Phototherapy during treadmill training improves quadriceps performance in postmenopausal women
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Key words: PHOTOTHERAPY, INFRARED, PHYSICAL TRAINING, MUSCLE PERFORMANCE, POSTMENOPAUSE

ABSTRACT

Objective To evaluate the effects of infrared-light-emitting diode (LED) during treadmill training on functional performance.

Methods Thirty postmenopausal women aged 50–60 years were randomly assigned to one of three groups and successfully completed the full study. The three groups were: (1) the LED group, which performed treadmill training associated with phototherapy (n = 10); (2) the exercise group, which carried out treadmill training only (n = 10); and (3) the sedentary group, which neither performed physical training nor underwent phototherapy (n = 10). Training was performed over a period of 6 months, twice a week for 45 min per session at 85–90% of maximal heart rate, which was obtained during progressive exercise testing. The irradiation parameters were 100 mW, 39 mW/cm² and 108 J/cm² for 45 min. Quadriceps performance was measured during isokinetic exercise testing at 60°/s and 300°/s.

Results Peak torque did not differ amongst the groups. However, the results showed significantly higher values of power and total work for the LED group (Δ = 21 ± 6 W and Δ = 634 ± 156 J, p < 0.05) when compared to both the exercise group (Δ = 13 ± 10 W and Δ = 410 ± 270 J) and the sedentary group (Δ = 10 ± 9 W and Δ = 357 ± 327 J). Fatigue was also significantly lower in the LED group (Δ = −7 ± 4%, p < 0.05) compared to both the exercise group (Δ = 3 ± 8%) and the sedentary group (Δ = −2 ± 6%).

Conclusions Infrared-LED during treadmill training may improve quadriceps power and reduce peripheral fatigue in postmenopausal women.

INTRODUCTION

The decline in peak exercise performance occurs with advancing age. There is reduction of fast powerful movements that may contribute to a loss of the type II motor units. In addition, a reduction in maximal oxygen consumption (VO₂max), lactate threshold and energetic cost are associated with aging. Endurance ‘masters’ athletes strive to maintain or even improve upon the performance they achieved at younger ages, but some level of decline in athletic performance is inevitable. Low estrogen levels during menopause can result in skeletal muscle atrophy and weakness, lower aerobic capacity and a progressive increase in fat mass. These factors may lead to early fatigue and decreased physical performance. However, it is obvious that moderate- to high-intensity physical activity is a goal by which the physiologic and functional losses associated with aging may be altered. According to Tanaka and Seals, ‘masters’ endurance athletes are capable of remarkable athletic and physiological functional performance, thereby representing a uniquely positive example of ‘exceptional aging’.
In addition, new methods to increase physical performance and promote health can be applied in aging people. Adjunctive technologies, used in parallel with traditional exercise training, have been shown to elicit additional improvement in muscle function in postmenopausal women, such as neuromuscular electrical stimulation associated with exercise (climbing up and down the stairs)\(^3\), unloaded static and dynamic exercises on a vibration platform (whole-body-vibration)\(^4\), and phototherapy (850 nm light-emitting diodes, LEDs) during a treadmill training\(^5\).

Some studies also suggest that the acute and chronic increases in muscle performance might be potentiated by using adjunctive technology in younger people participating in exercise training. Phototherapy (660/850 nm LEDs) applied before exercises in males was able to promote an acute attenuation in knee-extensor torque fatigue during a high-intensity concentric protocol\(^6\). In another similar study, 810 nm laser therapy applied before exercise can increase knee-extensor peak torque in young males\(^8\) and, when applied after a cycle ergometer training program, resulted in the reduction of quadriceps fatigue in young females\(^9\). The authors theorized that phototherapy enhanced mitochondrial function and increased aerobic adenosine triphosphate (ATP) synthesis, thereby reducing both blood lactate accumulation and biochemical markers of muscle damage.

Previous studies from our group have found that phototherapy significantly improved aerobic exercise performance in postmenopausal women participating in a high-intensity training program\(^10\). However, strength parameters during a 6-month longitudinal study, to our knowledge, have not been investigated. Thus, the aim of this study was to evaluate the synergistic effect of infrared radiation, emitted from LEDs, and treadmill training on quadriceps strength and fatigue in postmenopausal women. Our hypothesis was that muscle performance in postmenopausal women would be enhanced through the use of infrared-LED illumination during treadmill training.

