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ORIGINAL ARTICLE

ISOTONIC EXERCISE PROVOKES GREATER THERMAL TENDINOUS STRESS THAN ISOMETRIC EXERCISE INDEPENDENT OF PHOTOBIOMODULATION

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LEVEL OF EVIDENCE: 1b

ABSTRACT

Aim: The aim of this study is to analyze thermal skin pattern over the Achilles tendon (AT) of healthy individuals submitted to isometric and isotonic exercises associated with photobiomodulation (PBM).

Materials and methods: This experimental, randomized, single-blind study included 32 healthy, physically active subjects that were randomly assigned to different groups, performing isometric (G_{ISM}, N = 16, 8 males/8 females) or isotonic (G_{IST}, N = 16, 8 males/8 females) exercise protocols for sural triceps preceded by application of real PBM and sham with a one-week washout. The subjects were evaluated by infrared thermography (IRT), isometric muscle strength (IMS), pain and rating of perceived exertion, before, during and after protocols.

Results: G_{IST} presented higher temperatures than G_{ISM} ($p = 0.001$) when performing the exercise protocol. The IMS showed no differences between interventions ($p > 0.05$). Previous application of PBM also did not cause significant changes in IRT ($p > 0.05$). G_{IST} presented a greater rating of perceived exertion ($p = 0.001$) and pain ($p = 0.001$) than G_{ISM}.

Conclusions: Isotonic exercise showed greater thermal amplitude on the AT exercised and could act preventively in ischemic tendinopathies, while isometric exercise could be well indicated in early rehabilitation of tendon ruptures due to greater tolerance.

Study registration: This study was published in the Brazilian Registry of Clinical Trials (ReBEC) under the number RBR-2ft3bxw.

KEYWORDS

Achilles tendon, isometric exercise, isotonic exercise, phototherapy, thermography

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INTRODUCTION

Tendinopathy constitutes one of the most common musculoskeletal disorders that mainly affects the physically active population and can be responsible for about 30 to 50% of sports injuries[1]. Among other repercussions, Achilles tendinopathy can be absent from sports competitions for months[2]. The degeneration of the Achilles tendon is linked to decreased blood flow and mechanical stress, resulting in localized oxygen deficiency and heightened injury susceptibility[3,4]. These changes can be detected using infrared thermography (IRT), which reveals decreased skin temperature (Tsk) in regions experiencing tissue oxygen deprivation[5]. Its application based on dynamic measurements during exercise has proven to be valid for understanding thermoregulatory processes and acute physiological adaptations to different types of exercises, but the literature still presents inconsistent findings regarding the reduction or increase in Tsk during resistance exercise due to the great methodological heterogeneity[6].

Eccentric exercises have been widely recommended for treating Achilles tendon tendinopathy[7-10]. However, recent studies have concluded that there is insufficient evidence to assert the superiority of isolated eccentric exercise over isotonic exercises, which involve both concentric and eccentric components[2,11-13]. Additionally, in severe tendon injuries, some authors adopt a precautionary stance regarding stretching and eccentric exercises during the initial rehabilitation phase[14]. Lastly, isometric exercises have been shown to enhance the tensile strength of the tendon without exerting excessive stress on its structure[1], thereby alleviating pain[15-17] and promoting improved adherence to treatment, leading to immediate reduction in Achilles tendon pain[18].

Evidence supports the use of photobiomodulation (PBM), such as light emitted by diodes (LEDs), as an adjunct to exercise in treating tendinopathies[19-23]. PBM modulates biological processes, stimulating cell proliferation and increasing metabolism, thereby enhancing collagen synthesis and angiogenesis[21,24,25]. Irradiation of LEDs with a range between 620-650 nm on muscles exercised immediately before resistance exercise improves muscle performance, accelerates recovery, and protects against exercise-induced muscle damage[26,27].

Considering that there is a knowledge gap regarding the immediate effects of exercise and the association with PBM on tendon temperature, and that it is not known whether the thermal pattern is different when using isometric and isotonic exercises, some questions arise on this topic:

1) Is there a difference between the thermal effects of isometric and isotonic exercises on the AT?
2) Is this thermal response altered by the prior application of PBM?

Therefore, this study aimed to analyze the Tsk pattern on the AT of healthy individuals submitted to PBM in association with isometric and isotonic exercises. The hypothesis adopted was that isotonic and isometric exercises promote an increase in Tsk over AT, which is potentiated by PBM.

