Effects of Moderate-Intensity Exercise on Polysomnographic and Subjective Sleep Quality in Older Adults With Mild to Moderate Sleep Complaints

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Background. This study sought to determine the 12-month effects of exercise increases on objective and subjective sleep quality in initially inactive older persons with mild to moderate sleep complaints.

Methods. A nonclinical sample of underactive adults 55 years old or older (n = 66) with mild to moderate chronic sleep complaints were randomly assigned to a 12-month program of primarily moderate-intensity endurance exercise (n = 36) or a health education control program (n = 30). The main outcome measure was polysomnographic sleep recordings, with additional measures of subjective sleep quality, physical activity, and physical fitness. Directional hypotheses were tested.

Results. Using intent-to-treat methods, at 12 months exercisers, relative to controls, spent significantly less time in polysomnographically measured Stage 1 sleep (between-arm difference = 2.3, 95% confidence interval [CI], 0.7–4.0; p = .003), spent more time in Stage 2 sleep (between-arm difference = 3.2, 95% CI, 0.6–5.7; p = .04), and had fewer awakenings during the first third of the sleep period (between-arm difference = 1.0, 95% CI, 0.39–1.55; p = .03). Exercisers also reported greater 12-month improvements relative to controls in Pittsburgh Sleep Quality Index (PSQI) sleep disturbance subscale score (p = .009), sleep diary–based minutes to fall asleep (p = .01), and feeling more rested in the morning (p = .02).

Conclusions. Compared with general health education, a 12-month moderate-intensity exercise program that met current physical activity recommendations for older adults improved some objective and subjective dimensions of sleep to a modest degree. The results suggest additional areas for investigation in this understudied area.

Key Words: Physical activity—Exercise—Sleep—Intervention—Older adult—Polysomnography—Subjective sleep.

METHODS

Study Design

Study eligibility consisted of: (a) age 55 years old or older; (b) not engaged in >60 minutes per week of moderate or more vigorous physical activity over the previous 6 months; (c) free of any medical condition that would limit participation in moderate-intensity exercise; (d) body mass index ≤ 35; (e) average alcohol intake ≤ 3 drinks per day and nonsmoker; (f) able to speak and understand English sufficiently to provide informed consent; (g) score ≥ 3 on at least two of three items of the Sleep Questionnaire and Assessment of Wakefulness (8) focused on getting to sleep, waking up during the night, and waking up in the morning; (h) free of sleep apnea or other clinically diagnosed sleep disorder, the former ruled out by a multivariate apnea prediction (MAP) score ≤ 0.8 (9) and an overnight pulse oximetry (Nellcor NPB-290) screening of <10% cumulative time of oxygen saturation (SaO2) < 90% and a desaturation index...
Measurement of Sleep: Self-Report Measures

The Pittsburgh Sleep Quality Index (PSQI).—The validated PSQI was used to evaluate rated sleep quality at

Exercise attendance sheets and logs.—Exercise instructors maintained attendance sheets recording individual participation in the exercise classes across the 12-month period (14). Exercisers also completed daily exercise logs that were turned into instructors weekly (3,14).

Measurement of Sleep Architecture

Nine-channel polysomnographic (PSG) recordings were made in participants’ homes using the Oxford Medilog MR95 digital recording system (Oxford Instruments, Oxford, U.K.). Electrode application followed standardized placements for electroencephalography (EEG) (C4-A1, C3-A2, Pz-A1), bipolar electrooculography (EOG), and surface mentalis electromyography (EMG) (16). An MR95 channel recorded ambient light, which was used to help determine the beginning of the sleep period (see below). Sleep was ad libitum.

Technologists arrived in participants’ homes between 7:00 and 8:00 PM for evening hook-up. Participants were instructed to press the event marker on the MR95 at the time they intended to go to bed. Participants removed electrodes in the morning, and technologists picked up the units shortly afterward. Participants maintained sleep diaries (see below) on nights of PSG recording. The beginning of the sleep period was defined using “lights out” as indicated on the MR95 illumination monitor. When this information was missing, the MR95 event marker as pressed by the participant was used to define “lights out.” Finally, when event marker information was missing, bedtime as indicated on the participant’s nightly sleep log was used. Retrospective examination indicated that the primary data sources for start of night were the luminescence monitor (46%) and event recorder (44%).

