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Efeitos da fotobiomodulação na prevenção de dano muscular induzido por exercício no Badminton

*Effects of photobiomodulation in the prevention of exercise-induced muscle damage in Badminton*Lilian Keila Barazetti¹, Susana Padoin², Fernando de Souza Campos³, Solange de Paula Ramos^{4*}¹ Department of Physical Education. State University of West Parana, Marechal Cândido Rondon, Brazil.² University Center of Cascavel. Department of Physical Education. Cascavel, Paraná, Brazil.³ Graduate student in Physical Education. State University of West Parana, Marechal Cândido Rondon, Brazil.⁴ Study group of Tissue Regeneration, Adaptation, and Repair. Center of Biological Sciences. State University of Londrina. Londrina, Paraná, Brazil.* Autor correspondente: ramossolange@uel.br**Citação:**

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Resumo:

Objetivo: Avaliar os efeitos da fotobiomodulação no dano muscular induzido pelo exercício em atletas de badminton durante um campeonato nacional. **Métodos:** Dezoito atletas masculinos foram randomizados para fotobiomodulação (LEDT, n=8) ou placebo (n=10). A intervenção foi aplicada diariamente antes dos jogos. Foram avaliados creatina quinase (CK), dor muscular (DOMS), salto com contramovimento (CMJ), salto com agachamento (SJ), força de preensão manual (HS) e percepção subjetiva de esforço (RPE). As análises utilizaram ANOVA de medidas repetidas e two-way ($p < 0,05$). **Resultados:** Não foram observadas interações significativas entre tempo e tratamento para CK, DOMS, SJ e HS ($p > 0,05$). O grupo LEDT apresentou aumento do desempenho no CMJ após os jogos nos Dias 1 e 2 ($p < 0,005$). A RPE foi maior no grupo LEDT no Dia 2 ($p < 0,005$). **Conclusão:** A fotobiomodulação não preveniu o dano muscular, mas melhorou o desempenho do CMJ em atletas de badminton.

Palavras-chave: Terapia de luz de baixa potência; performance atlética; fadiga muscular; esportes de raquete.

Abstract:

Objectives: Objective: To evaluate the effects of photobiomodulation on exercise-induced muscle damage in badminton athletes during a national championship. **Methods:** Eighteen male athletes were randomly assigned to either a photobiomodulation group (LEDT, n=8) or a placebo group (n=10). The intervention was applied daily before matches. Creatine kinase (CK), delayed onset muscle soreness (DOMS), countermovement jump (CMJ), squat jump (SJ), handgrip strength (HS), and rating of perceived exertion (RPE) were assessed. Data were analyzed using repeated-measures ANOVA and two-way ANOVA ($p < 0.05$). **Results:** No significant time-by-treatment interactions were observed for CK, DOMS, SJ, or HS ($p > 0.05$). The LEDT group showed improved CMJ performance after matches on Days 1 and 2 ($p < 0.005$). RPE was higher in the LEDT group on Day 2 ($p < 0.005$). **Conclusion:** Photobiomodulation did not prevent muscle damage but improved CMJ performance in badminton athletes.

Keywords: Low-level light therapy; athletic performance; muscle fatigue; racquet sports.

1. INTRODUCTION

Badminton is an indoor racket sport that involves a wide variety of short-duration, high-intensity actions, rapid arm movements, and jumps (Cabello Manrique & González-Badillo, 2003). It is the fastest racquet sport requiring great levels of physical conditioning and technical-tactical mastery (Faude et al., 2007), besides well-conditioned aerobic and anaerobic systems (Jaworski & Zak, 2015). Official Badminton competitions are performed over three to five consecutive days, with the athletes playing one to three games a day (Abian-Vicen et al., 2014). In Badminton, playing a simulated game, or two consecutive games per day of competition, causes muscle fatigue, decrements in performance, and increased circulating levels of creatine kinase (CK) and muscle soreness, suggesting Badminton matches can cause exercise-induced muscle damage (EIMD) (Abian-Vicen et al., 2014; Abian et al., 2016). To minimize muscle damage and loss of performance in sports, recovery strategies such as cold water immersion (Dupuy et al., 2018), massage (Dupuy et al., 2018), nutritional supplementation (Owens et al., 2019), and compression garments (Dupuy et al., 2018; Duffield et al., 2008) have been used. Although these strategies improved perceived recovery, decrements in performance and exercise-induced muscle damage were not satisfactorily inhibited (Dupuy et al., 2018; Owens et al., 2019; Duffield et al., 2008).

