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ORIGINAL ARTICLE

Effects of photobiomodulation therapy associated with resistance training in elderly men: a randomized double-blinded placebo-controlled trial

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Abstract

Purpose The purpose of this study was to investigate the effects of photobiomodulation therapy (PBMT) combined with resistance training on knee extensors muscle mass, strength and functional capacity in elderly men.

Methods In this randomized double-blinded placebo-controlled trial, healthy elderly men (age 60–80 years) completed 12 weeks of resistance training (2×/week) with application of placebo ($n = 13$) or active PBMT ($n = 11$) on quadriceps muscles (850 nm, 240 J per limb) before each training session. Leg press and knee extension one-repetition maximum (1RM) tests, isometric and concentric peak torques, rectus femoris (RF) and vastus lateralis (VL) muscle thickness, timed up-and-go (TUG) and chair rise-to-standing (CRS) tests were performed before and after the intervention period.

Results There were significant improvements in all outcomes for both groups ($p < 0.05$), except for RF muscle thickness for the placebo group ($p = 0.09$). Large effect sizes (ES > 0.8) were observed for leg press and leg extension 1RM and CRS tests for both groups, as well as for TUG test for PBMT group. Isokinetic peak torque for both groups and TUG for placebo group had moderate increases (ES > 0.5). Muscle thicknesses and isometric peak torque had small increases (ES > 0.2) in both groups. Both null hypothesis analysis and magnitude-based inference support similar effects of PBMT and placebo treatments.

Conclusion Different than previously evidenced in young subjects, PBMT with the parameters used in this study did not provide any additional benefits in comparison to placebo application on muscle mass, strength and functional capacity of healthy elderly men engaged in a resistance training program.

Keywords Phototherapy · Low-level laser therapy · Strength training · Older

Abbreviations

1RM	One-repetition maximum
ATP	Adenosine triphosphate
CRS	Chair rise-to-standing
ICC	Intraclass correlation coefficient
J	Joules
PBMT	Photobiomodulation therapy
RF	Rectus femoris
TUG	Timed up-and-go
VL	Vastus lateralis

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Introduction

It is well known that elderly individuals present multifactorial declines in physiological functions of all body systems, including the musculoskeletal system (Ali and Garcia 2014). The ageing process is associated with decreases in the muscle quantity and quality, as well as in the neural factors related to muscle strength and power output. Consequently, older people present reduced muscle strength and limited functional capacity (Mitchell et al. 2012). Sarcopenia (i.e. the age-related phenomenon characterised by progressive loss of muscle mass and strength) has been found in up to 33% of adults with 50 years old or older living in the community (Cruz-Jentoft et al. 2014), and it is considered a key component of frailty syndrome (i.e. a clinically recognizable state of increased vulnerability resulting from ageing-associated declines in reserve and function across multiple physiologic systems) (Clegg et al. 2013). Because of the relationship between muscle mass and strength with elderly longevity (Mitchell et al. 2012), maintaining or improving muscle mass and strength of older people has become a major health concern in the last decades (Mitchell et al. 2012; Cruz-Jentoft et al. 2014).

Resistance training has been proved to counteract at least part of the ageing process (Csapo and Alegre 2016). Knee extensors conditioning status is considered a factor for physical function of older subjects (Mitchell et al. 2012), and resistance training programs in this population have been proven effective for increasing muscle thickness and maximal strength by around 10% and 40%, respectively (Csapo and Alegre 2016). These localized changes on muscle structure and strength lead to significant improvements on the elderly's systemic functional capacity, such as those measured through tests involving functional motor tasks (e.g. stair climb test, chair rise-to-standing test, 6 min walk test) (Raymond et al. 2013). Therefore, increasing attention has been devoted to strategies that are potentially capable of maximizing the adaptations promoted by resistance training in the elderly (Mitchell et al. 2012; Malafarina et al. 2013), such as nutritional supplementation (Malafarina et al. 2013) and hormonal reposition (Hildreth et al. 2013). However, there is no consensus about safety and effectiveness of these approaches to enhance the muscular response to resistance training in elderly (Mitchell et al. 2012).

