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Original Research

Effect of a multimodal exercise training program on sleep in older adults: a randomized controlled trial

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ABSTRACT

Introduction: Improvement in sleep quality in older adults has been observed after aerobic, resistance, and combined (aerobic and resistance) training; however, little is known about multimodal exercise training, a combination of modalities that aims to improve functional capabilities in this population. *Purpose*: To investigate the effect of a multimodal exercise training program on sleep in older adults.

Methods: Thirty-two participants (70.1 ± 5.7 years; 29.9 ± 4.9 kg/m^2) were randomly assigned to multimodal exercise training or control groups in a 2:1 ratio, stratified by sex and age. Progressive training was carried out 3x/week, with each session lasting 45 to 60 minutes. Sleep was evaluated using Actigraphy for 7 consecutive days. All evaluations were performed by a blinded assessor.

Results: All evaluations were performed by a blinded assessor. After 16 weeks, the exercise group showed a significant within-group reduction in sleep latency (mean difference [MD] = −3.4 min; 95% confidence interval [CI]: −6.6, −0.2). In between-group comparisons, the multimodal exercise training group demonstrated significantly better outcomes than the control group, including improved sleep efficiency (MD = 6.6%; 95% CI: 1.8, 11.4) and reduced wake after sleep onset (WASO) (MD = −33.2 min; 95% CI: −65.9, −0.5) and sleep fragmentation (MD = −8.0; 95% CI: −15.6, −0.6). Intervention adherence was 90%. ***Conclusion***: Multimodal exercise training was effective in improving sleep in older adults, representing a promising strategy for this population due to its low cost and high participant adherence.

Introduction

Aging refers to the continuous, multifactorial decline in physiological functions and to increased vulnerability and mortality.[1,2] This cellular senescence predisposes the onset of chronic diseases. [3–5] and negative impacts on sleep. [6–8] Poor sleep quality, such as difficulty falling asleep, difficulty staying asleep, early morning awakenings, or daytime sleepiness, has been reported more frequently in older adults than in younger adults. [7]

Sleep regulation is conceptualized as a dynamic interaction among homeostatic and circadian processes, neuroendocrine pathways, and behavioral factors. According to the seminal Two-Process Model of Sleep Regulation, sleep propensity is governed by the accumulation of sleep pressure (Process S) and the synchronization of circadian rhythms (Process C) with environmental zeitgebers. Aging disrupts both processes, resulting in impaired sleep continuity and reduced sleep efficiency. [7,9]

Several strategies have been investigated to improve sleep, including regular physical exercise.[10–13] For more than two decades, studies have shown that physical exercise improves sleep in older people.[14,15] It is a low-cost therapy that improves sleep in middle-aged and older adults, especially those with sleep problems.[16] As a non-photic zeitgeber, exercise influences sleep by increasing the homeostatic drive for sleep, stabilizing circadian oscillators, and modulating thermoregulatory and neuroendocrine responses. These mechanisms are likely to improve sleep through regular and systematic exercise therapy. From a theoretical perspective, multimodal exercise may provide a broader systemic stimulus by engaging multiple regulatory mechanisms simultaneously,

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thereby potentially optimizing sleep outcomes in older adults.[17,18]

Among the types of physical exercise, aerobic training,[13] dynamic muscular resistance training,[19] and the combination of these modalities,[11] have been effective in improving sleep efficiency, reducing sleep latency and sleep fragmentation, and increasing total sleep time. [13,20,21]

Recent systematic reviews and meta-analyses have examined the effects of physical exercise on sleep quality in older adults, with a primary focus on traditional protocols combining aerobic and resistance training.[22] However, despite evidence from recent meta-analyses of these conventional combined training approaches, a notable gap remains regarding the effects of multimodal exercise programs that integrate the development of multiple physical capacities (e.g., strength, agility, balance, and coordination) and motor skills within a single, structured intervention. This integrative, functional approach may elicit distinct physiological adaptations beyond those observed with traditional exercise modalities, thereby warranting further investigation.[23] Moreover, multimodal exercise may offer superior functional and physiological benefits,[24,25] potentially inducing unique adaptations that influence sleep regulation mechanisms. To date, evidence examining the effects of multimodal exercise interventions on sleep parameters measured by actigraphy remains limited and inconclusive.

