CRP* C- reactive protein, *SOD* superoxide dismutase, *CAT* catalase

each trial independently for risk of bias. A third reviewer (EV) was consulted for consensus rating whenever needed.

Quality of evidence

The quality of evidence was assessed using the GRADE approach [22]. The quality of evidence of the included studies refers to a body of studies, and not to individual studies. Some factors, such as risk of bias, inconsistency, indirectness, imprecision, and publication bias, are associated with this judgment, and they may lead to upgrading or downgrading the quality of evidence of an outcome from a group of studies [22, 23]. The quality of evidence can be presented in four categories: high (enough evidence in the estimate of the effect), moderate (the true effect is close to the estimate of the effect), low (the confidence of the effect is limited), and very low (little confidence of the effect estimate) [23].

Data extraction

Data were extracted from studies on participants' characteristics (healthy adults), interventions (photobiomodulation therapy) compared with control and/or placebo groups, exercise protocol enrolled (short- or long-term exercise, any type of exercise protocol), moment of irradiation (before, during, or after an exercise session), and variables related to reducing fatigue signals and/or improvement of performance. Data extraction was performed by one reviewer in a standardized predefined way, and summarized by tabulation (Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11). In case data were not reported in the article, the correspondent author was contacted by e-mail. A reminder e-mail was sent after 1 week. Their answers or lack of "response" were noted.

For the purpose of this review, muscular *performance* is defined as the capacity of the skeletal muscle to generate force to be developed in a certain physical exercise or sport. The variables most related to muscular performance were strength [57], power, and endurance [58, 59], and they are generally measured by isokinetic dynamometer tests, functional tests, and variables related with exercise execution. Muscle fatigue can negatively affect optimal muscle capacity [60]; thus, both concepts are enrolled.

In this perspective, we define *muscle fatigue* as a gradual decrease in maintaining the maximal capacity of force generation or power output, and it reflects the decrease of performance and impairment in motor control [58, 61–63]. Peak torque, total work, fatigue index, mean peak torque are variables frequently associated with muscle function; therefore, the rate of decrease of these indices can estimate muscle fatigue [58, 62]. Muscle fatigue is frequently related to the inability to continue the execution of the exercise, impairment in muscle contraction, effort perceived, and increase in blood levels of muscle damage markers [64, 65].

With these concepts in mind, the variables chosen are involved in modulating biochemical marker release (such as

Table 2 Photobiomodulation therapy parameters (intervention)

Authors	Source of light	Wavelength (nm)	Energy density per diode (J/cm^2)	Energy per site (J)	Power density per diode (W/cm^2)	Spot size (cm^2)
Almeida et al. [24]	Red or Infrared LLLT	660 or 830	1.785	5	17.85	0.0028
Alves et al. [25]	Infrared LLLT (cluster with 7 diodes)	850	40	14 (2 J per diode)	2	0.05
Antonialli et al. [14]	Super-pulsed LLLT, red LEDTs and infrared LEDTs	Cluster of 12 diodes (4 of 905 nm, 4 of 875 nm and 4 of 640 nm)	10 J: 0.05 (905 nm) 1.27 (640 nm) 1.48 (875 nm) 30 J: 0.16 (905 nm) 3.80 (640 nm) 4.42 (875 nm) 50 J: 0.27 (905 nm) 6.35 (640 nm) 7.41 (875 nm)[a]	10, 30 or 50	0.00071 (905 nm) 0.01666 (640 nm) 0.01944 (875 nm)	20 cm^2 (cluster): - 0.44 cm^2 (905 nm) - 0.9 cm^2 (875 nm and 640 nm)
Baroni et al. [26]	Infrared LLLT (cluster with five diodes)	810	206.89[a]	30 J (6 J each diode)	6.89[a]	0.029
Baroni et al. [27]	Red and infrared LEDTs (cluster probe with 34 diodes of red and 35 diodes of infrared)	660 and 850	1.5 J/cm^2 (red), 4.5 J/cm^2 (infrared)	41.7	0.05 (red), 0.15 (infrared)	0.2
Baroni et al. [66][b]	Infrared LLLT (cluster with five diodes)	810	206.89[a]	30 J (6 J each diode)	6.89[a]	0.029
Borges et al. [28]	Red LEDT (single diode)	630	5.1	9[a]	0.1695[a]	1.77
De Marchi et al. [29]	Infrared LLLT (cluster with 5 diodes)	810	164.85	30 (6 J each diode)	5.495	0.0364
De Marchi et al. [17]	Red and infrared LEDTs (cluster with 34 red and 35 infrareds diodes)	660 and 850	1.5 (red) and 4.5 (infrared)	41.7 (0.3 from each red LED and 0.9 from each infrared laser)	0.05 (for red) and 0.15 (for infrared)	28.2 (cluster)-0.2 each diode
De Paiva et al. [18]	Super-pulsed LLLT, Red LEDTs and Infrared LEDTs	Cluster of 9 diodes (1 of 905 nm, 4 of 875 nm and 4 of 640 nm)	0.85 (905 nm) 5 (640 nm) 5.83 (875 nm)	39.37	0.00284 (905 nm) 0,01667(640 nm) 0,01944 (875 nm)	4 cm^2 - 0.44 cm^2 (905 nm) - 0.9 cm^2 (875 nm and 640 nm)
De Souza et al. [19]	Infrared LLLT (single diode)	808	1785[a]	5	35.7	0.0028
Denis et al. [30]	Red and Infrared LEDTs (cluster probe with 34 red LEDs and 35 infrared LEDs)	660 and 950	1.5 (red) and 2.25 (infrared)[a]	25.95	0.05 (red) and 0.075 (infrared)	0.2
Felismino et al. [31]	Infrared LLLT (single diode)	808 nm	357.14	1	35.71	0.0028
Ferraresi et al. [32]	Infrared LLLT (cluster with six diodes)	808	214.28	0.6	21.42	0.0028
Ferraresi et al. [56]	LEDT (array of 200 diodes—100 infrared and 100 red)	850 and 630	105 J: 0.93 (850 nm) and 0.57 (630 nm) 210 J: 1.86 (850 nm) and 1.14 (630 nm) 315 J: 2.78 (850 nm) and 1.71 (630 nm)	105, 210 or 315	0.1625 (infrared) and 0.1 (red)	0.2
Fritsch et al. [33]	Infrared LLLT (cluster with five diodes)	850	206.9	30	6.9	0.029
Gorgey et al. [34]	Infrared LLLT	808	na	3 or 7	0.0083	Not applicable
Hemmings et al. [35]	Red and Infrared LEDTs (cluster with 34 red and 35 infrared diodes)	660 and 850	41.7 J: 1.4 (red) and 4.5 (infrared) 83.4 J: 3 (red) and 9 (infrared) 166.8 J: 6 (red) and 18 (infrared)	41.7 (0.3 from each red LED and 0.9 from each infrared LLLT) 83.4 (0.6 from each red LED and 1.8 from each infrared) 166.8 (1.2 from each red LED and 3.6 from each infrared)	0.05	28.2 (cluster)–0.2 each diode
Higashi et al. [36]	Infrared LLLT (single diode)	808	250	7	35.7	0.0028
Kelencz et al. [37]	Red LEDT (single diode)	640	2, 4, or 6	1.044, 2.088, or 3.132	0.222	0.522
Leal-Junior et al. [38]	Red LLLT (single diode)	655	500	5	5	0.01
Leal-Junior et al. [39]	Infrared LLLT (single diode) or red and infrared LEDTs (cluster with 34 red and 35 infrareds diodes)	810 (LLLT)/660 and 850 (LEDs)	164.84/1.5 and 4.5	6/41.7	5.50/0.05 and 0.15	0.0364/0.2
Leal-Junior et al. [40]	Red and infrared LEDTs (cluster with 34 red and 35 infrareds diodes)	660 and 850	1.5 (red) and 4.5 (infrared)	41.7 (0.3 from each red LED and 0.9 from each infrared laser)	0.05 (red) and 0.15 (infrared)	0.2
Leal-Junior et al. [41]	Infrared LLLT (single diode)	830	1071.42 or 1428.57	3 or 4 J	35.71	0.0028
Leal-Junior et al. [42]	Infrared LLLT (single diode)	830	1785.71	5	35.7	0.0028
Leal-Junior et al. [43]	Infrared LLLT (cluster with 5 diodes)	810	164.85	30 J (6 J each diode)	5.495	0.0364
Leal-Junior et al. [44]	Red and infrared LEDTs (cluster with 34	660 and 850	1.5 (red) and 4.5 (infrared)	41.7 (0.3 from each red LED and 0.9	0.05 (red) and 0.15 (infrared)	0.2

Table 2 (continued)

Authors	Source of light	Wavelength (nm)	Energy density per diode (J/cm^2)	Energy per site (J)	Power density per diode (W/cm^2)	Spot size (cm^2)
	red and 35 infrareds diodes)			from each infrared laser)		
Leal-Junior et al. [45]	Red and infrared LEDTs (cluster with 34 red and 35 infrareds diodes)	660 and 850	1.5 (red) and 4.5 (infrared)	41.7 (0.3 from each red LED and 0.9 from each infrared laser)	0.05 (red) and 0.15 (infrared)	0.2
Maciel et al. [46]	Infrared LLLT (single diode)	830	5.68	11	0.25	0.12
Malta et al. [47]	Red and infrared LEDTs	Cluster of 104 diodes (56 diodes of 660 nm and 48 diodes of 850 nm)	1.5 J/cm^2 (red) and 4.5 J/cm^2 (infrared)	60 J at each point (0.3 J from each red LED and 0.9 J from each infrared LED)	0.05 (660 nm) and 0.15 (850 nm)	69 cm^2 (cluster) 0.2 per diode
Miranda et al. [20]	Super-pulsed LLLT, Red LEDTs and Infrared LEDTs	Cluster of 12 diodes (4 of 905 nm, 4 of 875 nm and 4 of 640 nm)	30 J: 0.16 (905 nm) 3.80 (640 nm) 4.42 (875 nm)[a]	30	0.00071(905 nm) 0.01666 (640 nm) 0.01944 (875 nm)	20 cm^2 (cluster): - 0.44 cm^2 (905 nm) - 0.9 cm^2 (875 nm and 640 nm)
Pinto et al. [48]	Super-pulsed LLLT, Red LEDTs and Infrared LEDTs	Cluster of 12 diodes (4 of 905 nm, 4 of 875 nm and 4 of 640 nm)	30 J: 0.16 (905 nm) 3.80 (640 nm) 4.42 (875 nm)	30	0.00071(905 nm) 0.01666 (640 nm) 0.01944 (875 nm)	20 cm^2 (cluster): - 0.44 cm^2 (905 nm) - 0.9 cm^2 (875 nm and 640 nm)
Reis et al. [49]	Infrared LLLT (cluster with 6 diodes)	830	214.28	0.6	21.43	0.0028
Rossato et al. [50]	Large cluster probe (33 diodes) vs. Small cluster probe (9 diodes) - Both clusters have Laser and LEDTs.	Large cluster (5 lasers 850 nm, 12 LEDTs 670 nm, 8 LEDTs 880 nm and 8 LEDTs 950 nm). Small cluster (5 Lasers 850 nm and 4 LEDTs 670 nm)	Large cluster - 53.33(850 nm) - 0.156 (670 nm) - 0.625 (880 nm) - 0.391 (950 nm) Small cluster - 93.33 (850 nm) - 0.875 (670 nm)[a]	Large cluster 30 (total) - 3.2 (850 nm) - 0.3 (670 nm) - 0.8 (880 nm) - 0.5 (950 nm) Small cluster 30 (total) - 5.6 (850 nm) - 0.56 (670 nm)	Large cluster - 1.666(850 nm) - 0.0052 (670 nm) - 0.01953 (880 nm) - 0.01171 (950 nm) Small cluster - 1.666 (850 nm) - 0.01562 (670 nm)	Large cluster: 30.2 (total) - 0.06 (850 nm) - 1.92 (670 nm) - 1.28 (880 nm) - 1.28 (950 nm) Small cluster: 7.5 (total) - 0.06 (850 nm) - 0.64 (670 nm)
Vanin et al. [51]	Infrared LLLT (cluster with five diodes)	810	54.95, 164.84, 274.73	10, 30 or 50 (2, 6 or 10 J each diode)	5.495	0.18 (0.0364 each diode)
Vanin et al. [52]	Super-pulsed LLLT, Red LEDTs and Infrared LEDTs	Cluster of 12 diodes (4 of 905 nm, 4 of 875 nm and 4 of 640 nm)	30 J: 0.16 (905 nm) 3.80 (640 nm) 4.42 (875 nm)	30	0.00071(905 nm) 0.01666 (640 nm) 0.01944 (875 nm)	20 cm^2 (cluster): - 0.44 cm^2 (905 nm) - 0.9 cm^2 (875 nm and 640 nm)
Vieira et al. [53]	Infrared LLLT (cluster with six diodes)	808	214.28	3.6 (0.6 per diode)	21.42	0.0028
Vieira et al. [54]	Infrared LLLT (single diode)	808	1428.57	4	35.71	0.0028
Zagatto et al. [55]	Infrared LLLT (single diode)	810	107.14	3	3.57	0.028

