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# *Sleep, Sleep Deprivation, and Daytime Activities*

# A Randomized Controlled Trial of the Effect of Exercise on Sleep

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**Summary**: We tested the hypothesis that exercise would improve subjective sleep quality and activity in depressed elders. A 10-week randomized controlled trial was utilized. Participants consisted of a volunteer sample, aged >60 with a diagnosis of major or minor depression or dysthymia. A total of 32 subjects aged 60–84 years with a mean age of 71.3 ± 1.2 years was used. Intervention consisted of a supervised weight-training program three times a week or an attention-control group. Main outcome measures were Pittsburgh Subjective Sleep Quality Index (PSQI), Likert Scale of Subjective Sleep Quality and Quantity, Paffenbarger Activity Index, Geriatric Depression Scale (GDS), Beck Depression Inventory (BDI), Hamilton Rating Scale of Depression (HRSD), and the Medical Outcomes Survey Short Form 36 (SF-36). Results showed that exercise significantly improved all subjective sleep-quality and depression measures. Depression measures were reduced by approximately twice that of controls. Habitual activity was not significantly increased by exercise. Quality of life subscales significantly improved. In a forward stepwise multiple regression, percent improvement in GDS and percent increase in strength remained significant predictors of the improvement in total PSQI score ($r$ = 0.71, p = 0.0002). In conclusion, weight lifting exercise was effective in improving subjective sleep quality, depression, strength, and quality of life without significantly changing habitual activity. **Key Words**: Exercise—Activity—Elderly—Sleep—Depression.

Most sleep surveys of the elderly report increased nocturnal awakenings and reduced quality of sleep (1). Such sleep disturbance is common because of the increased frequency of illness such as heart failure, respiratory complaints, sleep-disordered breathing, nocturia, pain, polypharmacy, menopausal status, headache, depression, and functional decline (2–6). In addition, factors such as inactivity, less light exposure, decreased arousal threshold, elevated-autonomic activity, and circadian-rhythm changes diminish the functional reserves for quality sleep as we age (7–9). However, when the effect of physical illness and medications are controlled for, the increase in insomnia associated with aging is almost nonexistent (2,10–12).

There are strong objective and subjective data demonstrating sleep disturbance in depressed elderly (13–17). Pharmacologic treatment of depression is effective in ameliorating sleep disturbance (18), while cognitive behavioral therapy appears to be less effective (19). However, compared to younger patients, sleep disturbance in the depressed elderly is likely to be multifactorial due to the medical-illness burden that accompanies advancing age and may correlate less with severity of depression and have a less predictable response to pharmacologic treatment (20). In addition, in the elderly, drugs for insomnia and depression are associated with many side-effects, including increased falls and confusion (21). An intervention that could treat depression, increase activity levels, and favorably affect co-morbity would be an attractive alternative treatment option for sleep disturbance in depressed elders. Exercise may be such an intervention.

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In large surveys, up to 80% of people spontaneously report exercise as a factor in promoting sleep (22,23). However, the experimental evidence for a positive effect of exercise on sleep is sparse and conflicting (24). Progressive resistance training (PRT), a specific form of weight-lifting exercise, has been demonstrated to be effective in reducing depression in clinically depressed populations (25–27). It also addresses much of the co-morbidity and physiological impairments of frailty, lacks the undesirable side effect profile of antidepressant medications in the elderly, may reduce falls, and has been associated with spontaneous increases in habitual physical activity (28,29). There is no published clinical trial of the effects of resistance-training exercise on sleep in either normals or clinical populations.

Therefore, we tested the following hypotheses: (1) progressive resistance training would improve subjective sleep quality in depressed elders and would concomitantly increase habitual physical activity levels, and (2) the increase in total (experimental exercise plus habitual) physical activity would correlate with improvement in subjective sleep quality.

## METHODS

### Study design

A complete description of study methods appears in Ref. 25. In brief, this was a randomized, controlled, 10-week clinical trial in which depressed subjects received either a progressive resistance-training program or a health-education program. The study was approved by the Human Investigations Committee at the New England Medical Center and written, informed consent was obtained from each subject.

