Published in final edited form as:

Med Sci Sports Exerc. 2015 May ; 47(5): 960–966. doi:10.1249/MSS.0000000000000506.

Decline in Cardiorespiratory Fitness and Odds of Incident Sleep Complaints

Rodney K. Dishman¹, Xuemei Sui², Timothy S. Church³, Christopher E. Kline⁴, Shawn D. Youngstedt⁵, and Steven N. Blair^{2,6}

¹Department of Kinesiology, University of Georgia, Athens, GA

²Department of Exercise Science, University of South Carolina, Columbia, SC

³Pennington Biomedical Research Center, Baton Rouge, LA

⁴Department of Psychiatry, University of Pittsburgh School of Medicine, Pittsburgh, PA

⁵College of Nursing and Health Innovation and School of Nutrition and Health Promotion, Arizona State University, Phoenix, AZ

⁶Department of Epidemiology and Biostatistics, University of South Carolina, Columbia, SC

Abstract

Purpose—To examine longitudinal change in cardiorespiratory fitness and odds of incident sleep problems.

Methods—A cohort of 7368 men and 1155 women, aged 20–85 years, from the Aerobics Center Longitudinal Study. The cohort did not complain of sleep problems, depression, or anxiety at their first clinic visit. Cardiorespiratory fitness assessed at 4 clinic visits between 1971–2006, each separated by an average of 2–3 years, was used as a proxy measure of cumulative physical activity exposure. Sleep complaints were made to a physician during follow-up.

Results—Across visits, there were 784 incident cases of sleep complaints in men and 207 cases in women. After adjustment for age, time between visits, body mass index, smoking, alcohol use, chronic medical conditions, complaints of depression or anxiety at each visit, and fitness at Visit 1, each minute decline in treadmill endurance (i.e., a decline in cardiorespiratory fitness of approximately one-half MET) between ages 51 to 56 increased the odds of incident sleep complaints by 1.7% (1.0–2.4%) in men and 1.3% (0.0–2.8%) in women. Odds were ~8% higher per minute decline in people with sleep complaints at 2 or 3 visits.

Conclusion—The results indicate that maintenance of cardiorespiratory fitness during middle-age, when decline in fitness typically accelerates and risk of sleep problems is elevated, helps protect against the onset of sleep complaints made to a physician.

Copyright © 2014 American College of Sports Medicine

Address correspondence to: Rodney K. Dishman, PhD, Department of Kinesiology, University of Georgia, Ramsey Student Center, 330 River Road, Athens, Georgia 30602-6554. rdishman@uga.edu. Phone (706) 542-9840; Facsimile (706) 542-3148.

This work was performed in the University of Georgia.

Conflicts of Interest: None. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Keywords

exercise capacity; sleep; clinic complaints

INTRODUCTION

Poor sleep is recognized as a public health burden (17). Several medical conditions and chronic diseases (e.g., coronary heart disease, hypertension, obesity, diabetes, and metabolic syndrome) are associated with poor sleep, which also contributes to emotional distress and impairment of daytime function. About 17%–24% of middle-aged men and women in the U.S. report trouble falling or staying asleep, or sleeping too much, during the past two weeks (14). About half of people who seek treatment for poor sleep will receive a drug prescription, usually a hypnotic, anxiolytic benzodiazepine, or a serotonergic antidepressant (35), that will have varying efficacy and often uncertain safety with long-term use (6,25,28). Many people who do not seek treatment purchase over-the-counter sleep aids or use alcohol to get to sleep at night, which then disrupts sleep during the night (33). The cumulative evidence suggests that regular exercise may compare favorably with other behavioral options (6) for successful management of sleep disturbance.

Randomized controlled trials of exercise training have shown improvements in ratings of sleep quality in middle-aged or older healthy adults (19,20), post-menopausal women (24), and older adults diagnosed with depression (37) or primary insomnia (34); better daytime functioning in patients with sleep apnea (22); and favorable changes in polysomnographic measures of sleep disturbance, as well as ratings of sleep quality, in a non-clinical sample of adults with mild-to-moderate sleep complaints (21).