Authors	Treatment time per point or site (s)	Power output per diode (mW)	Total Energy delivered (J)	Number of treated points or sites	Muscle treated	Moment of application
Almeida et al. [24]	100	50	20	4	Biceps brachii	Before
Alves et al. [25]	20	100	56[a]	4 (3 in quadriceps and 1 in gastrocnemius)	Quadriceps and gastrocnemius	Before
Antonialli et al. [14]	76, 228 or 381	- 0.3125 (905 nm) - 17.5 (875 nm) - 15 (640 nm)	60, 180, or 300	6	Quadriceps	Before
Baroni et al. [26]	30	200	180	6	Quadriceps	Before
Baroni et al. [27]	30	10 (red) and 30 (infrared)	125.1	3	Quadriceps	Before
Baroni et al. [66][b]	30	200	240	8	Quadriceps	Before
Borges et al. [28]	30	300	36[a]	4	Biceps brachii	After
De Marchi et al. [29]	30	200	360 per lower limb	12 sites per lower limb	Quadriceps (6 sites) Hamstrings (4 sites) Gastrocnemius (2 sites)	Before
De Marchi et al. [17]	30	10 (red) and 30 (infrared)	41.7	1	Biceps brachii	Before
De Paiva et al. [18]	300	- 1.25 (905 nm) - 15 (640 nm - 17.5 (875 nm)	236.22 per lower limb	6 sites on the nondominant lower limb	Quadriceps	After
De Souza et al. [19]	49	100	25	5	Soleus	Before
Denis et al. [30]	30	10 (red) and 15 (infrared)	103.8 per lower limb	4 per lower limb	Quadriceps	After
Felismino et al. [31]	10	100	4	4	Biceps brachii	Between the sets of exercise
Ferraresi et al. [32]	10 s each site—70 s per lower limb (total 140 s)	60	25.2 per lower limb	42 (total 84)	Quadriceps	After
Ferraresi et al. [56]	20, 40, or 60	32.5 (infrared) and 20 (red) each diode[b]	315, 630 or 945 each lower limb	3 sites (bilaterally)	Quadriceps, hamstrings and triceps surae	Before
Fritsch et al. [33]	30	200	240 per lower limb	8	Quadriceps	Before or after

Table 2 (continued)

Authors	Treatment time per point or site (s)	Power output per diode (mW)	Total Energy delivered (J)	Number of treated points or sites	Muscle treated	Moment of application
Gorgey et al. [34]	300 or 600	500	3 or 7 (scanning mode-no total energy described)	Scanning mode (no defined points)	Quadriceps	Before (scanning mode)
Hemmings et al. [35]	30, 60, and 120	10 (red) and 30 (infrared)	250.2, 500.4, or 1000.8[a]	6	Quadriceps	Before
Higashi et al. [36]	70	100	56	8	Biceps brachii	Before
Kelencz et al. [37]	9, 18 or 27	116	8.352, 16.704, or 25.056	8	Right masseter	After
Leal-Junior et al. [38]	100	50	20	4	Biceps brachii	Before
Leal-Junior et al. [39]	30 (both)	200/10 and 30	12/83.4 each lower limb	2 per lower limb (total of 4)	Quadriceps	Before
Leal-Junior et al. [40]	30	10 (red) and 30 (infrared)	41.7	1 (with 69 diodes)	Biceps brachii	Before
Leal-Junior et al. [41]	30 or 40	100	15 or 20 per lower limb	5 per lower limb (total of 10)	Quadriceps	Before
Leal-Junior et al. [42]	50	100	20	4	Biceps brachii	Before
Leal-Junior et al. [43]	30	200	60	2 (cluster with 5 diodes)	Biceps brachii	Before
Leal-Junior et al. [44]	30	10 (red) and 30 (infrared)	208.5 per lower limb	5 per lower limb (total of 10)	Triceps surae, rectus femoris and hamstrings	Before
Leal-Junior et al. [45]	30	10 (red) and 30 (infrared)	83.4 per lower limb	2 per lower limb (total of 4)	Quadriceps	Before
Maciel et al. [46]	22	30	220[a]	20	Triceps surae	After
Malta et al. [47]	30	10 mW (660 nm) and 30 mW (850 nm)	300 J per lower limb	5 in each lower limb	Quadriceps (two sites), Biceps femoris (two sites), Triceps surae (one site)	Before
Miranda et al. [20]	228	- 0.3125 (905 nm) - 17.5 (875 nm) - 15 (640 nm)	510 per lower limb	17 sites on each lower limb	Quadriceps, hamstring, and gastrocnemius muscles	Before
Pinto et al. [48]	228	- 0.3125 (905 nm) - 17.5 (875 nm) - 15 (640 nm)	510 per lower limb	17 sites on each lower limb	Quadriceps, hamstring, and gastrocnemius muscles	Before
Reis et al. [49]	10 per site (total 70s per lower limb)	60	25.2 per lower limb	7 per lower limb	Quadriceps	After
Rossato et al. [50]	Large cluster: 32 Small cluster: 56	Large cluster - 100 (850 nm) - 10 (670 nm) - 25 (880 nm) - 15 (950 nm) Small cluster - 100 (850 nm) - 10 (670 nm)	60	2	Biceps brachii	Before
Vanin et al. [51]	60, 180 or 300	200 per diode (total of 1000)	60, 180 or 300	6 sites	Quadriceps	Before
Vanin et al. [52]	228	- 0.3125 (905 nm) - 17.5 (875 nm) - 15 (640 nm)	180 per lower limb	6 sites on each lower limb	Quadriceps	Before and/or after
Vieira et al. [53]	10 per site (total 50s per lower limb)	60	18 per lower limb	5	Quadriceps	After
Vieira et al. [54]	40	100	20 each time point—applied three times (total 60 J)	5	Quadriceps	Between sets of exercise and after the last series (three applications in the same day)
Zagatto et al. [55]	30	100	24 per lower limb	8 each lower limb	Adductor magnus and adductor longus	After

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy

[a] Data calculated

[b] Authors cited that the device was the same of previous study

lactate, creatine kinase [CK], and C-reactive protein [CRP]), improving training response (peak torque, total work, and 1-RM test), and reducing fatigue signals (such as number of repetitions and time to exhaustion).

Data syntheses and analysis

A meta-analysis was performed using RevMan review management software (version 5.3) to summarize the treatment effect of photobiomodulation therapy on improving muscular performance and reducing muscular fatigue. Meta-analysis was only performed for those studies that compared photobiomodulation therapy to a placebo group due to the large amount of comparisons. Consequently, four studies were omitted from the meta-analysis [32, 34, 53, 66], but we presented these data descriptively.

Meta-analysis on continuous outcomes was conducted using means and standard deviations (SDs) from each of the eligible trials. Data were presented by standardized mean difference (SMD) when the data were presented in different outcome

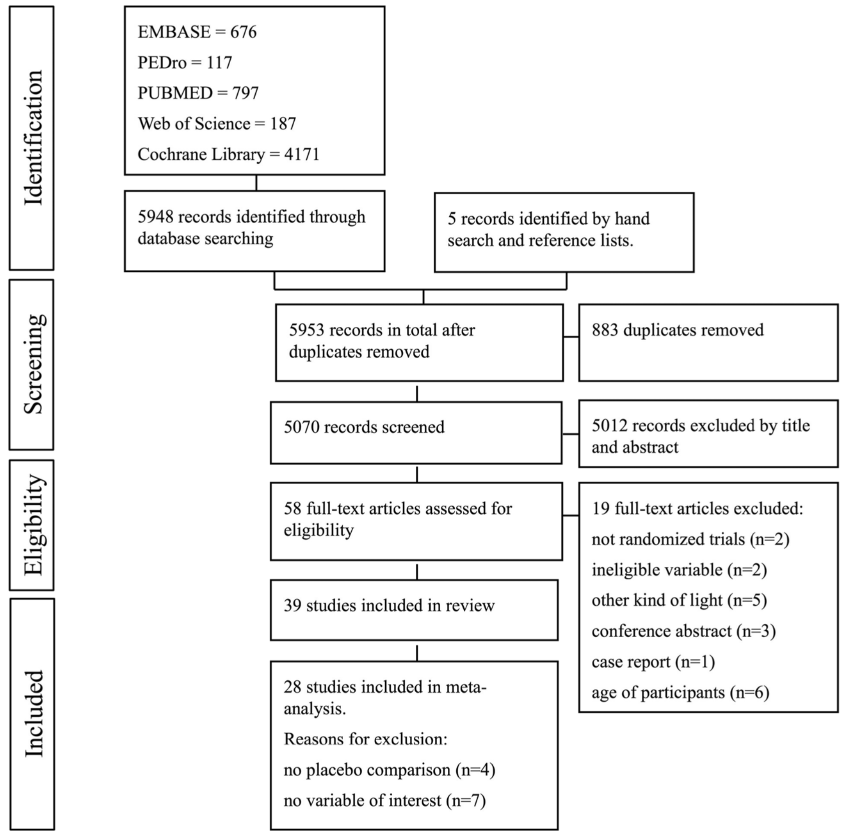


Fig. 1 Flowchart

measures and as mean difference (MD) if the studies used the same outcome measure [22]. Pooled effects were calculated using fixed effects to estimate the effect [22]. The within-group variation was assumed to be known. Heterogeneity was analyzed using Higgins I^2 values.

When there was more than one comparison from a single group, the number of participants in the common arm was divided by the number of comparisons [22]. If more than one time point was found in the study, all were shown in tables, but only the closest time point of the photobiomodulation therapy application was chosen for the analysis. Furthermore, if more than one photobiomodulation therapy dosage was tested in the experiment, the dosage with the largest effect was chosen for the meta-analysis.

Results

We included 39 randomized controlled trials (n = 861 participants) (Fig. 1). The study sample sizes ranged from 5 to 60 participants (median, 22.07 [13.82]). These studies were published between 2008 and 2017. Detailed description of the study characteristics can be found in Table 1. Twenty-one of the included studies performed crossover designs, and 18 were parallel trials (Table 1). The authors of 16 studies were contacted by e-mail for additional information, 11 authors (68.75%) provided the required data [28, 30, 31, 38, 43, 48–51, 53, 55], with 1 (6.25%) answering that they did not have the information anymore [34], and 4 authors (31.25%) did not answer [25, 32, 36, 56].

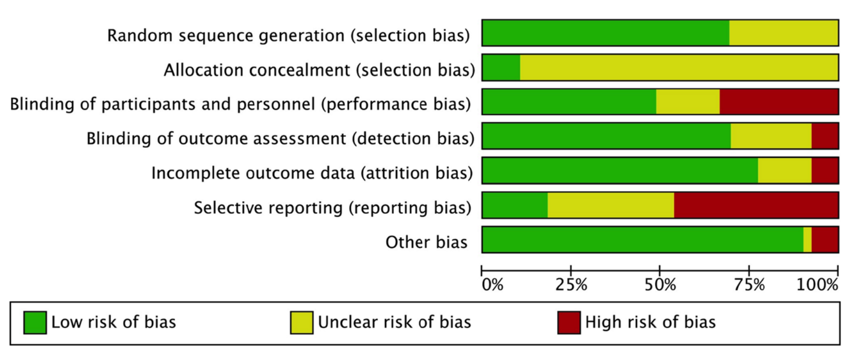


Fig. 2 Risk of bias graph

Risk of bias assessment

In general, trials showed a high risk of bias. The risk of bias analysis demonstrated a lack of information for most studies regarding allocation concealment (90%; n = 35), selective reporting of the outcomes (46%, n = 18), and lack of blinding (33%, n = 13). The details of the risk of bias assessment of all included studies are summarized in Figs. 2 and 3.

