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ORIGINAL ARTICLE

Photobiomodulation therapy as a tool to prevent hamstring strain injuries by reducing soccer-induced fatigue on hamstring muscles

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Abstract

Muscle fatigue is a potential risk factor for hamstring strain injuries in soccer players. The aim of this study was to verify the effect of photobiomodulation therapy (PBMT) on the hamstrings' muscle fatigue of soccer players during a simulated match. Twelve male amateur soccer players (~ 25 years) participated in this randomized, crossover, double-blinded, placebo-controlled trial. The volunteers were evaluated in two sessions, with a minimum 7-day interval. At each session, volunteers received either PBMT (300 J per thigh) or placebo treatment on the hamstrings prior to the simulated soccer match. Muscle strength and functional capacity were evaluated through isokinetic dynamometry and countermovement jump (CMJ) tests, respectively, before and immediately after the simulated soccer match. Players had lower reductions on hamstring eccentric peak torque [4.85% (ES = 0.31) vs. 8.72% (ES = 0.50)], hamstring-to-quadriceps torque ratio [3.60% (ES = 0.24) vs. 7.75% (ES = 0.50)], and CMJ height [1.77% (ES = 0.09) vs. 5.47% (ES = 0.32)] when treated with PBMT compared to placebo. Magnitude-based inference supports that PBMT promoted 75%, 69%, and 53% chances for beneficial effects on hamstring eccentric peak torque, hamstring-to-quadriceps torque ratio, and CMJ height, respectively, compared to placebo treatment. In conclusion, PBMT applied before a simulated soccer match proved to be effective in attenuating the hamstrings' muscle fatigue. These findings support PBMT as a promising tool to prevent hamstring strain injury in soccer players.

Keywords Phototherapy · Muscle injury · Prevention · Football

Introduction

The hamstring strain injury (HSI) is one of the major problems soccer players face in sports practice. A 13-year longitudinal analysis of European elite soccer teams reported that 22% of the players sustained at least one hamstring injury in each season [1]. It means that a soccer team with a 25-player squad can expect about 5–6 injured players per season. In addition, the recurrence rate is high (1–2 out of 10 injured players usually sustain a re-injury within 2 months of return to play) and the average absence time per injury is about 17 days [1]. Despite the persistent deficits after a HIS [2], players "off the pitch" due to injuries compromise the team performance [3] and negatively affect the club finances [4]; hence, prevention is the primary goal. Soccer clubs have invested in a range of tests for screening players who might be prone to injury and in specific prevention programs [5, 6], but HSI rates have not decreased throughout the years [1].

HSI is typically a non-contact injury (high-speed running is responsible for 60–80% of soccer HSIs) [7, 8]. Therefore, the scientific community has paid great attention to the intrinsic risk factors associated with HIS [9, 10]. Age and previous injuries are well-accepted non-modifiable risk factors [9, 10]. Among the modifiable risk factors, there is great attention on the hamstring eccentric strength [8, 11, 12] and the hamstring-to-quadriceps (H:Q) strength ratio [11, 13, 14]. It is important to note that both factors are expected to be affected by fatigue during a soccer match. Studies with intermittent exercise protocols designed to mimic demands of competitive

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soccer have found significant decreases (up to 31%) in hamstring eccentric strength with few or no impact on quadriceps strength [15–18], thus affecting the agonist–antagonist strength balance. The link between eccentric weakness and increased HSI risk suggests that players would be more susceptible to injury in fatigue situations, and this hypothesis is supported by the fact that most HSIs sustained during matches occurred during the last third of the first and second halves of the match (31–45′ and 76–90′, respectively) [7]. Therefore, muscle fatigue has been commonly stated as a potential risk factor for HSI [9].

Photobiomodulation therapy (PBMT), also known as phototherapy, is a non-invasive and non-pharmacological therapy largely employed to treat a series of musculoskeletal disorders [19]. Positive effects on pain [20], inflammation [20], and tissue repair [21] have been reported with application of low-level LASERs or light-emitting diodes (LEDs) over a target tissue [22]. Along the last decade, a growing body of evidences has been published regarding the PBMT action on muscle fatigue—for a review, see Vanin et al. [23]. Improved exercise performance and/or reduced fatigue markers have been found with a single application of PBMT immediately before a range of exercise protocols, such as exercise with free weights [24], isokinetic exercise [25], cycling [26], running [27], and intermittent sprints test [28].