Accordingly, the present study was designed to address this gap by evaluating whether a structured, multimodal exercise training program could improve sleep quality in older adults. It was hypothesized that this training modality would increase sleep efficiency and reduce wake after sleep onset (WASO), sleep latency, and sleep fragmentation.

Methods

Characterization of the study

Randomized and controlled clinical trial, longitudinal with a parallel group, which followed the recommendation of the Consolidated Standards of Reporting Trials (CONSORT 2010). This study was approved by the Local Ethics Committee (protocol number: 5.505.112) and was registered on the Brazilian Clinical Trials Registry platform (RBR-6zpc65f).

Casuistry and eligibility criteria

Men and women aged $\geq$ 60 years with a BMI $\leq$ 34.9kg/m^2 were included. Smokers, those with a diagnosis of chronic lung disease or sleep disorders, being on drug therapy to initiate or maintain sleep, and having osteomioarticular involvement that made it impossible to carry out the physical exercise protocol were excluded. To begin physical training, the older adults were required to present a medical certificate. Any older people who missed more than 30% of physical training sessions, or who started another physical intervention or drug therapy that influences sleep, were discontinued from the study.

Randomization, allocation concealment, blinding, and intention-to-treat analysis

Randomization was stratified to ratio 2:1 by sex and age. After the older adults were categorized into their strata by sex, they were allocated to the multimodal exercise training or control groups. Randomization was performed by an independent researcher who was not involved in recruitment, intervention, or evaluation. Allocation was kept confidential by using opaque envelopes opened by an independent researcher at study initiation. The actimetry records were also renamed by a researcher collaborating with the study to allow blind assessment of sleep and statistical analysis. In cases of withdrawal or inability to continue in the study, an intention-to-treat analysis was used. Participants were not informed about the specific hypothesis regarding the effects of exercise on sleep. They were told only that the study aimed to assess general health parameters in response to a physical activity program. This strategy was adopted to minimize performance bias by reducing expectations about sleep outcomes.

Study design

Participants were recruited through non-probability convenience sampling via social networks and in public squares in the city of João Pessoa, PB. After inclusion, participants were evaluated and subsequently randomized to the multimodal exercise training or control groups. After the older adults were allocated to the experimental groups, they performed their respective interventions. Outcome assessments were conducted in the week prior to the start of the experimental protocol and up to two weeks after its completion (Fig. 1, panel A).

Intervention

The multimodal exercise training protocol followed the recommendations of the American College of Sports Medicine Guidelines [26] for FITT and was designed for older people according to Silva-Grigoletto and Resende-Neto (2019). This protocol consists of movement patterns that improve the physical capabilities of resistance, strength, speed, and flexibility, and motor skills such as agility, coordination, power, and balance, as well as cognitive tasks. The training program followed the structure of working on posture, mobility, and stability, as well as improving aerobic endurance in the first month. In the first two weeks of the second month, aerobic resistance was prioritized, and in the following weeks, exercises to develop muscular strength. In the third month, especially in the first two weeks, exercises were included to improve strength in the lower and upper limbs, and in the subsequent two weeks, the focus shifted to improving agility and speed. In the final month of training, the aim was to develop agility, speed, and power. Training progressed every month to provide adequate stimuli and consistent gains. The training session lasted 40-60 minutes (Fig. 1, panel B). All participants underwent moderate-intensity training, which was constantly monitored using the Borg Scale. [27] One professional delivered the training to each group of five participants. All exercise sessions were conducted under the direct supervision of certified physical education professionals to ensure strict adherence to the prescribed protocol. Prior to the intervention, the research team participated in a standardization meeting to align the structure, execution, and progression criteria of the multimodal program.[25,26] The complete multimodal training protocol is provided in the supplementary material (Appendix A). Additionally, biweekly calibration meetings were held throughout the intervention to monitor fidelity, address operational issues, and reinforce consistency across sessions and participants. For four months, the older adults in the control group were not exposed to the systematized exercise protocol, but at the end of this period, they were invited to carry out the same training offered to the multimodal exercise training group.