Photobiomodulation therapy (PBMT) has been considered an innovative, non-invasive and non-pharmacological ergogenic approach (for a review, see Vanin et al. 2018). The absorption of light energy by specific chromophores at mitochondria lead to a series on intracellular reactions that increase the ATP production, the respiratory chain reactions, the nitric oxide synthesis and the antioxidant capacity (Karu 2010; Huang et al. 2011). Consequently, these effects are believed to be related to the increase in exercise performance and to improve post-exercise recovery (Vanin et al. 2018). In addition, studies that associated PBMT with resistance training programs have found greater muscle hypertrophy and strengthening compared to resistance training alone or combined with placebo treatment (Ferraresi et al. 2011; Baroni et al. 2015; Vanin et al. 2016). However, the PBMT positive effects have been tested almost exclusively in young and athletic populations. When applied in the older population, contradictory results have been found regarding its acute effects on muscle fatigue (Toma et al. 2013; Vassão et al. 2016), and the single study that investigated the PBMT long-term effects associated with resistance training in elderly found no advantages on strength gains compared to resistance training alone (Toma et al. 2016). Nevertheless, Toma et al. (2016) used a single probe instead of a cluster probe to irradiate the whole quadriceps muscle, and their total energy dose of 56 J is below the suggestions of the most recent systematic review for PBMT application on large muscular groups (i.e. 60–300 J) (Vanin et al. 2018). PBMT has a typical biphasic dose–response effect, and optimal treatment parameters are specific to the therapy's goals, the target tissue, and the subject/tissue status (Huang et al. 2011). Thus, further investigations are needed to elucidate whether PBMT may maximize training-induced adaptations in elderly.

The objective of the present study was to investigate the long-term effect of PBMT combined with resistance training on knee extensor muscle mass, strength and functional capacity of healthy elderly men. Our hypothesis was that volunteers receiving PBMT before each resistance training session with proven effective parameters (Baroni et al. 2015) would have a greater exercise performance during the training session (i.e. they would support heavier loads) and an optimized post-exercise recovery (i.e. they would be in a better condition for the next session) (Vanin et al. 2018) in comparison to volunteers treated with placebo. We also expected that greater mechanical work along the training program could maximize training-induced adaptations (Raymond et al. 2013; Csapo and Alegre 2016).

Methods

Study design

This study was a randomized double-blinded placebo-controlled trial. Participants were engaged in a 12-week resistance training program. Placebo or PBMT treatments were applied to their quadriceps muscles before each training session, according to the groups' allocation. Knee extensors ultrasonography, isokinetic dynamometry, one-repetition maximum (1RM) tests, and functional capacity tests were performed before and after the resistance training program. This study was approved by the University's Ethics Committee, prospectively registered at ClinicalTrials.gov (NCT03287284), and conducted according to the 1964 Helsinki Declaration and its later amendments. All individuals were informed on the procedures, benefits, and risks prior to signing an informed consent document to participate in the study. There were no changes in the methods after trial commencement.

Participants

Individuals were recruited to participate in the study through newspaper and social media advertisement. During the first visit, all volunteers were informed about the study procedures and performed a health screening. To be included in the study, participants had to be 60–80 years old, have no cardiovascular, neurological or musculoskeletal restrictions to resistance training; and, be at least 3 months without performing any systematic, regular resistance training. Participants had to also present a recent exercise electrocardiogram test reviewed by a cardiologist evidencing their capacity to perform physical exercises. If they did not present one, they were indicated to consult with the cardiologist of the university. Participants were excluded if they presented difficulties in understanding or performing tests and training exercises. As elderly men and women present specific quadriceps muscle mass and sarcopenia progression (Janssen et al. 2000), we decided to include only men to not interfere in the PBMT effects.

Sample size calculation

Sample size was calculated using the G*Power software (version 3.1.9.2) based on previous trials (Cadore et al. 2013; Van Roie et al. 2013) that determined that a sample of seven participants per group would provide a statistical power over 0.90. The outcomes used to calculate the sample size were leg press (15.2 ± 61.5 kg between groups expected change) and knee extension 1RM (7.8 ± 13.8 kg between groups expected change), as well as rectus femoris muscle thickness (0.9 ± 3.6 mm between groups expected change).

Randomization and blinding

As shown in Fig. 1, 40 men volunteered for the study. A greater number of participants than previously planned was included in the trial as we had resources to attend this high demand. Thirty-one volunteers met the inclusion/exclusion criteria and were allocated into the two experimental groups through an on-line computer randomization program: Placebo Group ($n = 16$) and PBMT Group ($n = 15$). There were seven drop outs during the training period, as shown in Fig. 1. Therefore, 24 volunteers completed the study schedule and were included in the final analyses: Placebo group ($n = 13$), and PBMT group ($n = 11$).

Concealment was guaranteed, as the researcher who applied the therapy was the only one aware of the randomization, while the researchers who were involved in the training sessions and assessments remained blinded. Because PBMT provoked no thermic or other perceptive effects and PBMT and placebo treatments followed the same application procedures, volunteers were also blinded to their allocation into PBMT or placebo groups.