### Study population

Volunteers were recruited from the community through two volunteer databases: the Jean Mayer USDA Human Nutrition Research Center on Aging (HNRC) and the Harvard Cooperative on Aging.

Subjects included in the study were aged >60 and fulfilled Diagnostic and Statistical Manual of Mental Disorders IV diagnostic criteria (DSMIV) (30) for either unipolar major or minor depression or dysthymia.

Subjects were excluded if demented clinically by DSMIV criteria, if their Folstein Mini Mental State (31) score was <23 or if they were suffering with unstable ischemic heart disease or recent myocardial infarction (MI) (<6 months). Other excluding factors were severe progressive neurological disease, symptomatic inguinal hernia, bipolar disorder, active psychosis, or suicidal plans; subjects were also excluded if currently seeing a psychiatrist or on antidepressant drugs (currently or in the last 3 months) or participating in any progressive resistance training. Subjects participating in aerobic exercise more than twice a week in the month prior to enrollment were also excluded.

A total of 32 subjects was enrolled in the study. Results are presented for 28 of these subjects who had sleep outcomes assessed. Four subjects had commenced the study prior to collection of sleep outcomes.

### Intervention

Subjects assigned to exercise training underwent a regimen of high-intensity progressive resistance training of the large muscle groups, 3 days a week for 10 weeks. These muscle groups were chosen for their importance in functional activities. Exercise machines included chest press, overhead pulldown, leg press, knee extension, and flexion (Keiser Sports Equipment, Inc., Fresno, CA). For each machine, the resistance was set at 80% of the one repetition maximum (the maximal load that could be lifted fully one time only) (32). To maintain the intensity of the stimulus, the load was increased at each session as tolerated by the subjects. Strength testing was repeated at 4 weeks to establish a new baseline value. Each session lasted approximately 1 hour and was followed by 5 minutes of stretching. All sessions were supervised. Ninety percent of the supervised sessions were conducted by the P.I. (N.A.S.). Due to rolling recruitment, the size of the group varied from one to eight subjects being trained simultaneously. Discussion of depression was minimized. All sessions occurred at the HNRC.

### Control group

All subjects not randomly assigned to resistance training engaged in a health-education program designed as an attention control group. The program was in an interactive form of lectures and videos followed by discussion with participation encouraged. Topics were tailored to subjects' requests and included general nutrition, vitamins, heart disease, first aid, falls, incontinence, medical ethics, eye and ear disease, etc. The group met 2 days a week for 1 hour each session. All sessions were supervised. Eighty-six percent of supervised sessions were conducted by the P.I. (N.A.S.) and discussion of depression was minimized. All sessions occurred at the HNRC and the group size varied from one to nine subjects participating simultaneously.

Subjects in both groups were asked not to commence any new exercise regimen other than that which had been prescribed within the study during the

10-week intervention. Transportation costs were provided for all subjects.

### Outcome measures

Baseline demographics, medical history and exam, strength, and the diagnostic psychiatric interview were performed by the P.I. (N.A.S.) at baseline and at 10 weeks. The Pittsburgh Sleep Quality Index (PSQI), Likert Scales of Quality and Quantity of Sleep, and the Beck Depression Index (BDI) were self-administered. All other outcome measures reported were performed by a blinded assessor (K.M.C.).