Measures and procedures

Sleep evaluation. Participants wore a WGT3-X accelerometer (Actigraph, model WGT3-X, Florida) on the non-dominant wrist for seven consecutive days and nights. These data were collected at 60 Hz, in 60-second epochs, and analyzed using the Cole–Kripke algorithm. Sleep start times were recorded by each participant in an individual diary and later manually entered into the manufacturer's software (Actilife, version 6.13.3).a[28–30] Sleep latency, total sleep time (TST), time wake after sleep onset (WASO), total time in bed (TTB), sleep efficiency, and nighttime awakenings were analyzed. Sleep latency, TST, TTB, and WASO are presented in minutes, sleep efficiency as a percentage value, and nighttime awakenings as the number of occurrences. This instrument demonstrates a high level of agreement with polysomnography for key sleep parameters, including sleep efficiency and wake after sleep onset and WASO.[31,32]

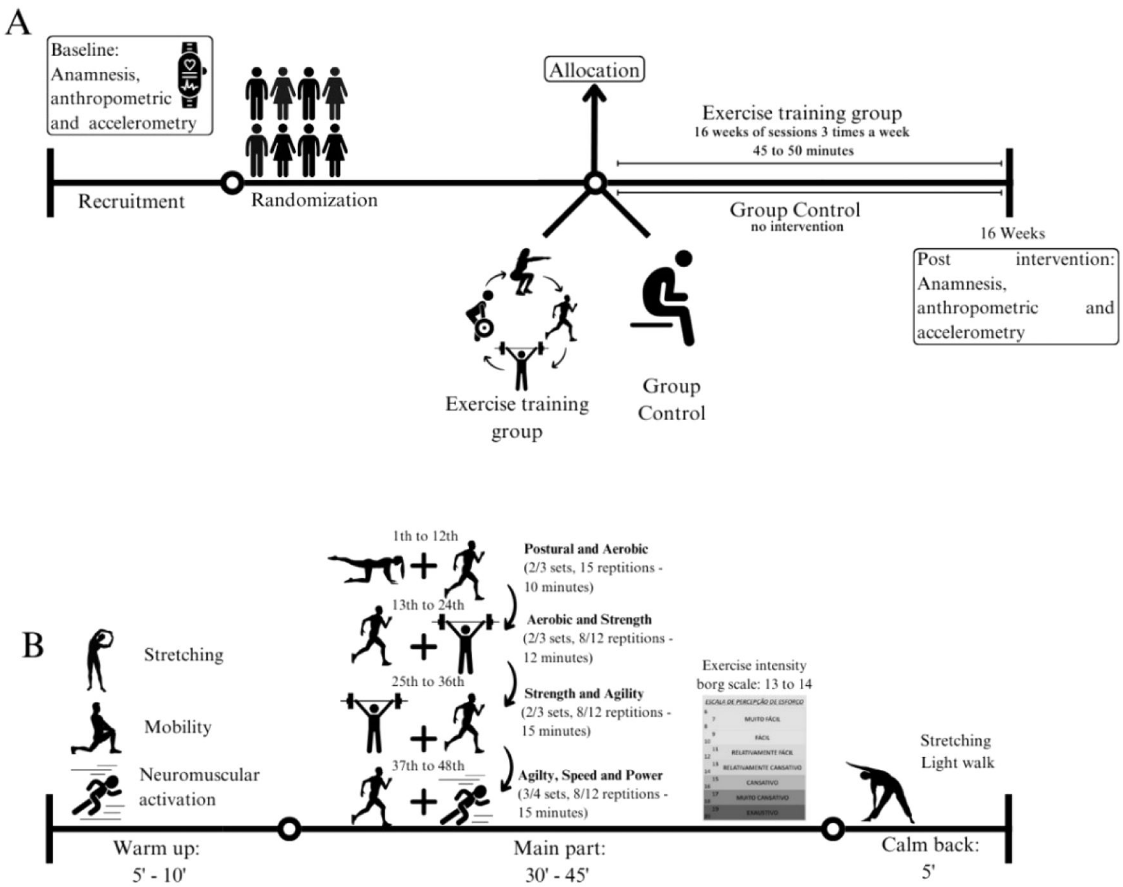

Fig. 1. Study design (panel A) and multimodal exercise training protocol (panel B).

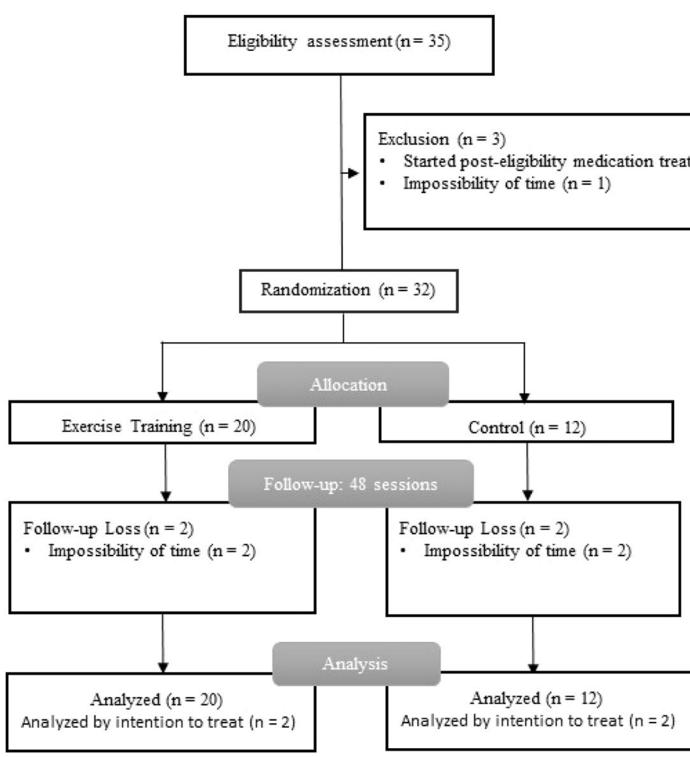

Fig. 2. Flowchart of the study.

Statistical analysis