Photobiomodulation can be used in exercise as an ergogenic and recovery method, preventing EIMD and delaying fatigue, as well as improving performance (Camargo et al., 2012; Nampo, Cavalheri, Dos Santos Soares et al., 2016; Nampo, Cavalheri, Ramos et al., 2016; Padoin et al., 2020; Molina Correa et al., 2020). Studies have shown that photobiomodulation can increase the time to exhaustion (Nampo, Cavalheri, Dos Santos Soares et al., 2016; Rossato et al., 2016), peak torque and power (Nampo, Cavalheri, Dos Santos Soares et al., 2016; Molina Correa et al., 2020), and the number of repetitions in concentric contractions of both lower and upper limbs (Nampo, Cavalheri, Dos Santos Soares et al., 2016), as well as decrease signs and symptoms of exercise-induced muscle damage and accelerate muscle recovery (Padoin et al., 2020), which may be essential for maintenance or improvement of Badminton performance.

Tissue irradiation using low levels of energy (10 to 1000mW) with wavelengths ranging from the red to near-infrared spectrum (600 to 1000nm) can interact with living tissues, evoking several biological responses (photobiomodulation). Mitochondrial enzyme cytochrome c oxidase is known as one of the primary photoacceptors, increasing ATP synthesis under low-level light irradiation (Hayworth et al., 2010). These effects may contribute to fatigue delay and improved aerobic performance, an important requirement in Badminton performance. Recent data also suggested that anaerobic performance can also be improved by photobiomodulation (Molina Correa et al., 2020), which may be important for Badminton fast actions such as lunging, jumping, and strokes (Cabello Manrique & González-Badillo, 2003). Clinical and experimental studies have demonstrated that photobiomodulation also acts as a recovery method, protecting skeletal muscle from exercise-induced muscle damage (Camargo et al., 2012; Padoin et al., 2020; da Costa Santos et al., 2014; Vasconcelos et al., 2019) and inflammatory reactions (Camargo et al., 2012; da Costa Santos et al., 2014; Vasconcelos et al., 2019). These effects have been associated with faster physical recovery after acute exercise bouts (Padoin et al., 2020; de Oliveira et al., 2017). Photobiomodulation improved physical recovery after EIMD reducing the circulating levels of CK, decreasing delayed-onset muscle damage (DOMS), and attenuating post-exercise loss of muscle function (Padoin et al., 2020; Borges et al., 2014).

Therefore, the purpose of this study was to assess the effects of photobiomodulation (630 nm) on muscle fatigue and recovery in Badminton athletes during two consecutive days of a national championship. We hypothesized that photobiomodulation would delay fatigue, maintaining physical performance, as well as attenuating signs and symptoms of EIMD, during two consecutive days of competition.

2. MATERIAL AND METHODS

Participants

The study was approved by the Committee of Ethics in Research involving human beings from the State University of West Parana, under protocol number 2.515.358/2018. The athletes and their caregivers were informed about the study procedures and signed the Informed Consent Form before data collection. The Badminton athletes competing in the Brazilian National Badminton Championship, in March 2018, were invited to participate in this study through a phone call or personal contact. Twenty-seven athletes volunteered, but seven were excluded because did not fulfill inclusion criteria. The athletes were included from under 17 years (U17), under 19 years (U19), and adult categories and were ranked from first to 22nd position in the official national athletes' ranking from the Brazilian Confederation of Badminton (2018).

Experimental design

The study was a double-blind randomized clinical trial with an ecological design, performed during an official competition in order to examine the usefulness of photobiomodulation in preventing EIMD and physical fatigue in athletes during first and second days of competition, and morning of third day. The exclusion criterion adopted was presenting any traumatic injury that impaired the jumping and handgrip tests. Before and after games, blood samples were collected, after which delayed-onset muscle soreness (DOMS), countermovement (CMJ) and squat jump (SJ) heights, and handgrip strength (HS) were recorded. After physical tests and 30 minutes before warm-up and the games, the athletes were submitted to photobiomodulation with the Light-Emitting Diode (LED) apparatus turned on (LEDT) or turned off (Placebo). After the games, the rate of perceived exertion (RPE) was recorded and blood sampling and physical tests were performed again (Figure 1). The study adhered to the CONSORT 2010 statement guideline for reporting parallel group randomized trials.

Athletes were paired by Brazilian official ranking position (Brazilian Federation of Badminton) and category and randomly sorted to receive Placebo or LEDT intervention by drawing opaque envelopes. The allocation into experimental groups and treatments was performed by two researchers who did not take part in the sample collection and analysis. Two athletes in the LEDT group were excluded from the final analysis due to missing data (did not perform all evaluations).