**METHODS**

All procedures were approved by the National Ethics Committee of the Ministry of Health in Brasilia, Brazil (approval no. 688/2009) and by the Ethics Committee of Federal University of São Carlos in São Carlos, Brazil (approval no. 262/2009). All subjects provided written informed consent and agreed to participate in the study. The study was registered with NIH Clinical Trials (NCT01610232).

**Participants**

A prospective randomized trial was undertaken. A computer program was used for the randomization. The schematic flow chart describing the participants in this study can be seen in Figure 1. Postmenopausal women from São Carlos City, São Paulo State in Brazil were invited to participate in the study. The inclusion criteria were postmenopausal Caucasian women, aged between 50 and 60 years, non-users of hormone replacement therapy.
replacement therapy (HRT) and untrained. Postmenopausal status was defined by an absence of menstruation for more than 1 year. The exclusion criteria were: signs and symptoms of any neurological, metabolic, inflammatory, pulmonary, oncological or cardiac disease or endocrinopathy, musculoskeletal or articular injuries and cigarette smoking. We excluded diseases, disorders or injuries which would have limited the ability to exercise, such as osteoarthritis. The anamnesis and clinical evaluation permitted the exclusion of 24% for a history of exercise training (n = 57); 21% for lower limb pain/disorders/injuries (n = 52); 18% for use of HRT (n = 44); 15% for being non-Caucasian (n = 36); 12% for cardiovascular disease (n = 28); 5% for smoking habits (n = 12); 3% for cancer (n = 8); and 2% for psychiatric symptoms (n = 5). Thirty postmenopausal Caucasian women with a mean age of 55 ± 2 years, mean menopause duration of 8 ± 5 years, and mean estradiol level of 17 ± 9 pg/ml were randomly divided into three groups: (1) the LED group which performed treadmill training associated with phototherapy, (2) the exercise group which carried out treadmill training only, and (3) the sedentary group which did not perform treadmill training or phototherapy. The demographic characteristics of this sample can be seen in Table 1.

### Phototherapy and training

For the phototherapy performed during treadmill training, LED arrays were specially designed by the Optics Group from the Physics Institute of São Carlos, University of São Paulo to be used at the sides of the treadmill, illuminating the subject’s thighs. The quadriceps muscles were illuminated because of their role during the stance and swing phases of gait cycle. Infrared radiation (850 nm) is not visible and was selected because this spectral range shows better skin penetration compared to the (visible) red light. The average power and power density on the women’s skin was 100 mW and 39 mW/cm², respectively. The treatment time was 45 min bilaterally on both thighs during treadmill training. These parameters led to an approximate fluence of 108 J/cm². The volunteers wore safety glasses during infrared-LED illumination⁵,¹⁰,¹¹. Figure 2 illustrates treadmill training with infrared-LED illumination; the women wore swimwear to ensure infrared absorption through the bare skin. However, the women in the exercise group wore sports clothing as they were not illuminated.

Treadmill training with and without phototherapy was performed twice a week, for 6 months; each session lasted 45 min at high intensity¹² (85–90% of maximal heart rate, HRmax, obtained during a progressive exercise testing as previously described¹⁰). Briefly, the women underwent a progressive aerobic exercise test on a treadmill (using the modified Bruce protocol). The test was terminated when the women demonstrated signs and/or limiting of maximal effort, such as fatigue of the lower limbs, general physical fatigue, dizziness, nausea, cyanosis, arrhythmias, excessive sweating, angina, or when the patient reached age-predicted HRmax.

Heart rate measurements were obtained by 12-lead electrocardiogram (ECG; HeartWare, Belo Horizonte, Minas Gerais, Brazil). The predicted HRmax for women was calculated by the formula: 210 minus age. For treadmill exercise, this formula provides a reasonable prediction of the HRmax response¹³. The maximal time of tolerance, the last stage of