The sample size was calculated using sleep duration as the outcome variable[33] with G*Power 3.1.9.2 software (Heinrich-Heine-Universitat Dusseldorf, Germany), assuming an error probability of 0.05 and a sampling power of 0.80. Based on these parameters, a minimum sample size of 28 participants was estimated, with 19 older people in the multimodal exercise training group and 9 in the control group. Statistical Package for the Social Sciences (SPSS, version 25.0) and GraphPad Prism (version 8.0) were used for data analysis. Outcomes were assessed using intention-to-treat (ITT) and per-protocol (PP) analyses, with missing data in the ITT analysis imputed using the maximum likelihood method. Data are reported as means and standard deviations, absolute and relative frequencies (%), mean differences, and 95% confidence intervals. The characteristics of the older adults were assessed using the Mann-Whitney U test and Fisher's Exact test (sex and comorbidities). Intervention adherence was calculated as the percentage of the 48 offered sessions completed by each participant ([sessions completed/48] x 100). Generalized Estimating Equations were used to analyze sleep outcomes across groups (Exercise training versus Control) and time points (pre versus post-intervention), with analyses adjusted for sex and age. Linear and gamma models were used to analyze parametric and non-parametric data, respectively. Pairwise comparisons were made using the Bonferroni post hoc test. A significance level of $p < 0.05$ was considered.