### Sleep

Subjective sleep quality was measured by the PSQI, a self-rated questionnaire assessing subjective sleep quality over a 1-month time interval. There are 19 individual items that generate seven component scores to give a total score reflecting subjective sleep quality (0–21), with higher scores reflecting poorer sleep quality. It is a valid, sensitive, and specific measure of subjective sleep quality in the elderly and depressed (33,34). In addition to reporting total scores as a continuous variable, subjects were dichotomized into "poor" sleepers (PSQI $> 5$) and "good" sleepers (PSQI $\leq 5$) according to previous methodology (34) at baseline and 10 weeks. In addition to the above long-term measures of subjective sleep quality, we used a short-term measure to capture the subjects' sleep during the final week of the intervention period when the intervention effect would be hypothesized to be maximal. Therefore, a Likert scale, as has been previously used in many studies for self-report of symptoms, was administered (35). Two Likert scales were used: one of sleep quantity and one of sleep quality over the last 7 days. The scales were 10-inches long and graded in 0.5-inch intervals from zero to 10. Zero represented the worst subjective sleep quality and quantity and 10 the optimal quantity and best quality of sleep imaginable. Subjects were asked at baseline and 10 weeks to place an "X" on each of these scales representing their last seven nights' sleep.

### Activity

Subjective activity was assessed by the Paffenbarger Activity Index (36). This gives a measure in kilocalories of energy expenditure over a 7-day period and includes subscales of walking, stairclimbing, and other activities. Data were collected blindly by K.M.C. and habitual activity (e.g. outside of the prescribed exercise) was totaled. The P.I. (N.A.S.) also calculated the total activity level by the addition of habitual activity at 10 weeks with prescribed exercise calculated on the number of sessions trained in week 10 and their kilocalorie equivalent.

### Depression

The primary self-rated measure of depression was the Geriatric Depression Scale (GDS) (score 0–30). It was chosen as it contains exclusively psychological symptoms and no direct measure of sleep disturbance. Additionally, it is known to be valid, sensitive, and specific in the elderly (37). The BDI (score 0–63), also validated in the elderly (38), was a secondary self-reported measure that captured intensity of both psychological and somatic symptoms (39). The Hamilton Rating Scale of Depression (HRSD) 17-item scale (score 0–52) (40) was the therapist-rated measure and was chosen to allow comparison with prior published work in exercise and clinically depressed populations (27). Higher scores on all depression measures reflect worsening depression.

### Quality of life

This was assessed by the Medical Outcomes Survey Short Form (SF-36). This questionnaire measures eight domains, each ranging from zero to 100 with higher scores reflecting a higher quality of life. It is a reliable and valid measure in community dwelling elderly (41).

### Food frequency questionnaire

The modified Gladys Block Food Frequency Questionnaire (42) was administered by a blinded diet technician over the telephone at baseline to capture habitual food intake over the prior 4 months. Results of alcohol and caffeine usage are reported.

### Physiological measures

The one repetition maximum (1RM) was used to determine strength change. This is defined as the maximum weight that could be lifted correctly for one repetition within 5° of full range of motion. To minimize improvement related to repeat testing, the better of two measures taken at least 48 hours apart was used as the baseline value (32). Strength is reported as the summation of all five exercises in Newtons taking the best 1RM at baseline and 10 weeks. Weight was obtained after overnight fasting, and height was measured with a stadiometer from which BMI ($kg/m^2$) was calculated.

**TABLE 1.** *Baseline characteristics*

| Variable | Exercise (n = 15) | Control (n = 13) | p value |
|---|---|---|---|
| Age (years) | 70.0 ± 1.6 | 72.0 ± 1.9 | 0.27 |
| Range | (61–82) | (60–84) | |
| Gender | | | 0.50 |
| Male | 5 | 6 | |
| Female | 10 | 7 | |
| Body mass index (kg/m$^2$) | 29.4 ± 1.3 | 26.2 ± 1.0 | 0.07 |
| Duration of any symptoms of depression (months) | 24 ± 9 | 32 ± 14 | 0.62 |
| Known sleep disorder (OSA, restless legs, etc.) | 0 | 0 | |
| Sleep medication usage (n) (months prior to study) | 4 | 3 | 0.82 |
| Benzodiazepine usage (n) | 1 | 1 | 0.94 |
| Diphenhydramine/acetaminophen usage (n) | 3 | 2 | 0.72 |
| Ethanol (g/day) | 3.6 ± 1.5 | 7.4 ± 4.7 | 0.40 |
| Caffeine (g/day) | 198.1 ± 38.2 | 144.0 ± 15.2 | 0.23 |