MATERIAL AND METHODS

This is an experimental, randomized, single-blind study that used two independent exercise groups: 1. Isometric; and 2. Isotonic, associated with sham and real photobiomodulation, with a washout time of one week. Published in the Brazilian Registry of Clinical Trials (ReBEC) under the number RBR-2ft3bxw. The study was carried out at the Laboratory of Thermography (LabTerm) of the Post Graduate Program in Physiotherapy of the University and was approved by the Ethics and Research Committee of the Center for Health Sciences of the University under the review board approval number CAAE: 42496921.0.0000.5188 and opinion number 4563980. The subjects were informed about the objectives of the study and signed an Informed Consent Form (ICF) obeying Resolution no. 466/12 of the National Health Council and in accordance with the declaration of Helsinki which regulates research with human beings.

Sample characteristics

Subjects of both sexes, healthy, aged between 18 and 35 years. Of these, 14 individuals classified as “very active” and 18 classified as “active” according to the International Physical Activity Questionnaire (IPAQ) - Short Version[28] classification were included in the study. Furthermore, the volunteers should not have tendinopathies or have suffered ruptures or undergone a surgical procedure in the AT.

The 32 selected volunteers were randomized into two exercise groups: isotonic (G_{IST}, n = 16, 8 males/8 females) and isometric (G_{ISM}, n = 16, 8 males/8 females). LED photobiomodulation was applied in four blocks (LED real + isotonic, LED sham + isotonic, LED real + isometric, LED sham + isometric) using http://www.randomization.com. Each participant underwent two experimental sessions, with the real or sham LED application alternated during the second evaluation, which took place one week later. The sample calculation was performed using the G*Power version 3.0.10 software program (Franz Faul Kiel, Germany) *a priori*, considering an F-test; repeated measures Anova; power of 0.95 adopting a significance level of 5%; correlation coefficient of 0.5; non-sphericity correction of 1; and an effect size of 0.25. It was found that 28 subjects + 10% would be needed to compensate for possible sample losses, and we ended up with 32 volunteers and a statistical power of 0.96.

A total of 39 volunteers were initially recruited, but three were not included because they did not meet the inclusion criteria and two withdrew from participating. Thus, 34 subjects were randomized into two groups: 17 for the Isometric group and 17 for the Isotonic group. Of these, one subject from the isometric group was excluded for not

having performed the two assessments recommended in the study and one subject from the eccentric group for not having been able to complete the exercise protocol. Therefore, the final sample consisted of 32 subjects, eight males and eight females in each group. The CONSORT flowchart summarizing the distribution of volunteers and the experimental procedures performed is illustrated in *Figure 1*.

Demographic and temperature data at baseline were tested using the independent student's t-test and are presented in *Table 1*, in which it is observed that there was no significant difference between the volunteers assigned to the two groups.

Data collection

The volunteers were also evaluated for body weight and Body Mass Index (BMI) using the In Body 120 Bioimpedance scale (In body Co., Ltd. Seoul, South Korea). Height was measured using a Standard ES 2030 stadiometer (Sanny®, Brazil).

Upon each visit to the laboratory, the subjects were submitted to an infrared thermographic video assessment during the experimental protocol; assessment of the isometric muscle strength of the sural triceps (pre and post-exercise); pain evaluation using the Numerical Pain Scale (NPS); and rating of perceived exertion (RPE) in the post-exercise period using the modified BORG scale[29,30].

Thermographic evaluation

A T-360 thermographic camera (FLIR SYSTEMS, USA) with IR resolution of 320 x 240 pixels, temperature range from -20 to 120ºC, thermal sensitivity of 0.05ºC and accuracy of ± 2% was used for the infrared videothermography. The thermographic examination followed the guidelines of Moreira et al.[31]. The laboratory has black walls and is illuminated by LED lamps with room temperature and relative humidity controlled by a WMR86 digital meteorological station (Oregon Scientific, China) and kept between 22º and 24ºC (23,1 ºC ± 0,5) and less than 50% (42% ± 6,5), respectively.

