

Effects of a Yearlong Moderate-Intensity Exercise and a Stretching Intervention on Sleep Quality in Postmenopausal Women

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Study Objectives: To examine the effects of a moderate-intensity exercise or stretching intervention and changes in fitness, body mass index, or time spent outdoors on self-reported sleep quality and to examine the relationship between the amount and timing of exercise and sleep quality.

Design: A randomized intervention trial.

Setting: A cancer research center in Seattle, Washington.

Participants: Postmenopausal, overweight or obese, sedentary women not taking hormone replacement therapy, aged 50 to 75 years, and recruited from the Seattle metropolitan area.

Interventions: A yearlong moderate-intensity exercise (n=87) and a low-intensity stretching (n=86) program.

Measurements and Results: Among morning exercisers, those who exercised at least 225 minutes per week had less trouble falling asleep (odds ratio [OR]: 0.3, $P \leq .05$) compared with those who exercised less than 180 minutes per week. However, among evening exercisers, those who exercised at least 225 minutes per week had more trouble falling asleep (OR: 3.3, $P \leq .05$) compared to those who exercised less than 180 minutes per week. Stretchers were less likely to use sleep medication

(OR=0.4, $P \leq .05$) and have trouble falling asleep (OR: 0.7, $P \leq .10$) during the intervention period compared with baseline. A greater than 10% versus a 1% or less increase in maximum O₂ consumption over the year was associated with longer sleep duration ($P \leq .05$), less frequently falling asleep during quiet activities ($P \leq .05$), and less use of sleep medication ($P \leq .05$). Reductions in body mass index and increases in time spent outdoors had inconsistent effects on sleep quality.

Conclusions: Both stretching and exercise interventions may improve sleep quality in sedentary, overweight, postmenopausal women. Increased fitness was associated with improvements in sleep. However, the effect of moderate-intensity exercise may depend on the amount of exercise and time of day it is performed.

Key Words: exercise, stretching, fitness, sleep, intervention, postmenopausal women

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INTRODUCTION

POOR SLEEP QUALITY IS A COMMON PROBLEM AMONG MIDDLE-AGED AND OLDER ADULTS AND IS ASSOCIATED WITH DECREMENTS IN LEARNING, MEMORY, AND ALERTNESS; REDUCED IMMUNE FUNCTION; AND DEPRESSION.¹ A recent study suggests that too little or too much sleep may increase the risk of cardiovascular disease in women.² Older men and women spend more time in bed than do younger people, but they get less sleep.³ In 1 study, 42% of healthy middle-aged women reported some type of sleep disturbance over the previous 6 months.⁴ The prevalence of sleep disturbances

was higher among women with truncal obesity and those who did not take hormone replacement therapy after becoming postmenopausal.⁴

Physical activity and stretching are possible interventions to improve sleep. In a study of older men, fit individuals had shorter sleep-onset latencies and higher sleep efficiencies than did sedentary men.⁵ Nonrandomized interventions have reported improvements in the rest-activity cycle,⁶ increases in slow-wave sleep,⁷ higher sleep efficiencies,⁸⁻¹⁰ and fewer awakenings⁸⁻¹⁰ with moderate-intensity exercise. One study, however, reported no change in sleep patterns after a 12-week exercise program in 9 unfit young women.¹¹

Five randomized trials have examined some aspect of the effect of physical activity or stretching on sleep quality in older adults. Among 32 depressed men and women compared to controls, subjective sleep quality and sleep-onset latency significantly improved after 10 weeks of weight training.¹² Another study, which compared 43 sedentary men and women with moderate sleep complaints to controls, reported that a 4-month exercise intervention significantly improved subjective sleep quality, sleep-onset latency, and sleep duration.¹³ Vitiello et al reported an increase in slow-wave sleep in 36 exercisers but not in 21 stretching control subjects, from baseline to 6 months; however, both groups reported improved sleep quality and latency.¹⁴⁻¹⁶ Another study reported longer sleep duration after a 9-month moderate- or light-intensity exercise intervention (N=72).¹⁷ A fifth study compared the effect of structured sleep hygiene plus moderate exercise and structured sleep hygiene plus light therapy compared to sleep hygiene alone in a small group of insomniacs (N=30, aged 18-55 years).¹⁸ Although not statistically significant, they reported increases in total sleep time using both sleep-diary data and actigraphy after 4 weeks in the group using sleep hygiene

Disclosure Statement

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plus moderate exercise. Three of these studies reported that the intervention occurred before the evening meal^{13,14,18}; however, in none of these studies was the effect of time of day considered as a potential modifier of the exercise-sleep relationship.

We undertook the present study to assess the impact of a yearlong moderate-intensity exercise or low-intensity stretching intervention on subjective sleep quality in a population at high risk for sleep problems, namely sedentary, overweight, postmenopausal women not taking hormone replacement therapy. We also examined whether changes in fitness, body mass index (BMI), and time spent outdoors were associated with sleep quality. Among exercisers, we explored the relationship between the amount and timing of exercise and sleep quality. This study is unique in that it has a larger sample size and was conducted over a longer period of time than previous studies, and it can assess the possible modifying effect of exercise at different times of day.

METHODS

Study Population

Subjects are from the Physical Activity for Total Health Study, which has been described in detail elsewhere.¹⁹ Briefly, the study was designed to investigate the effect of a yearlong moderate-intensity exercise intervention versus stretching control in postmenopausal women on various hormone biomarkers and, secondarily, on changes in BMI, adiposity, fat distribution, and immune function. We randomly assigned 173 women, aged 50 to 75 years, who were sedentary (less than 60 minutes per week of moderate- to vigorous-intensity exercise) and overweight or obese (BMI ≥ 25.0 or a BMI between 24.0 and 25.0 and percentage of body fat $> 33\%$) to 1 of the 2 treatment groups. Participants resided in the greater Seattle, Washington, area.