Figure 1. Experimental design. CK: creatine kinase, DOMS: delayed-onset muscle soreness, SJ: squat jump test, CMJ: countermovement jump test, HS: handgrip strength test, and RPE: rate of perceived exertion.

Photobiomodulation with light-emitting diodes (LEDT)

The photobiomodulation (LEDT group) was applied 30 min before games using two Bios Therapy II equipment (Bios medical equipment, São José dos Campos, Brazil) emitting a red light wavelength of 630 ± 20 nm. The irradiation was performed in both lower limbs and the dominant shoulder, with the probe in stationary mode in direct contact with the skin at 17 points (Figure 2). The probe had a mean output power of 300 mW, power density of 230 mW/cm², and spot area of 1.32 cm². The treatment lasted for 20 seconds of irradiation per point (5 min and 30 s of total of treatment per athlete), yielding an energy density of 4.6 J/cm², and a total energy per point of 6 J. Total energy of 84 J (18.5 cm² of irradiated area) was delivered in each leg and 18 J (3.9 cm²) in the upper dominant arm. Previous studies demonstrated that this irradiation protocol

applied in the lower limb had an ergogenic effect and improved muscle recovery (Padoin et al., 2020; Molina Correa et al., 2020). The Placebo group was positioned on the stretcher, in the same positions and conditions as the LEDT group, however, with the equipment turned off. In both LEDT and Placebo groups, athletes were instructed to wear eye protection bandages blocking the view and headphones with music to avoid identification as to which allocation group they were included in. The irradiation equipment irradiation does not emit heat and vibration when the LED is on.

[Figure 2 – Photograph of application points]

Figure 2. Application points (black circles) used for LED photobiomodulation.

Rate of perceived exertion (RPE)

The rate of perceived exertion was assessed using the Borg scale 15 min after each match (Foster et al., 2001). Subsequently, the internal match load was calculated by multiplying the reported value by the match duration in minutes (arbitrary units). Athletes reported being familiarized with the Borg scale during their training routines.

Exercise-induced muscle damage

On the first day of competition, the baseline blood samples were collected 30 minutes before (between 7 a.m. and 9 a.m.) and 5 minutes after the last game each day. On the second day, blood samples were collected again 30 minutes before and 5 minutes after the last game. Serum levels of creatine kinase (CK) were determined using commercial kits (Siemens, Munich, German) in a biochemical automated system (Dimension XL, Siemens, Munich, German), according to the manufacturer's instructions.

Muscle soreness was evaluated before (Pre) and after (Post) games using a visual analog scale (Cook et al., 1998). Athletes were previously familiarized with the scale. The athletes were instructed to squat with their knees at a 90° angle for five seconds to report how much pain they felt in their muscle legs.

The explosive and reactive strength of the athletes' lower limbs were evaluated indirectly before and after the games on a contact mat connected to computer software (Jump System Pro, CEFISE, Nova Odessa, Brazil). The athletes performed three countermovements (CMJ) and squat (SJ) jumps, respectively, with 10-second intervals between attempts. The best jump was recorded for statistical purposes.

The handgrip strength (HS) was measured in the upper dominant limb immediately before and after games using a Takey - Mechanical Smedley Dynamometer (Cardiomed, São Paulo, Brazil). Athletes stood erect, arms outstretched and forearms in neutral rotation. They were instructed to exert maximum force in the three attempts, with a 5-second interval between them, and the best measure was recorded.

Statistical analysis

Normality distribution was tested with the Shapiro-Wilk test. Data are expressed as mean and standard deviation (parametric distribution) or median and 25 to 75% interquartile range (non-parametric distribution). Differences between RPE in Placebo and LEDT groups were identified using the Mann-Whitney U test. The two-way ANOVA test was used to investigate differences in DOMS, CK, CMJ, SJ, CMJ, and HS between groups and during Day 1 and Day 2 of the competition. Differences were considered significant if $p < 0.05$. The data analysis was performed with GraphPad Prism software version 5.01 (GraphPad Software, La Jolla, CA, USA). The Cohen's effect size (ES) was calculated for group differences in relation to Day 1 Pre values, and between groups at different times of evaluation.

3. RESULTS

Eighteen athletes were included in the analysis (Table 1). One athlete missed an evaluation and one was not classified for Day 2 of the competition. Of the investigated athletes, only three (30%) in the Placebo group and five (62.5%) in LEDT were classified for Day 3 and Day 4 (final) of the competition.

Table 1. Athletes' characteristics and categories.