<table>
<thead>
<tr>
<th>Demographic data</th>
<th>LED group</th>
<th>Exercise group</th>
<th>Sedentary group</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>56 ± 2</td>
<td>55 ± 2</td>
<td>55 ± 2</td>
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<tr>
<td>Duration of menopause (years)</td>
<td>8 ± 6</td>
<td>9 ± 6</td>
<td>7 ± 6</td>
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<tr>
<td>Progressive exercise testing (baseline)</td>
<td></td>
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<tr>
<td>Heart rate at rest (bpm)</td>
<td>73 ± 9</td>
<td>73 ± 10</td>
<td>71 ± 8</td>
</tr>
<tr>
<td>Modified Bruce (last stage)</td>
<td>2.5 ± 0.5</td>
<td>2.5 ± 0.5</td>
<td>2.5 ± 0.5</td>
</tr>
<tr>
<td>Maximal time of tolerance (min)</td>
<td>14 ± 2</td>
<td>13 ± 2</td>
<td>12 ± 2</td>
</tr>
<tr>
<td>Estimated VO2max (ml.kg.min)</td>
<td>33 ± 8</td>
<td>29 ± 5</td>
<td>27 ± 7</td>
</tr>
<tr>
<td>Predicted heart rate (bpm)</td>
<td>154 ± 2</td>
<td>155 ± 3</td>
<td>154 ± 2</td>
</tr>
<tr>
<td>Maximal heart rate (bpm)</td>
<td>165 ± 9</td>
<td>156 ± 14</td>
<td>157 ± 15</td>
</tr>
<tr>
<td>Heart rate recovery (bpm)</td>
<td>95 ± 7</td>
<td>92 ± 12</td>
<td>96 ± 14</td>
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**Figure 2** Infrared-LED illumination during treadmill training
modified Bruce and the estimated maximal oxygen consumption \((\text{VO}_{2\text{max}})\) were determined from the progressive exercise test\(^{10}\). Baseline values obtained for these variables are listed in Table 1. Baseline data for progressive exercise testing showed that the predicted HR\(_{\text{max}}\) was achieved and the estimated \(\text{VO}_{2\text{max}}\) indicated a sedentary state\(^{14}\) for all groups, as observed in Table 1.

A cardiofrequencimeter monitor (Polar A3; Polar Electro, Woodbury, NY, USA) was used to monitor heart rate during training. The training heart rate and exercise velocity are illustrated in Figure 3. The training intensity of the exercise program was gradually increased until it reached a target of 85–90% of the HR\(_{\text{max}}\) obtained from the progressive exercise test. The training program was individualized for each subject, under the direction of a physical education teacher and a physiotherapist. All women wore heart rate monitors and they were instructed to maintain the heart rate prescribed for training. The feedback was the same for both exercise groups. The treadmill speed was titrated upward until the individualized training heart rate was obtained.

Training sessions and evaluations were carried out in a laboratory at an air temperature between 22°C and 24°C and a relative humidity between 50% and 60%, at the same time of day.

**Anthropometric characteristics and body composition**

Anthropometric data were used to determine body mass index (BMI, body weight (kg) divided by height (m)\(^2\)), Percent body fat, fat mass and lean mass were determined via bipolar electrical bioimpedance of the upper limbs (Omron BF306; Omron, Kyoto, Japan)\(^{15}\).

**Isokinetic testing**

Peak torque (absolute and relative values, normalized by body mass), power, work, fatigue and the number of contractions of the dominant quadriceps were measured using an isokinetic dynamometer (Biodex Multi Joint System III; Biodex Medical Systems, New York, USA)\(^{16,17}\). Prior to the test, the load cell was properly calibrated using a standard weight and dynamometer lever arm horizontally positioned and stabilized in relation to the ground, according to the manufacturer’s recommendations.

The positioning and stabilization of the subjects were standardized by maintaining the same measures of the Biodex accessories (e.g. chair and lever) during the pre- and post-test\(^5\). The subjects were seated in a comfortable, upright position (90° at the hip) on the Biodex accessory chair, with the knee at a 90° knee-flexion angle. In order to minimize extraneous body movements during the contractions and therefore avoid the contribution of muscles other than the knee extensors, straps were applied across the chest, pelvis and at mid-thigh level. The dynamometer lever arm was attached 2–3 cm above the lateral malleolus using a strap. The knee joint axis was adjusted to the Biodex ensuring an alignment between the center of rotation of the dynamometer resistance adapter and the axis of rotation of the knee at the lateral femoral epicondyle. The subjects were asked to relax their legs so that the passive determination of the effects of gravity on the limb and lever arm could be measured.