The recruitment process identified potentially eligible women primarily via mass mailings and media advertisements.²⁰ Recruitment materials emphasized that women would help scientists understand how exercise may reduce breast-cancer risk and learn about how to incorporate exercise or stretching into their lives; the materials made no mention of sleep. Interested women were screened for eligibility by a phone interview. Major ineligibility criteria included the use of any type of hormone replacement therapy, smoking, and medical conditions contraindicating moderate-intensity exercise. Eligible women were scheduled for a screening clinic visit and Bruce treadmill test, in which subjects were asked to walk until reaching maximal exertion. Those who successfully completed the screening process were randomly assigned to an aerobic exercise ($n=87$) or stretching ($n=86$) intervention. Informed consent was obtained following the requirements of the Fred Hutchinson Cancer Research Center Institutional Review Board.

Study Interventions

The aerobic-exercise intervention goal was to exercise at a moderate intensity for at least 45 minutes, 5 days per week.¹⁹ For the first 3 months of the intervention, participants completed 3 exercise sessions per week at a training facility under the supervision of a trained exercise physiologist and 2 sessions at home. During the last 9 months, participants exercised at a training facility 1 to 3 times per week and did the remainder of the 5 sessions at home. At the exercise facility, subjects started with a 5-minute warm-up on a cardiovascular machine, followed by 5 minutes of stretching (7 stretches), 45 minutes of cardiovascular exercise (usually treadmill walking and stationary bicycling), 5 to 10 minutes of weight training, and a 5-minute cool down on a cardiovascular machine. Home exercise primarily consisted of walking.²⁰ The program gradually increased activity intensity until reaching a target of 60% to 75% of maximal heart rate for 45 minutes per session.²¹ Subjects wore heart-rate monitors during exercise in the facility and were encouraged to wear them during exercise at home. Classes were offered from 10:30 AM to noon and from 6:00 PM to 7:30 PM. Participant adherence was assessed via daily activity logs, on which participants reported the type and dura-

tion of exercise they performed. Six (7%) women dropped out of the exercise intervention, all after 3 months.

Women assigned to the stretching intervention attended a 60-minute low-intensity stretching and relaxation session each week, conducted by a trained exercise physiologist. Stretching sessions consisted of a 5-minute walk around the classroom followed by 8 to 10 upper-body and 8 to 10 lower-body stretches for 45 minutes and a 10-minute progressive relaxation session. Attendance was recorded at each session. Classes were offered from 10:00 AM to 11:00 AM and from 6:15 PM to 7:15 PM. Women were encouraged to do an additional 15- to 30-minute stretching session at home 3 times per week. Adherence to the stretching program at home was not monitored explicitly as this condition was the control group for the primary study endpoints. Women in the stretching group were asked to not change their other exercise habits during the trial, and both groups were asked to not change their diet. Six (8%) stretchers began exercising at levels similar to the exercise-intervention goal, all after 3 months. All participants from both intervention groups were included in the analyses in their originally assigned treatment group.

Study Data

Participants completed study questionnaires before randomization (baseline) and at 3, 6, 9, and 12 months after randomization. Questionnaires assessed subjective sleep quality over the previous month using the Women's Health Initiative Insomnia Rating Scale (Appendix).²² Other questions included job status, marital status, amount of time outdoors, and a depression screening tool using the short version of the Center for Epidemiologic Studies Depression Scale.²³ At baseline, 3 months, and 12 months, weight was measured to the nearest 0.1 kg on a balance-beam scale, and height was measured to the nearest 0.1 cm on a stadiometer; these were used to calculate BMI.

Maximal oxygen consumption ($VO_2\max$) was determined at baseline and at 12 months, after a 4-hour fast, via a maximal-graded treadmill test, completed after a screening Bruce treadmill test. Since the Bruce treadmill test is very similar to the $VO_2\max$ test, we would not expect changes between the baseline and 12-month $VO_2\max$ test (ie, the second and third repetitions of the test) to be due to a practice effect.²⁴ Heart rate and oxygen consumption were monitored by an automated metabolic cart (Medgraphics, St. Paul, Minn). The test ended when subjects reached volitional fatigue. We used 2 criteria to determine whether the subject had given maximal effort: reaching a respiratory exchange ratio of at least 1.1 or reaching a maximal heart rate of at least $0.85 \cdot (220 - \text{age})$. These are standard criteria^{25,26} and have been validated for obese, postmenopausal women.²⁷

We used 6 items from the Women's Health Initiative Insomnia Rating Scale as measures of subjective sleep quality: sleep quality (*very restless/restless, average, sound/very sound*), use of sleep medications or alcohol to help sleep (*yes, no*), sleep duration (≤ 6 hours, > 6 hours), trouble falling asleep (*no, <1 time/wk, ≥ 1 time/wk*), falling asleep during quiet activities (*no, <1 time/wk, 1-2 times/wk, ≥ 3 times/wk*), and napping during the day (*no, <1 time/wk, ≥ 1 time/wk*). We included the first 3 items because they are similar to the scales of the commonly used Pittsburgh Sleep Quality Index,²⁸ while the question about having trouble falling asleep may be an important component of how exercise affects sleep.²⁹ The last 2 questions reflect the daytime consequences of nighttime sleep quality.