	Placebo	LEDT	Total
Number of athletes	10	8	18
Age (years) ¹	16[16.0 to 21.1]	16.2[15.8 to 18.5]	16.5[16 to 18.5]
Height (cm) ¹	177.5[175.0 to 183.3]	178.0[170.0 to 180.0]	178.0[175.0 to 180.5]
Weight (kg) ²	69.07 ± 12.12	68.60 ± 7.10	68.86 ± 10.04
Category			
U17	5 (50%)	5 (62.5%)	10 (55.5%)
U19	3 (30%)	2 (25%)	5 (27.8%)
Adult	2 (20%)	1 (12.5%)	3 (16.7%)

¹ Median (interquartile range 25 to 75%), $p > 0.05$, Mann-Whitney test.² Mean ± standard deviation, $p > 0.05$, Unpaired t-test.

The median internal match load (Figure 3a) was not significantly different between groups on Day 1 ($p=0.62$, Mann-Whitney U test). However, on Day 2, the LEDT group reported increased match load after games ($P=0.003$, Mann-Whitney U test). This difference could not be attributed to time since mean game durations on Day 1 (22.6 ± 7.5 and 22.1 ± 5.1 min, $p=0.67$, Mann-Whitney U test) and Day 2 (26.5 ± 6.0 and 28.9 ± 8.9 min, $p=0.40$, Mann-Whitney U test) were not different between Placebo and LEDT groups, respectively.

There was no interaction of time and treatment for CK levels ($F=0.97$, $p=0.47$, $\eta^2=1.16$). The time contributed to the variation of CK levels ($F=20.23$, $p<0.001$, $\eta^2=34.56$) but there was no significant effect of treatment ($F=0.67$, $p=0.47$; $\eta^2=1.5$) (Figure 3b). DOMS did not present an interaction between time and treatment ($F=0.35$, $p=0.78$, $\eta^2=0.8$). The time increased DOMS symptoms ($F=7.67$, $p=0.003$, $\eta^2=17.4$) but without effect of treatment ($F=0.00$, $p<0.95$, $\eta^2=0.09$) (Figure 3c).

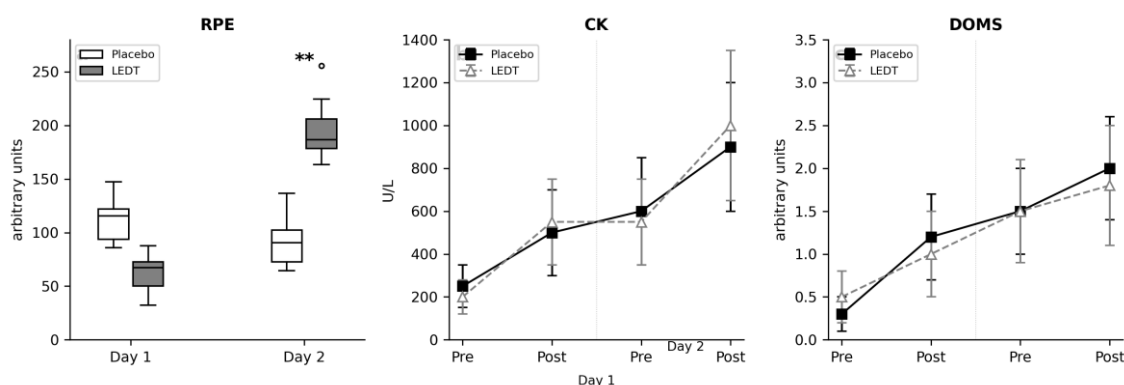


Figure 3. Rate of perceived exertion (match load) (a), circulating levels of creatine kinase (b), and delayed-onset muscle soreness perception (c) on Day 1 and Day 2 of competition. a) Median and 25 to 75% interquartile range. ** $p < 0.01$, Mann-Whitney U test. b) and c) Mean and standard deviation, $p > 0.05$ two-way ANOVA.

The performance in the SJ test (treatment x time: $F=0.02$, $p=0.65$, $\eta^2=0.12$) did not present interaction with time ($F=2.48$, $p=0.07$, $\eta^2=2.04$) and treatment ($F=0.54$, $p=0.65$, $\eta^2=0.45$) (Figure 4a). The performance in the CMJ test presented interaction with time and treatment ($F=5.91$, $p=0.001$, $\eta^2=2.6$) (Figure 4b). The time accounted for CMJ variation ($F=26.4$, $p<0.001$, $\eta^2=11.6$). The treatment improved CMJ performance (Figure 4b) from Pre to Post on Day 1 ($t=4.60$, $p<0.005$) and Day 2 ($t=5.49$, $p<0.005$, Bonferroni's test). There was no interaction between time and treatment for HS ($F=2.24$, $p=0.09$, $\eta^2=1.0$) (Figure 4c).