Subjects were instructed to dress in light, comfortable clothing that allowed complete exposure of their calves and ankles. Volunteers were also previously instructed not to consume tobacco, alcohol or drugs that affect body thermogenesis, not to perform moderate to intense physical activity on the examination day, to eat up to two

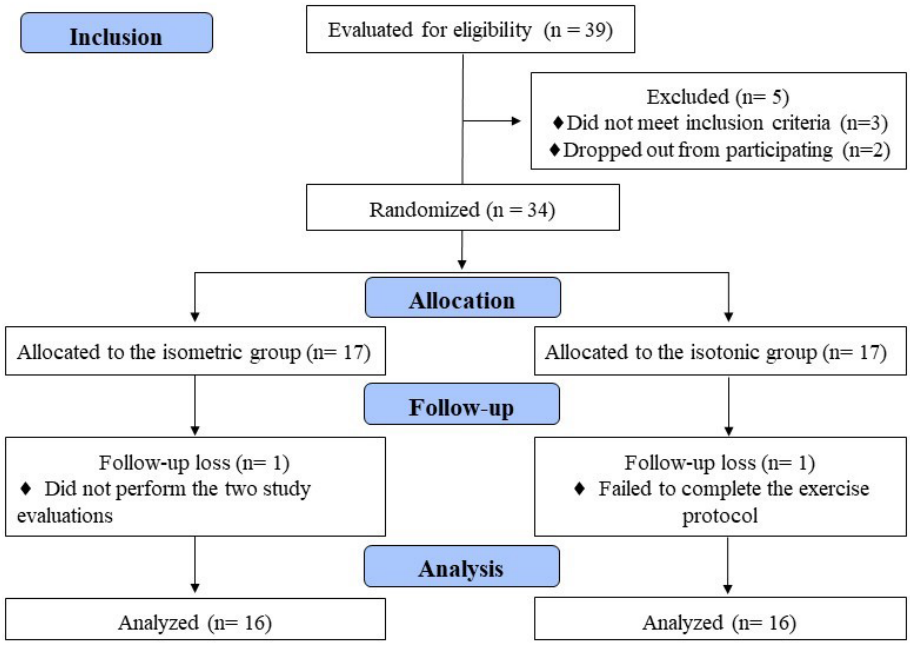


Figure 1. *Study flowchart according to CONSORT 2010.*

Variables	GISM	GIST	T-test	p value
Age	24 ± 3.6	25 ± 3.3	-0.102	0.091
Weight (kg)	68.45 ± 10	61.7 ± 13.6	-0.061	0.95
Height (cm)	166 ± 8.3	166 ± 8.5	-0.524	0.60
BMI (kg/m²)	23.9 ± 3.1	22.6 ± 3.4	-0.540	0.59
Sex	8M/8F	8M/8F		
Temperature (°C)	28.7 ± 0.9	28.5 ± 1.0	1.171	0.244

Table 1. *Demographic data and baseline temperature of subjects. Legend: BMI, body mass index; GISM, isometric group; GIST: isotonic group.*

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hours before and not to use moisturizing oils or creams in the regions to be examined. The subjects remained in the examination room for an acclimatization period of 15 minutes before performing the thermography[31].

The subjects were positioned in an orthostatic position on a step during the thermographic evaluation, as described for carrying out the exercise protocols, and the thermographic camera was fixed on an adjustable support at a distance of 1.30 m from the subject to enable complete visualization of the calf and AT. A video was recorded during the initial rest period (165 s), during photobiomodulation (240 s), exercise (165 s) and after exercise (165 s).

Next, 10 thermograms *(Fig. 2)* were extracted from the videos, as follows: T1 (initial rest); T2 (post-strength test); T3 (after the 1st LED point); T4 (post 2nd LED point); T5 (post 3rd LED point); T6 (post 4th LED point); T7 (after the 1st series of the exercise); T8 (after the 2nd series of the exercise); T9 (after the 3rd series of exercise); and T10 (final rest).

The thermograms were analyzed using the Flir Tools+ (version 6.4, Teledyne FLIR LLC) software program, in which the average temperature of the Region of Interest (ROI) was obtained from a rectangular area inferiorly delimited by inserting the tendon in the calcaneus.

Isometric muscle strength evaluation

A portable isometric dynamometer (model DD-300, Instrutherm, Brazil) was used to evaluate muscle strength of the sural triceps, which has scales from 0 to 100 Kgf, 220 LBf, 980 N and 1% precision.

Muscle strength was measured at two moments: before and after performing the intervention protocol with PBM (real or sham) associated with exercise (isometric or isotonic). The individual remained in the orthostatic position to carry out the test and wore a non-elastic "Y" shaped suspender resting on the shoulders and lying in a single band below the pelvis between the lower limbs of the subjects.

This band was connected to a ring at its lower end to which the dynamometer was attached, which in turn was connected to a hook fixed to the ground by a steel chain adjusted according to the volunteer's height *(Fig. 3)*.