Statistical Analysis

Our primary analysis was to identify changes in sleep quality during the intervention (3, 6, 9, and 12 months) compared to baseline, separately for participants randomly assigned to the exercise and stretching groups. The original study design of this randomized trial intended that the stretching group act as a control for the exercise-treatment arm. However, in this analysis, we treated exercise and stretching as distinct treatment groups because of literature suggesting that stretching and

relaxation may improve sleep on its own,^{16,30} and our preliminary analyses indicated that the stretching treatment had an independent effect on sleep outcomes. We adjusted for month-of-questionnaire completion (in 2-month intervals), time of day the subject attended the intervention class (morning, evening, both), job status (not working, retired, working, other), baseline marital status (never married, divorced/separated, widowed, married/living with partner), time spent outdoors at baseline (0 hour, 1-5 hours, ≥ 6 hours), and baseline depression score from the Center for Epidemiologic Studies Depression Scale (≤ 0.06 , > 0.06). All covariates were included as indicator variables and were chosen a priori as potential confounders. We evaluated adjusting for alcohol and caffeine use, which were assessed at baseline, 3 months, and 12 months via a food-frequency questionnaire,³¹ age, baseline VO₂max, and baseline BMI but found little difference in the regression estimates. Therefore, these variables were not included in the final model. We also performed an intent-to-treat analysis comparing the sleep outcomes at follow-up between exercisers and stretchers, after adjusting for the baseline sleep-quality measure; this analysis treated the stretchers as a true control group.

Odds ratios (OR) and 95% confidence intervals (95% CI) were determined using proportional odds logistic regression for sleep quality, trouble falling asleep, falling asleep during quiet activities, and napping during the day, as all had 3 or 4 ordered outcome levels, and ordinary logistic regression for sleep medication use and short sleep duration. The proportional odds model assumes a common OR for any cut-point between categories. With sleep quality, for example, it assumes that the following 2 comparisons have the same OR: (1) Restless/very restless sleep quality versus average/sound/very sound sleep quality and (2) Restless/very

restless/average sleep quality versus sound/very sound sleep quality. The OR is the risk for having the poorer sleep outcome. Due to the longitudinal nature of the data, we used generalized estimating equations with a binomial error, logit link, independent working correlation matrix, and robust SE.³²

In an exploratory analysis, we compared sleep quality, among exercisers only, by the average minutes per week of exercise during the previous 3 months (<180 min/wk, 180 - <225 min/wk, and ≥ 225 min/wk), stratifying by time of day of exercise (morning or evening). We adjusted for age, month the questionnaire was completed, job status, baseline marital status, baseline VO₂max, baseline BMI, time spent outdoors at baseline, and baseline depression score. Morning exercisers with less than 180 minutes per week of exercise served as the reference category for morning exercisers, and evening exercisers with less than 180 minutes per week of exercise served as the reference category for evening exercisers. We used the normal time that a woman attended the training

Table 1—Baseline demographic and other characteristics of the study participants, stratified by intervention status*

	Exercise n = 87 mean \pm SD	Stretching n = 86 mean \pm SD
Age, y	60.7 \pm 6.7	60.6 \pm 6.8
VO ₂ max, mL·kg ⁻¹ ·min ⁻¹	20.1 \pm 3.5	20.5 \pm 3.0
Body mass index, kg/m ²	30.5 \pm 4.1	30.6 \pm 3.8
	No. (%)	No. (%)
Time of day of intervention		
Morning	50 (57.5)	45 (52.3)
Evening	36 (41.4)	34 (39.5)
Both morning and evening	1 (1.1)	7 (8.1)
Month completed questionnaire		
December – January	10 (11.5)	15 (17.4)
February – March	22 (25.3)	23 (26.7)
April – May	17 (19.5)	10 (11.6)
June – July	13 (14.9)	15 (17.4)
August – September	14 (16.1)	11 (12.8)
October – November	11 (12.6)	12 (14.0)
Job Status		
Not working	9 (10.3)	7 (8.1)
Retired	18 (20.7)	20 (23.3)
Working	41 (47.1)	45 (52.3)
Other [†]	19 (21.8)	14 (16.3)
Marital status		
Never married	8 (9.2)	4 (4.6)
Divorced	23 (26.4)	21 (24.4)
Widowed	10 (11.5)	9 (10.5)
Married/living with partner	46 (52.9)	52 (60.5)
Time spent outdoors, h/wk		
0	10 (11.5)	7 (8.2)
1-5	45 (51.7)	46 (54.1)
≥ 6	32 (36.8)	32 (37.7)
Depression score [‡]		
≤ 0.06	78 (89.7)	73 (85.9)
> 0.06	9 (10.3)	12 (14.1)

*There were no significant differences between intervention groups.

[†]This category includes women who checked the "other" response on the question about job status or those who checked multiple categories.

[‡]Based on a depression screener using the short version of the Center for Epidemiologic Studies Depression Scale; the range is from 0 to 1.