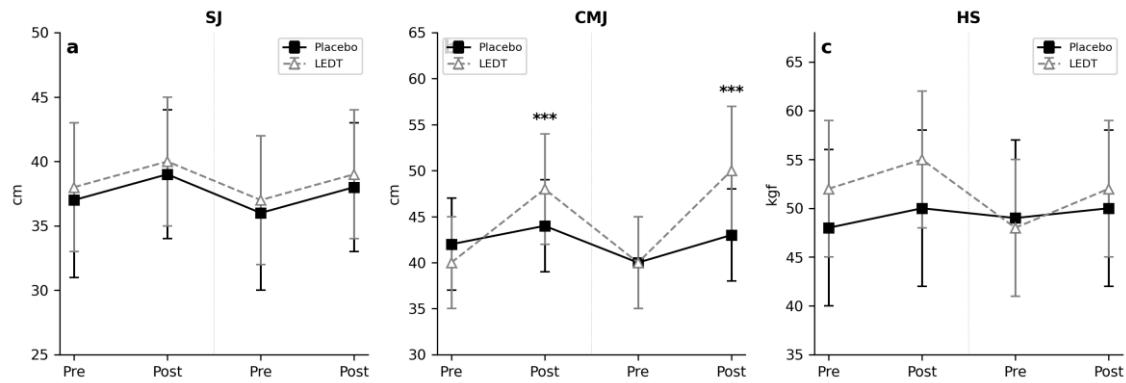


Figure 4. Mean (standard deviation) height change in squat jump (SJ) and countermovement jump (CMJ), and median (25 to 75% interquartile range) handgrip strength (HS). *** $p < 0.005$, from Pre to Post in LEDT group (Bonferroni test).

Table 2 presents EF for changes in indirect markers of EIMD at Post-Day 1, Day 2, and between groups. Large EF for CK increase was observed in the LEDT group at Post-Day 1 and Pre-Day 2 (Table 2). The CK levels presented a large EF for the Placebo group on Day 2. DOMS symptoms presented large EF for both groups at Post-Day 1 and Day 2. Large EF were observed for CMJ Post-Day 1 and Post-Day 2, however, these differences were trivial to small between groups. Reduction in HS in the LEDT group presented a large EF in relation to the Placebo group on Day 2.

Table 2. Cohen's Effect size (95% confidence interval) for changes in Creatine Kinase (CK), delayed-onset muscle damage (DOMS), squat jump height (SJ), countermovement jump height (CMJ) and handgrip strength (HS).

	Day 1 Pre	Day 1 Post x Pre Day 1	Day 2 Pre Day 2 x Pre Day 1	Day 2 Post Day 2 x Pre Day 1
CK				
LED	-	1.43 (0.27 to 2.44)*	1.15 (0.04 to 2.14)*	2.02 (0.73 to 3.09)*
Pla	-	0.69 (-0.24 to 1.56)	0.93 (-0.02 to 1.81)*	1.49 (0.44 to 2.41)*
LED x Pla	-0.04 (-0.97 to 0.89)	0.58 (-0.40 to 1.50)	-0.08 (-1.01 to 0.85)	0.28 (-0.67 to 1.20)
DOMS				
LED	-	0.82 (-0.24 to 1.79)*	1.30 (0.16 to 2.29)*	0.98 (-0.10 to 1.96)*
Pla	-	1.19 (0.20 to 2.09)*	1.52 (0.47 to 2.44)*	1.89 (0.77 to 2.85)*
LED x Pla	0.49 (-0.45 to 1.44)	-0.15 (-1.08 to 0.78)	0.19 (-0.75 to 1.11)	-0.22 (-1.15 to 0.72)
SJ				
LED	-	0.16 (-0.83 to 1.13)	-0.05 (-1.03 to 0.94)	0.26 (-0.73 to 1.23)
Pla	-	0.35 (-0.54 to 1.22)	-0.19 (-1.06 to 0.70)	0.29 (-0.60 to 1.16)
LED x Pla	0.00 (-0.93 to 0.93)	-0.10 (-1.02 to 0.84)	0.10 (-0.84 to 1.02)	0.08 (-0.85 to 1.01)
CMJ				
LED	-	0.80 (-0.25 to 1.77)*	0.07 (-0.91 to 1.05)	1.08 (-0.02 to 2.07)*
Pla	-	0.28 (-0.61 to 1.15)	-0.34 (-1.20 to 0.56)	0.25 (-0.64 to 1.12)
LED x Pla	-0.45 (-1.39 to 0.49)	0.17 (-0.77 to 1.09)	-0.07 (-1.00 to 0.86)	0.44 (-0.52 to 1.36)
HS				
LED	-	0.78 (-0.27 to 1.75)	-0.34 (-1.31 to 0.67)	0.08 (-0.91 to 1.05)
Pla	-	0.14 (-0.75 to 1.01)	0.14 (-0.74 to 1.01)	0.16 (-0.72 to 1.04)
LED x Pla	-0.58 (-1.52 to 0.37)	0.03 (-0.90 to 0.96)	-1.05 (-1.98 to -0.01)*	-0.82 (-1.74 to 0.18)*

