

The Effect of Photobiomodulation Therapy on Muscle Performance in Volleyball and Football Players: A Meta-Analysis of Randomized Controlled Trials

Abstract

Context:

The use of photobiomodulation therapy (PBMT) as an adjunct to improve muscle performance and accelerate recovery in high-level volleyball and football players remains controversial.

Objective:

To determine whether PBMT improves skeletal muscle performance in ball sports athletes, and whether there are differences in the improvement of skeletal muscle performance by PBMT between volleyballers and footballers.

Data Sources:

A comprehensive search of the Web of Science, Medline, Scopus, and PubMed databases was conducted through April 10, 2025.

Study Selection:

Eligible studies included those explicitly categorized as randomized controlled trials (RCT) of PBMT interventions for high-level volleyballers and/or footballers; 14 studies met the inclusion criteria.

Study Design:

Meta-analysis.

Level of Evidence:

Level 2.

Data Extraction:

The primary outcome measures included maximal voluntary contraction force (MVC), number of repetitions, and creatine kinase (CK) levels. Means and standard deviations for each variable of interest were used to calculate standardized mean differences (SMDs).

Results:

The active laser had no significant effect on MVC (mean difference [MD], 19.67; 95% CI, 7.36 to 31.72; $P = 0.31$); however, it significantly increased the number of repetitions (SMD, 0.58; 95% CI, -0.05 to 1.21; $P = 0.04$) and significantly decreased CK levels (MD, -45.37; 95% CI, -55.52 to -35.22; $P < 0.001$).

Conclusion:

PBMT can delay muscle fatigue onset and reduce CK levels in ball sports athletes. The improvement in skeletal

muscle performance induced by PBMT showed differences between volleyballers and footballers, as there was a significant increase the number of repetitions in volleyball players, whereas a significant decrease in CK levels was noted in footballers.

Keywords: meta-analysis, muscle performance, PBMT, volleyball and football players

To enhance muscle performance effectively, athletes often use various methods (eg, mechanical, psychological, and physiological) to increase energy generation and use, thereby achieving the goals of improving muscle strength, increasing resistance to fatigue, and accelerating recovery after exercise fatigue. Although skeletal muscle fatigue is a common phenomenon in athletes' daily training and competition, the basic mechanisms underlying its role and development, as well as the best preventive measures, remain unclear.¹⁴ Muscle damage in sports or other activities is often the result of skeletal muscle fatigue.¹ The activities of specific enzymes vary widely under both pathological and physiological conditions and are associated with cell necrosis and tissue damage after acute and chronic muscle injury.⁷ The most useful serum markers of muscle injury after intensely prolonged training include creatine kinase (CK), lactate dehydrogenase, aldolase, myoglobin, troponin, aspartate aminotransferase, and carbonic anhydrase III.³

Football and volleyball are recognized as high-intensity sports; during training and/or competition, volleyball players have to perform a large number of vertical jumps, whereas football players have to perform a great amount of high-intensity running and perform frequent accelerations. These activities have high neuromuscular demands, thereby causing transient or acute fatigue. The onset of fatigue reduces the performance of players in high-intensity competition, and strategies should be employed to improve and expedite recovery after matches to better prepare athletes for subsequent demands.⁶ Photobiomodulation therapy (PBMT), also known as low-level laser therapy (LLLT) or light-emitting diode therapy (LEDT),¹² is an innovative, noninvasive, and nonpharmacological method for promoting recovery from exercise.²³ The interaction of laser energy with biological tissues can trigger bioenergetic and proliferative effects at cellular and molecular levels.⁹ The effects of PBMT are related to photochemical and photobiological effects within tissues rather than heat.¹³ LLLT has the ability to reduce both the release of reactive oxygen species and the activity of creatine phosphokinase while increasing the levels of antioxidants and inducing the synthesis and expression of hsp-70i, decreasing muscle damage.^{2,25} LLLT can also enhance ATP production and preserve mitochondria,²⁸ which may boost muscle endurance and reduce fatigue. Studies have indicated that PBMT, when administered before exercise, can improve performance and reduce exercise-induced fatigue and damage in ball sports players.^{6,11,18,27} This study aimed to conduct a comprehensive meta-analysis to determine the impact of PBMT on the muscle performance of ball sports players, and explore differences in the improvement of skeletal muscle performance by PBMT between volleyballers and footballers. The study findings may provide evidence-based clinical practice recommendations and directions for future research in this field.