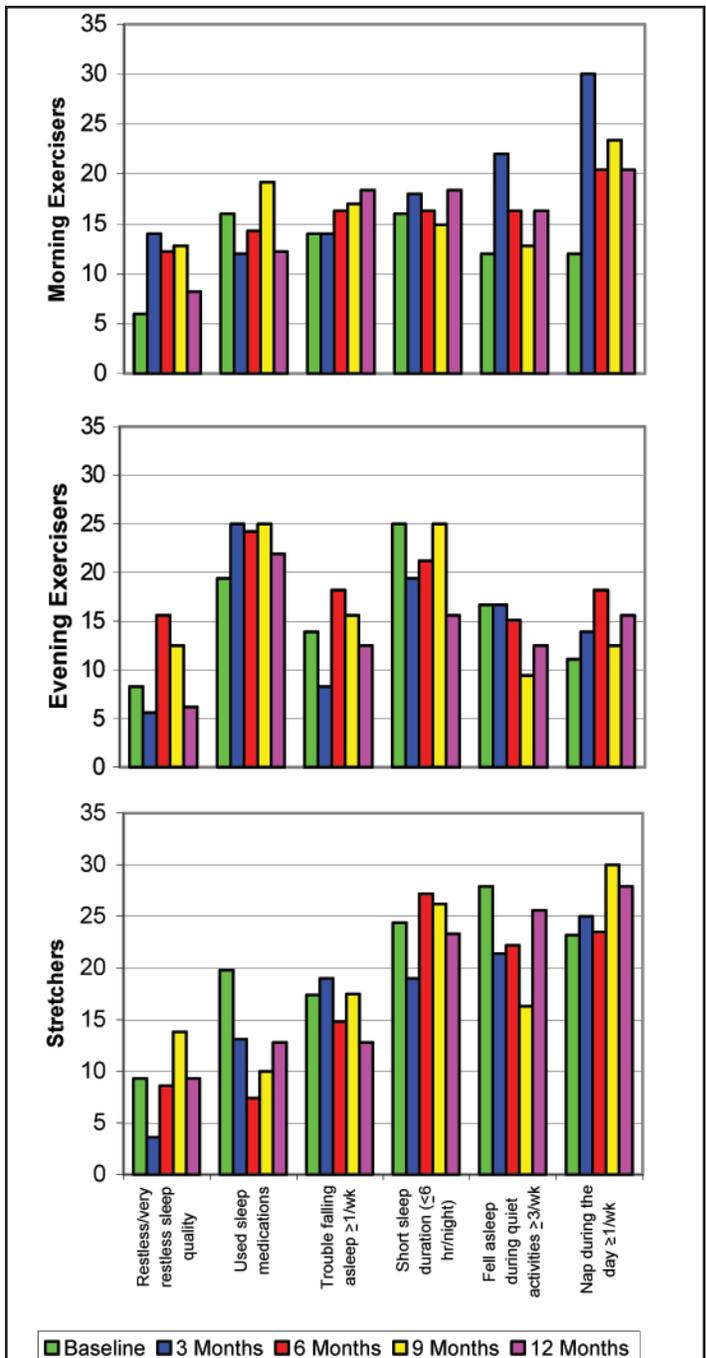


Figure 1—Percent of subjects reporting poor sleep measures over the previous month at baseline, 3, 6, 9, and 12 months.

facility as a surrogate for time of day of exercise, as this was the only data available about timing of exercise. We excluded 1 participant from this analysis who exercised equally at the morning and evening sessions.

For women in the stretching group, we considered the effect of percentage of class attendance over the previous 3 months (< 50%, 50-80%, ≥ 80%) on sleep quality, adjusting for time of intervention class, age, month the questionnaire was completed, job status, baseline marital status, baseline VO₂max, baseline BMI, time spent outdoors at baseline, and baseline depression score. The effect of percentage of attendance did not differ by time attending the intervention; therefore, all participants in the stretching intervention were combined for this analysis.

To understand how physical activity may affect sleep parameters, we examined, for all subjects combined, sleep quality at 12 months by the percentage change in VO₂max (≤ 1%, > 1-10%, ≥ 10%), change in BMI (increased, 0-1 kg/m² decrease, ≥ 1 kg/m² decrease), and change in the amount of time spent outdoors (decreased, increased 0-3 h/wk, increased ≥ 3 h/wk) from baseline to 12 months. We adjusted for the baseline sleep-quality measure, intervention group, age (50-54, 55-59, 60-64, 65-69, 70-75), time of intervention, job status, baseline marital status, baseline BMI (<27, 27-30, 30-33, ≥33), baseline VO₂max (< 21.0, ≥ 21.0), amount of time spent outdoors at baseline, and baseline depression score. Since the association between changes in VO₂max, BMI, or time spent outdoors and sleep quality did not differ by intervention group, we present data for both groups combined. We excluded 4 subjects from this analysis (2 exerciser and 2 stretchers) who did not meet either of the maximal exertion criteria on 1 of their VO₂max tests.

RESULTS

No significant differences in selected baseline characteristics, including the season of entrance into the study, existed between women in the exercise and stretching interventions (Table 1). More than half the women (55%) attended their respective intervention sessions in the morning hours, and 50% of participants worked for pay. Fifty-three percent of participants spent 1 to 5 hours outside each week.

At baseline, there were no statistically significant differences in sleep measures between participants in the exercise and stretching interventions, with the exception of napping during the day (Figure 1). About 23% of stretchers versus 13% of exercisers reported taking a nap 1 or

more times per week ($P = .04$). The percentage of morning exercisers reporting restless or very restless sleep quality and napping at least 1 time per week increased at all follow-up points compared to baseline. The percentage of evening exercisers reporting using sleep medications and napping at least 1 time per week increased at all follow-up points compared to baseline. Women in the stretching group reported less use of sleep medication during the entire intervention period compared to baseline.

In the intent-to-treat analysis comparing exercisers to stretchers (as controls), there were no significant differences in follow-up sleep outcomes, except for using sleep medication (OR: 2.7; 95% CI: 1.4, 5.2; $P = .004$) (Table 2). However, further analysis using a pre-intervention versus post-intervention comparison within treatment groups, indicated that exercisers did not use more sleep medication but that subjects in the stretching group used less sleep medication (OR: 0.4; 95% CI: 0.3, 0.7; $P = .001$) during the intervention period compared to baseline. Stretchers also were less likely to have trouble falling asleep (OR: 0.7; 95% CI: 0.5, 1.0; $P = .06$) during the intervention period compared to baseline. Subjects in the exercise group had a slightly increased risk of napping during the day (OR: 1.3; 95% CI: 1.0, 1.8; $P = .09$) during the intervention period compared to baseline.