Characteristics of the exercise protocols

Authors proposed exercises involving concentric [17, 19, 27, 54] or eccentric isokinetic contractions performed in the isokinetic dynamometer [14, 18, 26, 28, 35, 51, 66], as well as isometric contractions [24, 37, 46, 50]. Some studies proposed cardiopulmonary exercises using cycloergometer [25, 53], treadmill [20, 29, 47], or Wingate test to induce fatigue [30, 39, 41, 44, 45].

Furthermore, exercises encompassing dynamic concentric contractions with weights or workload machines were proposed, generally involving the quadriceps or biceps brachii muscles [31, 36, 38, 40, 42, 43, 49, 52]. Authors also used plyometric exercises [33, 46], sport-specific test [48, 55], or matches [56], and only one used an electric stimulation protocol [34].

Variables

The variables extracted from the articles were time until exhaustion and number of repetitions (Table 3), blood lactate (Table 4), CK (Table 5), CRP (Table 6), lactate dehydrogenase (LDH) (Table 7), concentric and isometric peak torques (Table 8), total work and 1-RM test (Table 9), peak and mean peak power (Table 10), and maximal and mean force (Table 11). Meta-analyses were possible for four variables: time to exhaustion, number of repetitions, blood lactate, and isometric peak torque.

Analysis of the outcomes related to time until exhaustion was possible for 12 studies. Based on these trials, low-quality evidence (downgraded due to risk of bias and imprecision) showed that photobiomodulation therapy can increase the time until exhaustion during exercise with a mean difference of 3.55 s (n = 348; 95% CI, 1.09–6.00; I^2 = 0%; p = 0.005) in favor of photobiomodulation therapy (Fig. 4). For the number of repetitions, eight trials showed a significant effect in favor of photobiomodulation therapy, and low-quality evidence (downgraded due to inconsistency and imprecision) showed that photobiomodulation therapy increases the number of repetitions of an exercise compared with placebo (n = 219; MD, 4.88; 95% CI, 0.14–9.62; I^2 = 59%; p = 0.04) (Fig. 4).

In the meta-analysis for isometric peak torque, maximal voluntary test (MVC) test, very low-quality evidence (downgraded due to risk of bias, inconsistency, and imprecision) showed that a

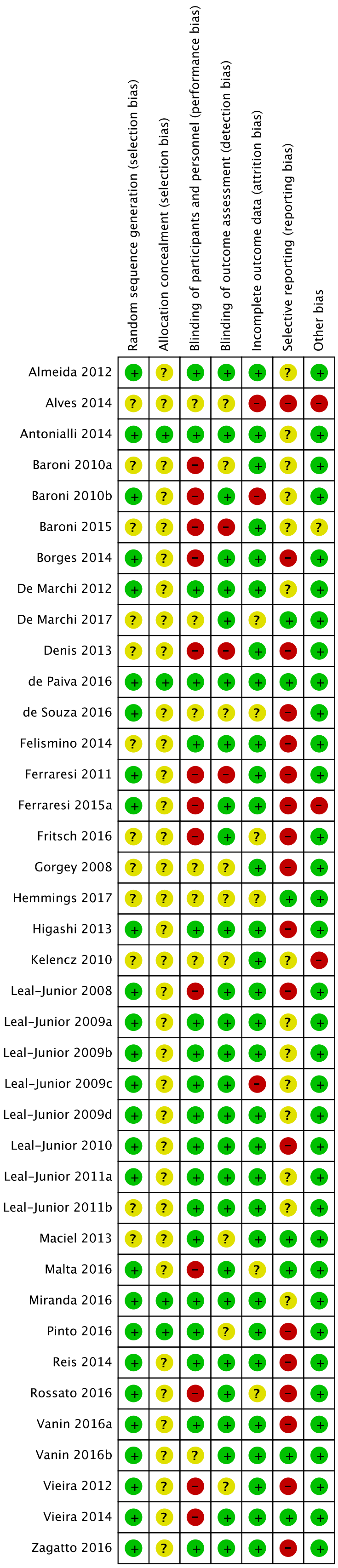


Fig. 3 Risk of bias summary

Table 3 Time until exhaustion (s) and number of repetitions

Authors	Time to exhaustion (s)						Number of repetitions				
Alves et al. [25]	LLLT 648 ± 95 $p > 0.05$			PL 648 ± 87							
De Marchi et al. [29]	LLLT 711.41 ± 87.47 *$p = 0.0467$			PL 697.27 ± 83.62							
Hemmings et al. [35]							PL 48.6 ± 32 *Significance compared to placebo ($p = 0.023$ and $p = 0.004$, respectively).	30s LED 51 ± 35.2	60s LED 61.9 ± 34.7*		120 s LED 61.8 ± 38.7*
Higashi et al. [36]							LLLT 25.1 ± 9.89 $p = 0.342$		PL 22.6 ± 7.58		
Kelencz et al. [37]	Treated 1.044 J (LED) 38.0 ± 10.8 $p > 0.05$	PL 1.044 J (LED) 38.0 ± 10.6	Treated 2.088 J (LED) 42.2 ± 14.7* $p < 0.05$*	PL 2.088 J (LED) 33.4 ± 12.4 $p > 0.05$	Treated 3.132 J (LED) 26.8 ± 10.4	PL 3.132 J (LED) 18.3 ± 7.9					
Leal-Junior et al. [38]	LLLT 53.8 (CI 46.2–61.4) $p = 0.0022$*			PL 41.1 (CI 33.6–48.7)			LLLT 29.33 ± 7.9 $p = 0.0001$*		PL 19.17 ± 7.1		
Leal-Junior et al. [40]	LEDT 47.37 ± 11.50 $p = 0.036$*			PL 42.46 ± 13.81			LEDT 38.6 ± 9.03 $p = 0.021$*		PL 34.2 ± 8.6		
Leal-Junior et al. [42]	LLLT 37.15 ± 6.45 $p = 0.096$			PL 34.34 ± 6.77			LLLT 30.10 ± 8.08 $p = 0.042$*		PL 25.60 ± 6.15		
Leal-Junior et al. [43]	LLLT 41.3 ± 5.1 $p = 0.034$*			PL 38.2 ± 3.2			LLLT 39.6 ± 4.3 $p = 0.037$*		PL 34.6 ± 5.6		
Maciel et al. [46]	Control 28.6 ± 16.3 p > 0.05	PL 25.4 ± 19.7			LLLT 34.5 ± 20.6						
Malta et al., [47]	LEDT 154.6 ± 36 $p = 0.80$			PL 155.5 ± 37							
Miranda et al. [20]	Phototherapy 780.2 ± 91 $p < 0.001$*			PL 742.1 ± 94							
Reis et al. [49]		PL	Prefatigue laser	Postfatigue laser	p			PL	Prefatigue laser	Postfatigue laser	*p*
	Day 1	41.1 ± 14.7	36.0 ± 9.2	34.2 ± 7.9	0.3996		Day 1	39.9 ± 17.1	31.0 ± 11.2	28.7 ± 8.9	0.1704
	Day8	40.4 ± 14.8	37.4 ± 9.6	37.8 ± 10.6	0.8424		Day8	41.2 ± 18.2	37.8 ± 13.1	41.6 ± 17.4	0.8965
Rossato et al. [50][a]	Large cluster 48.54 ± 8.99	Large cluster placebo 43.46 ± 12.45	Small cluster 49.67 ± 13.69		Small cluster placebo 44.13 ± 12.73						
	$p = 0.031$, $p = 0.038$, observed power = 0.83-comparison with respective placebo treatments. No differences between small or large cluster ($p = 0.662$)										
Vieira et al. [54]							LLLT 120.7 ± 41.8 *$p < 0.05$		PL 62.1 ± 13.5		

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo

*Statistically significant

[a] Unpublished data provided by author

Table 4 Blood lactate

Authors	Blood lactate (mmol/L)									
Alves et al. [25]	PL								LLLT	
	7.7 ± 2.7								7.2 ± 2.3	
	$p > 0.05$									
Denis et al. [30][a]	PL								LEDT	
	Baseline		Post-yoyo test		Post 3rd min,		Post 9th min		Post15th min	Baseline
	1.24 ± 0.69		14.52 ± 2.16		13.27 ± 3.73		10.81 ± 3.84		8.77 ± 4.46	1.38 ± 0.62
	$p > 0.05$								$p > 0.05$	
Hemmings et al. [35]	PL				30s LED					60s LED
	1.14 ± 1.69				1.18 ± 1.30					1.22 ± 1.71
	$p > 0.05$									
Higashi et al. [36]	Values not described in the text (p values)									
Leal-Junior et al. [38]	Before LLLT				Before PL				After LLLT	
	2.38 ± 0.27				2.4 ± 0.31				3.92 ± 0.50	
	$p > 0.05$									
Leal-Junior et al. [39]	Before LEDT		Before LLLT	Before PL		LEDT 3’	LLLT 3’		PL 3’	LEDT 10’
	1.55 ± 0.54		1.54 ± 0.38	1.66 ± 0.42		10.03 ± 1.74	9.94 ± 1.75		10.04 ± 2.59	10.84 ± 2.94
	$p > 0.05$					$p > 0.05$			$p > 0.05$	
Leal-Junior et al. [40]	Before LEDT					Before PL			After LEDT	
	3.40 ± 1.07					3.70 ± 1.25			11.60 ± 3.99	
	$p > 0.05$								$p = 0.042$	
Leal-Junior et al. [41]	Before LLLT		Before PL			LLLT 3’			PL 3’	
	2.52 ± 0.52		2.24 ± 0.33			13.27 ± 2.11			13.66 ± 2.89	
	$p > 0.05$					$p > 0.05$			$p > 0.05$	
Leal-Junior et al. [42]	Before LLLT					Before PL				After LLLT
	2.31 ± 0.36					2.16 ± 0.37				5.93 ± 0.90
	$p = 0.200$									
Leal-Junior et al. [43]	Before LLLT		Before PL		LLLT 5’	PL 5’	LLLT 10’		PL 10’	
	1.30 ± 0.10		1.43 ± 0.25		2.20 ± 0.54	5.32 ± 3.19	4.56 ± 1.05		4.84 ± 2.26	
	$p > 0.05$				$p < 0.01$*		$p > 0.05$			
Leal-Junior et al. [44]	PL					LEDT			Cold water immersion therapy	
	Pre		Post			Pre	Post		Pre	
	11 ± 2.61		9.17 ± 5.04			16 ± 3.22	10.50 ± 2.43*		13.83 ± 1.94	
	*$p < 0.05$									
Pinto et al. [48][a]	PL									Phototherapy
	Baseline		3 min	10 min		30 min		60 min		Baseline
	1.820 ± 0.6		15.10 ± 2.74	12.91 ± 3.15		7.990 ± 2.47		3.310 ± 1.02		1.940 ± 0.72
	$p > 0.05$									$p > 0.05$
Reis et al. [49][a]	PL						Prefatigue laser			
	5 min		10 min		15 min		5 min		10 min	
	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8
	4.53 ± 1.69	4.61 ± 1.85	3.36 ± 1.18	3.05 ± 1.02	2.76 ± 0.78	2.28 ± 0.55	4.7 ± 2.69	6.8 ± 2.88	4.2 ± 1.87	4.7 ± 2.24
	*ANOVA, $p = 0.0037$: placebo versus postfatigue laser: $p < 0.01$, **prefatigue laser versus postfatigue laser: $p < 0.05$.									