In summary, the ability of PBMT to reduce muscle fatigue in different types of exercise has elevated this therapy to the category of potential ergogenic agent in sports. Considering the relationship between fatigue and HSI in soccer players, it seems plausible that PBMT may also be a promising tool for this injury prevention. The first step in the application of preventive-based PBMT is to find therapy parameters capable of minimizing the loss of hamstring strength generated by soccer practice. Therefore, the aim of the current study was to verify the effect of PBMT on the hamstrings' muscle fatigue of amateur soccer players during a simulated match.

Methods

Study design

The study is characterized as a randomized, crossover, double-blinded, placebo-controlled trial. The volunteers were evaluated in two sessions, with a minimum 7-day interval. Both sessions were performed at the same hour of day and with similar climatic conditions. At each session, volunteers received either PBMT or placebo treatment on the hamstrings prior to a soccer match simulation protocol. The order of the PBMT and placebo sessions was randomized through the random.org website. Muscular performance tests were applied before and after a simulated soccer match. The following sequence of events was performed within each session: (1) general warm-up, (2) countermovement jump (CMJ) test, (3) isokinetic test, (4) PBMT or placebo therapy, (5) simulated soccer match, (6) CMJ re-test, and (7) isokinetic re-test (Fig. 1). The study was previously approved by the Ethics and Research Committee of the University where the study was conducted (no. 63299416.4.0000.5345), and all participants signed an informed consent.

Participants

Twelve male amateur soccer players were recruited to participate in the study (age, 25.17 ± 4.04 years; body mass, 73.75 ± 5.85 kg; height, 1.74 ± 0.04 m). All participants followed a minimum routine of one soccer match per week (1.75 ± 0.86 h per week of sports practice) and had competitive experience in amateur soccer leagues. Exclusion criteria for participation in the study were as follows: (1) the presence of any musculoskeletal injuries during the study period, (2) history of muscle injuries on lower limbs (e.g., hamstrings, quadriceps, groin) in the 6 months prior to the evaluations, (3) recent history of any lower limbs injuries that could interfere with the studied outcomes (e.g., anterior cruciate ligament rupture,

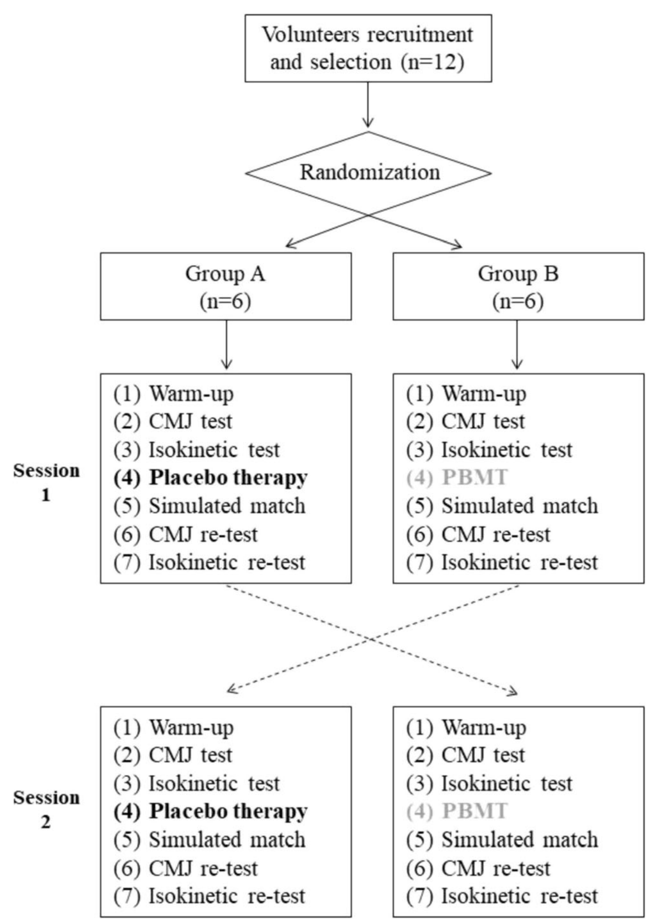


Fig. 1 Flowchart of study

meniscus injury, patellofemoral pain syndrome), (4) any contraindication to performing maximum exercises, and (5) difficulty in understanding and/or executing the testing protocols.