Assessment procedures

Volunteers responded to the International Physical Activity Questionnaire (Benedetti et al. 2007) and were familiarized for each test before evaluation sessions. All assessments were performed twice within 3 weeks before the start of the

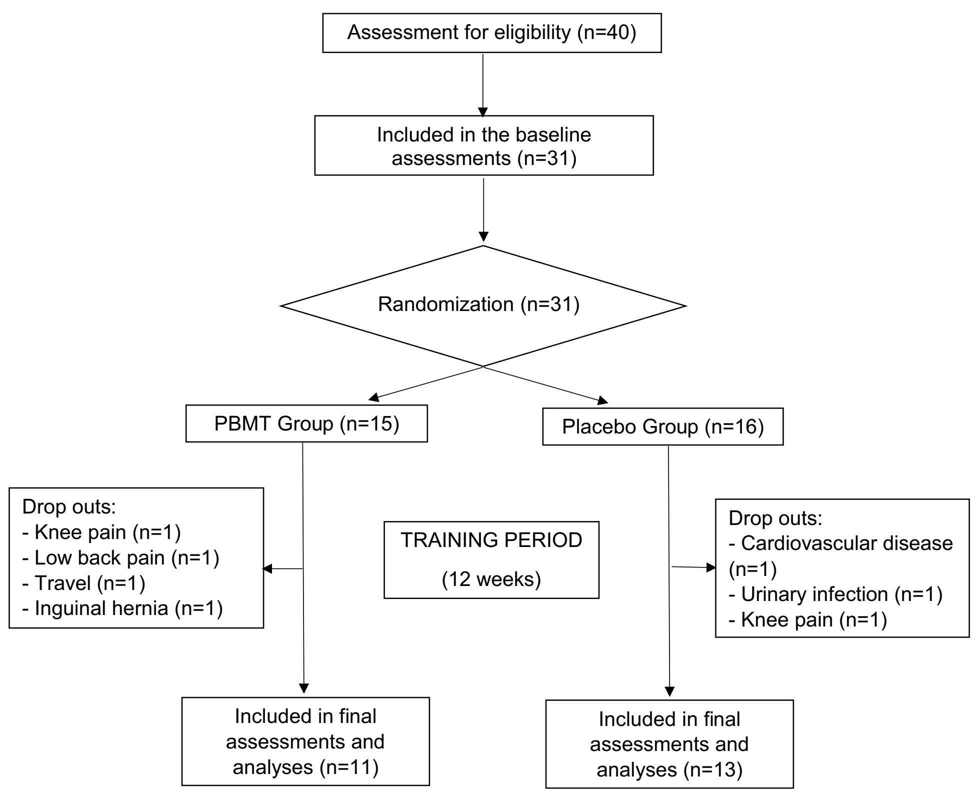


Fig. 1 Flowchart of the study

training program, and the test–retest served to assess the reliability of our measures. In addition, the evaluation protocol was divided in 2 days with a minimum 48-h interval period: day 1—ultrasound and isokinetic dynamometry; day 2–1RM and functional tests.

Ultrasonography

Muscle thickness of rectus femoris (RF) and vastus lateralis (VL) muscles was measured with the SSD 4000 ultrasound equipment (Aloka Inc., Japan) with a linear-array probe (60 mm; 7.5 MHz). Before each assessment, participants were required to rest for 10 min in the supine position with knees and hips in neutral position. The measurements were performed on the right lower limb at midway between the femur lateral condyle and the knee articular line at the thigh anterior side for RF, and at the thigh lateral side for the VL (Baroni et al. 2015). A single experienced examiner performed all ultrasound scans. To ensure that all measurements were performed at the same position, the probe position, as well as anatomical and skin references, were drawn in a transparent paper, which was used on the following evaluations. Three parallel images were taken from both RF and VL. Images were analysed in Image-J software (National Institutes of Health, USA). The superior and inferior muscle aponeuroses were identified, and the distance between them was measured at three points of each image (left border, middle, and right border). A mean value was calculated for each image and for the three images for each assessment, the last one being used for analysis (Baroni et al. 2015). The method presented high interclass correlation coefficient (ICC): 0.97 for RF thickness and 0.98 for VL thickness.

