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Exercise training improves sleep quality: A randomized controlled trial

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Abstract

Background: Exercise holds promise as a non-pharmacological intervention for the improvement of sleep quality. Therefore, this study investigates the effects of different training modalities on sleep quality parameters.

Material & methods: A total of 69 (52.7% women) middle-aged sedentary adults were randomized to (a) control group, (b) physical activity recommendation from the World Health Organization, (c) high-intensity interval training (HIIT) and (d) high-intensity interval training group adding whole-body electromyostimulation training (HIITEMS). Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) scale and accelerometers.

Results: All intervention groups showed a lower PSQI global score (all $P < .022$). HIIT-EMS group improved all accelerometer parameters, with higher total sleep time and sleep efficiency, and lower wake after sleep onset (all $P < .016$). No differences were found between groups in any sleep quality parameter.

Conclusion: In conclusion, exercise training induced an improvement in subjective sleep quality in sedentary middleaged adults. Moreover, HIIT-EMS training showed an improvement in objective sleep quality parameters (total sleep time, sleep efficiency and wake after sleep onset) after 12 weeks of exercise intervention. The changes observed in the HIIT-EMS group were not statistically different to the other exercise modalities.

KEYWORDS

concurrent training, high-intensity interval training, sleep quality, sleep quantity, whole-body electromyostimulation

1 | INTRODUCTION

Sleep is an essential physiological process with important recovery functions.[1] Notable quantitative and qualitative changes in sleep occur with age.[1] There is growing evidence pointing out a reduction in the duration of sleep concomitantly with an increase in the prevalence of sleep disorders as age increases.[2] Sleep disorders have a negative influence on mental and physical health and decreasing quality of life, which increases healthcare costs.[3] As examples, sleep disorders seem to increase the risk of depression/anxiety, cardiovascular disease, stroke and overall mortality.[4]

Several interventions have been proposed to attenuate the prevalence and/or consequences of age-associated sleep disorders including pharmacological agents,[5] chronotherapy,[6]

Castillo and Amaro-Gahete equally contributed to this work.

stimulus control therapy,[6] relaxation therapy,[6] dietary advice[7] and physical exercise.[3] Previous studies have reported that non-pharmacological interventions are as effective as pharmacological interventions[3] without accounting with the pharmacological-related negative effects.[4] In this sense, a bidirectional relationship between physical activity and sleep has been suggested.[8] Therefore, exercise holds promise as a non-pharmacological intervention for adults with poor quality or disordered sleep.[8]

A previous systematic review reported that exercise training provides a positive effect on sleep quality by decreasing sleep latency and the use of sleep medication in middle-aged and older adults.[3] Moderate-intensity exercise (both aerobic and resistance-based trainings) has shown positive effects on sleep quality in middle-aged and young adults.[9,10] A systematic review conducted by Yang et al[3] observed that the participation in an exercise training programme (moderate-intensity aerobic exercise or resistance exercise) had positive effects on sleep quality in middle-aged and older adults.

The high-intensity interval training has risen as a novel training modality in the last years, but its influence on sleep quality has not been extensively studied. However, there are not enough studies that investigated the effects of the high-intensity interval training on sleep quality parameters. A new training tendency, sometimes coupled to high-intensity training, is whole-body electromyostimulation, a training methodology which stimulates between 14 and 18 regions or between 8 and 12 different muscle groups up to 2.800 cm^2 electrode area.[11] However, little is known about its effects on physiological parameters.[11]

To our knowledge, there are no studies that evaluate the effects of those two novel training methods such as high-intensity interval training and whole-body electromyostimulation on sleep quality and quantity in sedentary middle-aged adults. Moreover, there is a lack of studies that compare the influence of different exercise training programmes (ie concurrent training [combination of endurance and resistance training] vs high-intensity interval training vs high-intensity interval training adding whole-body electromyostimulation) on sleep quality and quantity in sedentary middle-aged adults. Therefore, this study aimed to evaluate the effects of different exercise training programmes (ie (a) a concurrent training based on physical activity recommendations from the World Health Organization group [PAR], (b) a high-intensity interval training group [HIIT] and (c) a high-intensity interval training group adding whole-body electromyostimulation group [HIIT-EMS]) on sleep quality and quantity parameters in sedentary middle-aged adults. We hypothesize that all exercise training programmes will improve sleep quality and quantity parameters with higher improvements in the HIIT-EMS group. We also aimed to study which covariates could explain changes observed in sleep quality and quantity parameters.

2 | METHODS

2.1 | Participants

Eighty middle-aged adults (40 women, 40 men), aged 45-65 years, were enrolled in the FIT-AGEING study, an exercise-based randomized controlled trial (clinicaltrial.gov: ID: NCT03334357).[11] The participants were recruited from the province of Granada (Spain) using social networks, local media and posters. Interested individuals were screened via telephone and/or e-mail. Inclusion criteria were to report being sedentary (ie <20 minutes of moderate-intensity physical activity on 3 d/wk over the last 3 months), and to have a stable weight over the last 6 months. All participants reported to be free of disease, pregnant or lactating women, to not take any medication and/or not presence of a major illness that would limit the ability to perform the training programme. The study was approved by the Ethics Committee on Human Research at the University of Granada and "Servicio Andaluz de Salud" (CEI-Granada) [0838-N-2017], and all participants signed an informed consent. The study protocol and experimental design were applied in accordance with the last revised ethical guidelines of the Declaration of Helsinki. All of the baseline and follow-up examinations were performed at the same setting (Instituto Mixto Universitario Deporte y Salud [iMUDS] at the University of Granada).