CMJ test

After general warm-up (5-min run at moderate intensity), lower extremity functional capacity was assessed through the CMJ test [29]. The rater explained and demonstrated the CMJ proper execution. The volunteer should be standing with hands on hips and feet aligned respecting the same distance from the shoulders, then squat until a position of approximately 90° of knee flexion and perform a vertical jump as high as possible. Submaximal CMJs were performed to familiarize the volunteer with the movement. A smartphone was positioned 1.5 m away from the volunteer to record the execution of three maximal CMJs [29]. The volunteer was instructed to use the hip, knee, and ankle flexion movements to dampen the landing. The jump height analysis was done through the mobile application named *Jumpo* (available for free download). This application works similar to the previously validated application named *My Jump* [29]. Jumpo was chosen because it was the only available application for the iOS operating system when our data were collected. The highest height obtained between the jumps was considered for analysis. The CMJ re-test started 3 min after ending the simulated soccer match.

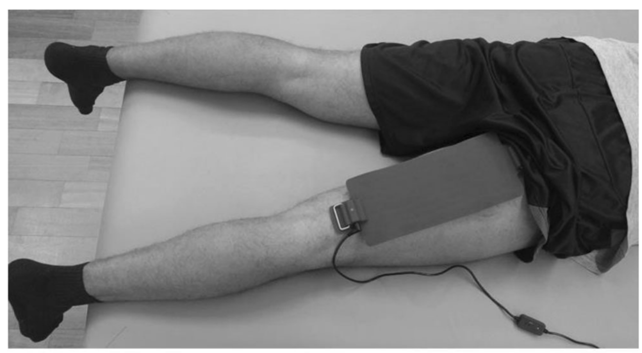
Isokinetic dynamometry

The volunteer was positioned on the isokinetic dynamometer Biodex System 3 Pro (Biodex Medical Systems, USA) according to the manufacturer's recommendations for evaluation of the knee flexion–extension movements with the dominant limb. Ten submaximal repetitions of knee flexion–extension in the concentric mode at an angular velocity of 90° s^{-1} were used as specific warm-up. The volunteer was familiarized with the execution of isokinetic concentric and eccentric tests through submaximal contractions. Two sets of three maximal knee extensors concentric contractions and two sets of three maximal knee flexors eccentric contractions were performed [30]. The 60° s^{-1} angular velocity was used for all tests, and a 1-min rest period was observed between sets [30]. The volunteer was verbally encouraged to produce as much strength as possible in all contractions. The highest peak torques in each contraction type were considered for analysis. The H:Q functional torque ratio was calculated as follows: hamstring eccentric peak torque/quadriceps concentric peak torque [31]. The isokinetic re-test started 5 min after the simulated soccer match end due to the time required for the volunteer's positioning at the dynamometer.

PBMT/ placebo treatments

Interventions with PBMT or placebo were administered immediately before the soccer match simulation protocol. A single researcher was responsible for the treatments' allocation (PBMT or placebo) in each session. The researchers responsible for the CMJ and isokinetic dynamometry assessments, and for the soccer match simulation protocol, were not inside the room during the PBMT/placebo application. The volunteers were blindfolded and used headphones plugged into a music player device during treatments to avoid identification of sounds emitted by the PBMT device. Since PBMT is a modality that does not promote any thermic, sensitive, and/or painful stimulus, participants did not know which treatment was applied in each session.