Isokinetic dynamometry

Participants were positioned seated according to the manufacturer's recommendations for knee flexion–extension assessment at the Biodex System 3 Pro equipment (Biodex Medical Systems, EUA). They performed a warm up of two sets of ten submaximal repetitions with a one-minute rest interval between sets of knee flexion–extension movements at angular velocity of 90° s^{-1}. Thereafter, individuals performed three 5-s maximal knee extensor voluntary isometric contractions at 60° of knee flexion (0° = full knee extension). If there was more than 10% difference between tests, a fourth attempt was performed. Next, subjects performed two sets of three repetitions of isokinetic concentric knee flexion–extension movements at angular velocity of 60°s^{-1} (range of motion = 90°–10°). A two-minute rest was given between each test to minimize possible fatigue effects (Baroni et al. 2015). The dynamometric tests were performed only with the right lower limb, and the highest peak torque values obtained during isometric and isokinetic concentric tests were used for statistical analyses. The tests' reliability presented ICC values of 0.92 for isometric peak torque and 0.86 for isokinetic concentric peak torque.

1RM tests

Maximal dynamic strength was assessed by the one-repetition maximum test (1RM) on bilateral leg press and knee extension exercises. Individuals walked for 10 min on a treadmill and performed the specific movements as warm up before the tests. Each subject's maximal load was determined with no more than five attempts with a 4-min recovery between tests. A 10-min recovery was respected between leg press and knee extension tests. Performance time for each contraction (concentric and eccentric) was 2 s, controlled by the researchers using an electronic metronome (Cadore et al. 2013). The movement range of motion was also controlled, so that volunteers had to reach 90°of knee and hip flexion in the 1RM leg press test as well as the maximal knee extension in the 1RM knee extension test. The tests presented high test–retest reliability (ICC 0.96 for both leg press and leg extension 1RM).

Functional tests

The Chair Rise-to-Standing (CRS) test was performed with the individuals seated in a hard-backed chair with a 43 cm height, next to the wall, with their arms across at their chest. They were requested to rise to a full standing position and return to the initial sitting position as fast as possible for five times (McCarthy et al. 2004). They performed three attempts with a 2-min interval between them, being the lower value registered for statistical analysis. The test–retest reliability presented an ICC value of 0.85.

The Timed Up-and-Go (TUG) test was performed with individuals seated in the same hard-backed chair with a 43 cm height, next to the wall, with their hands on their hips. They were requested to rise and walk as fast as possible without running until a cone positioned 3 m away and return to the initial sitting position. Timing started with the command 'go' and ended when subjects touched their back on the back of the chair (Podsiadlo and Richardson 1991). Volunteers performed three attempts, with a 2-min interval between attempts, and the lowest value was recorded for statistical analysis. The test–retest reliability ICC of the test was 0.88.

Intervention procedures

Photobiomodulation Therapy (PBMT)/Placebo

Before each training session, PBMT/placebo were applied on both lower limbs. Treatments were delivered with a cluster probe composed by five 850 nm laser diodes, each one with a 100 mW power output (Chattanooga Corp., Chattanooga, USA). Eight sites of the quadriceps muscle were defined by palpation and treated: two at vastus lateralis, three at vastus medialis, and three at rectus femoris (Fig. 2). Each site was treated for 60 s, leading to a dose of 6 J per diode, 30 J per site, and 240 J per leg (Baroni et al. 2015). The probe was held stationary in skin contact at 90° angle with light skin pressure. Placebo was applied on the same way, but with the device turned off. Participants were in the supine position, blindfolded and with headphones listening to music of their own choice to prevent clues about the active or placebo application. As soon as the application was finished, they were instructed to start their training session.

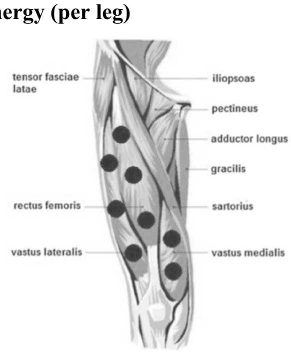
Resistance training

After the 10-min warm up on a treadmill, individuals started the resistance exercises. We standardized leg press and knee extension exercises as the first and the second exercises, respectively, for all participants in every training session to ensure a similar interval between the end of the PBMT/placebo application and the beginning of the goal exercises. After that, individuals performed other five exercises (seated supine, seated row, leg curl, abdominal curl and back extension exercises) so that they had a complete resistance training program. The periodization was performed as previously described (Cadore et al. 2013). Individuals performed two sets of 18–20 repetitions maximum (RM) during weeks 1 and 2, progressing to two sets of 15–17 RM at weeks 3 and 4, two sets of 12–14 RM in weeks 5–7, three sets of 8–10 RM in weeks 8–10 and finalizing with three sets of 6–8 RM in weeks 11 and 12. The recovery time between sets was of 90–120 s. All sets were performed until failure and the workload was constantly adjusted to keep the number of repetitions within the established interval. The load and number of repetitions performed in each exercise were recorded so that instructors could control the training of each participant and their workload. These data were used to calculate mean workload applied in each mesocycle (Fig. 3). The intervention was performed twice weekly for 12 weeks, leading to a total of 24 training sessions. The sessions were always performed on Mondays and Wednesdays afternoon, with the supervision of one experienced instructor for each volunteer, to ensure that exercises were performed correctly, within the interval of repetitions desired and until failure. It was established that if a volunteer missed one session, he could recover it on the following Friday. So, all the individuals completed all the training sessions.