2.2 | Study design

A 12-week randomized controlled trial was conducted with a parallel group design following the CONSORT (Consolidated Standards of Reporting Trials) guidelines[12] (Table S1). The study was performed between the months of September and December of 2016 and 2017. After the baseline examination, participants were randomized using a computer-generated simple randomization[13] to four different groups: (a) control group (no exercise), (b) PAR group, (c) HIIT group and (d) HIIT-EMS group. The participant's randomization assignment was blinded to the assessment staff. All participants were requested to maintain their habitual dietary habits. Individuals assigned to the control group were also requested not to change their physical activity habits or to engage in any kind of physical training programme. Individuals in the exercise groups were instructed to not perform additional exercise to their intervention programmes.

2.3 | Training modalities

To maximize transparency and replicability, the exercise programme described in this manuscript follows the

Consensus on Exercise Reporting Template (CERT; Table S2).[14] Reporting of the study conforms to CONSORT-revised statement along with references to CONSORT-revised statement and the broader EQUATOR guidelines.[15] A detailed description of each training modality can be found elsewhere.[11]

Participants in the PAR group performed a concurrent training based on the minimum physical activity recommended by the World Health Organization.[16] PAR group frequency was 3 d/wk. The training volume was 150 min/wk at 60%-65% of the heart rate reserve for the endurance training and ~60 min/wk, at a 40%-50% of one-repetition maximum for the resistant training. The exercises programmed for the endurance training section were treadmill, cycle ergometer and elliptical ergometer. And, weight-bearing and guided pneumatic machines were used in resistance training section (ie squat, bench press, dead lift or lateral pull down).

High-intensity interval training group did an intervention programme characterized by short and intermittent efforts of vigorous activity, interspersed with resting periods at passive or low-intensity exercises. Participants in the HIIT group trained two sessions/week performing two different complementary protocols[17]: (a) high-intensity interval training with long intervals (type A session) and (b) high-intensity interval training with short intervals (type B session). The training volume was 40-65 min/wk at >95% of the maximum oxygen uptake in type A session, and >120% of the maximum oxygen uptake in type B session. Treadmill with a personalized slope was chosen for type A session and eight weight-bearing exercises in circuit form (ie squat, dead lift, high knees up, high heels up, push up, horizontal row, lateral plank and frontal plank) for type B session.

High-intensity interval training group adding whole-body electromyostimulation group performed a training programme that followed the same structure as HIIT (volume, intensity, training frequency, type of exercise, and training sessions) with the addition of electrical impulses. Bipolar, symmetrical and rectangular electric pulse was applied with (a) a frequency of 15-20 Hz in type A sessions, and 35-75 hertz in type B sessions; (b) an intensity of 100 mA in type A sessions, and 80 milliamps in type B sessions; (c) an impulse breadth of 200-400 μsec; and (d) a duty cycle (ratio of on-time to the total cycle time: % duty cycle = 100/[total time/on-time]) of 99% in type A sessions, and 50%-63% in type B sessions. A whole-body electromyostimulation device manufactured by Wiemspro® was used.

All sessions started with a dynamic standardized warm-up that included general mobility exercises and ended with a cooling-down protocol (active global stretching), which alternated five posterior chain exercises with five anterior chain exercises.[11] Each training group followed a gradual progression in order to control the exercise dose.[11] All training sessions were performed in group supervised by a graduate in sport sciences. The training sessions took place in an airy, well-lighted and well-equipped gym of the iMUDS at the University of Granada (Spain). The starting level was individualized in each training group. All training modalities were delivered as planned. There were no changes in trial outcomes after the trial commencement.

Attendance at the training sessions was registered daily, and participants were contacted upon any missing session to ask for the reason and motivate them to replace it on an alternative session. There were no home-based or non-exercise components within this intervention. The study was ended when the training intervention programme was finished.

A graduate in sport sciences provided general advice to the control group through an information meeting. They were instructed to maintain their lifestyle and to not partake in any training programme during the time of the study.

2.4 | Sleep quality and quantity assessment

The sleep quality and quantity were assessed before (September) and after (December) the training programme (week 12) using the Pittsburgh Sleep Quality Index (PSQI) scale[18] and accelerometer-based estimates (see below).