LEAP SportsPOD (prototype by Multi Radiance Medical, Solon, OH, USA) was used for administration of PBMT and placebo treatments (Fig. 2). This device contains 152 infrared LEDs (880 nm) distributed evenly over an area of 252 cm^2 (10.5 cm × 24 cm); thus, it was possible to treat most of the posterior thigh area with a single application (differently than conventional cluster probes that are smaller and require multiple application sites). The PBMT device used here is a flexible pad, so it was coupled appropriately to the convexity of the posterior thigh. In addition, the researcher exerted a slight pressure with the hands to ensure the diodes contact with the



Number of LEDs	152
Wavelength (nm)	880
Frequency(Hz)	Continuous Mode
Power (mW) – each	33
Spot size (cm^2) – each	0.1357
Power density (mW/cm^2) - each	243.8
Total device power (W)	5.0
Total device area (cm^2)	252
Device power density (mW/cm^2)	19.84
Total dose (J)	300
Irradiation time (sec)	60

Fig. 2 Volunteer receiving PBMT/placebo treatment (top) and PBMT parameters used in this study (bottom)

volunteer's skin. The parameters used for PBMT application are shown in Fig. 2. The PBMT was applied for 60 s, totalizing an energy dose of 300 J in each of the volunteer's hamstring muscle. This pre-exercise energy dose provided the best results in a previous trial with high-level soccer players [32]. The placebo application was carried out in the same way as the active therapy, but with the equipment turned off.

Simulated soccer match

Based on movement analysis of the English Football League, Small et al. [18] designed and validated the protocol entitled soccer-specific aerobic field test ($SAFT^{90}$). The protocol consists of a sequence of activities that mimics the physiological demands of a soccer match within a 15-min module of intermittent exercise. To represent the 90 min of a soccer match, this module is repeated six times with a 15-min interval between the 3rd and 4th execution. Therefore, $SAFT^{90}$ accurately represents the physiological load associated with a soccer match, including multi-directional movements with different intensities and requiring changes in direction and speed (accelerations and decelerations) [18].

Since the present study included only amateur soccer players, the original protocol of $SAFT^{90}$ was adapted to a 45-min protocol (i.e., three executions of the intermittent exercise module that represents the first half of a soccer match). A single researcher provided commands and verbal encouragement during the simulated soccer match for all volunteers. At the end of each 15-min module, the volunteers ingested regular water ad libitum to avoid any influence of hypohydration on their fatigue level. The rating of perceived exertion (RPE) provided by the volunteer after completing the simulated soccer match was multiplied by the time duration (~ 45 min) to determine the internal workload generated by the exercise protocol in each volunteer [33].

Statistical analysis

Sample size was calculated through G*Power software (version 3.1.9.2) using results provided by a previous study that assessed the effect of simulated soccer match on the hamstring eccentric peak torque of amateur soccer players [15]. A sample of nine participants was estimated to provide a statistical power over 0.90. As we expected a dropout rate of approximately 20%, 12 subjects were initially included in the trial. Data normality was verified using the Shapiro–Wilk test. Internal workloads promoted by the simulated soccer match in placebo and PBMT sessions were compared through a paired sample Student's *t* test.

Subjects' behaviors within each session (PBMT and placebo) were analyzed with the following calculations: mean percent change (Δ% = post-exercise / pre-exercise 1); paired sample *t* test (pre-exercise vs. post-exercise), with a significance level set as 5% ($\alpha < 0.05$); and effect size (ES) through Cohen's *d* [$ES = (M_{post} - M_{pre})/SD_{pooled}$, where M_{post} is the mean post-exercise measure, M_{pre} is the mean pre-exercise measure, and SD_{pooled} is the pooled standard deviation of the pre- and post-exercise]. Effect sizes were considered as "trivial" (ES < 0.2), "small" (ES > 0.2), "moderate" (ES > 0.5), or "large" (ES > 0.8) [34].

Longitudinal percent changes (pre- to post-exercise) were used for comparison between PBMT and placebo treatments. Data were analyzed for practical significance using magnitude-based inferences because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to sports medicine than statistical significance [35]. The magnitude of between-treatments differences (PBMT vs. placebo) was calculated and expressed as standardized mean differences, considering the Cohen's criteria for the analysis (> 0.2 = small; > 0.5 = moderate; > 0.80 = large). The chances that the true (unknown) mean changes were trivial, harmful, or beneficial [i.e., greater than the smallest worthwhile change (0.2 multiplied by the between-participant standard deviation)] were determined. Quantitative chances of a beneficial or harmful effect were assessed qualitatively, as follows: < 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75% = possibly; 75–95% = likely; 95–99% = very likely; and > 99% = almost certain [36]. When the harmful and beneficial values were both > 5%, the inference was classified as unclear [36].