The average minutes per week of moderate-intensity exercise did not significantly differ between morning and evening exercisers; however the evening exercisers were significantly younger, more likely be working, more likely to be divorced, and less likely to have never married compared to the morning exercisers (data not shown). After adjustment for these and other potential confounders, morning exercisers who exercised at least 225 minutes per week had less trouble falling asleep (OR: 0.3; 95%CI: 0.1, 0.8; $P = .02$) compared to those who exercised less than 180 minutes per week (Table 3). Conversely, among evening exercisers, participants who exercised 180 to 225 minutes per week or those who exercised at least 225 minutes per week had more trouble falling asleep (OR: 3.5; 95% CI: 1.0, 12.0; $P = .05$ and OR: 3.3; 95% CI: 1.2, 8.8; $P = .02$, respectively) compared to participants who exercised less than 180 minutes per week. Although no other associations reached statistical significance, there was a general trend of improved sleep quality with increasing amount of exercise per week among morning exercisers but not evening exercisers.

Women with 50% to 80% attendance in the stretching sessions were

Table 2—Odds ratios (95% confidence interval) for the effect of a stretching (n=86) or exercise (n=87) intervention on sleep quality at follow-up compared to baseline* and the comparison of exercisers vs. stretchers (intent-to-treat)†.

Outcome	Baseline‡	3 mo	6 mo	9 mo	12 mo	P, trend§	Entire intervention period	Intent-to-treat (exercisers vs stretchers)
Poor sleep quality								
Stretching	1.0	0.9 (0.6, 1.3)	0.9 (0.6, 1.4)	1.2 (0.8, 1.9)	1.0 (0.7, 1.4)	.60	1.0 (0.7, 1.4)	
Exercise	1.0	1.0 (0.7, 1.6)	1.8 (1.1, 2.8) [¶]	1.3 (0.8, 2.2)	1.1 (0.6, 1.8)	.49	1.3 (0.9, 1.9)	1.1 (0.7, 1.7)
Sleep medication use								
Stretching	1.0	0.6 (0.3, 1.1) [¶]	0.3 (0.1, 0.6) [¶]	0.4 (0.2, 0.8) [¶]	0.5 (0.3, 1.1) [¶]	.05	0.4 (0.3, 0.7) [¶]	
Exercise	1.0	1.1 (0.6, 2.0)	1.0 (0.7, 1.6)	1.3 (0.8, 1.9)	0.9 (0.5, 1.8)	.93	1.1 (0.7, 1.7)	2.7 (1.4, 5.2) [¶]
Trouble falling asleep								
Stretching	1.0	0.8 (0.6, 1.2)	0.7 (0.4, 1.2)	0.6 (0.4, 0.9) [¶]	0.8 (0.5, 1.1)	.08	0.7 (0.5, 1.0) [¶]	
Exercise	1.0	0.9 (0.5, 1.6)	1.3 (0.8, 2.1)	1.0 (0.6, 1.7)	1.3 (0.8, 2.2)	.19	1.1 (0.7, 1.7)	1.2 (0.8, 1.9)
Short sleep duration								
Stretching	1.0	0.7 (0.4, 1.3)	1.3 (0.8, 1.9)	1.1 (0.7, 1.8)	1.0 (0.6, 1.7)	.55	1.0 (0.7, 1.5)	
Exercise	1.0	0.9 (0.5, 1.6)	0.9 (0.5, 1.6)	1.0 (0.6, 1.5)	0.9 (0.6, 1.6)	.86	0.9 (0.6, 1.4)	0.8 (0.4, 1.5)
Fall asleep during quiet activities								
Stretching	1.0	0.8 (0.6, 1.2)	0.8 (0.5, 1.2)	0.8 (0.5, 1.1)	1.0 (0.7, 1.4)	.84	0.8 (0.6, 1.1)	
Exercise	1.0	1.1 (0.8, 1.6)	1.1 (0.8, 1.6)	1.0 (0.7, 1.4)	1.2 (0.9, 1.8)	.44	1.1 (0.9, 1.4)	0.9 (0.6, 1.4)
Nap during the day								
Stretching	1.0	1.0 (0.7, 1.5)	0.9 (0.5, 1.3)	1.1 (0.8, 1.7)	1.2 (0.9, 1.8)	.18	1.0 (0.8, 1.4)	
Exercise	1.0	1.4 (1.0, 2.0) [¶]	1.3 (0.9, 1.9)	1.2 (0.8, 1.9)	1.4 (0.9, 2.0) [¶]	.31	1.3 (1.0, 1.8) [¶]	0.9 (0.6, 1.4)

*Adjusted for month questionnaire completed, time of intervention, job status, baseline marital status, amount of time spent outdoors at baseline, and baseline depression score.

†Analysis treats the stretchers as a true control group, comparing exercisers to controls; adjusted for baseline sleep measure.

‡Reference category.

§Tests the trend across the intervention period compared to baseline.

||Includes using medications or alcohol.

¶ $P \leq .05$

¶ $P \leq .10$

less likely to use sleep medications (OR: 0.2; 95% CI: 0.1, 0.8; $P = .02$) compared to women with less than 50% attendance; a similar decrease was observed for women with more than 80% attendance (OR: 0.4; 95% CI: 0.1, 1.6; $P = .18$) (Table 4). Although not significant, there appeared to be a decreased risk of poor sleep quality (OR: 0.5; 95% CI: 0.2, 1.2; $P = .13$) among stretchers with more than 80% attendance compared to those with less than 50% attendance.

Compared to the stretching group, exercisers had statistically significantly increased $VO_2\max$ (1% vs 12%, respectively) and decreased BMI (0.3 vs -0.3, respectively) over the year.²¹ However, there was no difference between the 2 groups for the change in amount of time spent outdoors ($P > .20$) over the year. Overall, subjects who increased their $VO_2\max$ by more than 10% during the intervention period were significantly less likely to have poor sleep quality (OR: 0.3; 95% CI: 0.1, 1.0; $P = .05$), have a short sleep duration (OR: 0.1; 95% CI: 0.05, 0.7; $P = .02$), or use sleep medications (OR: 0.2; 95% CI: 0.05, 0.9; $P = .03$) at 12 months compared to women whose $VO_2\max$ decreased or remained stable (Table 5). Further, participants who increased their $VO_2\max$ by more than 10% were somewhat less likely to fall asleep during quiet activities (OR: 0.4; 95% CI: 0.1, 1.1; $P = .08$), compared to women whose $VO_2\max$ decreased or remained stable. Reductions in BMI and increases in the amount of time spent outside during the intervention period did not have a clear consistent effect on sleep quality, although women who increased their time spent outdoors by more than 3 hours per week were somewhat less likely to fall asleep during quiet activities (OR: 0.4; 95% CI: 0.1, 1.1; $P = .08$) compared to those who decreased time spent outdoors. When we limited this analysis to exercisers only, we found similar trends; however, the CIs were much wider due to the smaller sample size.