Methods

The project adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.²⁴ Two independent assessors performed these steps. Disagreements were resolved through discussion or consensus with a third assessor.

Information Sources and Search Strategies

A literature search was conducted using scientific databases (PubMed, Scopus, Medline, Web of Science) for articles up to April 10, 2025, using the Boolean logic operators “AND” and “OR” in the subject search box and the following English keywords: the first search term included “PBMT” OR “LLLT” OR “Low Level Light Therapy” OR “Low Level Laser Therapy” OR “Low Power Laser Irradiation” OR “Low Power Laser Therapy” OR “Photobiomodulation Therapy,” the second search term included “exercise” OR “training” OR “activity,” and the third English search term included “Randomized Controlled Trial” OR “RCT.”

Study Inclusion and Exclusion Criteria

The inclusion criteria were in accordance with the Population, Intervention, Comparison, Outcomes, and Study (PICOS) principles. The following inclusion criteria were applied: (1) population: healthy athletes aged ≥ 18 years and ≤ 60 years, without differentiating according to nationality, age, or sex; (2) intervention: pre-exercise PBMT; (3) control: placebo or no intervention before exercise; (4) outcome measures: muscle endurance, muscle strength, and CK levels; (5) study design: randomized controlled trial (RCT), either parallel or crossover.

Exclusion criteria were as follows : (1) observational studies, case reports, review articles, conference abstracts, and preprints; (2) uncontrolled trials (eg, single-arm trials) or literature with unclear descriptions of the study methods; (3) unhealthy participants; (4) PBMT in conjunction with other interventions (including static magnetic fields and bloodflow restriction); (5) long-term interventions; (6) failure to include required primary outcome measures and inability to extract means and standard deviations; and (7) animal studies.

Data Extraction

Two researchers independently searched the 4 databases using the literature search methods described above. Search results were exported uniformly into EndNote X9.1 with key information such as article title, abstract, author, and year of publication. After duplicate articles were deleted, the article information was imported into Excel (Microsoft), and studies irrelevant to the research were excluded according to the literature exclusion criteria. If no information related to the exclusion criteria was provided in the abstract, the article was either included or excluded after reading the full text or supplementary documents. To avoid errors and reduce bias, a third researcher judged and arbitrated inconsistent decisions of the 2 researchers. Two researchers extracted the data independently, and the data in the article were extracted using Excel before the third researcher summarized the data.

Risk of Bias Evaluation

Two researchers assessed the risk of bias using the Cochrane Collaboration tool and evaluated the quality of the included studies, resolving differences by consensus with the participation of a third researcher, focusing primarily on the following areas: 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 biases. For each indicator, the literature was categorized into 3 levels: “low risk of bias,” “unclear risk of bias,” and “high risk of bias.” The levels were defined as follows: level A for studies with ≥ 4 low-risk items, level B for studies with 2 to 3 low-risk items, and level C for studies with 1 or no low-risk items. Egger’s method was used to detect publication bias using Stata/MP Version 14.0 (Stata Corp). Bias was indicated at $P < 0.05$.

Intervention Characteristics

All studies included a PBMT intervention in the experimental groups and a placebo in the control group. The primary method employed in this study randomized participants into at least 2 groups: one receiving active laser irradiation and the other receiving sham laser with active laser irradiation. After an initial assessment to determine baseline indicators, participants were instructed by a professional to undergo several exercise sessions according to a predesigned exercise program, incorporating PBMT or placebo, either before or after the exercise. The participants were blinded to the treatments using dark blindfolds or opaque goggles during the PBMT procedures. In addition, the researcher involved in the statistical analysis was blinded to the PBMT treatments.