Results

Of the 35 older adults who initially met the eligibility criteria, three were excluded, and 32 were randomly allocated to the exercise training and control groups (Fig. 2). All participants completed 90% of the training sessions, and 15 participants completed 48 sessions.

Table 1 presents the characteristics of the older adults in the exercise training and control groups, showing similar characteristics and presence of comorbidities.

The adjusted ITT and PP analyses of sleep parameters are presented in Table 2. In the ITT analysis, post-intervention outcomes in the training group were compared with those in the control group. The training group demonstrated lower wake after sleep onset (WASO) (mean difference [MD] = −34.1 min; 95% confidence interval [CI]: −67.8, −0.4) and reduced sleep fragmentation (MD = −8.0; 95% CI: −15.6, −0.6), as well as greater sleep efficiency (MD = 6.8%; 95% CI: 1.9, 11.7), compared with the control group. Within-group analyses showed that older adults in the exercise training group experienced a reduction in sleep latency (MD = −3.4 min; 95% CI: −6.6, −0.2). No statistically significant differences were observed in the control group.

Table 1
Characteristics of the older adults.

	All	Exercise Training	Control
N	32	20	12
Age, years	70.1±5.7	70.1±6.1	70.1±5.3
Sex M/F, n	7/25	4/16	3/9
Weight, Kg	70.8±12.8	70.2±14.0	71.9±11.3
BMI, kg/m^2	29.2±4.9	28.8±5.6	29.9±3.6
WHR, cm	0.95±0.06	0.94±0.06	0.98±0.07
Accelerometer time, min	7874±1037	7529±1259	8450±668
Comorbidities, n (%)			
Obesity	11 (34)	6 (30)	5 (41)
Diabetes Mellitus	16 (50)	10 (50)	6 (50)
Hypertension	25 (78)	14 (70)	11 (91)
Pharmacological Therapy, n (%)			
ARA	22 (68)	11 (55)	11 (91)
Thiazide diuretics	6 (18)	3 (15)	3 (25)
ACE	22 (68)	11 (55)	11 (91)
ACC	1 (3)	1 (5)	0 (0)
β-blockers	5 (15)	5 (25)	0 (0)
Biguanides	8 (25)	4 (20)	4 (33)
Sulfonylureas	10 (31)	7 (35)	3 (25)
SGLT-2 inhibitors	2 (6)	2 (10)	0 (0)

M/F, male/female; n, number of participants; WHR, Waist-hip ratio; BMI, Body mass index; ARA, Angiotensin receptor antagonist; ACE, Angiotensin-converting enzyme inhibitor; ACC, Calcium channel antagonists; β-blockers, Beta-adrenergic blockers; SGLT-2, sodium-glucose cotransporter-2.

Discussion

The current study analyzed the effects of 48 sessions of a multimodal exercise training program on sleep in older adults. The findings provide evidence of reduced sleep latency after training, increased sleep efficiency, and decreased WASO, average nighttime awakenings, and sleep fragmentation in the analysis between groups.

Participation in a physical training program had moderately positive effects on sleep quality in middle-aged and older adults. [34] In this way, physical exercise could be an alternative or complementary approach to other interventions to improve sleep in older adults, such as sleep hygiene, adjustments in dietary patterns and/or quality, and cognitive/-behavioral therapy.[10,35–37] The training program adopted in this study comprises a differentiated, combined exercise strategy using multimodal training, which improves various physical capabilities and motor skills, especially muscular strength and aerobic capacity. A previous study reported that a mild-to-moderate intensity of multimodal physical exercise, performed regularly for 6 months, can attenuate sleep disturbances in patients with a clinical diagnosis of Alzheimer's disease or Parkinson's disease.[38] Although this study used subjective sleep assessment in patients with chronic progressive and neurodegenerative processes that are most prevalent in the aging population, it suggests that multimodal training may help improve sleep.