DISCUSSION

Since disturbed sleep has multiple physical and emotional sequelae¹

and the use of sleep medications can have undesirable side effects,^{3,33} it is important to consider alternative methods for improving sleep quality. Our study explored the effects of a yearlong moderate-intensity aerobic exercise and a low-intensity stretching intervention on self-reported sleep quality in postmenopausal women. We examined whether changes in fitness, BMI, or time spent outdoors were associated with improved sleep quality and explored the potential modifying effects of the amount and timing of exercise. We found that subjects in both intervention groups reported some improvements in sleep quality, although the nature of the improvement differed between groups. It appeared that increased physical fitness, as indicated by a higher $VO_2\max$, was a strong indicator of improved sleep quality. Further, our results suggest that the effect of exercise on sleep quality may vary by the amount and timing of the exercise.

We found that 63% of participants reported at least 1 sleep problem at baseline (data not shown), which is consistent with an observational study in which 56% of 521 postmenopausal women not taking hormone replacement therapy reported having trouble sleeping over the previous 6 months.⁴ This same study also found that women with greater waist-to-hip ratios (overweight) had more trouble falling asleep than did women with lower ratios. The high percentage of subjects reporting sleep problems in our study may be due to the fact that we selected overweight women.

In an intent-to-treat analysis that considered the stretchers to be a true control group, we found little effect of the exercise intervention on sleep outcomes. This analysis did suggest that exercisers compared to stretchers had an increased risk of using sleep medication during the intervention. However, the adjusted pre-intervention and post-intervention comparison analyses among groups individually suggest that this was due to a decrease in sleep medication use by stretchers, while exercisers did not change. Similarly, exercisers had a nonsignificantly increased risk of trouble falling asleep compared to stretchers, but again this was due to the decreased risk of trouble falling asleep among stretchers, not due to a change among the exercisers. Therefore, although a pre-intervention-post-intervention comparison among individual groups is susceptible to confounding, we considered this analysis because the stretching control appeared to be acting as an intervention in this population.

Our study suggests that a stretching intervention may reduce the use of sleep medication or alcohol to help sleep and, potentially, may reduce trouble falling asleep, even though the attendance to stretching sessions was somewhat low. The effects were noticeable after only 3 months and stayed consistent throughout the intervention period. Our results are consistent with another study that reported that older men and women who participated in a stretching or flexibility intervention for 6 months

Table 3—Adjusted* odds ratios (95% confidence interval) for self-reported sleep quality, stratified by the average minutes per week of exercise over the previous 3 months and the time of day of exercise, among the exercise group only.

Outcome	<180 min/wk [‡]	180-225 min/wk [§]	≥225 min/wk [‡]	P, trend [¶]
Poor sleep quality				
Morning	1.0	1.0 (0.4, 2.7)	0.4 (0.1, 1.4)	.22
Evening	1.0	1.6 (0.5, 5.2)	1.3 (0.6, 3.0)	.40
Sleep medication use [#]				
Morning	1.0	1.1 (0.4, 2.6)	0.3 (0.1, 1.4)	.11
Evening	1.0	1.8 (0.5, 7.1)	2.0 (0.6, 7.1)	.25
Trouble falling asleep				
Morning	1.0	0.8 (0.2, 2.0)	0.3 (0.1, 0.8)**	0.12
Evening	1.0	3.5 (1.0, 12.0)**	3.3 (1.2, 8.8)**	0.01
Short sleep duration				
Morning	1.0	0.4 (0.1, 1.3)	0.5 (0.2, 1.4)	.15
Evening	1.0	0.8 (0.2, 3.1)	0.3 (0.1, 1.8)	.23
Fall asleep during quiet activities				
Morning	1.0	0.8 (0.3, 2.1)	1.3 (0.5, 3.1)	.64
Evening	1.0	1.3 (0.4, 4.5)	0.4 (0.1, 1.6)	0.21
Nap during the day				
Morning	1.0	1.0 (0.4, 2.3)	0.7 (0.3, 1.7)	.45
Evening	1.0	1.0 (0.2, 4.4)	0.6 (0.2, 2.0)	.48

*Adjusted for age, month questionnaire completed, job status, baseline marital status, baseline $VO_2\max$, baseline body mass index, time spent outdoors at baseline, and baseline depression score.

[†]n, morning/evening: 3 months=35/27, 6 months=18/21, 9 months=25/22, 12 months=32/24.

[‡]Reference category

[§]n, morning/evening: 3 months=9/5, 6 months=10/7, 9 months=11/5, 12 months=7/3.

[¶]n, morning/evening: 3 months=6/4, 6 months=22/8, 9 months=14/9, 12 months=11/9.

[¶]Tests the trend across categories of amount of exercise, separately for morning and evening exercisers.

[#]Includes using medications or alcohol.

** $P \leq .05$

Table 4—Adjusted* odds ratios (95% confidence interval) for self-reported sleep quality by percent attendance to weekly stretching sessions over the previous 3 months, among the stretching group only.