Statistical Analysis

Review Manager Version 5.4 (The Cochrane Collaboration) was used for data analysis and generating forest plots. When the units of measurement were inconsistent across groups with the same outcome indicator, the standardized mean difference (SMD) was used to eliminate the effect of different study units. Otherwise, the mean difference (MD) was used to combine the statistics. Statistically significant differences were indicated by a 95% CI around the MD (or SMD) that did not include zero. Cochrane’s Q and I^2 tests were employed to assess heterogeneity across multiple studies. In addition, the heterogeneity among multiple studies was quantitatively assessed using the I^2 test. When $I^2 < 50\%$, heterogeneity was considered acceptable, and a fixed-effects model was used to calculate the combined statistics; otherwise, a random-effects model was used.

Quality of Evidence Assessment

The use of the Grading of Recommendations, Assessment, Development and Evaluation (GRADEpro) was used to assess the quality of evidence. The synthesis and quality of evidence was assessed according to 5 domains of study limitations (risk of bias, inconsistency, indirectness, imprecision, and publication bias). The quality of evidence was rated as high, moderate, low, and very low.

Results

Study Selection

The initial search retrieved 2250 articles from the 4 databases, and 2183 articles were excluded after reviewing their titles. Following a comprehensive assessment of the full texts, 14 RCTs were included based on the article inclusion and exclusion criteria,^{1,4,6-9,11,17-22,27} as shown in Figure 1.

Figure 1.

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Flow diagram of literature search and study selection. PBMT, photobiomodulation therapy.

Study Characteristics

The mean and standard deviation of participant age, excluding 1 study that lacked this information, was 21.1 ± 3.09 years. The characteristics of the 14 included studies, involving 124 football players and 70 volleyball players, are summarized in Table 1. All participants were professional athletes. All studies were RCTs, and all control groups used placebo LEDT. The wavelength distribution of the low-intensity laser ranged from 630 nm to 940 nm. The laser dose ranged from 20 J to 850 J, and the treatment points were the leg or arm. Figure 2 shows the authors' judgments regarding the risk of bias for each included study. Five studies had a "B" quality level, whereas the other studies had an "A" quality level.

Table 1.

First author)	Country	Activity level	Sample size (T/C)	Age, years	Time interval between PBMT and exercise, minutes	Energy output, Joules	Application sites	Exercise programs	Comparison	Outcome measures
1)	Brazil	High-level soccer players	7/7/7/7	18.81±0.8	3	60/180/300 per leg	6 sites of quadriceps femoris	75 eccentric isokinetic contractions of the knee extensor musculature in the nondominant leg	RCT	MVC; CK
2)	Brazil	Female professional futsal player	10	20.4±3.3	0	48 per leg, 96 total	4 points distributed in the abdomen of the lateral femoral and rectus femoris muscles	80% 1RM load under leg press repeat failure test	RCT	Repetitions
3)	Brazil	Futsal professional athletes	6	26.16±6.91	40	510 per leg, 1020 total	17 sites per lower limb	Futsal game	RCT	CK
4)	Brazil	High-level soccer players	7/7/7/7	18.62 ± 0.73	3	300 per leg	6 different sites of the knee extensor muscles of the nondominant lower limb	75 eccentric isokinetic contractions of the knee extensors of the nondominant leg	RCT	MIVC; CK
5)	Brazil	Male amateur soccer players	12	25.17 ± 4.04	0	300 per leg	Convex surface at the back of the thigh	Simulated soccer match	RCT	Peak torque
6)	Brazil	Male professional soccer athletes	9/9	15-30	3	25.2J per leg, 50.4 total	Front side of thigh	Full bilateral knee extension to exhaustion under 75% 1RM load	RCT	Repetitions; CK
7)	Brazil	Male professional volleyball athletes	12	25.5 ± 5.3	40-60	630/1260/1890 per leg	Quadriceps, hamstrings and calf triceps	National Championship (Volleyball)	RCT	CK
8)	Brazil	Male volleyball athletes	8	18.5 ± 0.93	3	12 per leg, 24 total; 83.4 per leg, 166.8 total	2 irradiation points along the ventral side of the rectus femoris	Wingate test	RCT	CK