The PSQI is a self-report tool which consists of 19-item scale that provides seven component scores (ranges 0-3): (a) subjective sleep quality (very good to very bad), (b) sleep latency (≤15 to >60 minutes), (c) sleep duration (≥7 to <5 hours), (d) sleep efficiency (≥85% to <65% hours sleep/hours in bed), (e) sleep disturbances (not during the past month to ≥3 times per week), (f) use of sleeping medications (none to ≥3 times a week), and (g) daytime dysfunction (not a problem to a very big problem), with a total global score ranging from 0 to 21.[18] A PSQI global score higher than 5 indicates poor sleep quality.[18]

Objective characteristics of sleep-wake cycles were monitored with a wrist-worn accelerometer (ActiSleep, ActiGraph) for 7 consecutive days (24 h/d).[11] Participants received detailed information on how to wear the accelerometer and were asked to remove it only for water activities. They also recorded the times they went to bed every night, woke up every morning and removed the device every day. The accelerometers used an epoch length of 5 seconds and a frequency rate of 100 Hz to store raw accelerations.[19] The raw accelerations were exported in ".csv" format using ActiLife v. 6.13.3 software (ActiGraph) and processed using the GGIR package (v. 1.6-0, https://cran.r-project.org/web/packages/GGIR/index.html)[20] in R (v. 3.1.2, https://www.cran.r-project.org/). We derived the Euclidean Norm Minus One G (ENMO) as $\sqrt{(x^2 + y^2 + z^2)} - 1G$ (where 1G ~9.8 m/s^2) with negative values rounded to zero to describe physical activity and accelerometer's z angle to describe sleep patterns. We used a previously published

algorithm combining data from the accelerometers and diary reports to detect sleep period time.[21,22] According to this algorithm, sleep was defined as any period of sustained inactivity, in which there was minimal changes in the arm angle (ie as much 5 degrees for 5 minutes periods), during a period recorded as sleep by the participant in their diary reports.[21] The following variables were analysed: total sleep time (minutes slept between bedtime and wake time), sleep efficiency (percentage of time asleep while in bed) and wake after sleep onset (minutes awake between sleep onset and wake time). To note that only the participants wearing the accelerometers for ≥16 h/d during at least 4 days (including at least 1 weekend day) were included in the analyses.[19]

2.5 | Covariates

We assessed anthropometric and body composition through dual-energy X-ray absorptiometry. Cardiorespiratory fitness was assessed through a maximum treadmill exercise test following the modified Balke protocol,[23] and a digital hand dynamometer was used to assess hand grip strength. We collected blood samples and measured somatotropin levels (see Appendix S1 for more information).

2.6 | Statistical analysis

The sample size and power calculations are made based on the data of a randomized control trial (The FIT-AGEING project[11]; clinicaltrial.gov: ID: NCT03334357). The principal aim of the FIT-AGEING study was to determine the effect of different training modalities on physiological parameters (ie body composition and sleep quality and quantity among others) in sedentary healthy adults. The determination of the sample size and power of the study were made based on the data of a pilot sample (n = 30). We considered different physiological parameter (ie body composition and sleep quality and quantity among others) differences between pre- and post-treatment in order to assess the sample size requirements for the one-way analysis of variance. As a result, we expect to detect a clinically relevant effect size of each variable considering a type I error of 0.05 with a statistical power of 0.85. To meet these criteria, a minimum of 14 participants per group were necessary. Assuming a maximum loss at follow-up of 25%, we decided to recruit 20 participants (≈50% women) for each study group. Therefore, a total of ~80 participants (≈40 women and ≈40 men) were enrolled in FIT-AGEING study. There were no interim analyses during the study.

Shapiro-Wilk test, visual check of histograms, and Q-Q plots were used to verify the distribution of all variables. Descriptive characteristics of the sample are reported as mean and standard deviation.

We conducted an analysis of variance to determine differences in all variables between groups at the baseline.

Repeated-measures analysis of variance was used to determine changes in PSQI global score, total sleep time, sleep efficiency, wake after sleep onset and PSQI sub-scores across time, between groups and its interaction (time × group). Student's *t* tests for paired values were performed to evaluate differences in dependent variables before and after the intervention programme.

We found sex interaction in total sleep time outcome; hence, we repeated the previous analyses segmented by sex.

Analysis of covariance (ANCOVA) was used to examine the effect of groups (fixed factor) on sleep quality and quantity parameters changes, that is post-PSQI global score minus pre-PSQI global score (dependent variable), adjusting for baseline values. The same analyses were performed for changes in total sleep time, sleep efficiency, wake after sleep onset and PSQI sub-scores.

All analyses were adjusted by sex, age, and sex and age. We performed Bonferroni post hoc tests with adjustment for multiple comparisons to determine differences between all exercise modality groups.