Authors	Blood lactate (mmol/L)						
Alves et al. [25]	LLLT						
	7.2 ± 2.3						
	$p > 0.05$						
Denis et al. [30][a]	LEDT						
	Baseline	Post-yoyo test		Post 3rd min,		Post 9th min	Post15th min
	1.38 ± 0.62	13.75 ± 2.91		12.94 ± 3.53		11.16 ± 3.80	9.7 ± 4.14
	$p > 0.05$						
Hemmings et al. [35]	60s LED			120 s LED			
	1.22 ± 1.71			1.00 ± 1.36			
	$p > 0.05$						
Higashi et al. [36]	Values not described in the text (p values)						
Leal-Junior et al. [38]	After LLLT				After PL		
	3.92 ± 0.50				3.65 ± 0.51		
	$p > 0.05$						
Leal-Junior et al. [39]	LEDT 10’	LLLT 10’	PL 10’	LEDT 15’		LLLT 15’	PL 15’
	10.84 ± 2.94	10.35 ± 2.67	11.95 ± 1.89	10.15 ± 2.05		10.47 ± 2.22	11.04 ± 0.85
	$p > 0.05$			$p > 0.05$			
Leal-Junior et al. [40]	After LEDT			After PL			
	11.60 ± 3.99			15.20 ± 3.21			
	$p = 0.042$						
Leal-Junior et al. [41]	LLLT 10’		PL 10’		LLLT 15’		PL 15’
	13.15 ± 2.17		13.28 ± 1.42		11.07 ± 2.14		12.76 ± 1.82
	$p > 0.05$				$p = 0.01$*		
Leal-Junior et al. [42]	After LLLT			After PL			
	5.93 ± 0.90			6.10 ± 1.10			
	$p = 0.200$						
	PL 10’	LLLT 15’		PL 15’		LLLT 20’	PL 20’

Table 4 (continued)

Authors	Blood lactate (mmol/L)							
Leal-Junior et al. [43]	4.84 ± 2.26 $p > 0.05$	5.02 ± 3.06 $p > 0.05$		4.67 ± 1.74		3.94 ± 0.99 $p > 0.05$	3.57 ± 0.54	
Leal-Junior et al. [44]	Cold water immersion therapy							
	Pre			Post				
	13.83 ± 1.94 $^{*}p < 0.05$			11.67 ± 1.97				
Pinto et al. [48][a]	Phototherapy							
	3 min		10 min		30 min		60 min	
	14.11 ± 3.53 $p > 0.05$		11.95 ± 3.74		6.070 ± 2.46		2.370 ± 0.58	
Reis et al. [49][a]	Prefatigue laser		Postfatigue laser					
	15 min		5 min		10 min		15 min	
	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8
	3.3 ± 1.38	3.5 ± 1.54	4.42 ± 2.59	4.18 ± 1.98	2.7 ± 1.62	3.21 ± 1.37	2.02 ± 0.61	1.92 ± 0.65* **
	*ANOVA, $p = 0.0037$: placebo versus postfatigue laser: $p < 0.01$, **prefatigue laser versus postfatigue laser: $p < 0.05$.							

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo

*Statistically significant

[a] Unpublished data provided by author

significant difference was found between photobiomodulation therapy and placebo with some effect in favor of photobiomodulation therapy ($n = 286$; SMD = 0.57 Nm; 95% CI, 0.17–0.97; $I^2 = 59\%$; $p = 0.006$), based on ten trials (Fig. 5). For blood lactate levels measured immediately or until 5 min after the exercise, based on moderate-quality evidence (downgraded due to imprecision), 12 trials demonstrated a significant effect in favor of photobiomodulation therapy compared with placebo group ($n = 337$; MD 0.14 mmol/L; 95% CI, − 0.49 to 0.20; $I^2 = 16\%$; $p = 0.41$) (Fig. 5).

Based on 15 trials, very low-quality evidence (downgraded due to inconsistency, indirectness, and imprecision) showed that photobiomodulation therapy modulates CK activity after exercise compared with placebo, with a small effect in favor of photobiomodulation therapy. Due to the high level of heterogeneity, we did not combine the results for the meta-analysis ($I^2 = 75\%$), but we reported these descriptively.

For the variables of LDH levels, concentric peak torque, total work, 1-RM, peak power, mean peak power, maximal force, and mean force, performing meta-analysis was not possible because of the low amount of studies that address each one, but we evaluated the quality of evidence for each outcome, and the results are shown in Table 12. Due to the lack of studies and methodological variability, the quality of evidence for these variables were defined as very low, most of them being downgraded due to inconsistency, indirectness, and imprecision. The quality of evidence for each variable is summarized in Table 12.

Effectiveness and moment of application

With regard to the moment of application, 26 (67%) studies applied the photobiomodulation therapy before the exercise, 9 (23%) studies after the exercise, 2 (5%) studies between the sets of exercise, 1 before and/or after exercise, and 1 study before or after the exercise (Table 2).

Of the 39 studies included in the review, 32 showed positive results in at least one of the variables related to performance when photobiomodulation therapy was used in association with exercise. These positive results were achieved mainly when photobiomodulation therapy was applied before the exercise ($n = 24$), but also when applied after ($n = 5$), either before or after ($n = 1$), and between the sets of exercise ($n = 2$). No effect in favor to photobiomodulation therapy was observed in seven studies; three studies applied the photobiomodulation therapy after, and four studies applied the photobiomodulation therapy before the exercise, one of them in scanning mode.

Photobiomodulation therapy parameters

LLLT was the source of light most used in the studies ($n = 22$). LEDT was used in 11 studies, most of them combining red and infrared wavelengths ($n = 9$). Moreover, the combination of sources of light (LLLT + LEDT) and different wavelengths (red and infrared) in the same device were found in seven studies. Table 2 shows more details regarding the photobiomodulation therapy parameters.

A cluster device was used in 27 trials to reach a wider application area, and one study used the light application by scanning mode, whereas 38 conducted the application in direct contact with the skin.

In general, positive results were found using both LLLT and LEDT or a combination of both in a wavelength range from 655 to 950 nm. Most of the positive results were observed, with an energy dose range from 20 to 60 J for small muscular groups (representing 85%

Table 5 Creatine kinase (CK) activity

Authors	Creatine kinase (CK) activity (IU/L)						
Antonialli et al. [14]		Pre	Post	1 h		24 h	48 h
	PL	504.12 ± 54.69	581.55 ± 68.97	748.37 ± 84.92		1168.32 ± 170.80	1297.60 ± 163.18
	10 J	489.67 ± 46.02	448.50 ± 64.58	472.17 ± 41.30*		674.33 ± 44.26*	531.00 ± 80.36*
	30 J	521.00 ± 84.50	537.50 ± 78.53	567.33 ± 100.80*		576.00 ± 104.69*	502.67 ± 53.23*
	50 J	475.17 ± 112.59	530.83 ± 134.17	507.00 ± 108.12*		709.33 ± 105.08*	509.83 ± 120.99*
	* $p < 0.05$ compared to placebo						
Baroni et al. [26]	Baseline LLLT		Baseline PL			24 h LLLT	24 h PL
	144.69 ± 59.01		155.16 ± 51.27			271.70 ± 146.31	497.75 ± 362.97
						LLLT 24 h $p < 0.05$*	
De Marchi et al. [29]	Before LLLT					Before PL	After LLLT
	151.74 ± 45.15					150.10 ± 48.60	178.26 ± 82.36*
	$p = 0.0001$*						
De Marchi et al. [17]			Pre	Post		1 h	24 h
	PBMT		66.91 ± 8.70	109.61 ± 34.48		82.67 ± 38.02*	111.00 ± 69.00*
	*$p < 0.01$						
	PL		63.95 ± 5.44	132.37 ± 45.34		131.57 ± 84.45	294.53 ± 120.60
	$p > 0.05$						
De Paiva et al. [18]			Pre	Post		1 h	24 h
	PBMT		51.01 ± 12.35	55.53 ± 15.58		56.69 ± 16.03	54.63 ± 16.65*
			$p > 0.05$	$p > 0.05$		$p > 0.05$	$p < 0.05$
	PL		44.11 ± 7.77	51.30 ± 6.79		56.92 ± 16.86	100.84 ± 13.66
	$p > 0.05$						
Felismino et al. [31][a]	PL						LLLT
	Baseline		Immediately after	24 h	48 h	72 h	Baseline
	136.00 ± 12.8		156 ± 16.9	290.00 ± 45.6	3220.00 ± 189	4295.00 ± 200	409.00 ± 18.6
	* Difference from laser group ($p < 0.05$).						
Ferraresi et al. [56][a]	LEDT 105 J			LEDT 210 J			LEDT 315 J
	Before		After	Before	After		Before
	328.0 ± 188.9		499.6 ± 232.0	338.8 ± 130.3	364.1 ± 127.5		245.1 ± 126.9
	$p = 0.001$			$p = 0.993$			$p = 0.407$
Leal-Junior et al. [39]	Before cluster LEDT			Before LLLT	Before PL		After cluster LEDT
	190.75 ± 93.19			232.13 ± 153.28	192.50 ± 69.80		171.87 ± 41.48* **
	$p < 0.05$* cluster × placebo/ $p < 0.01$** cluster × probe						
Leal-Junior et al. [40]	Before LEDT			Before PL			After LEDT
	53.62 ± 23.37			52.91 ± 40.78			50.58 ± 4.47*
	$p > 0.05$						$p = 0.035$*
Leal-Junior et al. [41]	Before LLLT			Before PL			After LLLT
	108.64 ± 33.68			107.72 ± 41.12			111.16 ± 7.04*
	$p = 0.7737$						$p = 0.0133$*
Leal-Junior et al. [43]	Before LLLT			Before PL			After LLLT
	281 ± 196.3			340.6 ± 335.6			263.6 ± 134.2*
	$p > 0.05$						$p = 0.017$*
Leal-Junior et al. [44]	PL				LEDT		
	Baseline	Post exercise	Post treatment		Baseline	Post exercise	Post treatment
	90.55 ± 20.28	95.28 ± 7.92	88.83 ± 21.57		92.30 ± 19.67	107.52 ± 13.42	83.75 ± 9.56*
	$p < 0.05$						
Reis et al. [49][a]	PL				Prefatigue laser		
	Baseline		Post exercise		Baseline		Post fatigue
	Day 1	Day 8	Day 1	Day 8	Day 1	Day 8	Day 1
	297.0 ± 171.98	420.4 ± 314.31	314.01 ± 184.46	414.17 ± 302.08	239.4 ± 50.28	205.9 ± 90.1022396	248.2 ± 49.86
	*Prefatigue laser versus postfatigue laser $p < 0.05$. **Placebo versus $p < 0.01$. postfatigue laser						
Vanin et al. [51][a]		Pre	Post	1 h		24 h	
	PL	219.7 ± 50.50	277.01 ± 55.30	373.90 ± 59.50		689.12 ± 53.10	
	10 J	212.40 ± 59.78	249.93 ± 60.76	374.49 ± 65.73		467.92 ± 66.85	
	30 J	227.80 ± 65.28	291.90 ± 56.28	421.53 ± 61.20		680.3 ± 65.60	
	50 J	233.6 ± 52.21	268.92 ± 31.22	266.51 ± 51.11		456.76 ± 50.13	
	$p > 0.05$ compared to placebo						
Zagatto et al. [55]	LLLT group						PL group
	Pre	Post	24 h	48 h			Pre
	125.26 ± 70.25	114.06 ± 56.43	84.30 ± 33.36	60.76 ± 40.66^{ab}			97.30 ± 58.32
	(79.63–170.88)	(75.99–152.14)	(59.34–109.26)	(29.35–92.17)			(51.68–142.92)
	a $p < 0.05$ to pre in the same group b $p < 0.05$ to post in the same group						

Authors	Creatine kinase (CK) activity (IU/L)	
Antonialli et al. [14]	72 h	96 h
	1173.09 ± 404.15	1077.81 ± 372.23
	526.67 ± 58.59*	877.67 ± 111.72*

Table 5 (continued)