**TABLE 2.** *Sleep outcomes*

| Variable | Exercise (n = 15) | Control (n = 13) | Baseline p value | Time p value | Group × time p value |
|---|---|---|---|---|---|
| PSQI total | | | | | |
| Pre | 9.1 ± 1.3 | 7.2 ± 1.3 | 0.8 | 0.02 | 0.006 |
| Post | 6.4 ± 1.4 | 7.5 ± 1.2 | | | |
| PSQI subscales: | | | | | |
| Sleep quality subscale | | | | | |
| Pre | 1.4 ± 0.3 | 1.3 ± 0.3 | 0.94 | 0.005 | 0.32 |
| Post | 0.9 ± 0.2 | 1.1 ± 0.2 | | | |
| Sleep latency subscale | | | | | |
| Pre | 1.2 ± 0.3 | 0.8 ± 0.3 | 0.92 | 0.54 | 0.04 |
| Post | 0.7 ± 0.3 | 1.2 ± 0.3 | | | |
| Sleep duration subscale | | | | | |
| Pre | 1.7 ± 0.3 | 1.2 ± 0.3 | 0.52 | 0.16 | 0.19 |
| Post | 1.3 ± 0.3 | 1.2 ± 0.3 | | | |
| Sleep efficiency subscale | | | | | |
| Pre | 1.3 ± 0.3 | 0.8 ± 0.2 | 0.43 | 0.53 | 0.16 |
| Post | 1.0 ± 0.3 | 0.9 ± 0.3 | | | |
| Sleep disturbance subscale | | | | | |
| Pre | 1.4 ± 0.1 | 1.2 ± 0.2 | 0.85 | 0.59 | 0.12 |
| Post | 1.1 ± 0.2 | 1.4 ± 0.2 | | | |
| Sleep medications subscale | | | | | |
| Pre | 0.5 ± 0.3 | 0.5 ± 0.3 | 0.76 | 0.42 | 0.45 |
| Post | 0.3 ± 0.2 | 0.5 ± 0.3 | | | |
| Daytime dysfunction subscale | | | | | |
| Pre | 1.6 ± 0.2 | 1.2 ± 0.2 | 0.65 | 0.02 | 0.08 |
| Post | 1.0 ± 0.2 | 1.2 ± 0.2 | | | |
| Likert sleep quality | | | | | |
| Pre | 4.5 ± 0.6 | 6.0 ± 0.8 | 0.93 | 0.05 | 0.008 |
| Post | 6.8 ± 0.7 | 5.5 ± 0.7 | | | |
| Likert sleep quantity | | | | | |
| Pre | 5.0 ± 0.7 | 6.0 ± 0.8 | 0.78 | 0.008 | 0.12 |
| Post | 7.2 ± 0.7 | 6.7 ± 0.5 | | | |

### Statistical analysis

Continuous data are described as mean ± standard error or median and range, as appropriate. All statistical tests were two-tailed. Baseline differences in group characteristics were analysed by unpaired *t* tests for continuous variables and chi square or Fisher's exact test for categorical data. Analysis of change in sleep category was analyzed by the chi square test. Repeated measures ANOVA was used to analyze the effect of time and treatment for all outcome variables at baseline and 10 weeks. Gender was used as a between subjects factor as appropriate. Relationships between variables of interest were analyzed by simple and forward stepwise multiple regression models, as appropriate. Statistical significance was accepted at $p < 0.05$.

## RESULTS

### Characteristics of subjects

Baseline characteristics are summarized in Tables 1–3. There were no significant differences in any demographic, physiological, psychological, sleep, or activity measures at baseline. As previously reported (25), this group was highly functional, predominantly white, and community dwelling, with no differences in baseline quality of life, function, and number or type of medical diagnoses.