In contrast to studies of whether exercise improves sleep in people with sleep problems, much less research has focused on whether regular physical activity protects against the onset of sleep problems. In one study, older adults who reported frequent physical activity had a lower incidence of insomnia symptoms over 3 years compared to their sedentary peers (16). In another recent study, midlife women who consistently reported high levels of recreational physical activity over a 5–6 year span had significantly better sleep quality, sleep continuity and sleep depth, via self-report and polysomnographic assessments, compared to their inactive counterparts (23). However, in both of these prospective studies, physical activity was limited to self-report. Moreover, other epidemiological studies reporting an association between physical activity and lower odds of sleep complaints used cross-sectional designs or also relied on self-reports of physical activity and classifications of people into activity groups that were not equivalent across studies (30,39). None concurrently assessed objectively measured change in physical activity exposure, sequential measures of outcome, and discounted residual confounding by fluctuating traits common to physical inactivity and risk of sleep disturbance, including psychiatric co-morbidities such as depression and anxiety (36).

Cardiorespiratory fitness (CRF) provides an objective, surrogate measure of change in habitual physical activity exposure. The decline in CRF seen in healthy adults during ages 40–60 years, when problems of sleep duration and poor quality are elevated (8,14), is best

explained by reduced moderate-to-vigorous physical activity, after accounting for age, body mass index (BMI), and smoking (18). In a prior cross-sectional analysis of 2033 women and 1840 men from the Nord-Trøndelag Health Study, there was an inverse relation between CRF and insomnia symptoms that was independent of age, gender, BMI, cardiovascular risk factors, alcohol use, smoking, and symptoms of depression or anxiety (38). To extend those temporally uncertain findings to a prospective analysis of changing exposure, we hypothesized that steeper declines in CRF among men and women from the Aerobics Center Longitudinal Study (ACLS) cohort would be associated with higher odds of incident sleep complaints made to a physician.

METHODS

Study population

The ACLS is a prospective epidemiological study investigating health outcomes associated with physical activity and CRF at the Cooper Clinic, Dallas, TX (4). Participants elected to come to the clinic for periodic preventive medical examinations and for counseling regarding health and lifestyle behaviors, including diet and physical activity. The clinic broadly markets its services via mass media and among occupational groups and serves patients from all 50 states. Many participants were sent by their employer, some were referred by their physicians, and others were self-referred. At the time of their first clinic examination, the ACLS was described to patients who then provided written informed consent (nearly 100% of patients examined) for enrollment in the follow-up longitudinal study. The study protocol was approved annually by the Cooper Institute's Institutional Review Board.

All ACLS participants received comprehensive preventive medical examinations and maximal graded treadmill exercise tests. Between 1971 and 2006, 9503 participants aged 20–85 (14% of the enrolled population) without complaints of sleep problems, depression, and anxiety at their first clinic visit received at least four comprehensive medical examinations and maximal graded treadmill exercise tests at routine clinic visits. Participants were excluded from analysis if they did not achieve at least 85% of age-predicted maximal heart rate during the treadmill test ($n=289$) or had missing data on any covariate other than body mass index (BMI, $n=691$). Thus, 7368 men and 1155 women were included for analysis. The median (lower to upper quartile range) of the duration between Visit 1 and Visit 2, Visit 2 and Visit 3, and Visit 3 and Visit 4 was 1.13 (1.0 to 2.1), 1.19 (1.0 to 2.2), and 1.36 (1.0 to 2.6) years, respectively. Most participants were non-Hispanic whites, relatively well-educated, and from middle and upper socioeconomic strata.

Measures

Cardiorespiratory fitness—CRF was defined as the total time of a symptom-limited maximal treadmill exercise test, using a modified Balke protocol. The treadmill speed was 88 meters per minute for the first 25 minutes. The grade was 0% for the first minute, 2% for the second minute, and then increased 1% each subsequent minute until 25 minutes had elapsed. After 25 minutes, the grade remained constant while the speed increased 5.4 meters each minute until test termination. Patients were encouraged to give a maximal effort, and