r 18)	Brazil	male volleyball athletes	9	20.67 ± 2.96	3	40 total (volleyball), 30 total (soccer)	5 points on the belly of the rectus femoris muscle	Wingate test	RCT	CK
r 21)	Brazil	Male professional volleyball athletes	10	23.6 ± 5.6	3	41.7 total	middle point of biceps	Elbow flexion to exhaustion at 75% MVC load on the dominant side	RCT	Repetitions; CK
r 22)	Brazil	Male professional volleyball athletes	10	22.3 ± 6.09	1	20 per arm	4 points in the middle of the biceps muscle belly	Elbow flexion to exhaustion at 75% MVC load	RCT	Repetitions
r 20)	Brazil	Healthy male volleyball athletes	9	18.6 ± 1.0	3	60 per arm	2 points of the biceps	Elbow flexion to exhaustion at 75% MVC load on the nondominant side	RCT	Repetitions; CK
r 19)	Brazil	Male professional volleyball athletes	6/6	22 ± 3	1	20 per leg	4 points in the middle of the biceps muscle belly	Elbow flexion to exhaustion at 75% MVC load on the nondominant side	RCT	Repetitions
zoni 19)	Brazil	High-level male soccer athletes	22	18.85 ± 0.61	0	850 per leg, 1700 total	17 points of the lower limbs	High-intensity progressive running test until exhaustion	RCT	CK

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Data are expressed as mean ± SD.

1RM, 1 repetition maximum; C, control group; CK, creatine kinase; MIVC, maximum isometric voluntary contraction; MVC, maximum voluntary contraction; PBMT, photobiomodulation therapy; RCT, randomized controlled trial; T, trial group.

Figure 2.

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(a) Risk of bias assessment for the included studies using the key shown in (b).

Meta-Analysis Results

Maximum Voluntary Contraction

Three football studies measured the MVC. A mean increase of 19.67 Nm was observed in the experimental group compared with that of the control group (MD,19.67; 95% CI 7.36-31.72; heterogeneity: $\text{Tau}^2 = 2.37$, $\text{df} = 2$ [$P = 0.31$], $I^2 = 16\%$); however, this difference was not statistically significant (Figure 3). Therefore, using LLLT did not significantly improve MVC in footballers.

Figure 3.

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Forest plot of the differences in the effect of PBMT on the MVC in football and volleyball players between experimental and control groups. IV, inverse variance; MVC, maximum voluntary contraction; PBMT, photobiomodulation therapy.

Exercise Fatigue (Number of Repetitions)

Six studies assessed the onset of exercise fatigue and used the number of repetitions to reflect skeletal muscle fatigue. Compared with placebo LLLT, active laser treatment increased the number of repetitions in the experimental groups significantly (SMD, 0.58; 95% CI -0.05 to 1.21; heterogeneity: $\text{Tau}^2 = 0.34$, $\chi^2 = 11.73$, $\text{df} = 5$ [$P = 0.04$], $I^2 = 57\%$). The number of repetitions was increased in all volleyball active laser irradiation groups (SMD, 0.99; 95% CI, 0.19-1.79; heterogeneity: $\text{Tau}^2 = 0.35$, $\chi^2 = 6.61$, $\text{df} = 3$ [$P = 0.09$], $I^2 = 55\%$). Two studies assessed the number of repetitions of active laser irradiation used by footballers, with inconsistent results. One study found no change, whereas the other observed a decrease in the number of repetitions in the experimental group, and the forest plot results showed no significant change in the number of repetitions of active laser irradiation used by footballers (SMD, -0.10; 95% CI, -0.73 to 0.54; heterogeneity: $\text{Tau}^2 = 0.00$, $\chi^2 = 0.10$, $\text{df} = 1$ [$P = 0.75$], $I^2 = 0\%$) (Figure 4). These results indicate that PBMT can delay the onset of muscle fatigue of ball sports athletes, especially in volleyballers.