Upon morning collection of the MR95 equipment in participants’ homes, PSG data were de-identified and transferred to the Palo Alto Veterans Administration Medical Center (Woodward) for artifact removal and data compression. A total of 17 participant nights were eliminated from further analysis because of technical considerations (e.g., >25% of recording was unscoreable because of artifact, weak battery, etc.), resulting in a technical failure rate of 4.2%. Cleaned data were transferred to the Laboratory for Sleep, Aging and Chronobiology at Emory University Medical School (Bliwise) for stage scoring, which followed conventional scoring rules (16). Median inter-rater reliability (intra-class correlation coefficient) across the two trained and blinded PSG technologists was .90 for sleep stages. Scored data were subsequently transferred back to Stanford where data analysis occurred.

PSG data were collected for 3 nights during baseline and 2 nights at 6 and 12 months. Data were averaged from the 2nd and 3rd baseline nights (17) and for the 2 nights recorded at other time points when both nights were available. Only one participant had to be eliminated completely because of inadequate sleep recordings based on the above criteria. During the intervention, exercise participants were instructed to undertake their prescribed physical activity on at least one of the two PSG measurement days.
baseline and 12 months (18). Seven “component” scores are generated (using a 0–3 scale) along with a summary global sleep quality score (range = 0–21).

Sleep diaries.—Standard sleep diaries were used to provide an additional source of sleep data (19). Participants recorded sleep and lifestyle variables (e.g., caffeine intake) in a daily diary during a 2-week period at baseline and 12 months (3).

Measurement of Secondary Outcomes of Interest

Cardiorespiratory fitness and body mass index (BMI).—Participants underwent symptom-limited treadmill exercise testing at baseline and 12 months. Treadmill speed was increased gradually until the participant’s heart rate reached approximately 70% of age-predicted maximum heart rate. The participant walked at this speed for 4 minutes. Each subsequent stage was 2 minutes long, with grade increasing by 2%. The test continued until the participant requested to stop due to fatigue or until any one of the criteria listed under the American College of Sports Medicine (ACSM) standard stopping indications were met (20). Peak exercise oxygen consumption was measured during the exercise test (MedGraphics Corporation CPX/D; St. Paul, MN) and was defined as the average of the two highest oxygen consumption levels observed during the last minute of the exercise test (mL/kg/min). A physician supervised the test, and all staff administering the test were trained and certified. Body weight (kg) and height (meters) were assessed using standard procedures to obtain BMI (kg/m²) (21).

Sample Size and Statistical Analyses

No comparable exercise intervention data for sleep-impaired older adults were available for PSG-derived sample size determinations. A goal of the current study was the development of initial effect size estimates for those variables.

Prior to formal data analysis, principal components analysis with varimax rotation was applied to baseline data to reduce variable redundancies within each of the three sleep measurement domains (22). Components with eigenvalues ≥ 1.0 were used in identifying variables within each component with the greatest factor loadings for use in subsequent analysis (22).

Analysis of variance (ANOVA; general linear models procedure) (23) was used to evaluate baseline between-arm differences. Analysis of covariance (ANCOVA) (23), with baseline values as covariates, was used to assess 12-month differences. Analysis of covariance (ANCOVA) (23) was used to evaluate baseline between-arm differences and to reduce variable redundancies within each of the three sleep measurement domains (22). Components with eigenvalues ≥ 1.0 were used in identifying variables within each component with the greatest factor loadings for use in subsequent analysis (22).

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Adherence to the 12-Month Exercise Program

Participants demonstrated good overall adherence to the exercise program, with a mean of 3.7 ± 1.8 of 5 prescribed exercise sessions per week (74%) across the 12-month period (based on instructor-reported class attendance logs and participant logs). Across 12 months, mean number of home exercise sessions = 2.1 ± 0.9 and mean minutes of exercise per home session = 43.3 ± 19.4 (no significant differences between class and home sessions).