### Compliance and adverse events

All randomized subjects completed the 10-week study. Median compliance in the exercise group was 93% (range 45–100%) and 95% in the control group (range 44–100%). One subject in the exercise group was referred to a psychologist due to increasing sui-

**TABLE 3.** *Depression and strength outcomes*

| Variable | Exercise (n = 15) | Control (n = 13) | Baseline p value | Time p value | Group × time p value |
|---|---|---|---|---|---|
| GDS pre | 17.5 ± 1.7 | 13.0 ± 1.4 | 0.43 | 0.001 | 0.005 |
| GDS post | 9.7 ± 1.9 | 10.5 ± 1.7 | | | |
| BDI pre | 21.6 ± 1.9 | 17.0 ± 1.5 | 0.53 | 0.0001 | 0.01 |
| BDI post | 10.8 ± 2.6 | 11.8 ± 1.8 | | | |
| HRSD pre | 12.1 ± 0.9 | 11.3 ± 1.4 | 0.62 | 0.0001 | 0.06 |
| HRSD post | 5.8 ± 1.4 | 8.1 ± 1.3 | | | |
| Strength (n) | | | | | |
| Pre | 2,516 ± 180 | 2,935 ± 359 | 0.98 | 0.0001 | 0.0001 |
| Post | 3,293 ± 214 | 2,861 ± 345 | | | |
| Strength change (%) | 32.0 ± 4.7 | 0.4 ± 2.9 | 0.84 | 0.0001 | 0.0001 |

cidality at 6 weeks but was not treated with antidepressant medication.

## Primary outcomes

### *Sleep*

The exercise intervention significantly improved both long-term (PSQI) and short-term (Likert Scale) measures of self-reported subjective sleep quality compared to the control group (see Table 2). The direction and magnitude of this effect was similar for both measures. There was no significant effect of gender on subjective sleep quality at baseline or in response to the intervention. Using a cut-off on the PSQI of ≤5 as "good" sleepers and >5 as "poor" sleepers, 10/15 exercisers (66%), were classified as "poor" sleepers at baseline compared to 7/13 controls (53%), p = ns. At 10 weeks, 4/15 (26%) of exercisers were classified as "poor" sleepers and 9/13 (69%) of controls were so classified. Exercise was significantly better at improving sleep on a categorical basis: 6/15 improved, 0/15 worsened, and 9/15 remained the same. In the control group 0/13 improved, 2/13 worsened, and 11/13 remained the same; this difference between groups was significant (p = 0.017).

### *Activity*

Baseline activity levels did not correlate significantly with any depression measure or PSQI score. Habitual physical-activity level was not significantly altered over time or by group assignment. Total physical-activity level (inclusive of the intervention) was significantly higher over time and with exercise group assignment (p = 0.008). Strength increased significantly in exercisers compared to controls (see Table 3).

### *Depression*

Baseline GDS score did not correlate significantly with the PSQI. Both self- and therapist-rated scales of depression were significantly improved over time and by exercise. The magnitude of the antidepressant effect in the exercisers was 2–3 times greater than controls (Table 3).

### *Quality of life*

For detailed results see Ref. 25. Briefly, of the eight subscales of the SF-36, Physical functioning, Vitality, Social functioning, Role emotional, and Mental health were improved over time in both groups. Vitality, Bodily pain, Role emotional, and Social functioning were significantly improved by exercise compared to the control condition, General health showed a trend (p = 0.06) toward improvement in the exercise group only.

The percent change in sleep score (PSQI) was correlated with the percent improvement in depression score (GDS) ($r$ = 0.65, p = 0.0002), percent increase in strength ($r$ = 0.56, p = 0.002), absolute improvement in Bodily pain ($r$ = 0.40, p = 0.03), absolute improvement in General health ($r$ = 0.40, p = 0.03), and absolute increase in total activity ($r$ = 0.40, p = 0.03). In a forward stepwise multiple regression model in which these five variables with univariate associations with sleep improvement were entered, percent improvement in depression and percent increase in strength remained significant predictors of the improvement in subjective sleep quality ($r$ = 0.71, p = 0.0002).