In the current study, we used actigraphy for seven days to assess sleep and identified significant improvements in WASO, sleep efficiency, and fragmentation after exercise training. Similar results on WASO and sleep efficiency were observed by, [39] evaluating older adults who performed combined training and Tai-chi, 3 times a week for 12 weeks.

Similar to aerobic training, combined exercise training aims to improve cardiopulmonary conditioning, and these adjustments led to improvements in both sleep quality and sleep parameters assessed by actigraphy. [11,40] A study by Bornard et al.[10], which subjected older adults to 12 weeks of aerobic training, found improvements in both sleep efficiency and sleep fragmentation. Similar results were observed in older adults with poor sleep quality, who performed aerobic training for 12 weeks. The authors found improvements in sleep quality, along with reduced sleep latency and increased sleep efficiency.[40] In the same sense, aerobic training carried out in the aquatic environment also provided an increase in sleep efficiency and a reduction in sleep latency in the older population. [41]

Different from these findings, in a non-randomized trial,[42] which investigated the effects of 12 months of aerobic training in older adults, did not find significant improvements in sleep. The authors argued that the likely cause of these results was due to the participants being healthy and without the presence of or a history of sleep problems, while other studies included older participants who were institutionalized[43] and likely to demonstrate altered sleep patterns.[44] In the current randomized controlled trial, although the older adults did not undergo polysomnography and were not diagnosed with any sleep disorder, they did not present sleep complaints and did not take medications to help them sleep, which suggests that they had adequate sleep for the age range investigated (sleep efficiency >80%, and latency less than 12 minutes). Despite this, the proposed training improved the sleep of the older adults evaluated.

Similar to our study, other trials have evaluated the effect of moderate-intensity aerobic training on sleep in older adults and have verified beneficial effects.[39–41] In this sense, with the purpose of evaluating the effect of training intensity and volume, for 3 months, on sleep outcomes in people aged between 55 and 75 years, the authors in this

Table 2
Sleep parameters using actigraphy in older adults in the exercise training and control groups.