Participants randomized to the health education control arm had similarly good attendance (80%) at the weekly health education sessions across the 12-month period.
Change in 12-Month Physical Activity

At 12 months, using intent-to-treat analyses, exercisers (baseline-adjusted mean = 34.3 ± 2.2) showed significantly higher total energy expenditure levels compared to controls (baseline-adjusted mean = 32.9 ± 2.2) (F[1,65] = 5.6, p = .01, one-tailed).

Results from Principal Components Analyses of Sleep Measures

Home PSG.—For the nine PSG variables, principal components analyses (PCA) yielded four components with eigenvalues ≥ 1.0, which together accounted for 76% of the total variance. Top-loading variables included percent time in Stage 2 sleep (Factor 1), percent time in Stage 1 sleep and awakenings during the first third of the sleep period (Factor 2), percent time in slow-wave sleep (SWS) (Factor 3), and sleep latency (Factor 4). Because Stage 1 sleep percentage and awakenings represent clinically distinct variables (28) and were only modestly correlated (Spearman r = 0.3), these five variables were included in subsequent analysis.

PSQI.—For the seven PSQI subscales, PCA yielded three components with eigenvalues ≥ 1.0, which together accounted for 66% of the total variance. Top-loading variables included sleep duration (Factor 1), sleep disturbance (Factor 2), and daytime dysfunction (Factor 3). These three variables were included along with global PSQI score in subsequent analysis.

Two-week sleep diaries.—PCA of the five sleep diary variables yielded four components with eigenvalues ≥ 1.0, which together accounted for 66% of the total variance. Top-loading variables included nighttime awakenings (Factor 1), sleep duration (Factor 2), sleep-onset latency and feeling rested in the morning (Factor 3), and amount of daytime napping (Factor 4). Because sleep-onset latency and feeling rested in the morning represent clinically distinct variables (19), all five variables were included in subsequent analysis.

Change in 12-Month Primary Sleep Outcomes:

Home PSG

Using intent-to-treat methods, group differences were found on three of the five 12-month PSG sleep variables (Table 2). Exercisers showed significantly less percentages of time spent in Stage 1 sleep relative to controls (F[1,65] = 8.0, p = .003, one-tailed; group difference = 2.3, 95% confidence interval [CI], 0.7–4.0, effect size = 0.66).
Exercisers also showed a significantly greater percentage of time spent in Stage 2 sleep relative to controls ($F[1,65] = 3.2, p = .04$, one-tailed; group difference = 3.2, 95% CI, 0.6–5.7, effect size = 0.41). Finally, exercisers had significantly fewer awakenings during the first third of the sleep period relative to controls ($F[1,65] = 3.5, p = .03$, one-tailed; group difference = 1.0, 95% CI, 0.39–1.55, effect size = 0.50). No statistically significant 12-month group differences were observed for other PSG variables. Of note, participants spent an average of 1% or less of their baseline sleep time in SWS sleep (Table 2). (Additional spectral analyses of delta band activity using the Fast Fourier Transform function also failed to yield significant results.)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Study Arm</th>
<th>Baseline (SD)</th>
<th>12 Month (SD)</th>
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<tr>
<td>Sleep latency, min [36]</td>
<td>Exercise</td>
<td>15.06 (17.12)</td>
<td>14.22 (12.23)</td>
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<td>Control</td>
<td>17.74 (11.68)</td>
<td>18.42 (13.55)</td>
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<tr>
<td>Number of awakenings: 1st third of sleep period [36]</td>
<td>Exercise</td>
<td>4.65 (2.88)</td>
<td>4.28 (2.72)*</td>
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<td>3.26 (1.66)</td>
<td>4.27 (2.46)</td>
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<tr>
<td>Number of awakenings: 2nd third of sleep period [36]</td>
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<td>5.22 (2.89)</td>
<td>5.73 (3.38)</td>
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<tr>
<td>Control</td>
<td>4.36 (1.92)</td>
<td>4.78 (1.87)</td>
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<tr>
<td>Number of awakenings: last third of sleep period [36]</td>
<td>Exercise</td>
<td>8.78 (7.16)</td>
<td>7.93 (3.92)</td>
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<td>Control</td>
<td>5.66 (2.72)</td>
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<tr>
<td>% Sleep time in Stage 1 [36]</td>
<td>Exercise</td>
<td>9.13 (3.96)</td>
<td>7.88 (3.77)**</td>
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<tr>
<td>Control</td>
<td>8.24 (3.51)</td>
<td>9.37 (5.85)</td>
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<tr>
<td>% Sleep time in Stage 2 [36]</td>
<td>Exercise</td>
<td>52.79 (8.17)</td>
<td>53.68 (9.63)*</td>
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<td>Control</td>
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<td>% Sleep time in slow wave sleep [36]</td>
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<td>361.09 (65.48)</td>
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<td>Control</td>
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<td>Sleep efficiency, % [36]</td>
<td>Exercise</td>
<td>80.95 (9.52)</td>
<td>79.89 (10.53)</td>
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<td>Control</td>
<td>82.46 (9.37)</td>
<td>81.09 (10.36)</td>
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### Changes in 12-Month Secondary Sleep Outcomes: Self-Reported Sleep Quality