Each subject was required to fold her arms across her chest. The warm-up period and the familiarization exercises consisted of performing submaximal isometric contractions. All subjects were instructed to push the lever up and pull it down as hard and as fast as possible during knee extension. While the participants were performing the protocols, verbal encouragement and visual feedback were given. Details for the two protocols employed in the current study are as follows:

1. Protocol for the analysis of maximum isokinetic strength: the subjects performed five maximal efforts to determine maximal peak torque (N·m) at an angular velocity of 60°/s; and
2. Protocol for the analysis of isokinetic endurance: the subjects performed knee extension maneuvers for 1 min at an angular velocity of 300°/s to determine power (W), work (J), fatigue index (%) and the number of quadriceps muscle contractions. Muscle fatigue was determined using the following formula\(^6,16\): \[\text{Percent decrease} = 100 - \left(\frac{\text{work last third}}{\text{work first third}}\right) \times 100\]. The data were analyzed in absolute and relative terms, through normalization (%) by body mass.

**Statistical analysis**

Continuous data were expressed as mean and standard deviations. The Shapiro–Wilk test was used to analyze data normality and the homogeneity of variances using Levene’s test. One-way analysis of variance (ANOVA) was used to evaluate the differences in the demographic data and progressive exercise testing amongst the groups. Two-way ANOVA with repeated measures were used to compare changes before and after the treatment in the anthropometric characteristics, body composition, isokinetic parameters, training heart rate and exercise velocity. The independent factors were group (with three levels: LED group, exercise group and sedentary group) and time (with two levels: baseline and after 6 months), which was also considered as a repeated measurement (intragroup differences). The change between baseline and at 6 months (post-treatment - pretreatment) was used to compare groups using a one-way ANOVA (intergroup differences). When significant differences were found, Bonferroni adjustments were applied. The Statistica for Windows Release 7 software (Statsoft Inc., Tulsa, OK, USA) was used for the statistical analysis and the significance level was set at 5% \((p < 0.05)\).
RESULTS

Anthropometric characteristics and body composition

Data for anthropometric characteristics and body composition (secondary variables) for all three groups are listed in Table 2. Most of the characteristics amongst groups were similar (p ≥ 0.05), with the exception of BMI, which was significantly higher in the sedentary group following the intervention (p = 0.04).

Isokinetic testing

The results of isokinetic testing at angular velocities of 60°/s and 300°/s are listed in Table 2. Peak torque did not differ significantly for any of the groups (p ≥ 0.05, Table 3). Significant differences for the absolute values of average power and total work were found for all groups following completion of the 6-month protocol (p < 0.05). However, normalized values of average power and total work did not show significant differences for the sedentary group (p ≥ 0.05). The absolute and normalized values of the fatigue index significantly decreased only in the LED group (p = 0.003). Moreover, the number of contractions significantly increased only in the LED group (p = 0.01). However, the fatigue index and number of contractions did not show any significant differences for both the exercise and sedentary groups (p ≥ 0.05). In addition, a significant difference was found between the groups in the change between baseline and 6 months. Specifically, the LED group showed a higher change between baseline and 6 months for the average power (compared to the exercise group (p = 0.04) and compared to the sedentary group (p = 0.03), see Figure 4a), total work (compared to the exercise group (p = 0.03) and compared to the sedentary group (p = 0.03), see Figure 4b) and fatigue index (compared to the exercise group (p = 0.03)).

Table 2 Statistical results of the anthropometric characteristics and body composition (secondary variables) pre- and post-therapy. Data are given as mean ± standard deviation

<table>
<thead>
<tr>
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<th>LED group</th>
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<th>Sedentary group</th>
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<tr>
<td>Body mass (kg)</td>
<td>71 ± 11</td>
<td>71 ± 12</td>
<td>67 ± 11</td>
<td>67 ± 10</td>
<td>80 ± 17</td>
<td>83 ± 22</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>153 ± 7</td>
<td>153 ± 6</td>
<td>158 ± 6</td>
<td>157 ± 7</td>
<td>155 ± 5</td>
<td>154 ± 6</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>30 ± 5</td>
<td>30 ± 4</td>
<td>27 ± 4</td>
<td>27 ± 5</td>
<td>33 ± 7</td>
<td>35 ± 8*</td>
</tr>
<tr>
<td><strong>Body composition</strong></td>
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<td><strong>Body composition</strong></td>
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<tr>
<td>Body fat (%)</td>
<td>39 ± 7</td>
<td>37 ± 5</td>
<td>37 ± 4</td>
<td>36 ± 6</td>
<td>42 ± 5</td>
<td>43 ± 4</td>
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<tr>
<td>Fat mass (kg)</td>
<td>28 ± 8</td>
<td>27 ± 7</td>
<td>25 ± 6</td>
<td>24 ± 6</td>
<td>34 ± 11</td>
<td>36 ± 9</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>43 ± 5</td>
<td>43 ± 6</td>
<td>42 ± 6</td>
<td>42 ± 6</td>
<td>46 ± 6</td>
<td>47 ± 7</td>
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*, Significant difference for pre- vs. post-treatment (repeated measures ANOVA with Bonferroni adjustments) p < 0.05