The individuals were asked to perform a submaximal isometric contraction in unipodal plantar flexion of the experimental limb before the test for familiarization with the procedure. Next, three maximal voluntary isometric contractions (MVIC) of the triceps surae were requested using only the experimental dominant limb for evaluation, lasting 5 seconds and resting for 15 seconds between

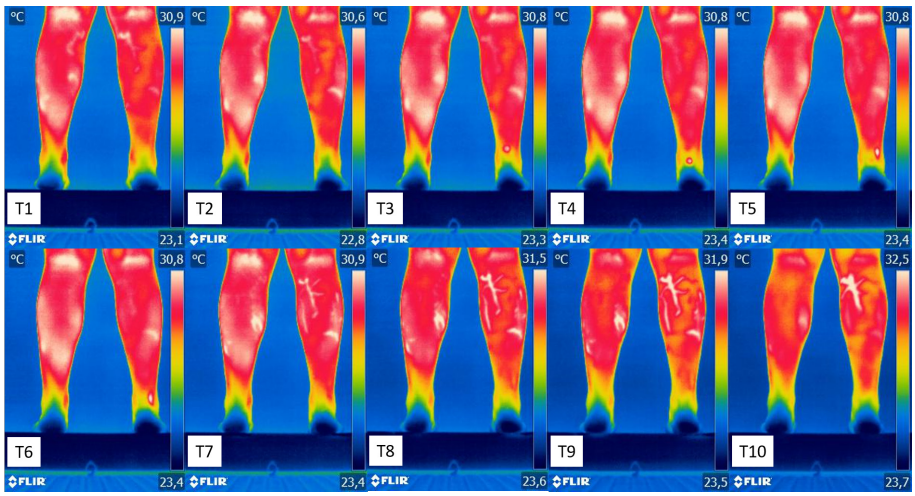


Figure 2. *Thermograms from T1 to T10 of a subject.*



Figure 3. *Isometric muscle strength evaluation of the triceps surae.*

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them. An arithmetic mean of the three measurements was used in Kgf for further analysis.

Evaluation of perceived physical exertion

The physical exertion perceived by the volunteers was evaluated using the modified Borg scale exertion[29,32]. It was applied immediately at the end of the execution of the experimental protocol based on the study by Zhao *et al.*[33], who evaluated the perceived exertion during isotonic strength exercise.

Pain evaluation

The evaluation of the perception and quantification of pain was performed using the Numeric Pain Scale (NPS), which consists of a linear scale from zero to ten, zero being total absence of pain and 10 being the maximum pain ever experienced by the subject[30]. The volunteers were asked about their pain perception during the exercise immediately after completing the protocol, and then instructed to indicate the number which matches it on the scale.

Exercise protocol

The experiment consisted of performing two different exercise protocols for G_{IST} and G_{ISM}. The study design can be seen in *Figure 4*. The exercise was only performed by the dominant limb, defined as the limb that the volunteer preferably uses to kick a ball. The contralateral limb served as a control and was only supported on the ground with the hallux touching, without bearing body weight.

In the G_{IST} protocol, the individual was instructed to stand on a step facing the wall with both parallel feet supported only on the forefoot with the hindfoot off the edge of the step. Then, the subject performed three sets of 15 repetitions of the maximum plantar flexion movement, lowering the heel to the maximum amplitude of dorsiflexion and returning to the initial position. The concentric phase was performed in 1s and the eccentric phase in 2 s controlled using the digital metronome application (Sound corset version 10.2.0 for *IPhone*). An interval of 15 s of rest was applied between each series, totaling 165 seconds of execution.

The isometric exercise protocol started with the subject standing on the step facing the wall with support on both feet. Then, they were asked to perform a maximum plantar flexion maintained for 45 s with only the support of the forefoot. The exercise was performed in three series with one contraction per series and a 15-second interval between each repetition, likewise totaling an exercise time of 165 seconds[15].

LED photobiomodulation

TENDLITE® LED equipment (Lumina Group Inc., San Diego, California, USA) pulsed, non-polarized operating mode, irradiation area of 2.54 cm^2, and wavelength of 660 nm was used, with: output power of 215 mW; power density of 84.64 mW/cm^2; frequency of 60 Hz; energy density of 5.07 J/cm^2; and exposure period of 60s per point, based on the study by Leal-Junior *et al.*[27], who found that more consistent results in muscle performance and post-exercise recovery were obtained when using red or infrared wavelengths with powers between 50 and 200 mW and doses of 5 and 6 J per point.