ITT Analysis							
	Exercise training			Control			
	Baseline	Post-intervention	MD (95% CI)	Baseline	Post-intervention	MD (95%CI)	MD_between-groups comparisons ($post_{exercise}$ - $post_{control}$)
Sleep Latency, min	6.6±4.6	3.1±3.1	-3.4 (-6.6, -0.2)	11.6±7.8	6.8±7.2	-4.8 (-10.9, 1.3)	-3.6 (-8.3, 1.0)
Sleep Efficiency, %	84.4±6.6	87.8±3.3	3.5 (-0.3, 7.3)	80.6±5.6	81.2±6.1	0.7 (-5.0, 6.5)	6.8 (1.9, 11.7)
TTB, min	453.6 ±56.1	430.6±59.8	-23.0 (-51.0, 5.0)	455.5 ±80.1	467.2±99.3	11.6 (-20.9, 44.1)	-37.6 (-117.2, 42.0)
TST, min	381.1 ±54.1	378.3±56.5	-3.0 (-28.0, 22.0)	366.4 ±65.5	378.3±62.7	11.9 (-22.3, 46.1)	-0.2 (-57.2, 56.7)
WASO, min	65.7±31.2	49.1±16.4	-15.2 (-31.4, 1.0)	77.5±30.9	82.3±43.0	7.4 (-26.5, 41.2)	-34.1 (-67.8, -0.4)
Number of awakenings, n	13.3±4.4	12.5±4.4	-0.8 (-2.9, 1.4)	17.0±6.0	16.4±6.8	-0.5 (-4.9, 3.9)	-3.9 (-9.4, 1.6)
Average awakenings	5.7±4.3	4.1±1.0	-1.4 (-3.6, 0.8)	4.6±1.2	5.0±1.1	0.5 (-0.6, 1.5)	-0.9 (-2.0, 0.1)
Sleep Fragmentation	30.7±8.6	26.7±6.8	-4.0 (-8.8, 0.9)	33.6±10.4	34.8±8.8	1.2 (-6.9, 9.3)	-8.2 (-15.9, -0.6)
PP Analysis							
	Exercise training			Control			
	Baseline	Post-intervention	MD (95% CI)	Baseline	Post-intervention	MD (95% CI)	MD_between-groups comparisons ($post_{exercise}$ - $post_{control}$)
Sleep Latency, min	6.6±4.8	3.2±3.2	-3.4 (-6.9, 1.7)	12.9±7.8	7.7±7.6	-4.1 (-11.8, 3.7)	-4.3 (-9.2, 0.6)
Sleep Efficiency, %	84.1±6.9	87.6±3.3	3.5 (-0.7, 7.7)	80.8±6.1	80.1±6.0	-0.6 (-7.0, 5.8)	7.8 (2.5, 13.0)
TTB, min	456.8 ±56.5	433.2±62.2	-23.6 (-54.8, 7.5)	476.8 ±63.2	490.7±86.9	13.8 (-25.2, 52.9)	-60.3 (-138.5, 17.9)
TST, min	383.0 ±55.6	378.9±59.6	-4,1 (-31.4, 23.2)	384.7 ±51.4	392.7±56.1	8.0 (-32.2, 48.2)	-14.6 (-71.4, 42.1)
WASO, min	67.1±32.4	51.0±15.8	-14,5 (-32.2, 3.3)	79.1±32.5	90.1±41.4	14.7 (-24.3, 53.7)	-41.6 (-77.7, -5.5)
Number of awakenings, n	13.3±4.6	12.8±4.4	-0.6 (-2.9, 1.8)	18.0±5.9	17.8±6.3	-0.2 (-5.2, 4.9)	-5.1 (-10.9, 0.7)
Average awakenings	5.8±4.5	4.1±1.0	-1.7 (-4.2, 0.9)	4.3±1.2	5.1±1.2	0.8 (-0.1, 1.7)	-1.1 (-2.3, 0.0)
Sleep Fragmentation	30.6±8.9	27.2±6.9	-3.4 (-8.6, 1.8)	33.6±11.4	36.5±8.2	2.9 (1.7, 17.7)	-9.7 (-17.7, 1.7)

ITT, Intention-to-treat analysis; PP, Per-protocol analysis; MD, Mean difference; CI, Confidence interval; TTB: Total time in bed, TST: Total sleep time, WASO: Time awake after sleep onset, ND: Number of awakenings, MD: Average number of awakenings.

pilot study did not observe significant changes in sleep assessed by actigraphy, [45] These findings were probably influenced by the characteristics of the population assessed, since the participants had chronic insomnia and depressive symptoms, in addition to the small number of subjects assessed. On the other hand, subjective sleep quality improved after 12 weeks, both in the group that performed moderate or vigorous walking three times a week (3.25 METs, 150 minutes per week) and in the group that performed vigorous-intensity walking once a week (6.5 METs, 75 minutes per week). [45] This result is probably due to the greater energy expenditure observed in groups that trained with greater intensity or volume, which may have impacted energy conservation and tissue restoration during sleep, [13,46] providing a better perception of sleep quality.