Authors	Creatine kinase (CK) activity (IU/L)				
	414.00 ± 90.39*			604.17 ± 64.76*	
	540.33 ± 194.00*			1078.50 ± 41.25	
	* $p < 0.05$ compared to placebo				
Baroni et al. [26]	48 h LLLT			48 h PL	
	435.95 ± 238.04			1327.58 ± 949.82	
	LLLT 48 h $p < 0.05$*				
De Marchi et al. [29]	After LLLT		After PL		
	178.26 ± 82.36*		290.42 ± 127.11		
	$p = 0.0001$*				
De Marchi et al. [17]	24 h		48 h	72 h	
	111.00 ± 69.00*		101.49 ± 69.01*	73.48 ± 27.00*	
	*$p < 0.01$				
	294.53 ± 120.60		291.82 ± 182.05	226.02 ± 101.12	
	$p > 0.05$				
De Paiva et al. [18]	48 h		72 h	96 h	
	56.55 ± 17.63*		52.35 ± 16.26*	43.66 ± 16.30*	
	$p < 0.05$		$p < 0.05$	$p < 0.05$	
	118.91 ± 12.45		99.55 ± 10.38	99.47 ± 11.01	
	$p > 0.05$				
Felismino et al. [31][a]	LLLT				
	Immediately after	24 h	48 h	72 h	
	448.00 ± 22.2	816.00 ± 67.03	2088.00 ± 84.11	2520.00 ± 94.72 *	
	* Difference from laser group ($p < 0.05$).				
Ferraresi et al. [56][a]	LEDT 315 J		PL		
	After		Before	After	
	318.0 ± 153.5		270.3 ± 112.4	406.1 ± 150.1	
	$p = 0.407$		$p = 0.012$		
Leal-Junior et al. [39]	After LLLT		After PL		
	275.51 ± 32.90		219.38 ± 15.18		
	$p < 0.05$* cluster × placebo/ $p < 0.01$** cluster × probe				
Leal-Junior et al. [40]	After PL				
	57.24 ± 8.65				
	$p = 0.035$*				
Leal-Junior et al. [41]	After PL				
	136.21 ± 22.62				
	$p = 0.0133$*				
Leal-Junior et al. [43]	After PL				
	525.7 ± 386.5				
	$p = 0.017$*				
Leal-Junior et al. [44]	LEDT	Cold water immersion therapy			
	Post treatment	Baseline	Post exercise	Post treatment	
	83.75 ± 9.56*	91.29 ± 20.49	92.99 ± 14.91	87.84 ± 13.67	
	$p < 0.05$				
Reis et al. [49][a]	Prefatigue laser	Postfatigue laser			
	Post fatigue	Baseline		Post fatigue	
	Day 8	Day 1	Day 8	Day 1	Day 8
	217.3 ± 89.23	234.56 ± 133.22	289.01 ± 215.67	238.84 ± 134.61	106.5 ± 66.53* **
	*Prefatigue laser versus postfatigue laser $p < 0.05$.				
	**Placebo versus $p < 0.01$. postfatigue laser				
Vanin et al. [51][a]	48 h	72 h		96 h	
	742.34 ± 62.90	578.59 ± 64.80		562.90 ± 58.60	
	447.96 ± 61.84	400.85 ± 58.13		360.12 ± 61.01	
	711.28 ± 64.0	498.49 ± 57.87		481.81 ± 59.85	
	390.14 ± 39.98	293.00 ± 52.40		280.96 ± 60.10	
	$p > 0.05$ compared to placebo				
Zagatto et al. [55]	PL group				
	Post		24 h	48 h	
	107.66 ± 51.22		82.22 ± 37.17	79.27 ± 47.93	
	(69.58–145.74)		(57.26–107.17)	(47.86–110.68)	
	a $p < 0.05$ to pre in the same group b $p < 0.05$ to post in the same group				

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo, *PBMT* photobiomodulation therapy

*Statistically significant

[a] Unpublished data provided by author

of doses with positive results), and 60 to 300 J for large muscular groups (representing 75% of doses with positive results), and maximal power output of 200 mW per diode (Fig. 6).

Table 6 C-reactive protein (CRP)

Authors	C-reactive protein (CRP) (mg/dL)								
Leal-Junior et al. [40]	Before LEDT		Before PL		Change after LEDT		Change after PL		
	1536.00 ± 742.09		1077.60 ± 643.24		(−) 364.80 ± 616.86		28.80 ± 361.65		
	$p > 0.05$				$p = 0.030$*				
Leal-Junior et al. [43]	Before LLLT		Before PL		After LLLT		After PL		
	38.7 ± 44		26.7 ± 29.3		1.3 ± 4		92 ± 115.1		
	$p > 0.05$				$p = 0.047$*				
Leal-Junior et al. [44]	PL			LEDT			CWIT		
	Pre	Postexercise	Posttreatment	Pre	Postexercise	Posttreatment	Pre	Postexercise	Posttreatment
	1068.65 ± 578.98	196 ± 156.58	182.0 ± 677.14	1112.35 ± 546.62	252.0 ± 654.28	− 66 ± 304.50	1087.52 ± 534.02	444.0 ± 802.87	150.0 ± 646.30
	$p > 0.05$			$p > 0.05$			$p > 0.05$		

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo, *CWIT* cold water immersion therapy

*Statistically significant

Table 7 Lactate dehydrogenase (LDH)

Authors	LDH (IU/L)					
Baroni et al. [26]	Baseline LLLT	Baseline PL	24 h LLLT	24 h PL	48 h LLLT	48 h PL
	186.02 ± 44.92	182.59 ± 43.84	296.93 ± 99.98	290.10 ± 87.54	366.06 ± 84.46*	483.85 ± 180.29
	LLLT PL at 48 h, $p < 0.05$*					
De Marchi et al. [29]	Before LLLT	Before PL		After LLLT	After PL	
	281.89 ± 44.36	274.93 ± 37.62		276.80 ± 32.86*	332.72 ± 63.07	
	*$p = 0.0001$					
Zagatto et al. [55]	LLLT group	Pre (IU/L)	Post (IU/L)	24 h (IU/L)	48 h (IU/L)	
		87.55 ± 25.07 (71.31–103.78)	79.03 ± 29.51 (60.37–97.69)	83.28 ± 14.21 (73.30–93.26)	99.04 ± 33.26 (81.44–116.65)	
		$p > 0.05$				
	PL group	64.12 ± 20.65 (47.91–80.37)	81.17 ± 22.90 (62.51–99.83)	82.34 ± 14.05 (72.36–92.33)	84.79 ± 11.66 (67.18–102.40)	
		$p > 0.05$				

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo

*Statistically significant

Table 8 Concentric peak torque and isometric peak torque

Authors	Concentric peak torque (Nm)						Isometric peak torque - MVC (Nm)		
Antonialli et al. [14]								Pre	Post
							PL	271.30 ± 28.71	187.95 ± 31.68
							10 J	279.50 ± 14.33	241.90 ± 25.35*
							30 J	286.63 ± 38.86	271.20 ± 26.55*
							50 J	254.38 ± 28.24	219.62 ± 26.88
							*Significant difference ($p < 0.05$) compared to placebo		
Baroni et al. [26]							Baseline LLLT	Baseline PL	Immediately after LLLT
							292.92 ± 42.93	283.98 ± 47.07	188.93 ± 43.04
							MVC immediately after $p < 0.05$*, MVC 24 h $p < 0.05$*, MVC 48 h $p < 0.05$* (compared to placebo)		
Baroni et al. [27]							Before LEDT		Before PL
							284.81 ± 54.52		282.65 ± 53.64
							$p = 0.034$*		
Baroni et al. [66]	Control		Training		Training + LLLT		Control		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
	215 ± 29.24	219.83 ± 33.78	219.86 ± 28.89	244.31 ± 30.61	217.58 ± 30.02	248.18 ± 35.98	257.94 ± 44.18	260.83 ± 45.80	
	$p = 0.26$		$p < 0.01$*		$p < 0.01$*		$p = 0.45$		
De Marchi et al. [17]								Pre	Post
							PBMT	71.66 ± 16.03	49.04 ± 10.94
							*$p < 0.05$		
							PL	67.11 ± 10.39	41.63 ± 9.13
							$p > 0.05$		
De Paiva et al. [18]								Pre	Post
							PBMT	256.31 ± 12.51	228.64 ± 12.91
							PL	258.24 ± 30.81	211.59 ± 29.50
							$p > 0.05$		
Ferraresi et al. [32]	Values not available in the text								
Fritsch et al. [33][a]							LLLT/placebo preexercise		
							PL		
							Pre	24 h	48 h
							319.7 ± 71.62	263.5 ± 76.95	275.02 ± 74.55
							LLLT/placebo postexercise		
							PL		
							Pre	24 h	48 h
							301.53 ± 45.07	266.24 ± 41.78	268.16 ± 50.20
Gorgey et al. [34]							Control		
							47 ± 16		
							$p = 0.99$		
Hemmings et al. [35]							PL		30s LED
							258.4 ± 69.4		259.8 ± 69.9
							$p > 0.05$		
Rossato et al. [50]							Large cluster		Large cluster placebo
							Pre	Post*	Pre
							88 ± 14	76 ± 11	88 ± 16
							*Time effect ($p < 0.001$)		
Vanin et al. [51]								Pre	Post
							PL	249.90 ± 22.65	228.14 ± 13.57

Table 8 (continued)

Authors	Concentric peak torque (Nm)	Isometric peak torque - MVC (Nm)		
		10	253.32 ± 24.53	226.67 ± 15.35
		30	246.79 ± 23.61	220.83 ± 24.00
		50	249.78 ± 15.71	259.04 ± 19.43*
		*Significant difference ($p < 0.05$) compared to placebo		
Vanin et al. [52]				Baseline
		MVC (Nm) right leg	Photo + photo	193.20 ± 23.27
			Photo + placebo	202.13 ± 24.55
			Placebo + photo	196.24 ± 21.38
			Placebo + placebo	204.97 ± 17.86
		MVC (Nm) left leg	Photo + photo	204.73 ± 11.02
			Photo + placebo	213.22 ± 14.14
			Placebo + photo	197.42 ± 18.57
			Placebo + placebo	209.44 ± 17.21
		[a]Significant difference compared to photo + photo group ($p < 0.05$)		
		[b]Significant difference compared to placebo + photo group ($p < 0.05$)		
		[c]Significant difference compared placebo + placebo group ($p < 0.05$)		

Authors	Isometric peak torque - MVC (Nm)				
Antonialli et al. [14]	1 h	24 h	48 h	72 h	96 h
	191.48 ± 37.83	220.18 ± 12.09	226.76 ± 10.25	252.82 ± 14.64	265.06 ± 24.79
	241.37 ± 15.19*	276.14 ± 23.82	280.17 ± 36.38	299.32 ± 34.35	325.25 ± 37.00
	278.57 ± 23.78*	281.52 ± 26.87*	281.62 ± 20.79*	317.90 ± 26.12*	336.88 ± 27.92*
	231.68 ± 24.46*	240.02 ± 22.29	262.51 ± 29.97*	282.68 ± 30.62	304.73 ± 26.23*
	*Significant difference ($p < 0.05$) compared to placebo				
Baroni et al. [26]	Immediately after PL	24 h LLLT	24 h PL	48 h LLLT	48 h PL
	154.03 ± 34.57	249.43 ± 42.61	205.09 ± 43.52	267.09 ± 37.40	216.14 ± 50.17
	MVC immediately after $p < 0.05$*, MVC 24 h $p < 0.05$*, MVC 48 h $p < 0.05$* (compared to placebo)				
Baroni et al. [27]	Before PL	After LEDT	After PL		
	282.65 ± 53.64	237.68 ± 48.82*	225.68 ± 44.14		
	$p = 0.034$*				
Baroni et al. [66]	Training		Training + LLLT		
	Pre	Post	Pre		Post
	267.86 ± 33.62	303.91 ± 36.03	252.58 ± 26.01		308.14 ± 32.88
	$p < 0.01$*		$p < 0.01$*		
De Marchi et al. [17]	1 h	24 h	48 h	72 h	
	64.14 ± 9.83*	70.73 ± 10.04*	72.09 ± 10.71*	76.66 ± 6.45*	
	*$p < 0.05$				
	47.06 ± 5.43	56.86 ± 7.22	58.08 ± 5.67	58.14 ± 9.44	
	$p > 0.05$				
De Paiva et al. [18]	1 h	24 h	48 h	72 h	96 h
	234.88 ± 31.08	289.34 ± 34.88*	287.24 ± 32.71*	275.91 ± 27.56*	293.71 ± 32.32*
	210.84 ± 20.76	221.24 ± 22.93	224.18 ± 16.16	234.25 ± 22.12	250.05 ± 21.91
	$p > 0.05$				
Ferraresi et al. [32]					
Fritsch et al. [33][a]	LLLT/placebo preexercise				
	PL	LLLT			

Table 8 (continued)