The volunteer remained in an orthostatic position on the step and wore glasses with black and opaque lenses to prevent knowledge regarding the application of the real or sham LED. The examiner applied the real LED taking the Achilles tendon insertion as reference, with the first application point being 1.5 cm above the insertion and the second point 1.5 cm above the first application site. Two points were irradiated in the posterior region exactly over the AT, and another 2 points in the lateral region of the AT, totaling a 20.3 J/cm^2 dose of total energy density.

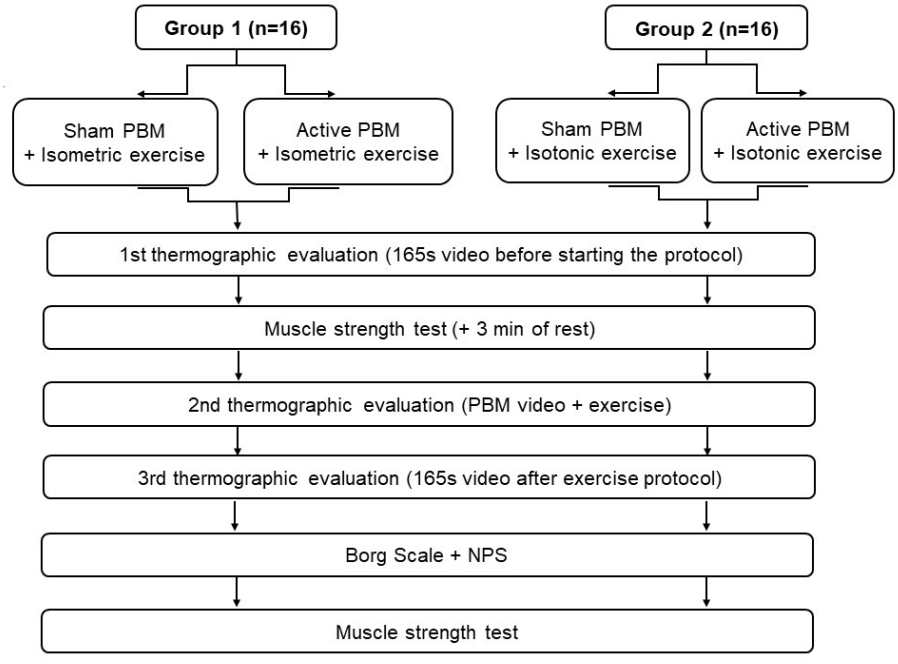


Figure 4. *Study design.*

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The procedure was the same for the simulated application of the LED, but using the device turned off. The LED was applied as close as possible to the skin but without direct contact to avoid heat exchange by conduction. The device was connected to a support so that the examiner could keep a certain distance from the volunteer, not causing interference in the infrared thermographic video performance.

Statistical analysis

All data processing was performed using the SPSS version 20.0 statistical package adopting a significance level of 5%. The dependent variables were the mean ROI temperature (°C), the degree of pain on the numerical pain scale (NPS) and the rating of perceived exertion on the Borg scale (RPE), while the independent variables were the intervention groups of the exercise (Isometric and Isotonic) and LED (Real and Sham), and limbs (experimental and control).

The data were initially grouped and tested for normality, homogeneity and sphericity of variances by applying the Shapiro Wilk, Levene and Mauchly tests, respectively. With the assumptions met for the parametric test, an Three-way Anova with repeated measures was applied to compare the average temperatures in the 10 evaluation times. The Greenhouse Geisser correction was used when sphericity was not assumed. Pain (NPS) and rating of perceived exertion (RPE) were tested using the Mann-Whitney test between groups. The partial eta (η^2) was calculated by SPSS to interpret the effect size, and the following classification was used: Eta of 0.01< 0.13 was considered medium and >0.14 classified as large[34].

Muscle strength was tested within each group between pre-led and post-final rest using the paired Student's t-test. The reproducibility of the test and retest strength measurements was also tested using a mixed Two-way model with absolute agreement and average of 3 measurements between two sessions of isometric muscle strength measurements of the triceps surae performed with an interval of one week. The ICC classification was estimated based on a 95% confidence interval, with values <0.5, between 0.5 and 0.75, between 0.75 and 0.9, and >0.90 being considered to indicate poor, moderate, good, and excellent reproducibility, respectively[35].