the test endpoint was volitional exhaustion or termination by the physician for medical reasons. The mean (standard deviation, SD) percentage of age-predicted maximal heart rate (HR) achieved during exercise was 101.5% (6.6%). Total time of the test using this protocol correlates highly with measured maximal oxygen uptake in both men ($r = 0.92$) (31) and women ($r = 0.94$) (32). Thus, CRF in this study is analogous to maximal aerobic power defined as METs (1 MET = 3.5 mL O₂ uptake per kilogram body weight per minute) when estimated from the final treadmill speed and grade (1). Each minute of maximal treadmill test time reported here predicted 0.49 maximal METs (SEE = 0.27, $r = .993$) for men and 0.46 maximal METs (SEE = 0.15, $r = .997$) for women. The exam included measurement of ECG during rest and exercise. Abnormal exercise ECG responses were broadly defined as rhythm and conduction disturbances or ischemic ST-T wave abnormalities. Trained laboratory technicians, with physician supervision, administered the exercise tests and other procedures according to a standardized manual of operations. At Visit 1, maximum HR (mean $\pm$ SD, bpm) was 175 ± 13 for women and 176 ± 14 for men. Maximum HR at subsequent visits did not differ ($p > .10$) between incident cases of sleep complaints and non-cases at subsequent visits.

Sleep Complaints—Sleep complaints were obtained from archived physician charts by the medical staff after follow-up to patient responses on a standardized medical history questionnaire that asked patients to indicate (yes or no) “whether you have ever had a significant problem with any of the symptoms or conditions listed below: difficulty sleeping” and whether difficulty sleeping was a current problem (“Is this still a problem?”). Complaints of depression and anxiety symptoms were assessed the same way.

Other measures—Height and weight were measured on a standard physician’s balance beam scale and stadiometer. Body mass index (BMI) was computed as weight (kg)/height (m)². Random missing BMI observations (because of manual recording omissions of either height or weight) were 13% of all observations and were replaced by the mean of 10 imputations using a maximum likelihood estimator (29). Resting blood pressure was measured using standard auscultation methods after a brief period of quiet sitting. Blood chemistry was analyzed for lipids and glucose using standardized automated bioassays. Hyperlipidemia was defined as fasting total cholesterol ≥ 6.2 mmol/L (240 mg/dL) or triglyceride ≥ 2.26 mmol/L (200 mg/dL). Individuals who reported a history of physician-diagnosed hypertension or who had blood pressure $\geq 140/90$ mmHg at the examination were classified as having hypertension. Diabetes was defined as a fasting glucose level ≥ 7.0 mmol/L (126 mg/dL), physician diagnosis, or treatment with insulin. Information on smoking habits (current smoker or not), alcohol intake (drinks per week), and other medical conditions (yes or no) was obtained from a standardized medical history questionnaire. Number of medical conditions was the sum of the seven medical conditions (heart attack, stroke, cancer, diabetes, hypertension, hyperlipidemia, and abnormal resting or exercising ECG).

Statistical analyses

Latent transition and class analysis—Participants in the cohort were classified as incident cases and non-cases at a subsequent clinic visit using latent transition analysis

(LTA) on observed cases and non-cases performed by *Mplus* 7.11 (29). LTA provided Bayesian probability estimates of people being classified as having a sleep complaint or not at Visits 3 and 4 given their sleep status at preceding Visits 2 and 3. Model fit was tested using a robust maximum likelihood ratio test. The number of classes for incident cases between Visits 2 and 4 (i.e., patterns of change) was tested by a significant chi-square change (χ^2) estimated by a bootstrapped likelihood ratio test.

Latent growth modeling—Trajectories of change in treadmill test duration in minutes were estimated using latent growth modeling (LGM) (5) in *Mplus* 7.11 after multivariate adjustment of treadmill time for between-participant differences in the covariates measured at each visit (simultaneous adjustment of the time varying covariates in LGM would not converge because of low within-participant variation in the covariates). The following covariates were included in the model: age at visit one, time between visits, BMI, smoking (yes/no), alcohol use, number of medical conditions, and complaints of depression or anxiety. The change latent variable was modeled twice – first using just a linear change function and second using both linear and quadratic change functions. Robust maximum likelihood parameters and their standard errors were estimated for initial status (i.e., mean at baseline), change (i.e., slope of differences across the 4 clinic visits), and the variances (i.e., inter-individual differences) of initial status and change.

Baseline status and change in CRF were compared between the two classes (i.e., cumulative incident cases vs. non-cases) using χ^2 difference tests (χ^2) between a freely estimated baseline model and a nested model in which parameters were constrained to be equal between the groups. Model fit was evaluated with multiple indices, including the comparative fit index (CFI), Tucker Lewis index (TLI), the root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR) (15).