Authors	Isometric peak torque - MVC (Nm)				
	72 h	Pre	24 h	48 h	72 h
	286.23 ± 68.90	316.33 ± 82.68	273.05 ± 83.04	276.62 ± 83.90	283.99 ± 68.46
	LLLT/placebo postexercise				
	PL	LLLT			
	72 h	Pre	24 h	48 h	72 h
	279.34 ± 52.02	293.52 ± 46.68	254.22 ± 43.13	263.53 ± 39.77	272.92 ± 44.22
Gorgey et al. [34]	3 J LLLT		7 J LLLT		
	45 ± 17		47 ± 17		
	$p = 0.99$				
Hemmings et al. [35]	30s LED	60s LED		120 s LED	
	259.8 ± 69.9	258.2 ± 70.1		256.2 ± 61.6	
	$p > 0.05$				
Rossato et al. [50]	Large cluster placebo	Small cluster		Small cluster placebo	
	Post*	Pre	Post*	Pre	Post*
	77 ± 13	86 ± 16	75 ± 16	89 ± 17	75 ± 14
	*Time effect ($p < 0.001$)				
Vanin et al. [51]	1 h	24 h	48 h	72 h	96 h
	213.86 ± 29.00	247.40 ± 11.40	249.72 ± 28.28	243.86 ± 12.41	256.86 ± 8.52
	238.41 ± 10.00	286.77 ± 22.78*	294.31 ± 21.75*	292.08 ± 20.71*	305.57 ± 23.30*
	215.91 ± 6.36	223.44 ± 9.23	242.11 ± 7.90	228.44 ± 12.73	240.79 ± 18.72
	262.17 ± 20.08*	275.97 ± 12.21*	261.92 ± 27.32	270.07 ± 13.43	281.22 ± 22.14
	*Significant difference ($p < 0.05$) compared to placebo				
Vanin et al. [52]	4 weeks		8 weeks	12 weeks	
	200.54 ± 19.98		215.43 ± 21.89	216.72 ± 25.18	
	227.07 ± 33.75		251.45 ± 35.76[a]	280.90 ± 38.68[a,b,c]	
	203.23 ± 25.15		224.48 ± 28.04	235.64 ± 31.84	
	213.33 ± 23.74		226.0 ± 30.0	233.16 ± 27.99	
	215.66 ± 23.71		229.23 ± 23.86	243.78 ± 24.16	
	239.04 ± 24.96[b]		281.98 ± 28.10[a,b,c]	311.27 ± 31.36[a,b,c]	
	207.62 ± 24.68		227.53 ± 27.08	239.13 ± 23.86	
	215.46 ± 19.92		225.47 ± 21.11	240.70 ± 26.15	
	[a]Significant difference compared to photo + photo group ($p < 0.05$)				
	[b]Significant difference compared to placebo + photo group ($p < 0.05$)				
	[c]Significant difference compared placebo + placebo group ($p < 0.05$)				

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo, *PBMT* photobiomodulation therapy

*Statistically significant

[a] Unpublished data provided by author

Table 9 Total work and 1-RM test

Authors	Total work (J)							1-RM
Baroni et al. [27]	LEDT 4113.25 ± 677.31			PL 4205.19 ± 746.15				
	$p = 0.182$							
Denis et al. [30][a]	Placebo Baseline	Post-yoyo	End	LEDT Baseline		Post-yoyo	End	
	18,592.8 ± 2585.09	16,862.5 ± 1934.4	18,216.9 ± 2930.6	18,369.9 ± 2699.7		17,511.7 ± 2589.13	18,332.8 ± 2885.3	
	$p > 0.05$							
Felismino et al. [31][a]								PL Baseline 39.45 ± 2.11 $p > 0.05$
Ferraresi et al. [32]								Values described only in percentage on the text and normalized by BM
Leal-Junior et al. [41]	LLLT (volleyball) 21,888.31 ± 2062.98			PL (volleyball) 22,429.79 ± 2842.71				
	$p = 0.3583$							
	LLLT (soccer)			PL (soccer)				
	16,214.97 ± 1639.88			16,289.21 ± 1700.34				
	$p = 0.8681$							
Reis et al. [49][a]								Day 1 (first session) Day 8 (second session)
Vanin et al. [52]								Leg press right leg Leg press left leg Leg extension right leg Leg extension left leg *Significant difference compared to placebo ($p < 0.05$) **Data from the other groups can be found in the manuscript.
Vieira et al. [53]		Control Before	After	Training Before	After	Training + LLLT Before	After	
	Nondominant leg	2309.8 ± 255.6	2403.4 ± 205.6	2435.8 ± 379.6	2636.6 ± 477.2	2340.1 ± 484.2	2644.3 ± 473.2	
		$p = 0.568$		$p = 0.011$*		$p < 0.001$*		
	Dominant leg	2350.5 ± 316.5	2417.4 ± 230.5	2501.3 ± 433.6	2813.0 ± 435.5	2373.1 ± 409.8	2682.5 ± 490.2	
		$p = 0.798$		$p < 0.001$*		$p < 0.001$*		

Table 9 (continued)

Authors	Total work (J)	1-RM
Vieira et al. [54]		PL Baseline 71.5 ± 12.6 0.027* decreased 1RM

Authors	Total work (J)	1-RM					
Baroni et al. [27]	LEDT 4113.25 ± 677.31 $p = 0.182$						
Denis et al. [30][a]	Placebo Post-yoyo 16,862.5 ± 1934.4 $p > 0.05$						
Felismino et al. [31][a]		PL	LLLT				
		Immediately after	Baseline	Immediately after	24 h	48 h	72 h
		34.91 ± 2.18	43.35 ± 2.02	36.36 ± 2.2	41.64 ± 2.28	42.73 ± 2.08	43.27 ± 2.9
		$p > 0.05$					
Ferraresi et al. [32]		Values described only in percentage on the text and normalized by BM					
Leal-Junior et al. [41]	LLLT (volleyball) 21,888.31 ± 2062.98 $p = 0.3583$ LLLT (soccer) 16,214.97 ± 1639.88 $p = 0.8681$						
Reis et al. [49][a]		PL	Prefatigue laser		Postfatigue laser		
		53.33 ± 12.95	54.07 ± 13.49		52.59 ± 14.20		
		$p = 0.9764$					
		55.55 ± 12.17	55.55 ± 17.21		56.29 ± 8.38		
		$p = 0.9915$					
Vanin et al. [52]			4 weeks	8 weeks		12 weeks	
		Photo + placebo	83.83 (± 8.79)	109.67 (± 13.14)*		144.83 (± 22.53)*	
		PL + PL	72.25 (± 12.05)	88.42 (± 17.05)		104.42 (± 19.46)	
		Photo + placebo	88.25 (± 11.52)	114.00 (± 17.04)		145.33 (± 18.23)*	
		PL + PL	83.42 (± 9.63)	106.92 (± 12.94)		123.08 (± 16.98)*	
		Photo + placebo	95.83 (± 14.80)*	114.75 (± 20.33)*		127.83 (± 22.93)*	
		PL + PL	76.67 (± 11.52)	83.25 (± 14.37)		94.17 (± 13.58)	
		Photo + placebo	96.67 (± 14.67)*	117.33 (± 15.88)*		132.92 (± 16.14)*	

Table 9 (continued)

Authors	Total work (J)	1-RM			
		PL + PL	74.67 (± 8.27)	85.33 (± 11.80)	95.75 (± 11.76)
		*Significant difference compared to placebo ($p < 0.05$) **Data from the other groups can be found in the manuscript.			
Vieira et al. [53]	Control Before 2309.8 ± 255.6 $p = 0.568$ 2350.5 ± 316.5 $p = 0.798$				
Vieira et al. [54]		PL	LLLT		
		Baseline	Baseline	Final	
		71.5 ± 12.6	78.4 ± 8.8	120 ± 41.8	
		0.027* decreased 1RM	0.027*		

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo, *Photo* phototherapy

*Statistically significant

[a] Unpublished data provided by author

Discussion

This systematic review aimed to summarize the evidence available regarding the effects of photobiomodulation therapy for the improvement of muscle performance and muscular fatigue reduction. We additionally tried to detect the best "therapeutic window" of the photobiomodulation therapy and the better time to apply the therapy to achieve the greater photobiostimulation effect.

Photobiomodulation therapy showed to be effective in most of the included studies for at least one variable related to performance or fatigue. Both LLLT and LEDT, or combination of both, in a wavelength range from 655 to 950 nm was used. Most of the positive results were observed with an energy dose range from 20 to 60 J for small muscular groups (representing 85% of doses with positive results), and 60 to 300 J for large muscular groups (representing 75% of doses with positive results), and a maximal power output of 200 mW per diode, mainly when applied before the exercise. Interestingly, positive results were found in most studies that combined different wavelengths and sources of light, and it must be explored because few studies used this kind of device. We also observed better results when a cluster device was used, especially in wide areas of application, such as in lower limb muscles. Our results corroborate with the findings in two previous reviews that identified ergogenic effect of photobiomodulation therapy on performance improvement when applied before exercise, using laser and/or LED sources of light [10, 11].

These reviews were performed with studies published until 2013. Thus far, many studies have been developed. To know, 13 studies have been included in the review performed by Leal-Junior et al. [11], whereas Borsa et al. [10] included 10 studies. In this review, we included 39 studies and statistical analysis was only performed if the variable of interest has at least eight studies. These data show the consistency of the results and the importance of a new review in this field.

The interaction of photobiomodulation therapy for the outcomes time to exhaustion, number of repetitions, isometric peak torque, and blood lactate, demonstrated by statistical analysis, indicates that this therapy can improve individual performance on exercise. However, these results are inconclusive due to heterogeneity and the low-level quality evidence between the studies and reaffirm the need to be more exploited. The mechanisms proposed are on increasing mitochondrial activity leading to more ATP production, and on modulating the release of inflammatory markers [10–12, 15, 26, 29, 32, 43, 48, 55]. It is an interesting field to be explored because this intervention may modulate the release of markers related to muscular damage and provide more energy to perform the exercise besides a shorter time to recover for the next event.

Few studies reported the results of CRP and LDH concentrations. Two studies of three reported positive results for each

Table 10 Peak power and mean peak power

Authors	Peak power (W/kg)						Mean peak power (W)		
Denis et al. [30][a]	Placebo			LEDT					
	Baseline	Post-yoyo	End	Baseline	Post-yoyo	End			
	12.6 ± 1.6	11.9 ± 1.1	11.9 ± 1.5	12.7 ± 1.1	11.9 ± 1.2	12.1 ± 1.5			
	$p > 0.05$								
Leal-Junior et al. [39]	Active LLLT		Active cluster LEDT		PL		Active LLLT	Active cluster LEDT	PL
	12.20 ± 0.46		12.31 ± 0.83		12.36 ± 0.59		9.55 ± 0.35	9.58 ± 0.57	9.64 ± 0.39
	$p > 0.05$						$p > 0.05$		
Leal-Junior et al. [44]	PL		LEDT		Cold water immersion		PL	LEDT	Cold water immersion
	12 ± 0.36		12.70 ± 1.23		12.01 ± 0.67		9.39 ± 0.48	9.98 ± 1.29	9.42 ± 0.59
	$p > 0.05$						$p > 0.05$		
Leal-Junior et al. [45]	LEDT			PL			LEDT W/kg	PL W/kg	
	12.22 ± 0.82			12.29 ± 0.60			9.54 ± 0.60	9.65 ± 0.42	
	$p > 0.05$						$p > 0.05$		

LLLT low-level laser therapy, *LEDT* light emitting diode therapy, *PL* placebo

*Statistically significant

[a] Unpublished data provided by author

of these outcomes (Tables 6 and 7). The authors attribute the lower concentrations of these inflammatory markers to the ergogenic effect of photobiomodulation therapy, such as blood lactate and CK outcomes [26, 29, 43].

The variables related to functional assessments, such as concentric peak torque, total work, 1-RM test, peak torque, mean peak torque, maximal force, and mean force were also described, few studies were found for each outcome, and the results were controversial (Tables 8, 9, 10, and 11). Increasing peak torque can be detected mainly in isometric contractions (MVC) in association to photobiomodulation therapy but without effect for other variables. These are important outcomes to consider for future studies because these variables can be related to "performance fatigability" (contractile capabilities) [67]. In addition, these measures could be related to the intensity of symptoms through self-report measurements [67], similar to performed by Pinto et al. [48].

The main reasons for the lack of positive results at any variable found in five studies are the small area covered by the photobiomodulation therapy irradiation or parameters used, showing the importance of the establishment of an optimal therapeutic window to reach the effects of photobiostimulation. The scanning mode of application used by Gorgey et al. [34] did not show positive results, which can be explained by the high refraction of the light and energy loss provided by this kind of application [11].

One of the limitations of this review is the risk of bias of included studies. In general, a high rate of unclear information was found, which means that some of our results could be uncertain. For example, a number of the included studies were hampered by unclear reporting of the technique used for allocation concealment and unclear selective reporting. It is important to note that the lack of allocation concealment may overestimate the effects of the therapy, and the observed effects may be due methodological bias.

An additional limitation is the small sample size of the included studies. Photobiomodulation therapy combined with an exercise program to reduce muscle fatigue and improve performance has been studied since 2006, with the publication of the first experimental trial in this field [68]. Since 2008, studies with humans have been performed [38], with an increase in publications to date. Although most of these studies presented a sample size calculation, many of the studies reported sample size to be one of the limitations [25, 34, 39, 40, 44, 45, 54]. Given the relative novelty of this topic, the number of studies is still limited, and it is important to note that most published studies were conducted by the same research groups, which can also be considered a limitation.