* Large Effect Size

4. DISCUSSION

Contrary to the study hypothesis, photobiomodulation did not prevent an increase in CK levels and DOMS symptoms from Post-Day 1 to Pre and Post-Day 2. Only the CMJ test performance improved after photobiomodulation. Importantly, LEDT athletes reported higher values of RPE than the Placebo group, despite the improved CMJ performance. The effects of photobiomodulation on RPE or internal training load are not clear in the literature, with some studies reporting improved effects depending on energy dose (Dellagrana et al., 2018) while others reported no effects (Mezzaroba et al., 2018) in continuous aerobic tests. However, the intermittent high-intensity efforts elicited by Badminton games and recovery of CMJ performance may contribute to increased perception of efforts in irradiated athletes. However, caution should be taken in interpreting RPE results, since it was not possible to evaluate the external training load during

games. Quantifying accelerations, total distance covered, and types of movements (Nagano et al., 2020), which could be not directly correlated with internal training loads (Abdullahi et al., 2019) may be of great interest to evaluate the internal and external efforts of Badminton players during games with opponents of same competitive level.

In Badminton, CK levels are elevated immediately and 24 h after simulated and official competitions (Abian-Vicen et al., 2014; Abian et al., 2016). In the present study, CK levels were matched 24 hours from the first to the second day of competition. CK levels were not significantly different between LEDT and Placebo groups at any time suggesting that photobiomodulation was not effective in preventing symptoms of EIMD in Badminton athletes. Although some studies demonstrated that CK was blunted by photobiomodulation at the same power density (Camargo et al., 2012; Padoin et al., 2020; Vasconcelos et al., 2019), contradictory results may be attributed to studies being performed on non-athletes volunteers or animals.

Different mechanisms have been implicated in the analgesic effects of photobiomodulation, including a reduction in inflammatory reactions, decreased activation of arachidonic acid metabolites, increased latency time in nerve conductivity, and opioid system activation (Vasconcelos et al., 2019). However, no differences in muscle soreness were observed between groups. Studies in untrained subjects and athletes also failed to demonstrate a photobiomodulation effect in the relief of muscle soreness (Nampo, Cavalheri, Ramos et al., 2016; Padoin et al., 2020). However, other authors showed that muscle soreness could be reduced after photobiomodulation only after 96h (Borges et al., 2014). Our results and previous studies suggest muscle soreness was not alleviated in a short period (post to 24h) and photobiomodulation may have limited usefulness in improving DOMS symptoms on successive days of Badminton competition.

Lower limb strength is a critical issue in Badminton performance since athletes perform successive jumps and change of directions during a game in offensive and defensive actions (Cabello Manrique & González-Badillo, 2003; Faude et al., 2007; Abian-Vicen et al., 2014). Despite a higher RPE, we observed improved jump performance after games, suggesting that no significant fatigue was evoked by a single official game, but that a post-activation potentiation effect might have occurred. In the present study, a post-activation potentiation effect was observed in the CMJ test in the LEDT group. Indeed, previous studies reported that photobiomodulation can increase peak torque and maximum isometric strength, suggesting it can potentiate muscle capacity to generate power (de Oliveira et al., 2017) and may improve CMJ performance when associated with the post-activation potentiation effect of games.

HS is important for racquet sports during actions of the wrist, arm, and shoulder rotations (Cronin et al., 2017). Other studies have reported the ergogenic effects of photobiomodulation on upper limbs (Rossato et al., 2016; Barbosa et al., 2017). Barbosa et al. (2017) found improved HS after photobiomodulation in healthy subjects. Rossato et al. (2016) demonstrated improved maximum isometric strength of elbow flexion after irradiation. However, no ergogenic or recovery effect of photobiomodulation in HS was observed in the present study. But a limitation of the study was the application of irradiation only in the shoulder region. This region was irradiated because it has been reported to be a vulnerable area to fatigue, pain, and shoulder lesions, and shoulder strength was correlated to racket velocity (Awatani et al., 2018; Fahlstrom et al., 2006).