Statistical analyses

Baseline characteristics (age, height, weight, and body mass index) of placebo and PBMT groups were checked for data distribution with Shapiro–Wilk test and compared through independent samples *t* test. A two-way repeated

PBMT PARAMETERS	
Number of sites (per leg)	8 sites
Treatment time (per site)	60 s
Number of diodes used (cluster probe)	5 diodes
Wavelength	850 nm
Frequency	Continuous
Spot size (per diode)	0.029 cm²
Peak power (per diode)	100 mW
Power density (per diode)	3.4 W/cm²
Energy density (per diode)	206.9 J/cm²
Energy (per diode)	6 J
Energy (per site)	30 J
Energy (per leg)	240 J



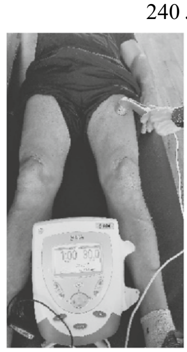


Fig. 2 Photobiomodulation therapy (PBMT) parameters

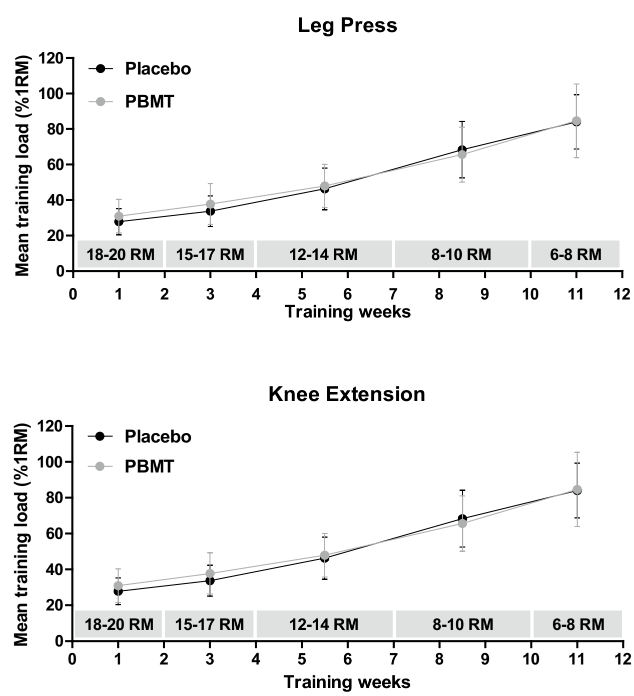


Fig. 3 Leg press and knee extension mean training load relative to baseline 1RM test on each mesocycle

measures ANOVA [group (PBMT and Placebo) × time (five mesocycles)] was applied for assessing performance along the training program (leg press and knee extension mean training load). A two-way repeated measures ANOVA [group (PBMT and Placebo) × time (pre-training and post-training)] was applied to assess the interventions' effect on each outcome related to muscle structure, strength and functional capacity. The retrospective statistical power provided by SPSS after analyses was over 0.9 in time-effect analyses of all variables with exception of isokinetic peak torque, which was of 0.83.

Data were analysed for practical significance using magnitude-based inference because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to clinicians than statistical significance (Hopkins et al. 2009). Within-group analysis included the percent change calculation (Δ% = post-training/pre-training-1), as well as the effect size (ES) calculation through the Cohen's d [ES = $(M_{post} - M_{pre})/SD_{pooled}$, where M_{post} is the mean post-training measure, M_{pre} is the mean pre-training measure, and SD_{pooled} is the pooled standard deviation of the pre- and post-measurement]. Training effects were considered as "trivial" (ES < 0.2), "small" (ES > 0.2), "moderate" (ES > 0.5) or "large" (ES > 0.8) (Cohen 1977).

The longitudinal percent changes (pre- to post-training) were used to assess the chances of a possible substantial effect favourable to placebo or PBMT groups [i.e., greater that the smallest worthwhile change (0.2 multiplied by the between-subject standard deviation)]. Quantitative chances of trivial effects and substantial effects for each group were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75% = possibly; 75–95% = likely; 95–99% = very likely; >99% = almost certain (Batterham and Hopkins 2006). When the Placebo and PBMT values were both > 5%, the inference was classified as unclear (Batterham and Hopkins 2006).