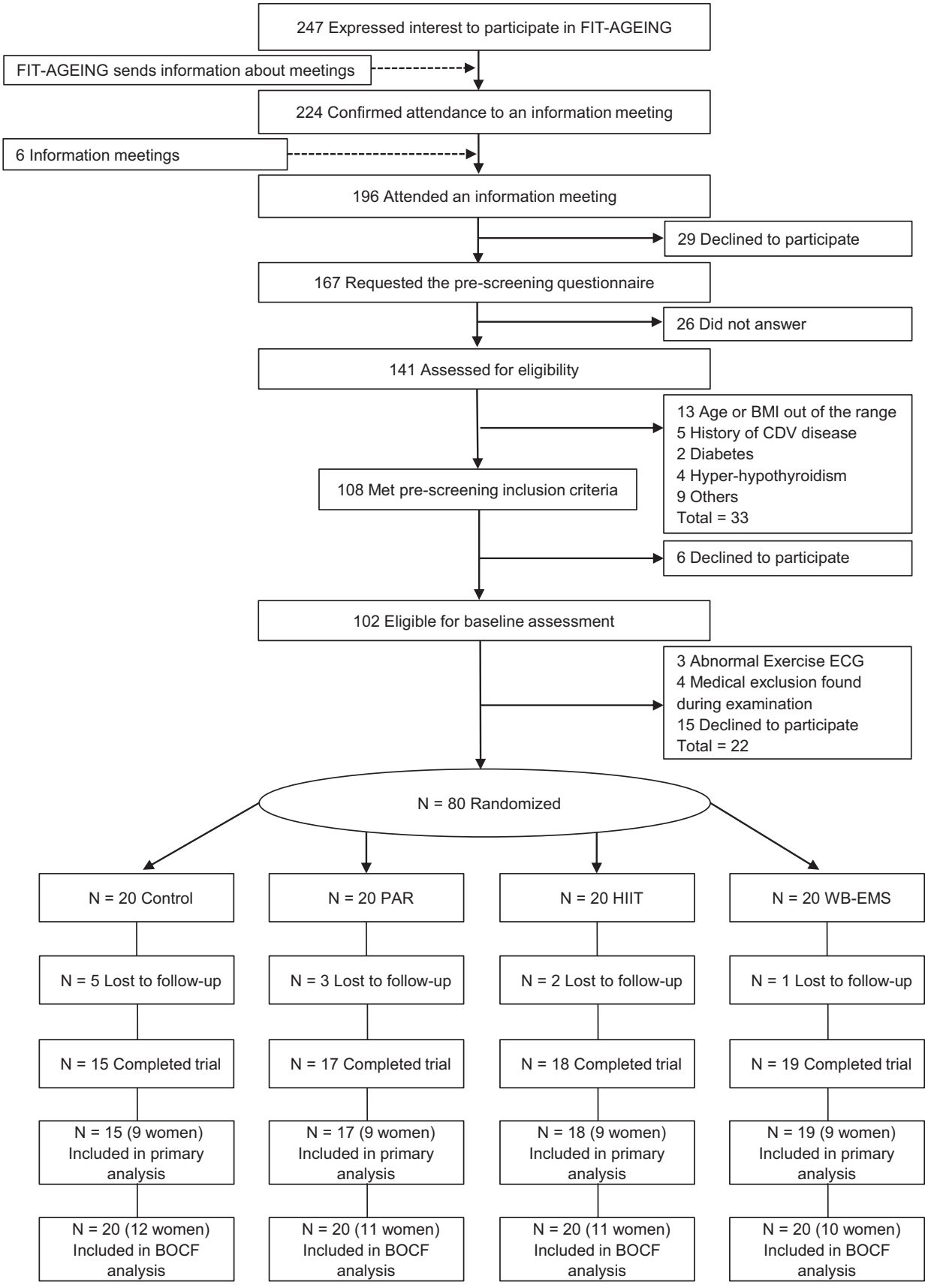
We conducted linear regression analysis to examine the relationship between changes in sleep variables (PSQI global score, total sleep time, sleep efficiency and wake after sleep onset) and changes in body composition variables (body mass index, lean mass, lean mass index, fat mass, fat mass index, bone mineral density), physical fitness (VO_2 max., VO_2 max., relative and total hand grip) and somatotropin levels, and we conducted simple linear regressions.

Considering that we aimed at assessing efficacy, we conducted a primary analyses per-protocol, in which we excluded participants who did not finish the intervention programme and/or did not reach a minimum of 70% of attendance. To check the robustness of our results, we performed the following sensitivity analysis: baseline carried forward (BOCF) imputation.

All analyses were conducted using the Statistical Package for Social Sciences (SPSS, v. 25.0, IBM SPSS Statistics, IBM Corporation), and the level of significance was set at <.05. Graphical presentations were prepared using GraphPad Prism 5 (GraphPad Software).

FIGURE 1 Flow chart diagram. BMI, body mass index; BOCF, baseline observation carried forward imputation; CDV, cardiovascular; ECG, electrocardiogram; HIIT, high-intensity interval training group; HIIT-EMS, high-intensity interval training group adding whole-body electromyostimulation group; PAR, physical activity recommendations for adults proposed by the World Health Organization group

Captation flow:
The FIT-AGEING study



3 | RESULTS

The flow chart of the current study is presented in Figure 1. Eleven participants were lost at follow-up (control group: 5; PAR: 3; HIIT: 2; HIIT-EMS: 1). Data from PSQI were missed in six participants. A total of 63 participants were included in the analysis for PSQI and 69 for objective sleep outcomes.

Table 1 shows the participant's baseline characteristics. We only observed differences among groups in the component 7 of the PSQI questionnaire. No differences were observed in the remaining variables. Participants attended to 98.7% of their exercise sessions. There were no adverse events occurring during the exercise sessions.