A limitation of this study was we could not control the external training load, since games could not be recorded. Since time and effort may vary depending on the competitive level of the opponent, athletes were paired by official ranking. Of note, the competition was held between the best athletes ranked in the Brazilian Badminton Federation, playing in different sports clubs. Female athletes were not included in the analysis due to different responsiveness to efforts, muscle mass volume, and responsiveness to EIMD between male and female athletes.

5. CONCLUSION

Photobiomodulation did not prevent muscle damage during two successive days of competition. However, improvement in CMJ performance may be advantageous considering physical performance demands

in Badminton games. Team staff should be aware of the increased perception of internal training load to avoid cumulative fatigue during competition.

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7. FUNDING

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8. INSTITUTIONAL REVIEW BOARD STATEMENT

The study was approved by the Committee of Ethics in Research involving human beings from the State University of the West of Paraná – Marechal Cândido Rondon, under protocol number 2.515.358/2018.

9. AUTHOR CONTRIBUTIONS (CREDIT)

L.K.B.: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review and editing.

S.P.: Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review and editing.

F.S.C.: Investigation, Data curation, Writing – original draft, Writing – review and editing.

S.P.R.: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review and editing, Supervision, Project administration, Funding Acquisition.

10. CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

- Abdullahi, Y., Coetzee, B., & van den Berg, L. (2019). Relationships Between Results of an Internal and External Match Load Determining Method in Male, Singles Badminton Players. *Journal of Strength and Conditioning Research*, 33(4), 1111-1118.
- Abian, P., Del Coso, J., Salinero, J.J., Gallo-Salazar, C., Areces, F., Ruiz-Vicente, D., et al. (2016). Muscle damage produced during a simulated badminton match in competitive male players. *Research in Sports Medicine*, 24(1), 104-117.
- Abian-Vicen, J., Castanedo, A., Abian, P., Gonzalez-Millan, C., Salinero, J.J., & Del Coso, J. (2014). Influence of successive badminton matches on muscle strength, power, and body-fluid balance in elite players. *International Journal of Sports Physiology and Performance*, 9(4), 689-694.
- Awatani, T., Morikita, I., Urata, T., Shinohara, J., & Tatsumi, Y. (2018). Correlation between isometric shoulder strength and racket velocity during badminton forehand smash movements: study of valid clinical assessment methods. *Journal of Physical Therapy Science*, 30(6), 850-854.
- Barbosa, R., Marcolino, A., Souza, V., Bertolino, G., Fonseca, M., & Guirro, R. (2017). Effect of Low-Level Laser Therapy and Strength Training Protocol on Hand Grip by Dynamometry. *Journal of Lasers in Medical Sciences*, 8(3), 112-117.
- Borges, L.S., Cerqueira, M.S., dos Santos Rocha, J.A., Conrado, L.A., Machado, M., Pereira, R., et al. (2014). Light-emitting diode phototherapy improves muscle recovery after a damaging exercise. *Lasers in Medical Science*, 29(3), 1139-1144.