Results

There was no difference ($p > 0.05$) between placebo and PBMT groups for baseline characteristics (Table 1). Moreover, there was no between-group difference ($p > 0.05$) for the loads used along the resistance training program (Fig. 3).

There was no group-time interaction for any outcome investigated in this study (Table 2). The training programs increased VL muscle thickness in both groups with a small effect size, while RF muscle thickness achieved only trivial effect sizes. Both groups presented small and moderate effect sizes for isometric and concentric peak torques, respectively; whereas leg press 1RM, knee extension 1RM and the CRS had large effect sizes. TUG improved with a small effect size in placebo group and a moderate effect size in PBMT group.

Figure 4 presents the magnitude-based inference analyses. Unclear nuclear differences were found for all outcomes, which support similar adaptations to resistance training in placebo and PBMT groups for knee extensor muscle thickness, strength and functional capacity.

Discussion

As expected, independent of PBMT or placebo therapy, resistance training increased knee extensor thickness, maximal strength and functional capacity of elderly men. The main finding of the current study is that the addition of PBMT prior to resistance training sessions did not add any benefit to resistance training compared to the placebo therapy in older men, since both training groups showed similar enhancements in all investigated outcomes.

Resistance training programs are known to increase muscle strength and mass, as well as physical function in older adults (Raymond et al. 2013; Borde et al. 2015; Csapo and Alegre 2016). However, the training periodization (frequency, duration, training volume) and subjects' characteristics (age, sex, physical activity level) interfere directly on the magnitude of the muscular adaptations (Borde et al. 2015; Brocca et al. 2017). Comparison between studies should be made with caution, and

Table 1 Baseline characteristics of Placebo and PBMT groups

Variables	Placebo group ($n = 13$)	PBMT group ($n = 11$)	p value
Age (years)	66.67 ± 05.84	68.93 ± 07.47	> 0.05
Height (m)	01.71 ± 00.05	01.74 ± 00.06	> 0.05
Weight (kg)	76.64 ± 08.82	80.81 ± 12.24	> 0.05
Body Mass Index (kg/cm^2)	26.25 ± 02.82	26.78 ± 04.13	> 0.05
Physical activity level	75.0% active 12.5% sedentary 12.5% irregularly active	66.7% active 20.0% sedentary 13.3% irregularly active	

Table 2 Muscle structure, muscle strength and functional tests of Placebo and Photobiomodulation therapy (PBMT) groups at pre- and post-training evaluations [mean (±SD)]

	PBMT group ($n=11$)				Placebo group ($n=13$)				Group effect	Time effect	Group-time effect
	Pre	Post	Δ%	ES	Pre	Post	Δ%	ES			
Muscle structure											
RF MT (cm)	1.53 (±0.27)	1.58 (±0.28)	2.83 (±5.35)	0.19	1.54 (±0.40)	1.58 (±0.43)	2.64 (±3.64)	0.10	0.876	0.002[a]	0.118
VL MT (cm)	1.96 (±00.34)	2.10 (±0.36)	7.55 (±5.91)	0.41[b]	2.02 (±0.28)	2.15 (±0.27)	6.74 (±8.12)	0.50[b]	0.446	0.001[a]	0.887
Muscle strength											
Isom PT (Nm)	191.17 (±36.66)	201.91 (±37.64)	6.22 (±8.64)	0.27[b]	201.43 (±27.70)	214.40 (±26.87)	6.70 (±5.03)	0.48[b]	0.462	0.001[a]	0.726
Conc PT (Nm)	154.95 (±27.81)	170.45 (±28.98)	10.34 (±5.19)	0.57[c]	168.30 (±21.62)	179.69 (±19.97)	7.14 (±6.22)	0.55[c]	0.220	0.006[a]	0.866
LP 1RM (kg)	241.38 (±56.43)	332.54 (±55.18)	40.00 (±14.75)	1.63[d]	234.18 (±27.14)	326.68 (±38.69)	40.23 (±12.54)	2.81[d]	0.747	0.000[a]	0.908
KE 1RM (kg)	88.69 (±17.26)	108.77 (±19.50)	23.43 (±12.74)	1.09[d]	93.91 (±18.08)	116.82 (±23.83)	24.75 (±12.54)	1.11[d]	0.463	0.000[a]	0.532
Functional tests											
TUG (s)	6.38 (±0.86)	5.96 (±0.88)	6.59 (±5.98)	0.48[b]	6.38 (±0.54)	6.04 (±0.32)	4.59 (±6.39)	0.79[c]	0.904	0.001[a]	0.648
CRS (s)	9.23 (±1.26)	8.29 (±0.94)	9.73 (±7.50)	0.85[d]	9.78 (±0.60)	8.94 (±0.67)	8.57 (±5.68)	1.33[d]	0.121	0.000[a]	0.739