We additionally observed that most of the studies performed a crossover design. Not reporting these studies would be a waste of research information, and it did not encompass the whole scientific information available. However, in this context, we cannot fully analyze the difference within-individual because the studies did not provide sufficient data for this kind of analysis. For such, we decided to consider that the differences within individuals were known. The effects of the photobiomodulation therapy have been shown to be short-lived and reversible [43], and the crossover design can be considered suitable to investigate the effects of photobiomodulation therapy. Ideally, investigators should provide a rationale for using a crossover design, as well as testing the carryover effects, and missing data must be clear in the manuscript [69].

The authors should carefully report the reason for selecting this approach, how many days comprise the washout period, existence of carryover effects, and missing data. In the same rationale, the authors should be clear when reporting the results and provide the within-participants effects [70, 71]. In this review, some included

Table 11 Maximal force and mean force

Authors	Maximal force (kgf)									
Almeida et al. [24]	Red LLLT 23.83 ± 4.51 Red LLLT × PL $p < 0.05$* Infrared LLLT × PL $p < 0.01$* Red LLLT × infrared LLLT $p > 0.05$						Infrared LLLT 24.33 ± 4.88	PL 21.25 ± 4.93		
Borges et al. [28]							LEDT			
	Pre 23.96 ± 5.52	24 h 13.69 ± 3.75	48 h 14.19 ± 3.72	72 h 14.75 ± 4.32	96 h 15.38 ± 4.09	Pre 22.36 ± 5.71	24 h 17.31 ± 6.56	48 h 18.22 ± 7.51	72 h 20.57 ± 8.91	96 h 21.12 ± 9.16
Kelencz et al. [37]	Control 1.044 J 33.6 ± 9.8 $p > 0.05$	Treated 1.044 J 37.4 ± 13.9			Control 2.088 J 31.7 ± 9.7	Treated 2.088 J 32.8 ± 8.0	Control 3.132 J 20.0 ± 7.8		Treated 3.132 J 20.3 ± 7.8	
Maciel et al. [46][a]	Control 86.14 ± 26.01 $p > 0.05$				PL 79.28 ± 34.67		LLLT 78.67 ± 31.29			

Authors	Mean force (kgf)					
Almeida et al. [24]	Red LLLT 15.46 ± 1.98 Red LLLT × PL $p < 0.05$* Infrared LLLT × PL $p < 0.05$* Red LLLT × infrared LLLT $p > 0.05$		Infrared LLLT 15.48 ± 2.84		PL 13.67 ± 2.05	
Borges et al. [28]						
Kelencz et al. [37]	Control 1.044 J 18.6 ± 7.5 $p > 0.05$	Treated 1.044 J 19.7 ± 7.8	Control 2.088 J 19.6 ± 9.2	Treated 2.088 J 19.4 ± 7.3	Control 3.132 J 7.2 ± 4.9	Treated 3.132 J 7.9 ± 4.2
Maciel et al. [46][a]						

LLLT low-level laser therapy, *LEDT* light-emitting diode therapy, *PL* placebo

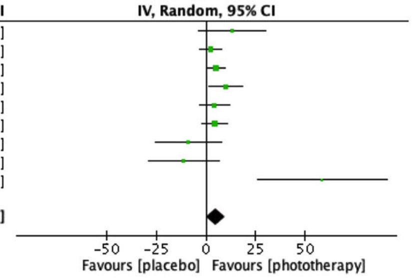
*Statistically significant

[a] Unpublished data provided by author (values originally in N converted to kgf)

A Time to exhaustion

Study or Subgroup	Phototherapy Mean	Phototherapy SD	Phototherapy Total	Placebo Mean	Placebo SD	Placebo Total	Weight	Mean Difference IV, Random, 95% CI
Hemmings 2017	61.8	38.7	34	48.6	32	34	5.9%	13.20 [-3.68, 30.08]
Higashi 2013	25.1	9.89	20	22.6	7.58	20	17.7%	2.50 [-2.96, 7.96]
Leal Junior 2010	39.6	4.3	9	34.6	5.6	9	19.0%	5.00 [0.39, 9.61]
Leal-Junior 2008	29.33	7.9	6	19.17	7.1	6	13.3%	10.16 [1.66, 18.66]
Leal-Junior 2009b	38.6	9.03	10	34.2	8.6	10	14.3%	4.40 [-3.33, 12.13]
Leal-Junior 2009d	30.1	8.08	10	25.6	6.15	10	16.4%	4.50 [-1.79, 10.79]
Reis 2014 (pre-LLLT day1)	31	11.2	9	39.9	17.1	5	6.0%	-8.90 [-25.58, 7.78]
Reis post-LLLT day1	28.7	8.9	9	39.9	17.1	4	5.5%	-11.20 [-28.94, 6.54]
Vieira 2014	120.7	41.8	7	62.1	13.5	7	1.9%	58.60 [26.06, 91.14]
Total (95% CI)			**114**			**105**	**100.0%**	**4.88 [0.14, 9.62]**

Heterogeneity: Tau² = 25.28; Chi² = 19.39, df = 8 (P = 0.01); I² = 59%
Test for overall effect: Z = 2.02 (P = 0.04)



B Number of repetitions

Study or Subgroup	Phototherapy Mean	Phototherapy SD	Phototherapy Total	Placebo Mean	Placebo SD	Placebo Total	Weight	Mean Difference IV, Random, 95% CI
Alves 2014	648	95	18	648	87	18	0.2%	0.00 [-59.51, 59.51]
De Marchi 2012	711.41	87.47	22	697.27	83.62	22	0.2%	14.14 [-36.43, 64.71]
Kelencz 2010 (2.088J)	42.2	14.7	10	33.4	12.4	10	4.3%	8.80 [-3.12, 20.72]
Leal Junior 2010	41.3	5.1	9	38.2	3.2	9	39.0%	3.10 [-0.83, 7.03]
Leal-Junior 2008	53.8	7.242	6	41.15	7.1943	6	9.1%	12.65 [4.48, 20.82]
Leal-Junior 2009b	47.37	11.5	10	42.46	13.81	10	4.9%	4.91 [-6.23, 16.05]
Leal-Junior 2009d	37.15	6.45	10	34.34	6.77	10	18.0%	2.81 [-2.99, 8.61]
Maciel 2013	25.4	19.7	7	34.5	20.6	7	1.4%	-9.10 [-30.22, 12.02]
Malta 2016	154.6	36	15	155.5	37	15	0.9%	-0.90 [-27.02, 25.22]
Miranda 2016	780.2	91	20	742.1	94	20	0.2%	38.10 [-19.24, 95.44]
Reis 2014 (pre-LLLT day1)	36	9.2	9	41.1	14.7	4	2.5%	-5.10 [-20.71, 10.51]
Reis post-LLLT day1	34.2	7.9	9	41.1	14.7	5	3.1%	-6.90 [-20.78, 6.98]
Reis post-LLLT day8	37.8	10.6	9	40.4	14.8	5	2.8%	-2.60 [-17.31, 12.11]
Reis pre LLLT day8	37.4	9.6	9	40.4	14.8	4	2.4%	-3.00 [-18.80, 12.80]
Rossato 2016	48.54	8.99	10	43.46	12.45	10	6.7%	5.08 [-4.44, 14.60]
Rossato 2016	49.67	13.69	10	44.13	12.73	10	4.5%	5.54 [-6.05, 17.13]
Total (95% CI)			**183**			**165**	**100.0%**	**3.55 [1.09, 6.00]**

Heterogeneity: Tau² = 0.00; Chi² = 13.65, df = 15 (P = 0.55); I² = 0%
Test for overall effect: Z = 2.83 (P = 0.005)

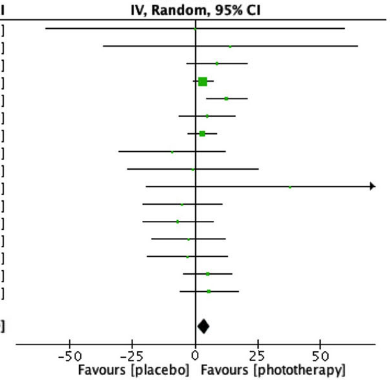
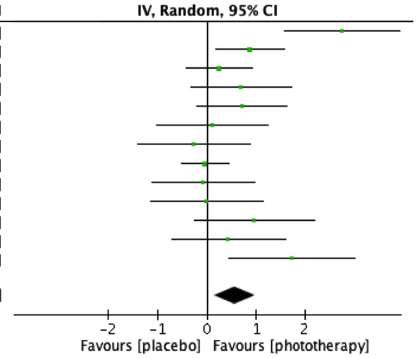


Fig. 4 Meta-analysis time to exhaustion (a) and number of repetitions (b)

A Isometric Peak Torque

Study or Subgroup	Phototherapy Mean	Phototherapy SD	Phototherapy Total	Placebo Mean	Placebo SD	Placebo Total	Weight	Std. Mean Difference IV, Random, 95% CI
Antonialli 2014	271.22	26.55	12	187.95	31.68	12	6.5%	2.75 [1.58, 3.92]
Baroni 2010a	188.93	43.04	18	154.03	34.57	18	10.0%	0.87 [0.19, 1.56]
Baroni 2010b	237.68	48.82	17	225.68	44.14	17	10.1%	0.25 [-0.42, 0.93]
De Marchi 2017	49.04	10.94	8	41.63	9.13	8	7.5%	0.70 [-0.32, 1.71]
de Paiva 2016	228.64	12.91	10	211.59	29.5	10	8.2%	0.72 [-0.19, 1.63]
Fritsch 2016	273.05	83.04	6	263.5	76.95	6	6.7%	0.11 [-1.02, 1.24]
Fritsch 2016	254.22	43.13	6	266.24	41.78	6	6.7%	-0.26 [-1.40, 0.88]
Hemmings 2017	256.2	61.6	34	258.4	69.4	34	11.8%	-0.03 [-0.51, 0.44]
Rossato 2016	76	11	7	77	13	7	7.2%	-0.08 [-1.13, 0.97]
Rossato 2016	75	16	6	75	14	6	6.7%	0.00 [-1.13, 1.13]
Vanin 2016	239.04	24.96	6	215.46	19.92	6	6.1%	0.96 [-0.26, 2.19]
Vanin 2016	227.07	33.75	6	213.33	23.74	6	6.6%	0.43 [-0.72, 1.59]
Vanin 2016 MsC	259.04	19.43	7	228.14	13.57	7	5.8%	1.73 [0.44, 3.02]
Total (95% CI)			**143**			**143**	**100.0%**	**0.57 [0.17, 0.97]**

Heterogeneity: Tau² = 0.30; Chi² = 29.07, df = 12 (P = 0.004); I² = 59%
Test for overall effect: Z = 2.77 (P = 0.006)



B Blood Lactate Levels

Study or Subgroup	Phototherapy Mean	Phototherapy SD	Phototherapy Total	Placebo Mean	Placebo SD	Placebo Total	Weight	Mean Difference IV, Fixed, 95% CI
Alves 2014	7.2	2.3	18	7.7	2.7	18	4.5%	-0.50 [-2.14, 1.14]
Denis 2013	12.94	3.53	18	13.27	3.73	18	2.1%	-0.33 [-2.70, 2.04]
Hemmings 2017	1	1.36	34	1.14	1.69	34	22.6%	-0.14 [-0.87, 0.59]
Leal Junior 2010	2.2	0.54	9	5.32	3.19	9	2.7%	-3.12 [-5.23, -1.01]
Leal-Junior 2008	3.92	0.5	6	3.65	0.51	6	36.7%	0.27 [-0.30, 0.84]
Leal-Junior 2009a	9.94	1.75	8	10.04	2.59	4	1.5%	-0.10 [-2.91, 2.71]
Leal-Junior 2009a (LED)	10.03	1.74	8	10.04	2.59	4	1.5%	-0.01 [-2.82, 2.80]
Leal-Junior 2009b	11.6	3.99	10	15.2	3.21	10	1.2%	-3.60 [-6.77, -0.43]
Leal-Junior 2009c	13.27	2.11	20	13.66	2.89	20	4.9%	-0.39 [-1.96, 1.18]
Leal-Junior 2009d	5.93	0.9	10	6.1	1.1	10	15.5%	-0.17 [-1.05, 0.71]
Leal-Junior 2011a	10.5	2.43	6	9.17	5.04	6	0.6%	1.33 [-3.15, 5.81]
Pinto 2016	14.11	3.53	12	15.1	2.74	12	1.9%	-0.99 [-3.52, 1.54]
Reis 2014 (post-LLLT day1)	4.42	2.59	9	4.53	1.69	5	2.4%	-0.11 [-2.36, 2.14]
Reis 2014 (pre-LLLT day1)	4.7	2.69	9	4.53	1.69	4	2.1%	0.17 [-2.24, 2.58]
Total (95% CI)			**177**			**160**	**100.0%**	**-0.15 [-0.49, 0.20]**

Heterogeneity: Chi² = 15.41, df = 13 (P = 0.28); I² = 16%
Test for overall effect: Z = 0.82 (P = 0.41)

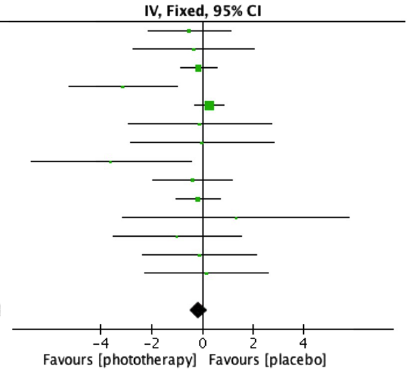


Fig. 5 Meta-analysis isometric peak torque (a) and blood lactate levels (b)

Table 12 Quality of evidence assessment (GRADE)

Phototherapy compared to placebo for the improvement of muscle performance and reduction of muscular fatigue in healthy people

Bibliography: Phototherapy for the improvement of muscle performance and reduction of muscular fatigue in healthy people. Cochrane Database of Systematic Reviews [year], Issue [issue].