- Cabello Manrique, M., & González-Badillo, J.J. (2003). Analysis of the characteristics of competitive badminton. *British Journal of Sports Medicine*, 37(1), 62-66.
- Camargo, M.Z., Siqueira, C.P., Preti, M.C., Nakamura, F.Y., de Lima, F.M., Dias, I.F., et al. (2012). Effects of light emitting diode (LED) therapy and cold water immersion therapy on exercise-induced muscle damage in rats. *Lasers in Medical Science*, 27(5), 1051-1058.
- Cook, D.B., O'Connor, P.J., Oliver, S.E., & Lee, Y. (1998). Sex differences in naturally occurring leg muscle pain and exertion during maximal cycle ergometry. *International Journal of Neuroscience*, 95(3-4), 183-202.
- Cronin, J., Lawton, T., Harris, N., Kilding, A., & McMaster, D.T. (2017). A brief review of handgrip strength and sport performance. *Journal of Strength and Conditioning Research*, 31(11), 3187-3217.
- da Costa Santos, V.B., de Paula Ramos, S., Milanez, V.F., Correa, J.C., de Andrade Alves, R.I., Dias, I.F., et al. (2014). LED therapy or cryotherapy between exercise intervals in Wistar rats: anti-inflammatory and ergogenic effects. *Lasers in Medical Science*, 29(2), 599-605.
- de Oliveira, A.R., Vanin, A.A., Tomazoni, S.S., Miranda, E.F., Albuquerque-Pontes, G.M., De Marchi, T., et al. (2017). Pre-exercise infrared photobiomodulation therapy (810 nm) in skeletal muscle performance and postexercise recovery in humans: What is the optimal power output? *Photomedicine and Laser Surgery*, 35(11), 595-603.
- Dellagrana, R.A., Rossato, M., Sakugawa, R.L., Baroni, B.M., & Diefenthaler, F. (2018). Photobiomodulation Therapy on Physiological and Performance Parameters During Running Tests: Dose-Response Effects. *Journal of Strength and Conditioning Research*, 32(10), 2807-2815.
- Duffield, R., Edge, J., Merrells, R., Hawke, E., Barnes, M., Simcock, D., et al. (2008). The effects of compression garments on intermittent exercise performance and recovery on consecutive days. *International Journal of Sports Physiology and Performance*, 3, 454-468.
- Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugue, B. (2018). An Evidence-Based Approach for Choosing Post-exercise Recovery Techniques to Reduce Markers of Muscle Damage, Soreness, Fatigue, and Inflammation: A Systematic Review With Meta-Analysis. *Frontiers in Physiology*, 9, 403.
- Fahlstrom, M., Yeap, J.S., Alfredson, H., & Soderman, K. (2006). Shoulder pain -- a common problem in world-class badminton players. *Scandinavian Journal of Medicine and Science in Sports*, 16(3), 168-173.
- Faude, O., Meyer, T., Rosenberger, F., Fries, M., Huber, G., & Kindermann, W. (2007). Physiological characteristics of badminton match play. *European Journal of Applied Physiology*, 100(4), 479-485.
- Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., et al. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, 15(1), 109-115.
- Hayworth, C.R., Rojas, J.C., Padilla, E., Holmes, G.M., Sheridan, E.C., & Gonzalez-Lima, F. (2010). In vivo low-level light therapy increases cytochrome oxidase in skeletal muscle. *Photochemistry and Photobiology*, 86, 673-680.
- Jaworski, J., & Zak, M. (2015). The Structure of Morpho-Functional Conditions Determining the Level of Sports Performance of Young Badminton Players. *Journal of Human Kinetics*, 47, 215-223.
- Mezzaroba, P.V., Pessoa Filho, D.M., Zagatto, A.M., & Machado, F.A. (2018). LED session prior incremental step test enhance VO2max in running. *Lasers in Medical Science*, 33(6), 1263-1270.
- Molina Correa, J.C., Padoin, S., Varoni, P.R., Demarchi, M.C., Flores, L.J.F., Nampo, F.K., et al. (2020). Ergogenic Effects of Photobiomodulation on Performance in the 30-Second Wingate Test: A Randomized, Double-Blind, Placebo-Controlled, Crossover Study. *Journal of Strength and Conditioning Research*.
- Nagano, Y., Sasaki, S., Higashihara, A., & Ichikawa, H. (2020). Movements with greater trunk accelerations and their properties during badminton games. *Sports Biomechanics*, 19(3), 342-352.
- Nampo, F.K., Cavalheri, V., Dos Santos Soares, F., de Paula Ramos, S., & Camargo, E.A. (2016). Low-level phototherapy to improve exercise capacity and muscle performance: a systematic review and meta-analysis. *Lasers in Medical Science*, 31(9), 1957-1970.
- Nampo, F.K., Cavalheri, V., Ramos, S.P., & Camargo, E.A. (2016). Effect of low-level phototherapy on delayed onset muscle soreness: a systematic review and meta-analysis. *Lasers in Medical Science*, 31(1), 165-177.
- Owens, D.J., Twist, C., Cogley, J.N., Howatson, G., & Close, G.L. (2019). Exercise-induced muscle damage: What is it, what causes it and what are the nutritional solutions? *European Journal of Sport Science*, 19(1), 71-85.
- Padoin, S., Zeffa, A.C., Molina Correa, J.C., de Angelis, T.R., Moreira, T.B., Barazetti, L.K., et al. (2020). Phototherapy Improves Muscle Recovery and Does Not Impair Repeated Bout Effect in Plyometric Exercise. *Journal of Strength and Conditioning Research*.
- Rossato, M., Dellagrana, R.A., Lanferdini, F.J., Sakugawa, R.L., Lazzari, C.D., Baroni, B.M., et al. (2016). Effect of pre-exercise phototherapy applied with different cluster probe sizes on elbow flexor muscle fatigue. *Lasers in Medical Science*, 31(6), 1237-1244.

Vasconcelos, A.B., Nampo, F.K., Molina, J.C., Silva, M.B., Oliveira, A.S., de Angelis, T.R., et al. (2019). Modulation of exercise-induced muscular damage and hyperalgesia by different 630 nm doses of light-emitting diode therapy (LEDT) in rats. *Lasers in Medical Science*, 34(4), 749-758.