In the current study, the training protocol also aimed to improve muscular strength and endurance; in this regard, previous studies have shown gains in muscular endurance in older adults, providing relevant findings on sleep. [47–49] Most studies verified a favorable effect of muscular resistance training on sleep quality, assessed by subjective instruments, [47,48,50] and few studies have shown results through actigraphy. A randomized clinical trial with moderate intensity (65–70% 1RM), showed that after 12 weeks of training, older adults presented an improvement in sleep efficiency and reduced sleep fragmentation, as quantified by WASO.[19]

Despite observed improvements in several sleep parameters, no significant changes were found in total sleep time (TST) or total time in bed (TTB) following multimodal exercise training. This may be explained by the fact that both TST and TTB were already within the normal range for healthy older adults at baseline, suggesting a potential ceiling effect.[37,51] In addition, TST and TTB are influenced by individual behavioral patterns, lifestyle habits, and chronotype, which can vary substantially among older adults and are less likely to be modified solely through exercise interventions.[52] Therefore, future studies incorporating subjective sleep measures alongside actigraphy, and controlling for or stratifying by chronotype and behavioral profiles, may help clarify the conditions under which exercise interventions influence these parameters.

Although multimodal exercise training appears to have a positive impact on sleep in this group, the underlying mechanisms are not yet fully understood. As this randomized controlled trial was not designed to evaluate these specific mechanisms, it is reasonable to assume that the effects may be similar to those observed in aerobic training programmes.[13] These effects may occur through adjustments in hormone secretion, as brain-derived neurotrophic factor (BDNF) appears to play an important role in shaping sleep architecture, particularly by influencing the depth and quality of slow-wave sleep—a critical stage for brain restoration and physical recovery. Evidence suggests that exercise-induced increases in BDNF may improve sleep by supporting circadian rhythm regulation and reducing hypothalamic–pituitary–adrenal axis activity. This reduction in stress-related physiological arousal may create more favourable conditions for sleep initiation and maintenance. Notably, slow-wave sleep has been associated with greater sleep efficiency, partly due to shorter sleep latency and reduced nocturnal wake time.[13,53,54] Furthermore, exercise-induced circadian modulation involves synchronized adjustments in core body temperature, hormone secretion, and neurotransmitter dynamics, contributing to more consolidated sleep architecture and fewer nocturnal awakenings.[13,53]

The main limitation of the current study is the small number of older people, but we reached the minimum sample size indicated by the sample calculation, with a power of 85% and an effect size of 0.40. The majority of participants were female, and women experience greater sleep disruption.[55] It is worth noting that the results were adjusted for sex, and no significant difference was observed between the groups; however, the results must be analyzed with caution and cannot be extrapolated to older males. Another limitation of this study was the absence of polysomnography, which remains the gold standard for sleep assessment. Instead, actimetry was used as a valid and objective measure that has demonstrated high accuracy, sensitivity, and specificity compared with polysomnography for the sleep outcomes assessed. However, subjective sleep measures, such as the Pittsburgh Sleep Quality Index (PSQI), were not included, limiting insight into participants' perceived sleep quality. It is also important to note that increased physical activity may lead to behavioral improvements, including enhanced mood, reduced anxiety, and a more consistent daily routine, which can contribute to improved sleep even in the absence of direct physiological changes. Mental or psychological conditions were not assessed in the present study, preventing further examination of these relationships. Due to the nature of the intervention, participants and intervention staff could not be blinded to exercise training. Nevertheless, participant allocation, outcome assessment, and statistical analyses were conducted by blinded personnel to minimize bias.

The current study presents relevant points for this older population: a) we obtained a high adherence rate to the training protocol, in which 90% of participants completed the training protocol, and of these, 85% participated in all training sessions; the sleep assessment was objectively verified by actigraphy for 7 days, which demonstrates the reliability of the data.

Conclusion

This study demonstrated the effectiveness of multimodal exercise training in improving sleep efficiency and reducing WASO, sleep latency, and sleep fragmentation in older adults. The training protocol also demonstrated high adherence, indicating that it can be implemented as a practical, feasible strategy to improve sleep quality in this population. However, future research should include larger and more diverse groups, longer follow-up periods, and additional assessments to evaluate participants' subjective perceptions of sleep.

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Declaration of Competing Interest

The authors declare no competing interest.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.bjpt.2026.101602.

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