RESULTS

In the analysis of the results over the 10 evaluations over time, it was observed that the time factor caused significant changes in temperature [F (4.36, 523.34) = 35.36; p = 0.001 η2 = 0.228]. It was additionally observed that there was a significant interaction in the time x limb analysis [F (4.36, 523.34) = 3.259; p = 0.01 η2 = 0.026] and in the time x exercise analysis [F (4.36, 523.34) = 11.140; p = 0.001 η2 = 0.085], but there was no interaction in the time x intervention analysis (real led x led sham) or in the time x limb x intervention analysis (p >0.05). In the analysis between subjects, it was observed that there was an effect for the Limb [F (1, 120) = 6.383; p = 0.013 η2 = 0.051] and Exercise [F (1, 120) = 4.394; p = 0.038 η2 = 0.035] factors, as can be seen in *Table 2*.

In the analysis of the time factor, it was observed that there was a decrease in skin temperature over AT at all times

	G_{ISM}				G_{IST}+			
	C_sham	C_led	E_sham§	E_led§	C_sham	C_led	E_sham§	E_led§
T1	28.6 ± 0.9	28.7 ± 0.9	28.7 ± 1.0	28.8 ± 1.0	28.3 ± 1.2	28.8 ± 0.8	28.3 ± 1.0	28.7 ± 0.9
T2	27.9 ±0.9	27.9 ± 1.2	28.2 ± 1.1	28.1 ± 1.0	27.7 ± 0.9	28.2 ± 0.6	28.3 ± 0.8	28.5 ± 0.9
T3	27.9 ± 0.9	27.9 ± 1.2	28.1 ± 1.1	28.2 ± 1.3	27.8 ± 0.8	28.2 ± 0.6	28.4 ± 0.7	28.5 ± 0.8
T4	27.9 ± 0.9	27.9 ± 1.2	28.2 ± 1.1	28.3 ± 1.1	27.8 ± 0.8	28.2 ± 0.7	28.5 ± 0.6	28.5 ± 1.1
T5	27.8 ± 0.9	27.9 ± 1.2	28.0 ± 0.9	28.3 ± 1.1	27.8 ± 0.8	28.2 ± 0.7	28.5 ± 0.7	28.5 ± 0.7
T6	27.8 ± 0.9	27.8 ± 1.1	28.0 ± 1.1	28.2 ± 1.1	27.9 ± 0.7	28.2 ± 0.7	28.4 ± 0.7	28.5 ± 1.0
T7	27.5 ± 0.9	27.5 ± 1.2	27.8 ± 1.0	27.9 ± 1.1	27.7 ± 0.7	28.1 ± 0.7	28.3 ± 0.6	28.4 ± 0.6
T8	27.4 ± 0.9	27.4 ± 1.3	27.7 ± 1.0	27.8 ± 1.1	27.6 ± 0.7	27.9 ± 0.7	28.3 ± 0.5	28.1 ± 0.9
T9	27.7 ± 0.6	27.3 ± 1.2	27.5 ± 0.9	27.8 ± 1.1	27.6 ± 0.7	28.0 ± 0.6	28.4 ± 0.5	28.6 ± 0.7
T10	27.6 ± 1.0*	27.4 ± 1.1*	27.9 ± 1.2*	27.7 ± 1.0*	27.8 ± 0.6*	28.1 ± 0.5*	28.7 ± 0.6#	28.8 ± 0.7#

Table 2. *Descriptive statistics (means and standard deviations) of the skin temperature (ºC) of the Achilles tendon during the experimental protocol.*

*Legend: C, control limb; E, experimenta limb; GISM, isometric group; GIST, isotonic Group. * significant decrease compared to T1 (p <0.05); # significant difference between exercises by comparing experimental limbs (p <0.05); + significant difference compared to isometric exercise (p = 0.038); § significant difference in relation to the control limb for the same exercise performed (p = 0.013).*

	G_{ISM}		G_{IST}	
	Real LED	**Sham LED**	**Real LED**	**Sham LED**
Strength - pre	78.35 ± 19.2	72.60 ± 19.9	77.9 ± 18.7	70.6 ± 18.8
Strength - post	75.03 ± 19.7	78.15 ± 19.8	79.8 ± 19.5	73.9 ± 17.8
p value	0.79	0.28	0.60	0.09

Table 3. *Strength measurements pre and post experimental protocol with real LED and sham LED.*

when compared to time 1 (p = 0.001), with the exception of the experimental limb of the G_{IST}. In the analysis of the Time x Limb interaction, it was generally observed that the experimental limb temperature was higher than that of the control (p <0.05 to p = 0.001 CI T10 = -0.897 to -0.275 η2 = 0.104) at all times, except for T1 and T2 (p >0.1). It was additionally found that the experimental limb temperature decreased over time (p <0.05), except when comparing T1 with T4, T5, and T10 (p >0.05). The control limb also had a decrease throughout the evaluation period when comparing time 1 (p = 0.001).