Results

The simulated soccer match represented similar internal workloads in PBMT (368.18 ± 60.06 a.u.) and placebo (363.34 ± 85.08 a.u.) sessions ($p = 0.863$).

Quadriceps concentric peak torque was not affected by the simulated soccer match in any experimental condition ($p > 0.05$; trivial effect size; Table 1). Hamstring eccentric peak torque decreased significantly in both conditions ($p < 0.05$), while a significant fall of H:Q torque ratio was observed only in placebo session ($p < 0.05$). Greater effect sizes were observed with placebo treatment for both hamstring eccentric peak torque and H:Q torque ratio (Table 1). There was no statistically significant reduction on jump height ($p > 0.05$ for both conditions), but a small effect size was observed only with placebo treatment (Table 1).

As shown in Fig. 3, PBMT promoted 75%, 69%, and 53% chances for beneficial effects on hamstring eccentric peak torque, H:Q torque ratio, and CMJ height, respectively, compared to placebo treatment. PBMT had no beneficial or harmful effects compared to placebo treatment on quadriceps concentric peak torque (Fig. 3).

Table 1 Soccer players' isokinetic and jump performance in photobiomodulation (PBMT) and placebo sessions

	Pre	Post	Δ%	*p* value	ES
Quadriceps CON PT (Nm)					
PBMT	229.95 ± 40.56	226.74 ± 43.72	− 1.40	0.407	0.08
Placebo	229.06 ± 41.31	224.21 ± 41.11	− 2.12	0.200	0.12
Hamstring ECC PT (Nm)					
PBMT	188.33 ± 29.20	179.19 ± 32.32	− 4.85	0.005*	0.31†
Placebo	190.78 ± 35.01	174.13 ± 34.85	− 8.72	0.001*	0.50†
H:Q torque ratio (a.u.)					
PBMT	0.83 ± 0.13	0.80 ± 0.13	− 3.60	0.056	0.24†
Placebo	0.85 ± 0.17	0.78 ± 0.12	− 7.75	0.008*	0.50†
CMJ height (cm)					
PBMT	35.06 ± 7.04	34.44 ± 7.46	− 1.77	0.531	0.09
Placebo	35.29 ± 5.87	33.36 ± 6.65	− 5.47	0.085	0.32†

CON concentric, *ECC* eccentric, *PT* peak torque, *CMJ* countermovement jump, *Δ%* mean percent change, *ES* effect size

*Significant difference ($p < 0.05$)

† Small effect size (ES > 0.2)

Discussion

The main finding of the current study was that PBMT applied before a simulated soccer match reduced the losses of hamstring eccentric strength, H:Q functional ratio, and CMJ height. Our results become relevant to clinical practice from the following rationale: hamstring fatigue generated by a soccer match is a potential risk factor for HSI, and PBMT can reduce soccer-induced fatigue on hamstring muscles; thus, PBMT may be an innovative tool for HSI prevention.

Fatigue is frequently pointed out as a strong risk factor for non-contact injuries in soccer players [5, 6], specially the HSI [9]. Fatigue perhaps explain, at least partially, why most HSIs sustained during matches occurred during the last third of the first and second halves of the match [7]. However, the relationship between soccer-induced fatigue and HSI is only supported by indirect evidences, such as the fall of hamstring maximal eccentric strength promoted by simulated soccer matches [15, 16, 18]. Like our findings, Small et al. [18] and Jones et al. [15] found 5–8% reduced hamstring eccentric strength after 45 min of the SAFT^{90} in semi-professional and amateur soccer players, respectively. That strength loss seems to be higher than 16% after the full SAFT^{90} protocol [15, 18], and up to 31% with another simulated soccer match protocol called Loughborough intermittent shuttle test [16]. Prospective studies have evidenced that eccentric knee flexor weakness increases the risk of hamstring injury in soccer [8, 11] and other sports [12]. For instance, Timmins et al. [8] found a significant inverse relationship between pre-season hamstring eccentric strength and the incidence of HSIs along the season in premier league soccer players; for every 10-N increase in hamstring eccentric strength, the risk of HSI was reduced by 9%. Therefore, it is expected that a player with greater deficits on hamstring eccentric strength during a soccer