Logistic regression analysis—Logistic regression analysis using maximum likelihood estimation was performed in SPSS 21.0 to determine the odds that initial values and change functions (i.e., orthogonal contrasts for linear or quadratic trends) identified by the LGM for adjusted CRF across visits could accurately predict cases of incident sleep complaints (i.e., cumulative cases and non-cases defined the binary dependent variable). The group that never complained of sleep problems (i.e., non-cases) was the reference for all logistic odds-ratios. Statistical significance of likelihood ratios and goodness of model fit were tested by χ^2 tests. Sensitivity analysis tested the model while excluding first incidence cases at Visits 2 and 3 to help rule out a selection bias of early insomnia preceding the decline in fitness. Similarly, the decline in CRF was compared between the latent classes of cumulative cases and non-cases to estimate the decline in CRF among the patients most likely to have sleep complaints during Visits 2–4.

RESULTS

Latent Transition and Class Analysis

Prevalence of sleep complaints was 3.4%, 5.3%, and 7.2% of the cohort of men and 5.7%, 8.3%, and 12.4% of the cohort of women at Visits 2–4 (Table 1). There were 251, 389, and 532 first-incident cases of sleep complaints at Visits 2–4 in men and 66, 96, and 143 first-

incident cases in at Visits 2–4 in women. Table 2 shows that over all three follow-up visits, there were 784 incident cases in men and 207 in women. Cumulative incident rates were 10.6% in men and 17.9% in women (Table 2). Fit of the LTA model was good for men ($\chi^2(46)=50.7$, $P=0.293$) and women ($\chi^2(46)=10.0$, $P=1.00$). Probabilities of incident cases at Visits 3 and 4 were 3.6% and 4.5% in men and 6.0% and 7.8% in women. Conversely, probabilities that people who had sleep complaints at the preceding visit but did not complain of sleep problems at the next visit were 46.6% and 43.7% in men and 53% and 37.5% in women, respectively. The best fitting models indicated 2 classes of cases between Visits 2 and 4 for both men (294 cases at 2 or 3 of the visits) and 7074 non-cases; $\chi^2(4) = 1334.4$, $P<.001$) and women (74 cases at 2 or 3 of the visits) and 1081 non-cases; $\chi^2(4) = 243.6$, $P<.001$). Three-class models were not supported ($P>.50$).

Latent Growth Models

Figures 1 and 2 show initial status and growth trajectories of CRF in men and women, respectively, according to cumulative incident cases of sleep complaints and non-cases. Both linear and quadratic trajectories differed between cases and non-cases in men ($\chi^2(3) = 32.9$, $P<0.001$), whereas the linear trajectory differed ($\chi^2(1) = 3.8$, $P<0.05$) but the quadratic trajectory did not differ ($\chi^2(1) = 2.3$, $P=0.13$) between cases and non-cases in women. In men, incident cases had a linear decline (-0.347 min, 95% CI= -0.588 to -0.106) from their initial level of CRF (19.47 min, 95% CI= 19.20 to 19.74), followed by a smaller quadratic decline (-0.09 min, 95% CI= -0.16 to -0.02), whereas non-cases had a linear increase (.310 min, 95% CI= 0.23 to 0.39) from their initial level (19.12 min, 95% CI=19.03 to 19.21) followed by a larger quadratic decline (-0.223 min, 95% CI= -0.24 to -0.20). In women, incident cases had a non-significant linear change (-0.020 min, 95% CI= -0.45 to 0.41) and a quadratic decline (-0.143 min, 95% CI= -0.27 to -0.02) from their initial level of CRF (14.71 min, 95% CI= 14.22 to 15.20), whereas non-cases had a linear increase (0.450 min, 95% CI=0.246 to 0.654) followed by a similar quadratic decline (-0.241 min, 95% CI= -0.298 to -0.184) from their initial level (14.35 min, 95% CI= 14.11 to 14.59).

Logistic Regression Analysis

The logistic model of observed cases had good fit for men (linear change: $\chi^2(2)=30.3$, $P<0.001$; goodness of fit: $\chi^2(7365)=7380.6$, $P=0.447$; Hosmer and Lemeshow $\chi^2(8)=8.49$, $P=0.387$) and women (linear change: $\chi^2(2)=5.3$, $P=0.07$; goodness of fit: $\chi^2(1152)=1156.6$, $P=0.457$; Hosmer and Lemeshow $\chi^2(8)=6.15$, $P=0.631$). Odds of incident sleep complaints were 1.7% higher for each minute linear decline in CRF across visits in men (OR=1.017, 95% CI=1.010 to 1.024), and 1.3% higher for each minute linear decline in CRF across visits in women (OR=1.013, 95% CI=0.998 to 1.028).