Table 3 Statistical results of the isokinetic testing pre- and post-therapy. Data are given as mean ± standard deviation

<table>
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<tr>
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<th>LED group</th>
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<tr>
<td><strong>Isokinetic testing: 60°/s</strong></td>
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<td><strong>Isokinetic testing: 60°/s</strong></td>
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<td><strong>Isokinetic testing: 60°/s</strong></td>
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<tr>
<td>Peak torque (N·m)</td>
<td>107 ± 19</td>
<td>111 ± 14</td>
<td>101 ± 23</td>
<td>105 ± 18</td>
<td>108 ± 13</td>
<td>109 ± 19</td>
</tr>
<tr>
<td>Peak torque/body mass (%)</td>
<td>157 ± 39</td>
<td>162 ± 31</td>
<td>156 ± 37</td>
<td>162 ± 34</td>
<td>139 ± 26</td>
<td>134 ± 27</td>
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<tr>
<td><strong>Isokinetic testing: 300°/s</strong></td>
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<td><strong>Isokinetic testing: 300°/s</strong></td>
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<tr>
<td>Average power (W)</td>
<td>55 ± 9</td>
<td>76 ± 10*</td>
<td>62 ± 13</td>
<td>75 ± 12**</td>
<td>64 ± 14</td>
<td>74 ± 18**</td>
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<tr>
<td>Average power/body mass (%)</td>
<td>79 ± 20</td>
<td>110 ± 19**</td>
<td>94 ± 22</td>
<td>117 ± 26**</td>
<td>81 ± 14</td>
<td>91 ± 17</td>
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<tr>
<td>Total work (J)</td>
<td>1529 ± 336</td>
<td>2162 ± 319**</td>
<td>1646 ± 385</td>
<td>2055 ± 325**</td>
<td>1796 ± 404</td>
<td>2158 ± 579**</td>
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<tr>
<td>Total work/body mass (%)</td>
<td>2238 ± 684</td>
<td>3143 ± 632**</td>
<td>2517 ± 618</td>
<td>3198 ± 692**</td>
<td>2277 ± 409</td>
<td>2623 ± 198</td>
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<tr>
<td>Fatigue (%)</td>
<td>63 ± 6</td>
<td>57 ± 3*</td>
<td>51 ± 8</td>
<td>54 ± 6</td>
<td>59 ± 9</td>
<td>58 ± 5</td>
</tr>
<tr>
<td>Fatigue/body mass (%)</td>
<td>93 ± 19</td>
<td>83 ± 18*</td>
<td>79 ± 18</td>
<td>85 ± 24</td>
<td>79 ± 22</td>
<td>73 ± 20</td>
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<tr>
<td>Number of contractions</td>
<td>59 ± 5</td>
<td>64 ± 5*</td>
<td>59 ± 7</td>
<td>60 ± 5</td>
<td>64 ± 5</td>
<td>63 ± 6</td>
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</table>

Significant difference for pre- vs. post-treatment (repeated measures ANOVA with Bonferroni adjustments, *, p < 0.05; **, p < 0.01
The training intensity of the exercise program was gradually increased until it reached a target of 85–90% of HR_{max} obtained from the progressive exercise test. There were no significant changes in the baseline and after 6 months (repeated measures ANOVA, $p \geq 0.05$). In addition, no significant difference was found between the groups (one-way ANOVA, $p \geq 0.05$).