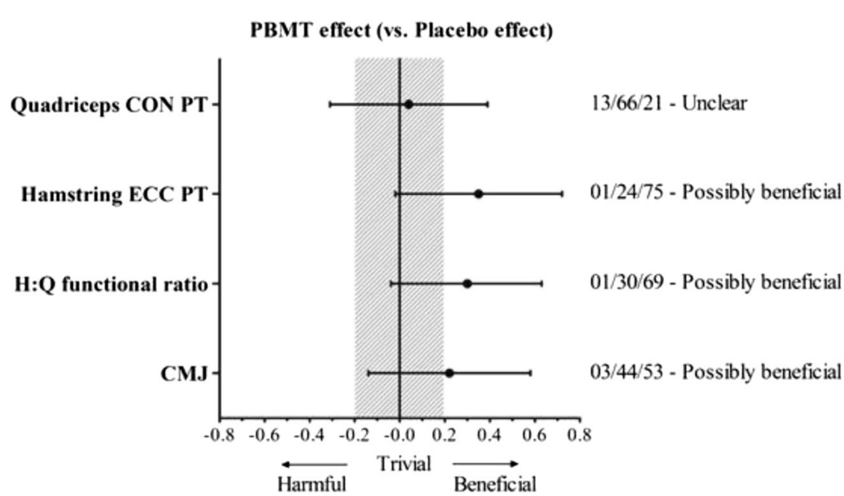


Fig. 3 Standardized mean differences and 95%CI for PBMT effect compared to placebo effect (forest plot); and chances of harmful, trivial, or beneficial effects with PBMT treatment (right column—percent values and magnitude-based inferences)

match may be closer to experiencing a HSI, although there is no data available in the literature to consistently support this hypothesis.

In contrast to the consistent loss of hamstring strength, the soccer match leads to a small (or even insignificant) fall on quadriceps maximal strength [16, 18]. Consequently, the H:Q torque ratio is also negatively affected throughout the soccer match, as supported by our results. It means that a player with proper strength balance between knee flexor and extensor muscles during laboratory tests (performed at a non-fatigued condition) may present an H:Q ratio increasingly poor throughout the soccer match. Although prospective studies have found conflicting results regarding the predictive value of the H:Q ratios for HSIs in soccer players [11, 13, 37], isokinetic dynamometry is largely used as a screening tool and muscle imbalance is considered one of the main risk factors for non-contact injuries by premier league soccer teams [5, 6]. The H:Q functional ratio (i.e., hamstring eccentric peak torque divided by quadriceps concentric peak torque) has been considered a "more functional" way to screen for injury risk in soccer players compared to the H:Q conventional ratio (i.e., hamstring concentric peak torque divided by quadriceps concentric peak torque). However, the usual landmark of 1.0 is rarely reached by professional male soccer players when assessed at the most traditional testing angular velocity (i.e., 60° s^{-1})—for a review, see Baroni et al. [31]. Independently of the accuracy and predictive value of any landmark, a poor H:Q functional ratio suggests a reduced hamstring capacity of "breaking" knee extension and hip flexion during the terminal swing phase of running [9], precisely the movement responsible for most HSIs in soccer [7, 8].

To the best of our knowledge, there is no evidence to support the CMJ performance as predictive of HSI. Jump tests are largely used to assess lower extremity power, and we added CMJ to the current study to verify the PBMT effect on a motor task closer to the multi-articular complex movements required in a soccer match. The primary hip extensor during CMJ is the gluteus maximus, but other hip extensors (including the hamstring muscles) are also activated during the CMJ stretch-shortening cycle [38]. Hamstrings execute a rapid eccentric contraction during squat phase, when energy is stored within the elastic components of the muscle-tendon unit and muscle spindle is activated; next, a powerful concentric contraction during jump phase is generated through a sum of muscle voluntary activation, myotatic reflex response, and elastic energy release [38]. Fatigue impairs all these factors, and consequently reduces the CMJ height [39]. Our findings support that PBMT minimized the fatigue effects on hamstring muscles and, consequently, the soccer match-induced impair on CMJ.