Odds of incident sleep complaints with declining fitness were equally strong in the sensitivity analysis that excluded people with first incidence at Visit 2 or Visit 3 in men (6584 non-cases and 278 first-incident cases at Visit 4; linear decline OR= 1.016, 95% CI=1.006 to 1.027) and women (948 non-cases and 76 first-incident cases at Visit 4; linear decline OR= 1.021, 95% CI=0.998 to 1.044).

Similarly, the model of latent classes of cumulative cases had good fit for men (quadratic change: $\chi^2(1)=21.6$, $P<0.001$; goodness of fit: $\chi^2(7364)=7405.6$, $P=0.364$; Hosmer and Lemeshow $\chi^2(8)=11.13$, $P=0.194$) and women (quadratic change: $\chi^2(1)=4.4$, $P=0.037$; goodness of fit: $\chi^2(1151)=1168.6$, $P=0.352$; Hosmer and Lemeshow $\chi^2(8)=11.74$, $P=0.163$). Odds of incident sleep complaints were 7.9% higher for each minute quadratic decline (OR=1.079, 95% CI=1.045 to 1.114) in CRF across visits in men and 7.6% higher for each minute quadratic decline in women (OR=1.076, 95% CI=1.004 to 1.154). The greater CRF decline among cases was between visits 2 and 3 in men and between visits 1 and 2 in women.

DISCUSSION

These prospective results extend prior findings from studies of self-reported physical activity and risk of sleep problems by showing that the odds of incident sleep complaints were increased by 1.7% in men and 1.3% in women for each minute (i.e., about one-half MET) of decline in treadmill performance time from the second to the fourth clinic visit (between ages 51 to 56 years). Though more modest in size than reported by prior observational studies of physical activity (30), these odds are not biased by self-reporting of physical activity. Also, they represent multiple assessments of exposure and sleep complaint outcomes, which had previously been reported only for a cohort of midlife women using a self-report of physical activity (23).

The analysis cannot fully rule out that incident sleep disturbance resulted in physical inactivity and, hence, reduced CRF. There is some evidence for this alternative interpretation (2,11,26). However, that is unlikely here given that the higher odds of sleep complaints with declining fitness held in the sensitivity analysis that excluded people with first incidence at Visit 2 and Visit 3, supporting that early onset sleep problems did not precede the decline in fitness. Moreover, when latent classes were formed of people most likely to report sleep complaints at 2 or 3 of the visits, decline in CRF among cases was greater than among non-cases between visits 2 and 3 in men and between visits 1 and 2 in women. Also, the similar maximum HR observed for incident cases and non-cases at each visit, and similar treadmill times for cases and non-cases at visits 2 and 3, indicate that people were not less able or willing to perform at their maximum level on the treadmill test when they were reported sleep problems.

Novel features of the study include the use of CRF as an objective, surrogate measure of cumulative physical activity exposure across time in men and women from the same cohort and repeated assessment of time varying covariates. There could be residual confounding by traits common to both physical inactivity and proneness to sleep problems. However, this is the first prospective report of physical activity or fitness and incident sleep complaints to sequentially assess and control for time-varying complaints of anxiety or depression problems, which are co-morbid with sleep complaints in middle-aged US adults (36).

A weakness of the study is the quantification of sleep complaints made to a physician without elaboration of the type (e.g., restless legs, difficulty initiating or maintaining sleep, snoring, sleep apnea) and/or severity of the underlying sleep problem (9,12). Nonetheless,

incident cases of a sleep complaint made to a physician have clinical relevance for public health (17). National U.S. survey reports of similarly non-specific sleep disturbances (13) have been associated with increased odds of obesity, diabetes, and coronary heart disease, which were adjusted for here. Moreover, the medical screening question we used asked patients whether they had a problem with sleep, which has good discriminant validity to detect symptom levels of low severity when compared with other single-item indicators of self-reported sleep disturbance (7). Thus, we believe our findings add new information about the modifying effect of cardiorespiratory fitness in the epidemiology of sleep, which typically has not distinguished between sleep complaints, sleep disturbance, and insomnia (27).