**PSQI**—Using intent-to-treat methods, exercisers reported lower 12-month sleep disturbance subscale scores compared to controls ($F[1,63] = 5.0, p = .014$, one-tailed, effect size = 0.55).

**Two-week sleep diaries.**—Using intent-to-treat methods, exercisers, compared to controls, reported reduced sleep-onset latency ($F[1,62] = 6.1, p = .008$, one-tailed, effect size = 0.63) and feeling more rested in the morning ($F[1,62] = 3.6; p = .03$, one-tailed, effect size = 0.47). There were no between-group differences reported for bedtime.
discovery is lacking in the sleep-exercise field, it is quite possible that we still
lacked statistical power for some objectively measured sleep variables (e.g., sleep latency, SWS), as well as discerning
differences between exercise and non-exercise days (p values ≥ .35). Nor were significant differences observed
when this group was combined with 11 additional exercisers who had consecutive exercise–no exercise
PSG nights at the interim 6-month visit (total n = 23, p values ≥ .19).

Change in Other Secondary Outcomes: Cardiorespiratory Fitness and Body Weight

Using intent-to-treat analyses, exercisers showed significantly greater 12-month cardiorespiratory fitness (baseline-adjusted mean = 24.7 ± 2.2) compared to controls (baseline-adjusted mean = 23.1 ± 2.3) (F[1,61] = 7.6, p = .004, one-tailed). Exercisers also had significantly lower BMI (baseline-adjusted mean = 27.1 ± 1.2) compared to controls (baseline-adjusted mean = 28.0 ± 1.3) (F[1,65] = 8.5, p = .002, one-tailed). These between-arm differences are comparable to or greater than changes in these variables obtained in other community-based exercise intervention studies that typically targeted younger individuals (21,29).

Discussion

To our knowledge, this study is the first to evaluate the sustained effects of a moderate-intensity exercise program on home-based PSG in older adults with sleep complaints. In a recent meta-analysis reviewing 23 behavioral intervention trials for insomnia, just three used PSG (30). Use of repeated nights of home-based PSG recordings increases the contextual validity of the PSG assessment over that occurring within the more typical context of a sleep laboratory (31). The results suggest that increases in moderate-intensity primarily endurance exercise may have modest positive effects on several dimensions of objectively measured sleep architecture as well as on subjective aspects of sleep. The significant 12-month shift observed from Stage 1 to Stage 2 sleep and the reduced number of awakenings observed during this early phase of sleep represents a small to moderate effect size (32), similar to those reported in a meta-analysis of the associations of exercise with increased Stage 2 and SWS in individuals without insomnia (33). The low levels of baseline SWS seen in our older participants—similar to other populations of older adults (28)—may have mitigated the detection of increases in those sleep stages. Notably, there are no well-accepted pharmacologic or nonpharmacologic interventions to increase SWS. Our data suggest that increases in regular moderate-intensity exercise levels commensurate with those identified in current population-wide recommendations, including those for older adults (7), can yield measurable changes in sleep architecture typically associated with better sleep. The significant associations found between 12-month Stage 2 sleep percentages and several self-reported sleep outcomes provide additional evidence that the increase in Stage 2 sleep percentage may be associated with more positive sleep perceptions. The potential public health impacts of these changes deserve further investigation. Of note, the intervention resulted in physical activity and fitness changes of similar magnitude to other community-based studies targeting younger populations (21,29).