Fatigue is classically defined as an exercise-induced reduction in the muscle's maximal force capacity [40], so reduction in the maximal strength that a person can produce provides a straightforward demonstration of fatigue level [41]. However, other fatigue-related deficits (not assessed in the current study) may contribute to a player experiencing a HSI. Animal experiments demonstrated that fatigued muscles absorbed less energy before failure when compared with unfatigued muscles [42], making fatigued hamstring muscles more likely to suffer a strain injury due to a reduced capacity to resist to over-lengthening. At the same time, fatigue negatively affects knee joint position sense [43] and execution of soccer-specific motor tasks [44]. These findings suggest decreased function in afferent output of the sensory organs, including the muscle spindles and their protective action against over-lengthening. Consequently, the player may perceive a normal hamstring muscle action during running, while in reality, repeated over-lengthening of the hamstrings is occurring [9]. That repeated over-lengthening leads to microscopic muscle damage that may accumulate to become macroscopic damage (i.e., muscle strain injury) [45].

To date, the usage of PBMT as a preventive tool against sport injuries remains unexplored. Previous studies have already evidenced that a single PBMT session, applied immediately before exercise, can minimize the muscle damage levels in animals [46] and humans [47], but the preventive goal of PBMT suggested here is totally new. Of course, a long-term prospective study is needed to verify if PBMT can reduce the HSI rate along a soccer season. The current study was just the kick-off for employing PBMT as a preventive tool in sports medicine, and our findings support that PBMT parameters used here may be applied to reduce the soccer-induced fatigue on hamstring muscles, exactly the primary effect to seek HSI prevention through PBMT.

The reduced fatigue after PBMT was firstly demonstrated in animal model [48], and a robust body of evidence has supported this ergogenic effect in humans [23]. The mechanisms responsible for this effect are not fully understood, and the current study had no intention to investigate how PBMT affects muscle fatigue from a physiological point of view. Evidences suggest that the absorption of light energy by specific chromophores at mitochondria lead to intracellular reactions that increase the ATP production and cellular metabolism [49], as well as improve microcirculation (and, consequently, oxygen supply to irradiated tissue) due to nitric oxide release [50], among other responses that may optimize the muscle cell functioning [22].

Given the typical biphasic dose–response effect of PBMT treatments [22], finding the optimal parameters of PBMT is a key factor for the treatment success. We cannot state that PBMT parameters used in the current study are the most effective ones because we tested a single dosage, which can be pointed out as a study limitation. However, the total energy dose applied per muscle group (i.e., 300 J) is within the range recommended to treat large muscle groups by the most recent meta-analysis [23]. In addition, previous findings support that pre-exercise PBMT with 300 J is better than lower dosages

(60–180 J) to improve performance and biochemical markers related to skeletal muscle damage and inflammation in soccer players [32]. Finally, the PBMT device used in the current study required 60 s to deliver that energy amount to each hamstring muscle (i.e., a 2-min treatment per player), so it is a feasible therapy for application before a soccer match or even during the half-time interval. The applicability of PBMT as proposed here to the real-world of competitive soccer (and other sports) is a strength of the current study.

Conclusion

PBMT applied on the posterior thigh muscles immediately before a simulated soccer match proved to be effective in attenuating fatigue-related impairments on hamstring maximal eccentric strength, H:Q strength ratio, and CMJ performance. Given the relation between soccer-induced hamstrings' fatigue and HSI, this study is pioneer to highlight PBMT as a promising tool to prevent HSI in soccer players. Long-term prospective studies are needed to verify if PBMT will be effective in reducing the HSI rate along a soccer season.

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Compliance with ethical standards

The study was previously approved by the Ethics and Research Committee of the Universidade Federal de Ciências da Saúde de Porto Alegre (no. 63299416.4.0000.5345), and all participants signed an informed consent.

Conflict of interest Professor Ernesto Cesar Pinto Leal-Junior receives research support from Multi Radiance Medical (Solon - OH, USA) and Douglas Scott Johnson is an employee and shareholder of Multi Radiance Medical, a photobiomodulation/laser device manufacturer. They didn't have any participation in data collection or data analysis in this study. Furthermore, Multi Radiance Medical didn't have any participation in any aspect related to this study. The remaining authors declare that they have no conflict of interests.

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