Information on sleep pharmacotherapy or other medication use, menopausal or pregnancy status, or dietary habits was not sufficient to include these factors in the analysis. Another limitation is that the cohort was predominantly white, relatively healthy and well-educated, and of middle-to-upper socioeconomic class (3). Like other epidemiological cohort studies, there is possible selection bias or lack of representativeness of the study population. However, the homogeneity of the ACLS population sample on sociodemographic factors enhances the internal validity of our findings, which are consistent with lower odds of incident insomnia symptoms in physically active Japanese elders¹⁵ and a positive cross-sectional association between cardiorespiratory fitness and sleep duration in Hispanic and Black youths (10). Incidence rates of sleep complaints in this predominantly middle-aged ACLS cohort (nearly 18% in women and 11% in men) were slightly lower than population estimates in US adults 50–60 years of age (14). Most of the patients here were middle-aged (i.e., between 35 and 65 years old) throughout the period of observation, and fitness was adjusted for age at the initial clinic visit (when average age was 49 and the interquartile range spanned from 41 to 56 years) as well as time between each visit. Hence, the findings should mostly apply to changes across middle-age in these cohorts. Nonetheless, the cohorts were not large enough to permit statistically powerful tests of growth models between cases and non-cases stratified by age groups, which would be needed to more precisely estimate the modifying effect of fitness on risk of sleep complaints across age-cohorts.

The decline in fitness seen here among non-cases (about 6% in men and 4% in women) is consistent with that observed in the total ACLS cohort (18). Among incident cases of sleep complaints, the linear decline across the 4 visits was about 8% in men and women, which approximates an additional loss of one-half minute of maximal treadmill time, an amount easily retained in most people by regular, moderate-to-vigorous physical activity consistent with current recommendations for health (30). A large randomized trial would be needed to determine how many incident cases of sleep complaints might be prevented by mitigating this decline in fitness.

CONCLUSION

In summary, the results suggest that maintenance of cardiorespiratory fitness during middle-age, when decline in fitness typically accelerates and risk of sleep problems is elevated, helps protect against the onset of sleep complaints made to a physician in both men and women.

ACKNOWLEDGMENT

This work was supported by the National Institutes of Health (grant numbers AG06945, HL62508, DK088195, and HL095799). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

The authors thank the Cooper Clinic physicians and technicians for collecting the baseline data and staff at the Cooper Institute for data entry and data management.