Figure 4.

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Forest plot of the differences in the effect of PBMT on the number of repetitions in football and volleyball players between experimental and control groups. IV, inverse variance; PBMT, photobiomodulation therapy.

CK Levels

Ten studies reported CK levels (skeletal muscle injury marker), and 5 studies each involved football and volleyball players. PBMT decreased CK levels significantly in the experimental groups compared with the control groups (MD, -45.37; 95% CI, -55.52 to -35.22; heterogeneity: $\text{Tau}^2 = 61.35$, $\text{df} = 9$ [$P < 0.001$], $I^2 = 85\%$). However, the effects of LLLT on CK activity were not consistent between football and volleyball players. The active LLLT groups had significantly lower CK levels (MD, -65.08; 95% CI, -78.33 to -51.82; Heterogeneity: $\text{Tau}^2 = 36.04$, $\text{df} = 4$ [$P < 0.001$], $I^2 = 89\%$) than the placebo groups in football players, whereas no statistically significant

differences were seen in volleyball players (MD, -17.38 , 95% CI -33.18 to -1.59 ; heterogeneity: $\text{Tau}^2 = 4.75$, $\text{df} = 4$ [$P = 0.31$], $I^2 = 16\%$) (Figure 5). LLLT reduces CK levels in volleyball and football athletes, especially in football players.

Figure 5.

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Forest plot of the differences of the CK activity on the football and volleyball players between the experimental and control groups. CK, creatine kinase; IV, inverse variance.

Publication Bias

As shown in Table 2, the Egger test indicated that 1 outcome measure (muscle endurance, muscle strength) had P values <0.05 (95% CI, 1.03 to 10.33; 95% CI, -7.27 to -1.70), suggesting the potential presence of small-study effects or publication bias. An overall assessment of the strength of evidence using GRADE (Figure 6) showed high quality of strength of evidence for MVC, low quality of evidence for number of repetitions, and low quality of evidence for CK levels.

Table 2.

Tests for publication bias of each outcome measure

	No. of studies	Coefficient	Standard error	t	$P> t $	95% CI
CK	10	-0.75	1.38	-0.54	0.60	-3.94 to 2.44
Muscle endurance	6	5.68	1.67	3.39	0.03	1.03 to 10.33
Muscle strength	3	-4.48	0.22	-20.44	0.03	-7.27 to -1.70

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Figure 6.

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Overall assessment of the strength of evidence using GRADE.

Discussion

To our knowledge, this is the first meta-analysis of PBMT in football and volleyball players; previous studies have focused solely on football or volleyball intervention trials. In high-intensity sports, the development of fatigue results in an overall decline in muscle performance and injury in some cases.¹⁶ Therefore, it is necessary to delay the onset of muscle fatigue and accelerate postexercise recovery.

A few studies have analyzed footballers' MVC. These studies indicated that the administration of PBMT with a power output of 100 or 200 mW before exercise may improve strength and enhance the recovery process.^{1,7} Irradiation with 10 J and a 200 mW power output per diode was observed to be optimal for improving muscle strength within 24 hours; however, irradiation with 10 J and 100 mW per diode was more suitable for strength improvement after 24 hours.⁷ Hayworth et al¹⁵ showed that treatment with PBMT or PBMT combined with cryotherapy recovered 100% of muscle strength at 24 hours after exercise. Our findings demonstrate that PBMT increased the mean MVC by 19.67 Nm; although not statistically significant, this indicates an improvement trend of muscle strength. Dutra et al¹⁰ showed that PBMT has no significant effect on muscle strength in single-joint exercises. Further research may provide more evidence to clarify the relationship between PBMT and muscle strength.