Quality assessment							Summary of findings				
No. of participants (studies) Follow-up	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall quality of evidence	Study event rates (%)		Relative effect (95% CI)	Anticipated absolute effects	
							With placebo	With phototherapy		Risk with placebo	Risk difference with phototherapy
Time to exhaustion											
348 (12 RCTs)	Not serious	Not serious	Not serious	Serious[a,b,c,d]	None	⊕⊕⊕○ Moderate	165	183	–	The mean time to exhaustion was 0	MD 3.55 higher (1.09 higher to 6 higher)
Blood lactate post-5 min											
337 (13 RCTs)	Not serious[b,e]	Not serious	Not serious	Serious[a]	None	⊕⊕⊕○ Moderate	160	177	–	The mean blood lactate post-5 min was 0	MD 0.14 lower (0.49 lower to 0.2 higher)
Creatine kinase											
266 (15 RCTs)	Not serious[b,e]	Very serious[f,g]	Serious[h]	Serious[a]	None	⊕○○○ Very low	133	133	–	The mean creatine kinase was 0	MD 0.63 lower (0.89 lower to 0.36 lower)
Number of repetitions											
219 (8 RCTs)	Not serious[b,e]	Serious[g]	Not serious	Serious[a]	None	⊕⊕○○ Low	105	114	–	The mean number of repetitions was 0	MD 4.88 higher (0.14 higher to 9.62 higher)
C-reactive protein (assessed with: blood sample)											
50 (3 RCTs)	Serious[b,e]	Not serious	Not serious	Very serious[c,i]	None	⊕○○○ Very low	25	25	–	Not pooled	Not pooled
Lactate dehydrogenase (LDH) (assessed with: blood sample)											
120 (3 RCTs)	Serious[b,e]	Not serious	Not serious	Very serious[c,i]	None	⊕○○○ Very low	60	60	–	Not pooled	Not pooled
Isometric peak torque											
286 (10 RCTs)	Very serious[b,d,j]	Serious[g]	Not serious	Serious[a]	None	⊕○○○ Very low	143	143	–	–	SMD 0.57 SD higher (0.17 higher to 0.97 higher)
Total work											
140 (4 RCTs)	Very serious[b,d,k,l,m]	Not serious	Not serious	Serious[a,i,m]	None	⊕○○○ Very low	70	70	–	Not pooled	Not pooled
1-RM test											
78 (4 RCTs)	Serious[b,d,n]	Not serious	Not serious	Very serious[a,i,m]	None	⊕○○○ Very low	39	39	–	Not pooled	Not pooled

Table 12 (continued)

Phototherapy compared to placebo for the improvement of muscle performance and reduction of muscular fatigue in healthy people

Bibliography: Phototherapy for the improvement of muscle performance and reduction of muscular fatigue in healthy people. Cochrane Database of Systematic Reviews [year], Issue [issue].

Quality assessment							Summary of findings				
No. of participants (studies) Follow-up	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall quality of evidence	Study event rates (%)		Relative effect (95% CI)	Anticipated absolute effects	
							With placebo	With phototherapy		Risk with placebo	Risk difference with phototherapy
Peak power											
152 (4 RCTs)	Serious[b,e,o]	Not serious	Not serious	Very serious[a,i]	None	⊕○○○ Very low	76	76	–	Not pooled	Not pooled
Mean peak power											
40 (3 RCTs)	Serious[b,e]	Not serious	Not serious	Very serious[a,i]	None	⊕○○○ Very low	20	20	–	Not pooled	Not pooled
Maximal force											
111 (4 RCTs)	Serious[b]	Very serious[p]	Not serious	Very serious[a,i]	None	⊕○○○ Very low	55	56	–	Not pooled	Not pooled
Mean force											
80 (2 RCTs)	Serious[b,o]	Serious[p]	Not serious	Very serious[a,i]	None	⊕○○○ Very low	40	40	–	Not pooled	Not pooled

CI confidence interval, *MD* mean difference, *SMD* standardized mean difference

[a] The sample size of the studies is small, and the variability between exercises and phototherapy protocols is wide

[b] Unclear allocation concealment

[c] Wide confidence intervals

[d] Selective report

[e] Unclear selective report

[f] Unexplained heterogeneity

[g] Wide heterogeneity

[h] Variability in time points and types of physical activities

[i] Few events and participants

[j] One pilot study

[k] Attrition bias

[l] Lack of blinding of participants and personnel

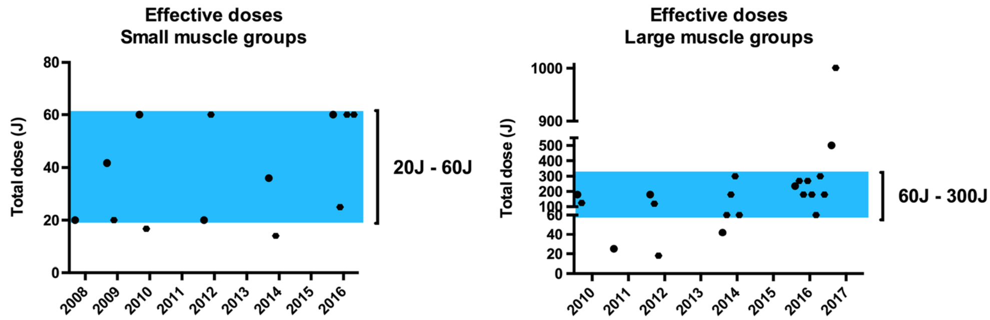
[m] No placebo group (one study)

[n] Lack of blinding of participants, personnel, and/or outcome assessors

[o] Unclear how the authors performed the randomization process

[p] Different target muscles

Fig. 6 Effective doses for small and large muscular groups



studies that reported 1 month [35], 1 week [20, 25, 30, 36, 39–45, 48], 72 h [27], and 48 h of washout [34, 46, 47, 50, 54]. One did not report the time between sessions [29]. Because some studies performed the assessments with a follow-up of 96 h, at least 1 week between the testing sessions seems reasonable to prevent carryover effects in studies with photobiomodulation therapy.

A further concern is regarding the variability of exercise protocols and photobiomodulation therapy parameters used in the studies. As our definition on performance comprises physical exercise or sport in general, and the research question does not limit to a specific kind of physical activity, we decided to include in the whole evidence. Nevertheless, replication of some studies would be necessary to confirm the effects.

Some studies evaluated the effects of photobiomodulation therapy in the field with specific sports testing [48, 55] or matches [56]. Positive effects were found in the study conducted by Ferraresi et al. [56] in preventing increases in CK activity when photobiomodulation therapy was applied before four volleyball matches. However, this study presented serious problems regarding methodology, data analysis and data interpretation [72] besides not monitoring the level of activity of each participant during each match, which can alter the level of this enzyme.

In fact, research with athletes in the field is very interesting and important for sports practice. It is a novel setting in the photobiomodulation therapy research, and it must be investigated to confirm the previous findings.

The primary strength of our study is that we systematically summarized important results related to photobiomodulation therapy in performance and fatigue, comprising all evidence in this research field to date. Another strength is our methodological design because we did not define any restriction on the date of publication or language. In addition, we performed manual search though references lists of the manuscripts and lists of publications from more cited authors in this field. By this approach, we believe that we could compile the whole scientific literature available. Furthermore, we registered the review protocol before starting the research, ensuring the transparency of the review process as suggested by the PRISMA statement [73].

With regard to data extraction, another strength of our study is that when data of the studies were unavailable or in case of any doubt regarding the studies, we contacted the authors through e-mail. Although not all authors have replied to e-mails, we managed to gather the most information possible.

Implications for current practice

The application of photobiomodulation therapy combined with exercise has shown to be effective on improving muscular performance and reducing the signals of fatigue. This is a promising area of research, and interesting results can be found in the current literature [74].

Photobiomodulation therapy associated with exercise seems to be a valuable alternative to improve muscular performance, and consequently, reduce the recovery time between exercise sessions. The beneficial effects could be observed in both untrained individuals and athletes, which means that this intervention could be an alternative to shorter rehabilitation processes for patients and also for better performance in sports, which could be observed from the data and author's conclusions of the most studies included in this systematic review. However, the quality of the body evidence assessment showed very low to moderate quality to the main outcomes, showing that further research must be performed to be confident about the effects. We attribute this quality level mainly to the risk of bias category and the imprecision of the results due the small sample size and wide confidence intervals of the outcomes (Table 12).

Meta-analysis was possible for only four outcomes, and we found that some evidence shows that photobiomodulation therapy has an effect for these outcomes. Therefore, more studies are needed to conclude the effect of this therapy in improvement of performance, both in functional outcomes and biochemical markers related to recovery.

Future recommendations

Important gaps for future studies were found in this review based on the methodological limitations. We strongly recommend the attention by researchers for reporting guidelines as the Consolidated Standards of Reporting Trials (CONSORT) statement to perform the trials [75, 76]. Recently, it was copublished on JOSPT (originally published in the Journal of Physiotherapy in 2016) an editorial encouraging authors to follow the Tidier checklist (template for intervention description and replication) to confirm if all items required were reported in the manuscript before submission [77]. This is a means to reduce bias and assist the authors to follow an adequate, clear, and transparent reporting and design.

However, there is no guideline for reporting crossover trials. The high proportion of lack of information in the reports found in this review led us to encourage reviewers and investigators regarding the need for reporting guidelines for crossover trials. Moreover, future studies should present their data in absolute values and their respective variation, as mean ± SD, with detailed description.

Further concern should be taken in reporting photobiomodulation therapy parameters. These parameters should be shown in detailed form, such as in a table in the manuscript, to provide more information for the reader regarding the device used and allow the study replication by other authors [78].

Finally, more research is needed in this area with greater sample size, better methodological design, and detailed photobiomodulation therapy parameters to increase the quality of evidence and confidence that the estimated effects are true. In this review, we could detect for the very first time a "therapeutic window" in this exciting field, and we encourage the authors to improve the investigation around this range of photobiomodulation therapy parameters.

Conclusion

Our results suggest that the application of photobiomodulation therapy associated with exercise may improve muscular performance and reduce the signals of muscle fatigue. The best effects of photobiomodulation therapy were observed mainly when LLLT, LEDT, or the combination of both sources of lights were used before the exercise in direct contact with the skin with wavelengths from 655 to 950 nm. Most of positive results were observed with an energy dose range from 20 to 60 J for small muscular groups and 60 to 300 J for large muscular groups and maximal power output of 200 mW per diode.

Despite the detailed analysis of the individual studies, it must be viewed with caution due to the very low- to moderate-quality evidence of the body of studies.

We conclude that more studies with better methodological quality, greater sample size, and following a therapeutic window are needed to predict the effects and effectiveness of this therapy.

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Compliance with ethical standards

Conflict of interests Professor Ernesto Cesar Pinto Leal-Junior receives research support from Multi Radiance Medical (Solon, OH, USA), a laser device manufacturer. AAV, EV, SDB, and LPC declare that they have no conflicts of interest.

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