Δ% mean percent change, *ES* effect size, *RF* rectus femoris, *VL* vastus lateralis, *MT* muscle thickness, *Isom* isometric, *PT* peak torque, *Isoc* isokinetic, *LP* leg press, *1RM* one-repetition maximum, *KE* knee extension, *TUG* timed up-and-go, *CRS* chair rise to standing

[a]Significant difference ($p<0.05$)

[b]Small effect size (>0.2)

[c]Moderate effect size (>0.5)

[d]Large effect size (>0.8)

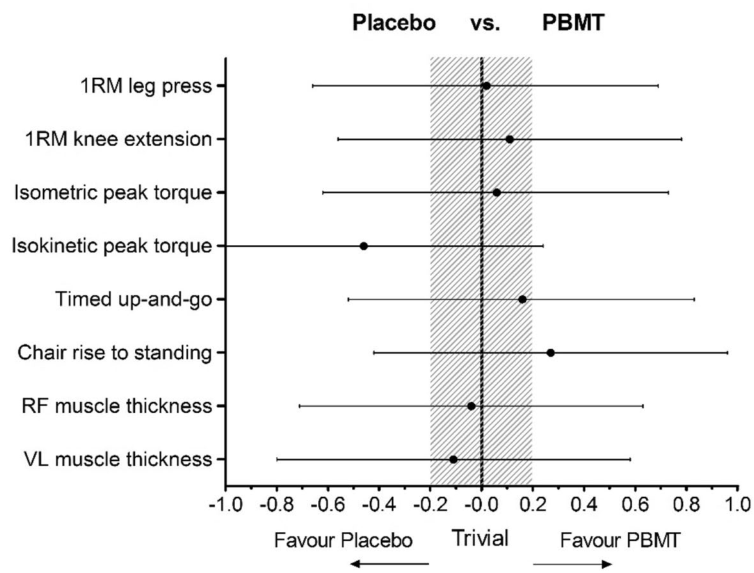


Fig. 4 Standardized mean differences and 95% CI for PBMT effect compared to placebo effect (forest plot); quantitative chances of substantial effects for placebo group, trivial effects, and substantial effects for PBMT group, as well as the magnitude-based inference (right column)

should always involve trials with similar study population and periodization (Borde et al. 2015; Brocca et al. 2017). Therefore, the adaptations magnitude of the current study should not be directly compared to previous studies that associated resistance training and PBMT in young men (Ferraresi et al. 2011, 2016; Baroni et al. 2015; Vanin et al. 2016) and elderly women (Toma et al. 2016) due to the participants' different training periodization, age and/or sex.

Changes on VL muscle thickness found in our study (6–7%) are similar to the ones previously reported with the elderly population (Lixandrão et al. 2016; Csapo and Alegre 2016). The current study did not assess neuromuscular adaptations, but this is a typical response to resistance training and partially explains the larger relative increases found in 1RM tests compared to those observed in muscle thickness (Häkkinen et al. 2000). The improvements found in leg press and knee extension 1RM (40% and 23–24%, respectively) are similar to those reported by studies that used the same resistance training periodization in elderly men (Cadore et al. 2012, 2013), as well as the increments found in isometric and isokinetic peak torques (6% and 7–10%, respectively) (Cadore et al. 2013; Van Roie et al. 2013). The smaller gains assessed by isokinetic dynamometry may be due to training specificity; isokinetic exercises were not performed along the training program and there is no full transference of training-induced strength gains to these tests (Issurin 2013). Similarly, the increments in the CRS and TUG tests (9% and 4–6%, respectively) are also in agreement with previous trials (Van Roie et al. 2013; Dias et al. 2015; Tiggemann et al. 2016); it represents a training transfer to functionality, since the leg press and knee extension exercises led to an improvement in untrained functional tasks (Issurin 2013).

Studies with young men have demonstrated that PBMT maximizes the strength gain and the hypertrophic response to resistance training (Ferraresi et al. 2011; Baroni et al. 2015; Vanin et al. 2016). Authors have justified the positive effects of PBMT mainly through the acute effects of PBMT, such as reduced muscle fatigue, enhanced exercise performance and optimized post-exercise recovery (Ferraresi et al. 2011; Baroni et al. 2015; Vanin et al. 2016). Evidence from resistance training studies and other previous investigations (see Vanin et al. 2018) supported our initial hypothesis that the PBMT group should have enhanced exercise performance during training sessions, leading to higher muscle mechanical work. We also expected a better between-training session's recovery for the PBMT group, contributing to a higher performance in the following training day compared to the placebo group. Consequently, we expected that the PBMT group would have faster increments in training load than the placebo group. However, training load progression was similar between PBMT and placebo groups (see Fig. 3). These findings refuted our initial hypothesis of PBMT acting as an ergogenic factor for elderly subjects engaged in a resistance training program.