The gain of the quadriceps performance obtained by the LED group ($21 \pm 6$ W and $634 \pm 156$ J) compared to the exercise group ($13 \pm 10$ W and $410 \pm 270$ J) and the sedentary group ($10 \pm 9$ W and $357 \pm 327$ J) in the change between baseline and 6 months. Results obtained for the fatigue index (c) are significantly lower for the LED group ($-7 \pm 4\%$) compared to the exercise group ($-3 \pm 8\%$) and the sedentary group ($-2 \pm 6\%$) in the change between baseline and 6 months. The changes in the average power, the total work and fatigue index between baseline and 6 months show significant inter-group differences. * Significant difference (one-way ANOVA, $p < 0.05$); ** significant difference (one-way ANOVA, $p < 0.01$).

**DISCUSSION**

This study emphasizes our previous findings concerning an improvement in muscle performance in postmenopausal women when combining infrared radiation with an aerobic exercise training program. However, compared to the previous study, the clinical protocol in the current analysis was modified (the power, time of treatment and dose of infrared radiation as well as the period of the physical training were increased) and the improvements were enhanced. The infrared-LED illumination during treadmill training improved quadriceps strength and reduced peripheral fatigue in postmenopausal women. These results were apparent group ($p = 0.006$) and compared to the sedentary group ($p = 0.04$), see Figure 4c).
during the 300°/s isokinetic assessment protocol, but not at the 60°/s protocol.

There were no significant changes in knee-extensor peak torque for all groups, when the isokinetic protocol at 60°/s was performed. Similar results were found in the study that investigated the immediate effects of infrared energy-emitting products (socks, T-shirts, bandages) activated before the exercise tests18. However, peak torque at 60°/s is an indicator of maximal muscle strength capabilities and requires the implementation of a strength training program to enhance this type of muscular performance19. The current investigation utilized an aerobic training program in conjunction with infrared-LED illumination. Thus, it is not entirely surprising that quadriceps performance was only improved during the isokinetic evaluation at 300°/s. The combination of infrared-LED illumination and strength training may elicit different outcomes.

The improvement of muscle performance in the LED group in the current study can also be explained by thermal effects20. The cutaneous temperature at rest (33.5 ± 0.5°C) increased by 1.08 ± 0.11°C during exercise with infrared-LED illumination. However, when exercise was performed without LEDs, there was a decrease in temperature of 0.86 ± 0.15°C11.

In a study by Heinonen and colleagues21, externally delivered local heating increased muscle blood flow in the lower legs due to vasodilation and warm blood shunted from the body’s core to skin followed by a vasoconstriction response and heat release. Moreover, local heating enhanced nitric oxide release, ATP synthesis and tissue oxygen consumption21.

We therefore believe that the higher circulation induced by local thermal effects can improve oxygen supply as well as transport and utilizes metabolic substrates (such as lactic acid), mainly when phototherapy is combined with the skeletal muscle pump during physical exercise, reducing muscle fatigue and increasing maximal exercise tolerance10,20.

Similar results to those observed in the present study were obtained in animal studies as well. The effects of phototherapy, using lamp (780–1400 nm)22 and laser (655 nm)23, on the fatigue induced by a neuromuscular electrical stimulation showed an increased resistance to fatigue associated with a higher peak force and muscular work in rats. Moreover, when infrared-LED (850 nm) was applied after high-intensity resistance training in ovariectomized rats, there was an observed modulation of tumor necrosis factor (TNF-α) and interleukin-6, as well as enhanced anabolic activity by stimulating the production of insulin growth factor-1 (IGF-1), thereby increasing muscle volume. This is an important finding given the fact that muscle atrophy and reduced muscle function during aging are influenced by elevated levels of inflammatory cytokines, such as TNF-α, which may inhibit IGF-1 signaling with proliferative exhaustion of satellite cells24.

Phototherapy with strength training appears to modulate some important skeletal muscle functions in young males as well25. Microarrays showed increased gene expression of mitochondrial biogenesis (peroxisome proliferative activated receptor-co-activator 1), protein synthesis (mammalian TOR) and tissue angiogenesis (angiogenic protein vascular endothelial growth factor) as well as reduced gene expression of protein degradation (muscle ring finger) and inflammation (interleukin-1β). These results suggest improved muscle repair and better muscle performance when phototherapy is applied25.