Outcome	0-50% attendance [‡]	50-80% attendance [§]	≥80% attendance [‡]	P, trend [¶]
Poor sleep quality	1.0	0.9 (0.4, 1.9)	0.5 (0.2, 1.2)	.20
Sleep medication use [#]	1.0	0.2 (0.1, 0.8)**	0.4 (0.1, 1.6)	.15
Trouble falling asleep	1.0	0.8 (0.4, 1.7)	0.7 (0.3, 1.8)	.48
Short sleep duration	1.0	1.7 (0.7, 4.0)	1.1 (0.4, 3.4)	.64
Fall asleep during quiet activities	1.0	1.4 (0.8, 2.4)	1.1 (0.6, 2.2)	.52
Nap during the day	1.0	0.7 (0.4, 1.2)	0.6 (0.3, 1.3)	.17

*Adjusted for age, month questionnaire completed, time of intervention, job status, baseline marital status, baseline $VO_2\max$, baseline body mass index, amount of time spent outdoors at baseline, and baseline depression score.

[†]n: 3 months=34, 6 months=40, 9 months=42, 12 months=41.

[‡]Reference category.

[§]n: 3 months=37, 6 months=28, 9 months=27, 12 months=32.

[¶]n: 3 months=15, 6 months=18, 9 months=17, 12 months=13.

[¶]Tests the trend across percentage attendance categories.

[#]Includes using medications or alcohol.

** $P \leq .05$

reported significant improvements in overall sleep quality, sleep latency, depth of sleep, and a sense of morning refreshment.¹⁶ Overall, these studies suggest that a stretching program may improve subjective sleep quality in older women.

It is unclear exactly how a stretching intervention may improve sleep quality. Our intervention consisted of learning specific stretches and relaxation techniques. These components may improve sleep quality through the use of relaxation techniques when in bed, increases in flexibility that reduce muscle stiffness, or general participation in an intervention study. Stretching or flexibility programs may work in a similar way as progressive muscle relaxation, which has been shown to improve subjective and objective sleep patterns in insomniacs.³⁰

We did not find significant effects of the exercise intervention on sleep quality among exercisers overall because the association between exercise and sleep appeared to differ by the amount and timing of exercise. Morning exercisers appeared to have improved sleep quality, particularly for trouble falling asleep, with increasing minutes per week of exercise. Our results for morning exercisers are consistent with previous randomized exercise trials, in which exercise usually occurred before dinner. These studies have reported improved sleep quality,^{12,13,16} longer sleep duration,^{13,17,18} shorter sleep latency,^{12,13,16} and more slow-wave sleep.^{14,15}

Evening exercisers did not show similar improvements with having trouble falling asleep as did morning exercisers, such that the evening exercisers who exercised the most had an increased risk of reporting having trouble falling asleep. One limitation in interpreting this result is that we did not collect information about the subjects' usual bedtimes. However, our data are consistent with an observational study of 23 elderly people, which reported that exercising in the morning, but not in the evening, was associated with improved sleep patterns.³⁴ A meta-analysis of the effect of acute exercise on sleep reported that exercising earlier, but not later, in the day was associated with improved sleep latency.²⁹ Further, in a survey of 1,600 middle-aged men and women, subjects reported that the balance of positive versus negative perceived effects of exercise on sleep was more favorable when exercise was performed early in the evening rather than late at night.³⁵ Conversely, several studies reported that moderate to vigorous exercise ending 30 minutes before bedtime did not substantially affect sleep latency, sleep time, or subjective sleep reports.³⁶⁻³⁸ However these studies had very small sample sizes (N=16, 8, and 5) of young, healthy men, possibly limiting the generalizability of these findings. One possible explanation for this disparity is that morning versus evening exercise may differentially modulate circadian rhythms that affect sleep quality.^{6,29} One study suggested that late evening exercise can cause a circadian phase delay³⁹; however, little else is known about the phase response curve for exercise.

The physiologic mechanisms underlying the relationship between exercise and sleep quality are still unclear but may include weight loss, increases in physical fitness, or increased exposure to outdoor light.^{18,40} We found little evidence to support increased light exposure or reductions in BMI as a possible mechanism because changes in these variables were not consistently associated with improvements in sleep quality. Our data instead suggest that improved sleep quality was associated with increases in physical fitness, suggesting that this may be a mechanism through which exercise improves sleep quality. King et al reported that treadmill duration on a VO₂max test was associated with increased sleep duration, decreased napping during the day, and reduced sleep latency.¹³ A 3-month fitness training program in 10 elderly men reported that increases in VO₂max were associated with reductions in fragmentation of the rest-activity rhythm.⁶ A review of both cross-sectional and prospective studies indicated that improved physical fitness was associated with improvements in total sleep time, sleep-onset latency, and time awake.⁴⁰ Thus evidence from multiple studies suggests that exercise may improve sleep quality through increasing physical fitness levels.

This study has several limitations. First, although the stretching group was designed to be the control group for the primary study outcomes, it had to be considered as a separate intervention with respect to sleep quality because stretching programs may themselves affect sleep patterns.¹³ Thus, we did not have a non-intervention control group, making a pre-intervention-post-intervention comparison the only feasible analysis scheme. However, we did compare exercisers versus stretchers and found few associations in that analysis. Therefore, it is possible that the changes we observed in the pre-intervention-post-intervention comparison reflect nonspecific effects of participating in an intervention trial, spontaneous improvements in sleep, or other behavioral artifacts. Second, our measure for the time of day of exercise is based only on a participant's usual exercise time at the training facility and not on the timing of exercise completed at home. Therefore, there is a potential for misclassification, which generally leads to conservative risk estimates.⁴¹ However, most of the participants in the evening classes worked, while most participants in the morning classes were retired or not working. It is likely then that the scheduling of the exercise sessions at home was similar to that of the exercise sessions at the facility. Third, only subjective sleep outcomes were available. While there may be some relationship between self-reported sleep patterns and more objective measures from polysomnography,^{28,42} the 2 measurement strategies may be assessing different aspects of the sleep experience.^{13,43,44} Although self-reported sleep quality is a subjective measure, it is important to note that an individual's perception of his or her sleep quality is a motivating factor

Table 5—Adjusted* odds ratios (95% confidence interval) for sleep quality at 12 months by percentage change in VO₂max, change in body mass index, and change in time spent outdoors from baseline to 12 months, including both exercisers and stretchers.