Figure 2 shows PSQI global score (Figure 2A), total sleep time (Figure 2B), sleep efficiency (Figure 2C) and wake after sleep onset (Figure 2D) before and after the intervention study. When comparing within-group changes, all intervention groups showed a lower PSQI global score in the final measurement compared to the baseline (4.81 ± 3.85 vs 3.06 ± 2.57, $P = .013$; 5.47 ± 3.74 vs 3.53 ± 2.53, $P = .003$; 5.56 ± 2.73 vs 3.44 ± 2.58, $P = .022$; for PAR, HIIT and HIIT-EMS, respectively), while no differences were observed in the control group. HIIT-EMS group showed significantly higher total sleep time (338.21 ± 47.97 vs 388.83 ± 37.16 minutes, $P = .004$), higher sleep efficiency (82.66 ± 6.83% vs 87.98 ± 3.76%, $P = .004$) and lower wake after sleep onset (72.03 ± 30.82 vs 54.46 ± 19.39 minutes, $P = .016$) after the intervention programme compared to the baseline, while no significant differences were found in the control group, PAR group and HIIT group after the intervention programme (all $P > .084$). Time × group interaction was found in total sleep time ($P = .047$), sleep efficiency ($P = .017$) and wake after sleep onset ($P = .027$).

Figure 3 shows changes in PSQI global score (Figure 3A), total sleep time (Figure 3B), sleep efficiency (Figure 3C) and wake after sleep onset (Figure 3D) after the intervention study among the four groups. No statistically significant intergroup differences were observed in these variables when we performed the post hoc analyses (all $P > .096$; Figure 3), neither controlling by sex nor age (all $P > .053$; Table 2).

TABLE 1 Descriptive characteristics of the sample

	N	All (n = 69)	Control (n = 15)	PAR (n = 17)	HIIT (n = 18)	HIIT-EMS (n = 19)	*P*
Age (y)	69	53.4 ± 5.0	51.7 ± 4.1	54.9 ± 4.5	53.1 ± 5.6	53.4 ± 5.4	.716
Sex (%)							
Men	33	47.8	40.0	47.1	50.0	52.6	.881
Women	36	52.2	60.0	52.9	50.0	47.4	
Body composition parameters							
Body mass index (kg/m^2)	69	26.8 ± 3.8	26.7 ± 3.9	25.4 ± 2.9	26.4 ± 3.1	28.1 ± 4.7	.063
Lean mass index (kg/m^2)	69	15.4 ± 2.8	15.9 ± 3.1	15.2 ± 2.5	14.9 ± 2.9	16.0 ± 2.9	.775
Fat mass index (kg/m^2)	69	10.7 ± 3.1	10.1 ± 2.7	9.6 ± 2.7	10.8 ± 2.7	11.3 ± 3.4	.151
Sleep parameters							
PSQI global score	63	5.5 ± 3.5	6.5 ± 4.0	4.8 ± 3.9	5.5 ± 3.7	5.5 ± 2.7	.500
Subjective sleep quality (Component 1)	63	1.13 ± 0.83	1.08 ± 0.95	0.81 ± 0.83	1.35 ± 0.86	1.24 ± 0.66	.266
Sleep latency (Component 2)	63	1.03 ± 0.86	1.15 ± 0.80	0.88 ± 0.72	0.94 ± 0.97	1.18 ± 0.95	.461
Sleep duration (Component 3)	63	0.98 ± 0.77	1.08 ± 0.76	0.94 ± 0.85	0.88 ± 0.78	1.06 ± 0.75	.884
Sleep efficiency (Component 4)	63	0.56 ± 0.95	0.46 ± 0.78	0.56 ± 1.03	0.65 ± 1.11	0.53 ± 0.87	.979
Sleep disturbances (Component 5)	63	1.13 ± 0.42	1.15 ± 0.38	1.00 ± 0.52	1.18 ± 0.39	1.18 ± 0.39	.557
Use sleeping medications (Component 6)	63	0.32 ± 0.78	0.85 ± 1.28	0.31 ± 0.79	0.06 ± 0.24	0.18 ± 0.39	.070
Daytime dysfunction (Component 7)	63	0.37 ± 0.55	0.69 ± 0.63	0.31 ± 0.48	0.41 ± 0.62	0.12 ± 0.33	.036
Total sleep time (min)	69	360.1 ± 49.0	369.0 ± 56.8	362.3 ± 45.9	366.7 ± 47.6	344.8 ± 46.8	.452
Sleep efficiency (%)	69	85.1 ± 6.2	85.5 ± 6.0	84.4 ± 6.9	87.2 ± 4.9	83.6 ± 6.7	.330
Wake after sleep onset (min)	69	62.9 ± 26.5	61.9 ± 25.9	67.8 ± 29.6	53.2 ± 19.1	68.4 ± 29.4	.309

Note: Data are shown as means ± standard deviation or percentages. *P* value of analysis of variance between groups.

Abbreviations: HIIT, high-intensity interval training group; HIIT-EMS, high-intensity interval training group adding whole-body electromyostimulation group; PAR, physical activity recommendations for adults proposed by the World Health Organization group; PSQI, Pittsburgh Sleep Quality Index.