## DISCUSSION

This is the first randomized controlled trial to document that exercise improves subjective sleep quality. A clinical appreciation of the degree of sleep impairment in our subjects and quantification of the effect of exercise that we observed in this study can be indirectly extrapolated from the literature. In a longitudinal study of 27 healthy 60–74-year olds with baseline HRSD scores of 0. 7, a mean PSQI score of 3.4 was found, and it remained relatively stable over 2 years

(12). In a group of 34 mixed inpatients and outpatients with major depression (34) of mean age 50.9 years and a HRSD score of 21.3, the mean PSQI was 11.09. Our exercise group, with mixed major and minor depression and a mean age of 70, with mean HRSD score of 12.5, had a baseline PSQI of 9.1, suggesting moderate sleep impairment. The reduction of 35% in mean PSQI score over 10 weeks, as well as the significant categorical change from poor to good sleepers, attests to the clinical significance of the exercise effect. We attempted to address the question of whether our subjects' subjective perception of poor sleep or its improvement was reflective of objective change in sleep pattern by using wrist-worn sleep and activity monitors (Ambulatory Monitoring, Inc., New York, NY). However, due to technical problems, data were retrievable in only a small subset of our subjects. This area requires further investigation in randomized controlled trials and geriatric populations to determine whether objective or subjective measures of sleep quality and quantity best reflect clinical disability and change.

The effect of both acute and chronic exercise on sleep has been reviewed by Trinder et al. (24), and the effect of exercise on sleep has been largely studied by the objective measure of polysomnography. Due to methodological problems in most of these studies, the efficacy of exercise in this regard remains controversial. There are no randomized trials of resistive exercise and the majority of studies are negative, reporting no changes in slow-wave (SWS) or REM sleep and sleep duration following acute or chronic exposure to exercise. Positive studies are predominantly reported in single bouts of exhaustive exercise (24). There are two studies in power lifters. The first tested 10 lifters with a mean age of 22.5 years, training a minimum of 2 hours per day, 5 days a week, for at least 12 months. They were studied on two consecutive nights when training and when not training during the day. There were no differences in any polysomnographic variables reported (43). The only other study relevant to weight-lifting exercise was a cross-sectional comparison of power lifters, non-athletic sedentary individuals, aerobically-trained long-distance runners, and football players who combined aerobic, anaerobic, and power training. Slow-wave sleep was highest in the aerobic and lowest in the power-trained group, with the mixed and control groups intermediate and equivalent to each other. Sleep duration and latency showed the same trend as SWS but failed to reach significance (44). None of the sleep and physical activity literature is reported in populations similar in demography, health status, or physiological characteristics to our subjects.

The depression of aged individuals is contributed to by many losses, including health, function, loved ones, and societal worth. Our depression measures (both self- and therapist-rated) were improved by a difference of two- to three-fold compared to controls at the end of the trial. In explaining our improvement in subjective sleep quality, our results indicated that improvement in depression, quality of life (bodily pain and general-health perception), and total energy expenditure in physical activity and strength were correlated with changes in sleep. While our multivariate model indicated that a large portion of the improvement in sleep was predicted by improvement in depression, increases in strength also independently predicted the sleep changes observed. In clinical practice, the sleep-disturbed, depressed elderly usually suffer from a combination of physical illness, functional impairment, and reduced-activity level. They, therefore, have an elevated risk for falls, confusion, and other adverse effects of sedating and antidepressant medications (21). We find it plausible that both psychological and physical change could impact sleep disturbance in this population and, therefore, progressive resistance training may represent a unique intervention that addresses both of these mechanisms while potentially lowering fall risk.

In conclusion, progressive resistance training has demonstrated benefits on subjective sleep quality, and further research is needed to confirm and extend these findings in both depressed and sleep-disturbed geriatric populations, where, as a single intervention, it may address multiple contributors to disturbed sleep. Clarification of its mechanism of action would be aided by future randomized controlled trials comparing different modalities of exercise to standard treatment for depression, as well as the employment of both objective and subjective measures of sleep and activity as outcomes.

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