Outcome	Percentage increase in VO ₂ max			P, trend [‡]
	≤1% (n _{ex} =14, n _{st} =42) [†]	>1-10% (n _{ex} =18, n _{st} =21)	>10% (n _{ex} =40, n _{st} =13)	
Poor sleep quality	1.0	0.5 (0.2, 1.3)	0.3 (0.1, 1.0) [§]	.04
Sleep medication use	1.0	0.5 (0.1, 2.0)	0.2 (0.05, 0.9) [§]	.03
Trouble falling asleep	1.0	1.8 (0.5, 6.0)	0.6 (0.2, 1.7)	.53
Short sleep duration	1.0	0.6 (0.1, 3.2)	0.1 (0.05, 0.7) [§]	.04
Fall asleep during quiet activities	1.0	0.5 (0.2, 1.6)	0.4 (0.1, 1.1) [†]	.08
Nap during the day	1.0	0.5 (0.2, 1.3)	0.5 (0.1, 1.5)	.16
Outcome	Change in body mass index			P, trend [‡]
	Increased (n _{ex} =30, n _{st} =48) [†]	Decreased 0-1 kg/m ² (n _{ex} =25, n _{st} =19)	Decreased >1 kg/m ² (n _{ex} =17, n _{st} =9)	
Poor sleep quality	1.0	0.8 (0.3, 2.2)	1.4 (0.4, 4.4)	.71
Sleep medication use	1.0	0.2 (0.05, 1.5)	0.5 (0.1, 4.2)	.44
Trouble falling asleep	1.0	2.8 (0.9, 8.5) [§]	1.1 (0.2, 5.9)	.49
Short sleep duration	1.0	0.3 (0.05, 2.3)	2.2 (0.4, 11.1)	.92
Fall asleep during quiet activities	1.0	0.5 (0.2, 1.2)	1.3 (0.4, 3.7)	.93
Nap during the day	1.0	0.7 (0.2, 1.9)	0.5 (0.1, 1.8)	.25
Outcome	Change in time spent outdoors			P, trend ^{**}
	Decreased (n _{ex} =27, n _{st} =38)	Increased 0-3 hr/wk (n _{ex} =20, n _{st} =19)	Increased >3 hr/wk (n _{ex} =25, n _{st} =19)	
Poor sleep quality	1.0	2.4 (0.8, 7.5)	0.5 (0.1, 1.6)	.19
Sleep medication use	1.0	0.8 (0.1, 4.1)	0.7 (0.1, 3.1)	.62
Trouble falling asleep	1.0	4.2 (1.0, 17.3) [§]	1.4 (0.3, 6.1)	.82
Short sleep duration	1.0	1.2 (0.4, 4.0)	0.3 (0.1, 1.7)	.17
Fall asleep during quiet activities	1.0	0.7 (0.3, 1.8)	0.4 (0.1, 1.1) [†]	.08
Nap during the day	1.0	0.7 (0.2, 2.1)	1.1 (0.3, 3.7)	.85

n_{ex} refers to the number of exercisers; n_{st}, the number of stretchers.

*Adjusted for baseline sleep outcome, intervention group, age, time of intervention, job status, baseline marital status, baseline body mass index, baseline VO₂max, amount of time spent outdoors at baseline, and baseline depression score.

[†]Reference category.

[‡]Tests the trend across categories of percent increase in VO₂max

[§]P≤0.05

^{||}Includes using medications or alcohol.

^{††}P≤0.10

^{‡‡}Tests the trend across categories of change in body mass index

^{****}Tests the trend across categories of change in time spent outdoors

for seeking treatment. Fourth, because we made many comparisons, some statistically significant results could be due to type I error (ie, rejecting the null hypothesis when in fact the null hypothesis is true). However, in most cases, we found significant trend tests and similar patterns across multiple time points, providing evidence that our results are not spurious.

In conclusion, it appears that a stretching and relaxation program may reduce the need for sleep medications and help older women fall asleep more easily. Also, a moderate-intensity exercise program may improve subjective sleep-quality measures in postmenopausal women; however, the effect could depend on the amount of exercise and the time of day it is performed. Future studies should attempt to further clarify mechanisms through which stretching or exercise may improve sleep, as well as determine the quantity and timing of exercise that will be most beneficial.

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APPENDIX

Questions used in this study from the Women's Health Initiative Insomnia Rating Scale

The next questions are about your sleep habits. Please mark one of the answers for each of the following questions. Pick the answer that best describes how often you experienced the situation in the past 4 weeks.

	No, not in past 4 weeks	Yes, less than once a week	Yes, 1 or 2 times a week	Yes, 3 or 4 times a week	Yes, 5 or more times a week
A. Did you take any kind of medication or alcohol at bedtime to help you sleep?	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
B. Did you fall asleep during quiet activities like reading, watching TV, or riding in a car?	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
C. Did you nap during the day?	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
D. Did you have trouble falling asleep?	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
E. Overall, was your typical night's sleep during the <u>past 4 weeks</u> :					
<input type="checkbox"/> Very sound or restful					
<input type="checkbox"/> Sound or restful					
<input type="checkbox"/> Average quality					
<input type="checkbox"/> Restless					
<input type="checkbox"/> Very restless					
F. About how many hours of sleep did you get on a typical night during the <u>past 4 weeks</u> ?					
_____ hours per night					