High-intensity exercise training programs in postmenopausal women have shown beneficial effects on aerobic fitness, muscle function and bone structure26–28, as also observed in the present study. However, the fatigue experienced by the exercise group was higher compared to that experienced by the LED group and was, surprisingly, also higher compared to that of the sedentary group. We found that twice-weekly, high-intensity physical training without infrared-LED was not sufficient to reduce fatigue. According to the recommendations of the American College of Cardiology/American Heart Association, older adults should perform moderate-intensity aerobic physical activity for a minimum of 30 min, most if not all days per week or vigorous-intensity aerobic activity for a minimum of 20 min, 3 days per week12. Thus, the amount of exercise training administered in the current study could have been greater. The metabolic stress induced by the physical exercise favors the actions of phototherapy, given that its effects are enhanced when the redox state of a cell is changed29. For this reason, we chose not to include a group receiving only infrared-LED during rest, given that it appears a training stimulus is needed to facilitate the positive effects of phototherapy.

Although electromyography and muscle biopsy were not performed in the current study, differences in percentage and/or recruitment of type I and II muscle fibers may have occurred between the groups. Infrared-LED may have improved muscle bioenergetics4, mainly oxidative, with a higher percentage and/or recruitment of type I fibers that possess a higher resistance to fatigue. Moreover, although scores of pain were not evaluated, the women in the exercise group reported pain in the lower limbs and in the region of the lumbar spine during the treadmill training and isokinetic testing. At the same time, the women in the LED group reported that they were not feeling any pain. Phototherapy stimulates both anti-inflammatory30 and analgesic31 effects which can lessen pain in muscles and articulations, so that physical exercises can be performed with less hindrance, leading to an enhanced training effect. These subjective observations may also explain differences in fatigue amongst the groups. However, future studies should be performed to investigate potential mechanisms that may explain these observations as the effects of infrared radiation and physical exercise on pain, metabolic/inflammatory markers, characteristics of muscle fibers and fatigue, mainly because aging is associated with an inflammatory process and loss of motor units, resulting in atrophy and fiber type shifts, and thus resulting in increased fatigue and delayed onset muscle soreness.
The positive effects on quadriceps function observed in the sedentary group may have been influenced by an increased BMI, given that higher muscle mass/strength in the lower extremities can be precipitated by additional weight-bearing demands. It became evident that, once the independent effects of body mass were controlled (i.e. normalized data), improvements in muscle performance in the sedentary group were no longer apparent.

This study has several limitations that warrant consideration. One of the limitations is the method for assessment of body composition; we only used bipolar electrical bio-impedance, which has an inherent degree of measurement error. Future studies should explore the results of body composition using other techniques that may provide better accuracy, such as whole body composition determined by dual-energy X-ray absorptiometry (DXA). However, DXA also shows limitations, such as the fact that calculations may not be accurate for separating bone and soft tissue or for separating soft tissue into fat and lean tissue at higher body masses. Other limitations are the possible placebo effect and lack of blinding; the participants can probably assume that a new treatment will be better than a standard treatment and this may influence the results. However, blinding becomes less important in reducing observer bias, as the outcomes become less subjective, since objective (hard) outcomes leave little opportunity for bias, as gold-standard measurements. In this context, the isokinetic dynamometer is considered a gold standard for measuring muscle performance, because the angular velocity is always controlled during articular movement and the force–velocity relationship does not affect muscle torque, work production or the muscle fatigue index. Finally, the intensity applied in both training groups was based on the HR_max obtained during progressive exercise testing. Future studies should focus on intensity prescription based on the percentage of measured VO_2max or anaerobic threshold, because its accuracy could be better than the percentage of HR_max obtained.

Phototherapy is currently a common practice for physical therapy and dermatology, and the results of the current study create potentially new clinical application for phototherapy. Specifically, the current study demonstrates that phototherapy is a potentially promising complement to exercise training which may further enhance performance. Moreover, infrared radiation (e.g. 850 nm) appears to have no side-effects for the parameters employed. Therefore, marketed devices which emit infrared radiation, such as laser and LED, may be used before or after physical exercise with the intent of further increasing muscle performance in the clinical and athletic arenas.

CONCLUSION

Postmenopausal women who underwent an aerobic training program on treadmill with or without phototherapy showed an improvement in power and work of the quadriceps. However, infrared LED irradiation combined with treadmill training led to a higher increase in both quadriceps power and work. In addition, the number of contractions increased and fatiguability was only reduced in the LED group.

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