Several studies have shown that PBMT administered in an appropriate dose range before exercise might increase muscle endurance and delay the onset of skeletal muscle fatigue response during high-intensity exercises by significantly increasing the number of repetitions.¹⁹⁻²² Our findings demonstrate that pre-exercise PBMT results in a mean increase in the number of repetitions by 0.58 in ball sports athletes. The wavelength range from 655 nm to 830 nm increases muscle endurance and is not influenced by optical output (50-500 mW), total energy delivered (20-96 J), or treatment time (30-368 seconds).^{4,9,19-22} Notably, 940-nm irradiation does not increase the number of repetitions in high-level female soccer players.⁴ Our findings suggest a disagreement in the literature regarding the effectiveness of lasers in improving muscle fatigue when applied to football and volleyball. PBMT appears to have better effects on muscle endurance in volleyball athletes than in football athletes. This may be attributed mainly to the vast heterogeneity of methods, protocols, and samples of participants in published studies, as well as to the PBM parameters (including LLLT vs LEDT) and type of muscles (including leg vs arm muscles).

Several studies have demonstrated that pre-exercise LLLT exerts ergogenic effects and protects muscles against damage.^{1,6,17,27} CK exhibits significant variability in response to exercise and is used commonly as a marker of muscle damage.^{1,26} Although athletes were exposed to the same exercise, differences in peak CK levels after exercise may be tenfold.²⁵ Our findings indicated that PBMT, when used before exercise, resulted in an average reduction of 45.37 U/l in CK levels postexercise in ball sports athletes. Moreover, PBMT resulted in a larger reduction in CK levels in footballers than in volleyballers. Several studies have demonstrated that a wavelength of 810 nm and optical outputs of 100 mW and 200 mW may significantly decrease CK levels in volleyball and

football athletes.^{1,7,9,12,21} When using a wavelength of 810 nm for LLLT, both 10 J and 50 J doses decreased CK levels, with better results observed for the 50 J dose at the same optical output (200 mW); however, under the same dose (10 J per diode), both power outputs of 100 mW and 200 mW reduced CK levels, with better results observed for the 100-mW output.^{1,7} Furthermore, the active LEDT cluster probes (660/850 nm or 640/875/905 nm) also had the same effect on reducing CK levels.^{6,20,21} The decrease in CK levels after active LLLT may be attributed to a laser-protective effect during the development of muscle ischemia.²⁰ The reason for the difference in the postexercise reduction in CK levels between football and volleyball players remains unknown. However, the differences in CK levels between different sports may require consideration of the amount of muscle mass used during exercise.⁵

Limitations

The following limitations should be considered when interpreting the findings of this meta-analysis: there are few studies including the 2 sports, which may induce some bias, and the outcome indicators and methods are different across studies. In addition, studies are practically heterogeneous and limited by the small number of subjects, so that low-quality studies cannot be excluded.

Conclusion

Our meta-analysis reveals that pre-exercise PBMT is an effective intervention to improve muscle endurance (number of repetitions) significantly, delay the onset of muscle fatigue, and decrease postexercise muscle damage (CK levels) in ball sports athletes. In addition, PBMT led to notable differences in the improvement in skeletal muscle performance between volleyball and football players. Whereas PBMT significantly increased the number of repetitions in volleyballers, footballers showed a significant decrease in CK levels. Currently, most studies using PBMT to improve ball sports players' muscle performance originate from Brazil. In the future, an increasing number of national research teams should be involved and pay special attention to PBMT used in high-level competitive sports.

Footnotes

The authors report no potential conflicts of interest in the development and publication of this article.