In the analysis of the time x exercise interaction, it was generally observed that the temperature in the G_{IST} was higher than in the G_{ISM} at time 7 (p = 0.013), 8 (p = 0.014) 9 and 10 (p = 0.01). However, when the exercises are analyzed separately, it is observed that the isometric exercise presented a significant decrease in temperature at all times (p = 0.001), and the isotonic exercise significantly decreased the temperature only in times 2 (p = 0.029), 7 (p = 0.002) and 8 (p = 0.001), compared to time 1.

In the test and retest reliability analysis of the isometric triceps surae muscle strength performed with an interval of one week, an ICC of 0.859 with a CI of 0.711 to 0.931 with p = 0.001 was verified, which denotes good reproducibility of the measurements. When the triceps surae muscle strength was analyzed for the pre and post-protocol, G_{IST} there was no significant difference for the real led (p = 0.597) and sham led (p = 0.092). The same result was presented for G_{ISM} with real LED (p = 0.790) and sham led (p = 0.280), *Table 3*.

In the rating of perceived exertion analysis by the Borg scale between the G_{ISM} and the G_{IST}, it was verified that there was a significant difference (p = 0.001) with the G_{IST} presenting a greater rating of perceived exertion than the G_{ISM} *(Table 4)*.

In the pain analysis using the NPS scale between G_{ISM} and G_{IST}, it was found that there was a significant difference (p = 0.001) with G_{IST} presenting greater discomfort than G_{ISM}.

	G_{ISM}	G_{IST}	
			p value
BORG - post	3.3 ± 1.18	4.3 ± 1.9	0.001
NPS - post	1.0 ± 1.7	4.3 ± 3.0	0.001

Table 4. *NPS and Borg scale scores.*

The comparison of the perceived exertion rate and NPS of the real LED with the Sham showed no difference between the groups (p >0.05) *(Table 4)*.

For the correlation analysis between the Borg scale and the NPS, it was found that there was a weak significant correlation (r = 0.336; p = 0.007).

DISCUSSION

In this study, it was the first time to our knowledge that skin temperature changes over AT were analyzed during isometric and isotonic exercise protocols associated with PBM by LED. Some important findings were verified, such as:

1) The skin temperature over AT significantly reduced over time for both analyzed limbs (experimental and control), except for experimental limb of G_{IST};
2) The skin temperature over AT of the experimental limb was higher than that of the control;
3) The temperature in isotonic exercise was higher than in isometric exercise during and after exercise;
4) Intervention with PBM by LED did not significantly influence temperature or muscle strength;
5) Isotonic exercise showed greater discomfort and perceived exertion than isometric exercise.

A reduction in skin temperature over AT was verified in this study during isometric exercise, but remained stable in isotonic exercise. Only a few studies have proposed to study the changes provided by exercise specifically regarding the skin temperature over the tendon[36,37], and a reduction in skin temperature over AT was verified in subjects submitted to similar isotonic resistance exercise to that performed in this study[36].

The study by Sanz-Lopes *et al.*[37] compared the temperature of the patellar and Achilles tendons of two groups of runners submitted to three consecutive days of running for one hour with 80% of the maximum heart rate. One of the groups underwent previous training with eccentric squatting exercises two days a week for six weeks. The authors verified that the group submitted to eccentric training experienced a smaller increase in temperature immediately before the first day of running and attributed this to a better metabolic adaptation, since there were similar increases in temperature in the tendons of both groups on the other days. However, this is a chronic effect of eccentric training, unlike this study in which the acute effects of exercise on AT were examined.

A finding which evidences the thermal alterations provided

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by exercise in this study was that the skin temperature over AT of the exercised experimental limb was higher than that of the non-exercised control limb, with higher skin temperature observed over the AT in the G_{IST} group compared to the G_{ISM}. This evidences that there was a distinct thermal response for the exercise types evaluated. This finding can be attributed to greater elastic energy storage in the tendon during isotonic exercise, which is dissipated in the form of heat during and after performing the exercise, and can be explained by the fact that the tendon is not a perfectly elastic structure, and therefore it is unable to return all the energy that was stored during eccentric phase of the exercise[38].