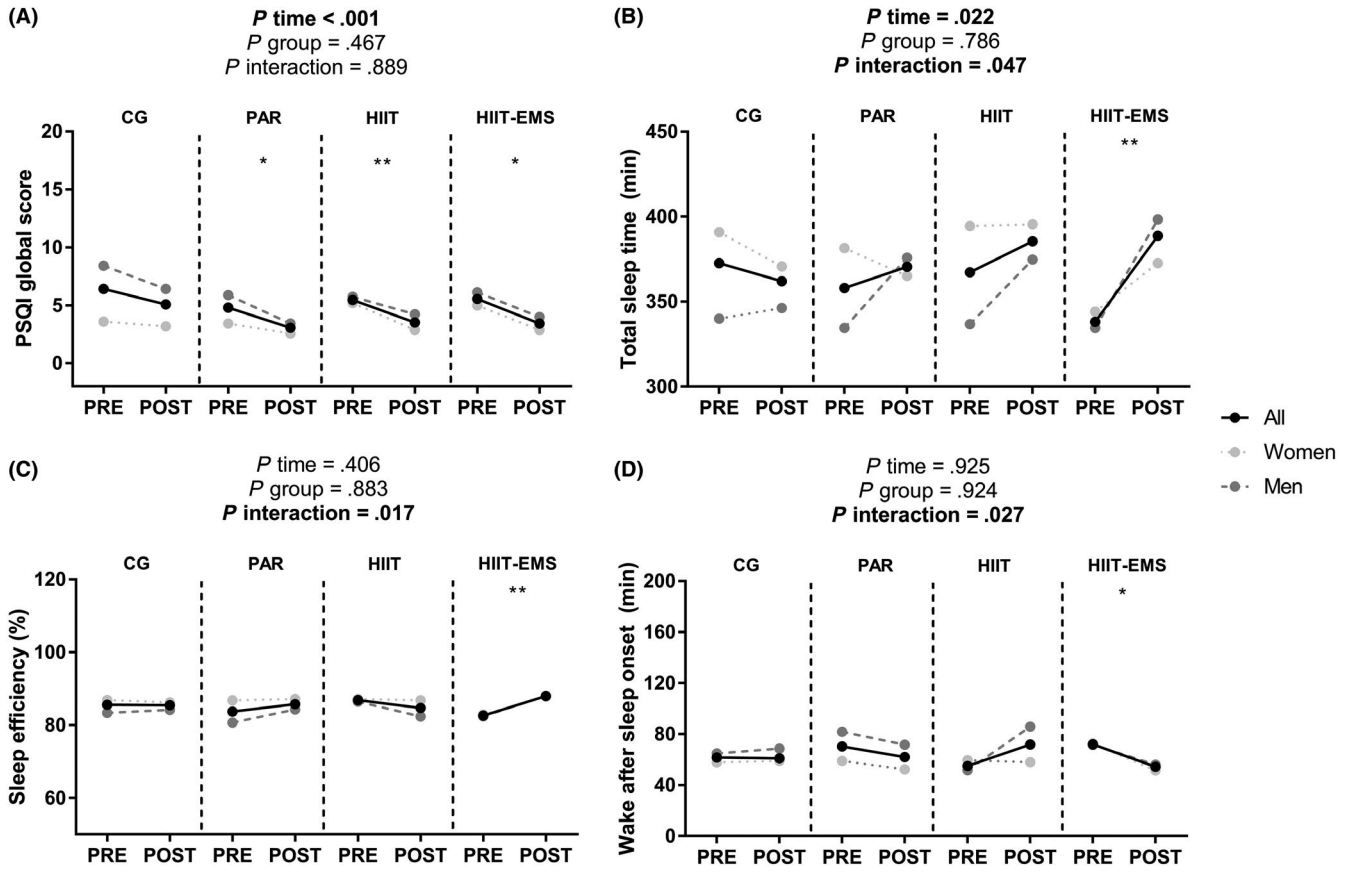


FIGURE 2 Sleep parameters before and after the intervention study. *P* value (time, group, and interaction [time × group]) of repeated-measures analysis of variance. $^{*}P < .05$, $^{**}P < .01$, Student's paired *t* test. Data are shown as means ± standard deviation. HIIT, high-intensity interval training group; HIIT-EMS, high-intensity interval training group adding whole-body electromyostimulation group; PAR, physical activity recommendations for adults proposed by the World Health Organization group; PSQI, Pittsburgh Sleep Quality Index