References

1. Aver Vanin A, De Marchi T, Tomazoni SS, et al. Pre-exercise infrared low-level laser therapy (810 nm) in skeletal muscle performance and postexercise recovery in humans, what is the optimal dose? A randomized, double-blind, placebo-controlled clinical trial. *Photomed Laser Surg.* 2016;34(10):473-482. doi: 10.1089/pho.2015.3992 [DOI] [PubMed] [Google Scholar]
2. Avni D, Levkovitz S, Maltz L, Oron U. Protection of skeletal muscles from ischemic injury: low-level laser therapy increases antioxidant activity. *Photomed Laser Surg.* 2005;23(3):273-277. doi: 10.1089/pho.2005.23.273 [DOI] [PubMed] [Google Scholar]
3. Brancaccio P, Lippi G, Maffulli N. Biochemical markers of muscular damage. *Clin Chem Lab Med.* 2010;48(6):757-767. doi: 10.1515/CCLM.2010.179 [DOI] [PubMed] [Google Scholar]
4. Cabreira LMB, Merlo JK, Jacinto JL, Nunes JP, Ribeiro AS, Aguiar AF. Photobiomodulation therapy with light-emitting diode does not improve lower-body muscle performance and delayed-onset muscle soreness in resistance-trained women: a randomized, controlled, crossover trial. *Sci Sports.* 2022;37(7):635.e1-635.e9. 10.1016/j.scispo.2021.06.006 [DOI] [Google Scholar]
5. Craig JA, Barron J, Walsh DM, Baxter GD. Lack of effect of combined low intensity laser therapy/phototherapy (CLILT) on delayed onset muscle soreness in humans. *Lasers Surg Med.* 1999;24(3):223-230. [Erratum in *Lasers Surg Med.* 1999;25(1):88] doi: [DOI] [PubMed] [Google Scholar]
6. De Marchi T, Leal-Junior ECP, Lando KC, et al. Photobiomodulation therapy before futsal matches improves the staying time of athletes in the court and accelerates post-exercise recovery. *Lasers Med Sci.* 2019;34(1):139-148. doi: 10.1007/s10103-018-2643-1 [DOI] [PubMed] [Google Scholar]
7. de Oliveira AR, Vanin AA, Tomazoni SS, et al. Pre-exercise infrared photobiomodulation therapy (810