The findings by Maganaris and Paul[39] and Kubo *et al.*[40] verified hysteresis rates of 18 and 20% for isometric contractions, respectively, compared to a rate of 26% verified by Lichtwark and Wilson[41] during unipodal jump, meaning for isotonic contractions.

Based on these findings, which suggest a greater metabolic demand and consequently a greater increase in blood flow provided by isotonic exercise compared to isometric exercise, we can infer that greater benefits can be provided by adding isotonic exercise in programs for preventing and treating Achilles tendinopathies. This is because one of the factors which may predispose an individual to AT injuries is the limited blood supply and that the increase in blood circulation contributes to tendon repair, since collagen synthesis and proliferation are related to oxygen availability in the tissue[15,42].

On the other hand, regarding early rehabilitation after tendon ruptures when there is no indication for carrying out eccentric exercises due to the strength in stretching muscle and tendon fibers, there is evidence of the importance of isometric exercises and their benefits, especially in pain reduction[14,43,44].

Regarding previous LED application, it was verified that the vasodilator stimulus provided by the PBM only induced a non-significant increase in temperature after the application of a dose of 10.14 J. In this regard, a study carried out by Stamborowski et al.[45] evaluated the influence of prior PBM application on the temperature of the biceps brachii muscle during a muscle fatigue protocol based on three MVIC lasting 50 seconds. The authors also did not verify significant alterations in the temperature of the experimental group in relation to the control and placebo groups. Recent studies suggest that thermal effects provided by the increase in local microcirculation are dose and wavelength dependent, being related to wavelength in the infrared light range and an average dose of 262 J/cm^2[46,47]. However, there are no studies that have monitored the tendon temperature after LED application prior to exercise.

A similar result to that reported in this study was found by Stamborowski *et al.*[45], who also did not verify changes in the average muscle strength of the three MVICs with the previous application of PBM (wavelength: 808 nm, power: 100 mW/point, energy of 3J/point in nine points totaling 27 J of energy). However, these authors report that the group submitted to PBM presented a smaller variation percentage of maximum and minimum forces, thereby indicating maintained strength and consequently better performance. However, unlike the study by Stamborowski *et al.*[45], the LED in this study was applied to the tendon and not the muscle.

Antonialli *et al.*[48] studied the effects of a single application of three different PBM doses (10, 30 and 50 J/point referring to 60, 180 or 300 J of energy) before an eccentric exercise protocol and found positive effects for all doses in reducing creatine kinase (CK), which is an indirect muscle damage marker, in increasing isokinetic strength, in addition to reducing late-onset muscle soreness. The authors pointed out superior results from applying a dose of 30 J, which provided an increase of up to 20% in muscle strength evaluated at 72 and 96 hours after exercise, in relation to the baseline, as well as being the only dose that provided an acute increase from pressure pain threshold up to 24 hours after exercise. In contrast, in a study with a PBM protocol (wavelength: 810 nm; power: 201 mW) prior to very similar eccentric exercise evaluating the same three doses, better results were obtained in terms of strength and reduced muscle damage with doses of 10 and 50 J[49]. However, the strength and pain assessments in the methodology adopted in our study were only performed immediately, and the total dosage was 20.3 J, which is completely different from those used by the latter study.

Finally, this study verified a greater rating of perceived exertion and pain in performing isotonic exercise than in isometric exercise. According to Zhao *et al.*[33], there is a greater perception of exertion during dynamic exercises due to peripheral and central alterations, such as recruitment of motor units and anaerobic glycolysis. On the other hand, greater pain perception may be related to microruptures of muscle fibers caused by the eccentric component of the exercise[50].

Despite this study presenting important information about the thermal profile of Achilles tendons submitted to exercise, it has limitations related to the sample studied which was formed by healthy subjects, the PBM dose (LED) applied (20.3 J), which may not have been enough to change the thermal profile and muscle strength of the subjects, and also the way of applying the PBM that was not performed by direct contact to avoid heat exchange between the applicator and the skin. Thus, it is suggested that future studies can be carried out with subjects affected by tendinopathy, with effective LED doses applied directly to the skin and evaluated for up to 72 hours after application.

CONCLUSION

The results reported in this study indicate that isotonic exercise has a greater thermal amplitude on the exercised AT, and may act preventively in tendinopathies. On the

other hand, isometric exercise can be used in the early rehabilitation stages of tendon ruptures due to a lower rating of perceived exertion and discomfort during its execution. In turn, PBM was not able to cause thermal changes or changes in muscle strength in healthy subjects at the dose applied in this study.

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