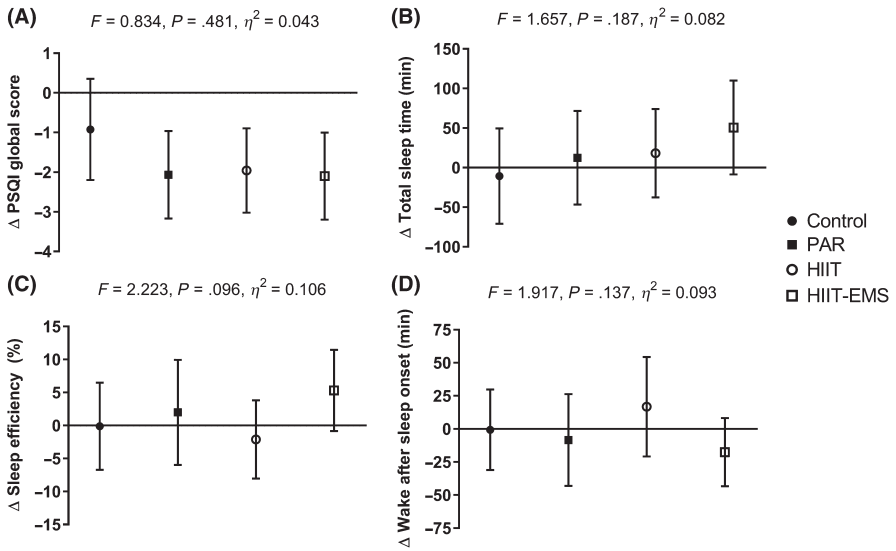


FIGURE 3 Changes in sleep parameters after the intervention study among the four groups. Data are shown as means ± 95% confidence interval. HIIT, high-intensity interval training group; HIIT-EMS, high-intensity interval training group adding whole-body electromyostimulation group; PAR, physical activity recommendations for adults proposed by the World Health Organization group; PSQI, Pittsburgh Sleep Quality Index

When we included both sex and age in the model, sleep efficiency becomes significant ($F = 2.828$, $P = .047$, $\eta^2 = .138$; Table 2), whereas no statistically significant differences were observed in the remaining variables (all $P > .070$; Table 2). All previous results persisted when we included changes in LMI and FMI in the model (data not shown). There were no pairwise differences among groups in PSQI global score, total sleep time, sleep efficiency and wake after sleep onset (all $P > .05$).

High-intensity interval training group significantly decreased subjective sleep quality component score in the final measurement compared to the baseline ($P = .007$; Table S3).

TABLE 2 Changes in sleep parameters adjusted for sex, age and sex and age

	F	*P* value	η^2
PSQI global score			
Model 1	0.825	.486	.043
Model 2	1.254	.299	.064
Model 3	1.231	.307	.064
Total sleep time (min)			
Model 1	1.516	.221	.076
Model 2	1.581	.204	.079
Model 3	1.467	.234	.075
Sleep efficiency (%)			
Model 1	2.623	.060	.127
Model 2	2.724	.053	.131
Model 3	**2.828**	**.047**	**.138**
Wake after sleep onset (min)			
Model 1	2.283	.089	.111
Model 2	2.205	.098	.107
Model 3	2.494	.070	.122

Note: P values (< .05) are in bold.

Model 1, baseline and sex; Model 2, baseline and age; Model 3, baseline, sex and age.

PAR group significantly decreased sleep latency component score in the final measurement compared to the baseline ($P = .007$; Table S3). All groups significantly decreased sleep duration component score in the final measurement compared to the baseline ($P = .025$; $P = .023$; $P = .002$; $P = .001$ for control group; PAR group; HIIT group and HIIT-EMS group, respectively; Table S3). No time × group interaction was found in any PSQI component score (all $P > .391$; Table S3).

No statistically significant intergroup differences were observed in all PSQI components scores when we performed the post hoc analyses (All $P > .05$; Figure S1). The sleep latency component score becomes significant when we included age ($F = 3.384$, $P = .024$, $\eta^2 = .156$; Table S4) and both sex and age ($F = 3.308$, $P = .027$, $\eta^2 = .155$; Table S4) in the model. No differences were observed in the remaining PSQI component scores when we included sex, age or both sex and age in the model (all $P > .088$). There were no pairwise differences among groups in any PSQI component scores (all $P > .05$).

In men, the PAR and HIIT-EMS groups showed significantly higher total sleep time after the intervention programme compared to the baseline (Figure S2), whereas no differences were observed in women in any group after the intervention programme compared to the baseline (all $P > .164$; Figure S2).

We did not observe associations between changes in sleep quality and quantity parameters and changes in growth hormone, body composition parameters (fat mass, muscle mass and bone mineral density) and physical fitness parameters (cardiorespiratory fitness and muscle strength; Table S5).

Overall, the sensitivity analyses corroborated the results obtained by per-protocol analysis (Table S6).

4 | DISCUSSION

The primary findings of this study were that: (a) all exercise training programmes (PAR, HIIT and HIIT-EMS) improved PSQI global score in sedentary middle-aged adults; (b) HIIT-EMS was the only group that improved objective sleep quality and quantity from baseline levels (ie total sleep time, sleep efficiency and wake after sleep onset); (c) no statistical differences were observed between different groups in any sleep quality and quantity parameter (nor subjective, nor objective); and (d) men but not women of the exercise groups improved total sleep time after the intervention programme.

All training groups improved the PSQI global score, PAR (−34.77%), HIIT (−34.85%) and HIIT-EMS (−40.71%), enhancing therefore the subjective sleep quality. Dolezal et al[9] in a recent systematic review showed that exercise increased subjective sleep quality regardless of the mode and the intensity of activity. Our results agree with a previous meta-analysis which revealed that exercise training has a benefit on sleep quality in middle-aged adults, indicated by decreases in the PSQI global score.[3] A previous meta-analytic review hypothesized that the mechanisms through an exercise programme could improve the perceived sleep quality could be body temperature changes, mood changes, heart rate and heart rate variability changes, growth hormone secretion, fitness improvement and body composition improvements among others.[24] Therefore, the prescription of exercise could help to improve sleep quality perception in sedentary middle-aged adults.