- nm) in skeletal muscle performance and postexercise recovery in humans: what is the optimal power output? *Photomed Laser Surg.* 2017;35(11):595-603. doi: 10.1089/pho.2017.4343 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
- 8. Dornelles MP, Fritsch CG, Sonda FC, et al. Photobiomodulation therapy as a tool to prevent hamstring strain injuries by reducing soccer-induced fatigue on hamstring muscles. *Lasers Med Sci.* 2019;34(6):1177-1184. doi: 10.1007/s10103-018-02709-w [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 9. Dos Reis FA, da Silva BA, Laraia EM, et al. Effects of pre- or post-exercise low-level laser therapy (830 nm) on skeletal muscle fatigue and biochemical markers of recovery in humans: double-blind placebo-controlled trial. *Photomed Laser Surg.* 2014;32(2):106-112. doi: 10.1089/pho.2013.3617 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 10. Dutra YM, Malta ES, Elias AS, Broatch JR, Zagatto AM. Deconstructing the ergogenic effects of photobiomodulation: a systematic review and meta-analysis of its efficacy in improving mode-specific exercise performance in humans. *Sports Med.* 2022;52(11):2733-2757. doi: 10.1007/s40279-022-01714-y [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 11. Ferraresi C, Dos Santos RV, Marques G, et al. Light-emitting diode therapy (LEDT) before matches prevents increase in creatine kinase with a light dose response in volleyball players. *Lasers Med Sci.* 2015;30(4):1281-1287. doi: 10.1007/s10103-015-1728-3 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 12. Ferraresi C, Huang YY, Hamblin MR. Photobiomodulation in human muscle tissue: an advantage in sports performance? *J Biophotonics.* 2016;9(11-12):1273-1299. doi: 10.1002/jbio.201600176 [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 13. Grandinetti Vdos S, Miranda EF, Johnson DS, et al. The thermal impact of phototherapy with concurrent super-pulsed lasers and red and infrared LEDs on human skin. *Lasers Med Sci.* 2015;30(5):1575-1581. doi: 10.1007/s10103-015-1755-0 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 14. Green SM, Langberg H, Skovgaard D, Bulow J, Kjaer M. Interstitial and arterial-venous [K⁺] in human calf muscle during dynamic exercise: effect of ischaemia and relation to muscle pain. *J Physiol.* 2000;529(3):849-861. doi: 10.1111/j.1469-7793.2000.00849.x [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 15. Hayworth CR, Rojas JC, Padilla E, Holmes GM, Sheridan EC, Gonzalez-Lima F. In vivo low-level light therapy increases cytochrome oxidase in skeletal muscle. *Photochem Photobiol.* 2010;86(3):673-680. doi: 10.1111/j.1751-1097.2010.00732.x [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 16. Ispirlidis I, Fatouros IG, Jamurtas AZ, et al. Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sport Med.* 2008;18(5):423-431. doi: 10.1097/JSM.0b013e3181818e0b [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 17. Leal Junior EC, Lopes-Martins RA, Baroni BM, et al. Comparison between single-diode low-level laser therapy (LLLT) and LED multi-diode (cluster) therapy (LEDT) applications before high-intensity exercise. *Photomed Laser Surg.* 2009;27(4):617-623. doi: 10.1089/pho.2008.2350 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 18. Leal Junior EC, Lopes-Martins RA, Baroni BM, et al. Effect of 830 nm low-level laser therapy applied before high-intensity exercises on skeletal muscle recovery in athletes. *Lasers Med Sci.* 2009;24(6):857-863. doi: 10.1007/s10103-008-0633-4 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 19. Leal Junior EC, Lopes-Martins RA, Dalan F, et al. Effect of 655-nm low-level laser therapy on exercise-induced skeletal muscle fatigue in humans. *Photomed Laser Surg.* 2008;26(5):419-424. doi: 10.1089/pho.2007.2160 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 20. Leal Junior EC, Lopes-Martins RA, Frigo L, et al. Effects of low-level laser therapy (LLLT) in the development of exercise-induced skeletal muscle fatigue and changes in biochemical markers related to postexercise recovery. *J Orthop Sports Phys Ther.* 2010;40(8):524-532. doi: 10.2519/jospt.2010.3294 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 21. Leal Junior EC, Lopes-Martins RA, Rossi RP, et al. Effect of cluster multi-diode light emitting diode therapy (LEDT) on exercise-induced skeletal muscle fatigue and skeletal muscle recovery in humans. *Lasers Surg Med.* 2009;41(8):572-577. doi: 10.1002/lsm.20810 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 22. Leal Junior EC, Lopes-Martins RA, Vanin AA, et al. Effect of 830 nm low-level laser therapy in exercise-induced skeletal muscle fatigue in humans. *Lasers Med Sci.* 2009;24(3):425-431. doi: 10.1007/s10103-008-0592-9 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 23. Li BM, Zhang CK, He JH, Liu YQ, Bao XY, Li FH. The effects of photobiomodulation on knee function, pain, and exercise tolerance in older adults: a meta-analysis of randomized controlled trials. *Arch Phys Med Rehabil.* 2024;105(3):593-603. doi: 10.1016/j.apmr.2023.06.016 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 24. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372:n71. doi: 10.1136/bmj.n71 [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]

- 25. Rizzi CF, Mauriz JL, Freitas Corrêa DS, et al. Effects of low-level laser therapy (LLLT) on the nuclear factor (NF)-kappaB signaling pathway in traumatized muscle. *Lasers Surg Med.* 2006;38(7):704-713. doi: 10.1002/lsm.20371 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 26. Sayers SP, Clarkson PM. Short-term immobilization after eccentric exercise. Part II: creatine kinase and myoglobin. *Med Sci Sports Exerc.* 2003;35(5):762-768. doi: 10.1249/01.MSS.0000064933.43824.E D [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 27. Tomazoni SS, Machado CDSM, De Marchi T, et al. Infrared low-level laser therapy (photobiomodulation therapy) before intense progressive running test of high-level soccer players: effects on functional, muscle damage, inflammatory, and oxidative stress markers-a randomized controlled trial. *Oxid Med Cell Longev.* 2019; 2019:6239058. doi: 10.1155/2019/6239058 [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
 - 28. Yu W, Naim JO, McGowan M, Ippolito K, Lanzafame RJ. Photomodulation of oxidative metabolism and electron chain enzymes in rat liver mitochondria. *Photochem Photobiol.* 1997;66(6):866-871. doi: 10.1111/j.1751-1097.1997.tb03239.x [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
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