Subjectively, 12-month improvements were observed in nighttime sleep disturbance (PSQI), sleep latency (diaries), and feeling rested in the morning (diaries). Given that it is the perceptual aspects of sleep that motivate physician visits, use of pharmacologic sleep aids, and other forms of medical intervention, subjective aspects of sleep remain an important domain for investigation (34). Similar to the behavioral treatment literature for insomnia, the exercise intervention did not have a significant impact on total sleep time in this older adult sample (30).

Prevalence studies suggest that more than half of the older population report some degree of sleep problems (2). Our participants probably represent this broader range of individuals experiencing “suboptimal” sleep for their age, as opposed to individuals with more severe sleep complaints that are represented in clinic- or laboratory-based insomnia studies.

It is conceivable that the increased light exposure accompanying home-based exercise sessions occurring outdoors could have had a positive impact on sleep quality (6). We do not have data on what percentage of home-based exercise sessions occurred outdoors, and thus were not able to differentiate these potential light effects from more general exercise effects.

Although the current investigation represents a sample size two- to threefold larger than trials typically undertaken in the sleep-exercise field, it is quite possible that we still lacked statistical power for some objectively measured sleep variables (e.g., sleep latency, SWS), as well as discerning acute effects of exercise on sleep architecture. While PCA was used to reduce redundancies among the sleep variables, a reasonably large number of tests were conducted to better validate the observed between-group differences.
understand which sleep variables might deserve further investigation. Given this, we urge caution in interpreting the study results.

The applicability of our findings to very old adults remains uncertain. An observational study including many individuals older than 80 years showed that regular physical activity was protective for insomnia (35). Although one trial implementing a limited physical activity regimen in nursing home patients (mean age = 84 years) was unsuccessful in impacting actigraphically measured sleep (36), a second study of nursing home residents (mean age = 87), which evaluated a multicomponent intervention that included daily low-level exercise, reported improved actigraphically measured rest/activity rhythms (37). Additional research with adults older than 80 years is clearly warranted.

Finally, the average changes in self-reported sleep quality found were smaller than those often reported in cognitive-behavioral or pharmacological intervention studies in the sleep area (1), although those studies typically have targeted a different population (clinically impaired, such as those presenting at a sleep clinic). Although statistically significant, our PSG results suggest effects that were modest and less dramatic than we originally expected. Increases in visually scored SWS following exercise in younger participants, for example, have been reported and were expected here. Perhaps owing to the relatively low amounts of SWS seen at baseline in our older participants, such changes were not detected. In contrast, several sleep architecture variables did show intervention-related changes that were entirely consistent with better sleep. Stage 1 sleep, typically considered a transition state from waking to sleep, was decreased with exercise and was converted to a sleep EEG pattern consistent with more stable sleep (i.e., increased Stage 2). The fact that sleep continuity in the first third of the night also showed such trends for improvement is compatible with the fact that sleep continuity in the first third of the night also was converted to a sleep EEG pattern consistent with better sleep. Stage 1 sleep, typically considered hypnogenic, was observed and was expected here. Perhaps owing to the relatively low amounts of SWS seen at baseline in our older participants, such changes were not detected. In contrast, several sleep architecture variables did show intervention-related changes that were entirely consistent with better sleep. Stage 1 sleep, typically considered a transition state from waking to sleep, was decreased with exercise and was converted to a sleep EEG pattern consistent with more stable sleep (i.e., increased Stage 2).

In light of the demonstrated positive impacts of regular moderate-intensity exercise on a range of health outcomes in addition to sleep in middle-aged and older adults (40), exercise interventions merit continued investigation among sleep-impaired adult populations.

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