It is important to note that almost all evidences supporting the ergogenic action of PBMT on human performance were provided by studies with young adults (Vanin et al. 2018). Interestingly, trials involving older subjects have presented inconsistent results. While Toma et al. (2013) found an increase in the number of repetitions for the knee extension exercise after PBMT application, Vassão et al. (2016) found no effect of its prior application on isokinetic exercise performance. At the same time, the only study so far with resistance training associated with PBMT in the elderly found no additional benefits of this therapy compared to placebo application (Toma et al. 2016), which is further supported by our findings. Even though the exercise protocols and the PBMT parameters differed among the trials, it is not clear why PBMT seems to work for young but not for elderly individuals.

Elderly usually have thicker subcutaneous fat layer and greater content of intramuscular fat and connective tissues compared to young adults (Hogrel et al. 2015), which possibly impair the light energy absorption in older subjects. Furthermore, mitochondrial function presents deficits with age and it has been considered as a potential mediator of sarcopenia (Carter et al. 2015). Aged muscles present mitochondria with less organelle content, reduced layer thickness, enzymes (being cytochrome oxidase one of them) and function, including protein synthesis, respiration and ATP production (Carter et al. 2015). Therefore, if there are less enzymes to absorb the light photons, its energy may be lost leading to no clinical effect. Following this rationale, it seems plausible that frail elderly subjects (i.e. individuals with poorer health status and greater sarcopenia) would have even lower capacity to absorb light energy; but our study cannot confirm or refute this hypothesis because we investigated only healthy elderly. Interestingly, PBMT does not seem to improve the exercise performance of patients with cardiovascular diseases (Bublitz et al. 2016; Stein et al. 2018), a population that also presents reduced mitochondrial activity and sarcopenia (Marzetti et al. 2013). However, the present study did not investigate the mechanism of action of PBMT in the elderly.

PBMT presents a typical biphasic dose–response effect (Huang et al. 2011), and there is still no consensus about the ideal parameters to optimize adaptations to resistance training in any population. Therefore, although the parameters used in our study have been proven effective in young subjects (Baroni et al. 2015), we cannot exclude the possibility that a different dosage may be needed to optimize training responses in older subjects. In fact, a few studies analysed the dose–response effect of PBMT in young subjects and found contradictory results (Aver Vanin et al. 2016; Lanferdini et al. 2018; Dellagrana et al. 2018). The application of dosages of 270 J and 300 J were the most effective ones for increasing performance outcomes of recreational runners during running tests (Dellagrana et al. 2018) and soccer players during isokinetic tests (Aver Vanin et al. 2016), respectively. However, only the application of 135 J, and not 270 J or 405 J, improved the exercise performance of cycling athletes in incremental tests until exhaustion (Lanferdini et al. 2018). It remains unclear if the exercise protocol, the sample characteristics and/or the other PBMT parameters were responsible for that specific dose–response effect. Different dosages with different PBMT parameters need to be tested to provide the best parameters for each population and exercise protocol before conclusions can be drawn.

It is important to note that only healthy men around 68 years old were engaged in the current study, thus results should not be extrapolated to elderly subjects with poorer health status or even older women. To the best of our knowledge, there are only a few previous studies that investigated the effects of PBMT in muscular performance of the elderly population (Toma et al. 2013, 2016; Vassão et al. 2016) and only one of them investigated the long-term effects of the therapy (Toma et al. 2016). Therefore, to allow a broader view on the effects of PBMT on resistance training responses in elderly and increase the external validity of the results, we recommend future studies should: assess older subjects of both genders and with different health status; apply training programmes longer than 12 weeks; apply PBMT treatments with different parameters; include subjective measures of effort and recovery between sessions; and add a control group (without training) to determine the normal course of outcomes over the intervention period.

Conclusions

The current study did not find any additional effect of PBMT with the tested parameters compared to placebo treatment combined with resistance training on knee extensor muscle mass, strength and functional performance of elderly men. Given the potential benefits of PBMT on the fight against sarcopenia and its deleterious effects, as well as the characteristic dose–response effect of PBMT, scientists are encouraged to perform further investigations on that issue.

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