However, although without significant differences, PAR and HIIT groups showed clinically relevant differences in total sleep time (3.48% and 4.96%, respectively), in sleep efficiency (2.37% and −2.43%, respectively), and in wake after sleep onset (−11.9% and 30.47%, respectively). A previous meta-analysis demonstrated that the participation in an exercise training programme (moderate-intensity aerobic exercise or high-intensity resistance exercise) did not produce improvements in objective sleep parameters in middle-aged adults, but the sleep quality perception was better.[3]. Regular exercise has also demonstrated to have benefits on total sleep time, sleep efficiency and sleep quality both subjective and objective.[24]

The most novel contribution of this study to the field is the inclusion of a HIIT-EMS group and the effect of this form of exercise to sleep quality parameters (subjective and

objective) in sedentary middle-aged adult. The HIIT-EMS group showed an improvement of 14.9% in total sleep time, 6.4% in sleep efficiency, and −24.4% in wake after sleep onset, enhancing therefore the objective sleep quality. These improvements could be related to several physiological mechanisms: (a) the electrical muscle stimulation (EMS) produces a greater growth hormone response than voluntary exercise in addition to voluntary muscular contractions,[25] which may stimulate rapid eye movement sleep[26]; (b) the EMS improves body composition parameters (fat mass, muscle mass and bone mineral density),[27] which may enhance sleep quality[28]; and (c) the EMS ameliorates physical fitness,[27] which could improve sleep quality.[28] However, this study did not support such mechanisms. We did not observe association between changes in sleep quality parameters and changes in growth hormone, body composition parameters (fat mass, muscle mass and bone mineral density) and physical fitness parameters (cardiorespiratory fitness and muscle strength). There are also other plausible mechanisms which were not controlled in the present study: the electrical muscle stimulation upregulates the brain-derived neurotrophic factor (BDNF) in rats,[29] whose levels are associated with sleep quality.[30] The electrical muscle stimulation shifts the cytokine profile towards anti-inflammation,[31] which may have a positive effect in sleep quality.[32] And the electrical muscle stimulation resulted in an increment in central nervous system fatigue,[33] which could improve sleep quality.[28]

In our study, we did not find differences between any group in any sleep quality parameters, although all three training groups improved their baseline values while the control group did not. Our results agree with others studies that demonstrated that the benefits of exercise in sleep quality parameters are independent of exercise type, exercise intensity and exercise duration.[3,9,24] However, the lack of differences between groups could be due to the underpowered sample size.

It is known that there are sex differences in sleep quality,[34] due to the differences in physiology between sexes like hormones and menstrual cycles.[35] These differences may explain the fact that women did not improve total sleep time after the intervention programme, mainly due to the differences in exercise physiology between men and women.[36] For example, women have lower gains in muscle mass,[37] lower cardiorespiratory fitness[38] or lower muscle strength[39] among others. Additionally, benefits of exercise appeared to be stronger for men than women in sleep parameters.[24] In women, we controlled for menopausal status (pre or post-menopausal), in order to avoid the possible cofounder of female hormones, and the results remained (data not shown).

Several limitations should be acknowledged. First, our results cannot be extrapolated to other populations, because the participants were middle-aged sedentary adults. Secondly, the lack of blood parameters mentioned above (such as BDNF or cytokine profile) does not allow to confirm that the exercise benefits on sleep quality are due to the proposed mechanisms. And lastly, the sample size was relatively small. More studies which include the plausible mechanisms (BDNF, inflammation, etc) are needed.

This is the first study showing that HIIT-EMS training could be an effective tool to improve sleep quality in sedentary middle-aged adults. In this sense, the HIIT-EMS could be positioned as an alternative to pharmacological interventions for adults with poor sleep quality or sleep disorders. In this sense, the HIIT-EMS did not show any negative effect, strengthening it vs pharmacological treatments. Future longitudinal studies are warranted to confirm these results.

In conclusion, our results show that different exercise training methodologies induced an improvement in subjective sleep quality in sedentary middle-aged adults. Moreover, a significant improvement in objective sleep quality and quantity parameters (total sleep time, sleep efficiency and wake after sleep onset) was observed in the HIIT-EMS group after 12 weeks of exercise intervention. Despite slightly greater improvements in objective sleep quality and quantity parameters, the changes observed in the HIIT-EMS group were not statistically different to the other exercise groups. However, further studies are needed to confirm the observed results in individuals with similar and different characteristics since the sample size was relatively small.

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CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

LJF, FAG, AOP, CMH, JHM and MCG conceived and designed the study; LJF, FAG, AOP and CMH acquired the data; JHM processed the data, LJF, FAG, elaborated the statistical section; LJF and FAG drafted the manuscript; MCG revised the manuscript; and all authors read and approved the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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