REFERENCES

1. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. 7th Ed.. Philadelphia, PA: Lippincott Williams & Wilkins; 2006. p. 286-299.
2. Baron KG, Reid KJ, Zee PC. Exercise to improve sleep in insomnia: exploration of the bidirectional effects. *J Clin Sleep Med*. 2013; 9(8):819–824. [PubMed: 23946713]
3. Blair SN, Kannel WB, Kohl HW, Goodyear N, Wilson PWF. Surrogate measures of physical activity and physical fitness: Evidence for sedentary traits of resting tachycardia, obesity, and low vital capacity. *Am J Epidemiol*. 1989; 129(6):1145–1156. [PubMed: 2729253]
4. Blair SN, Kohl HW III, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *JAMA*. 1989; 262:2395–2401. [PubMed: 2795824]
5. Bollen, KA.; Curran, PJ. Latent curve models. Hoboken, NJ: John Wiley & Sons, Inc.; 2006. p. 1-285.
6. Buysse DJ. Insomnia. *JAMA*. 2013; 309(7):706–716. [PubMed: 23423416]
7. Buysse DJ, Yu L, Moul DE, et al. Development and validation of patient-reported outcome measures for sleep disturbance and sleep-related impairments. *Sleep*. 2010; 33(6):781–792. [PubMed: 20550019]
8. Carrier J, Monk TH, Buysse DJ, Kupfer DJ. Sleep and morningness-eveningness in the 'middle' years of life (20–59 y). *J Sleep Res*. 1997; 6(4):230–237. [PubMed: 9493522]
9. Chesson A Jr, Hartse K, Anderson WM, et al. Practice parameters for the evaluation of chronic insomnia. An American Academy of Sleep Medicine report. Standards of Practice Committee of the American Academy of Sleep Medicine. *Sleep*. 2000; 23(2):237–241. [PubMed: 10737341]
10. Countryman AJ, Saab PG, Llabre MM, Penedo FJ, McCalla JR, Schneiderman N. Cardiometabolic risk in adolescents: associations with physical activity, fitness, and sleep. *Ann Behav Med*. 2013; 45(1):121–131. [PubMed: 23080394]
11. Dzierzewski JM, Buman MP, Giacobbi PR Jr, et al. Exercise and sleep in community-dwelling older adults: evidence for a reciprocal relationship. *J Sleep Res*. 2014; 23(1):61–68. [PubMed: 23980920]
12. Edinger JD, Bonnet MH, Bootzin RR, et al. American Academy of Sleep Medicine Work Group. Derivation of research diagnostic criteria for insomnia: report of an American Academy of Sleep Medicine Work Group. *Sleep*. 2004; 27(8):1567–1596. [PubMed: 15683149]
13. Grandner MA, Jackson NJ, Pak VM, Gehrman PR. Sleep disturbance is associated with cardiovascular and metabolic disorders. *J Sleep Res*. 2012; 21(4):427–433. [PubMed: 22151079]
14. Grandner MA, Martin JL, Patel NP, et al. Age and sleep disturbances among American men and women: data from the U.S. Behavioral Risk Factor Surveillance System. *Sleep*. 2012; 35(3):395–406. [PubMed: 22379246]
15. Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Struct Equat Model*. 1999; 6:1–55.
16. Inoue S, Yorifuji T, Sugiyama M, Ohta T, Ishikawa-Takata K, Doi H. Does habitual physical activity prevent insomnia? A cross-sectional and longitudinal study of elderly Japanese. *J Aging Phys Act*. 2013; 21(2):119–139. [PubMed: 22832375]
17. Institute of Medicine of the National Academies. Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem. Washington: Institute of Medicine; 2006. Available at <http://www.iom.edu/Reports/2006/Sleep-Disorders-and-Sleep-Deprivation-An-Unmet-Public-Health-Problem.aspx>. [Accessed November 8, 2013]

18. Jackson AS, Sui X, Hébert JR, Church TS, Blair SN. Role of lifestyle and aging on the longitudinal change in cardiorespiratory fitness. *Arch Intern Med*. 2009; 169:1781–1787. [PubMed: 19858436]
19. King AC, Baumann K, O'Sullivan P, Wilcox S, Castro C. Effects of moderate-intensity exercise on physiological, behavioral, and emotional responses to family caregiving: a randomized controlled trial. *J Gerontol A: Biol Sci Med Sci*. 2002; 57(1):M26–M36. [PubMed: 11773209]
20. King AC, Oman RF, Brassington GS, Bliwise DL, Haskell WL. Moderate-intensity exercise and self-rated quality of sleep in older adults: A randomized controlled trial. *JAMA*. 1997; 227:32–37. [PubMed: 8980207]
21. King AC, Pruitt LA, Woo S, et al. Effects of moderate-intensity exercise on polysomnographic and subjective sleep quality in older adults with mild to moderate sleep complaints. *J Gerontol A: Biol Sci Med Sci*. 2008; 63(9):997–1004. [PubMed: 18840807]
22. Kline CE, Crowley EP, Ewing GB, et al. The effect of exercise training on obstructive sleep apnea and sleep quality: a randomized controlled trial. *Sleep*. 2011; 34(12):1631–1640. [PubMed: 22131599]
23. Kline CE, Irish LA, Krafty RT, et al. Consistently high sports/exercise activity is associated with better sleep quality, continuity and depth in midlife women: The SWAN Sleep Study. *Sleep*. 2013; 36(9):1279–1288. [PubMed: 23997360]
24. Kline CE, Sui X, Hall MH, et al. Dose-response effects of exercise training on the subjective sleep quality of postmenopausal women: exploratory analyses of a randomised controlled trial. *BMJ Open*. 2012 Jul 12;2(4)
25. Kripke DF, Klauber MR, Wingard DL, Fell RL, Assmus JD, Garfinkel L. Mortality hazard associated with prescription hypnotics. *Biol Psychiatry*. 1998; 43(9):687–693. [PubMed: 9583003]
26. Lambiase MJ, Pettee Gabriel K, Kuller LH, Matthews KA. Temporal relationships between physical activity and sleep in older women. *Med Sci Sports Exerc*. 2013; 45(12):2362–2368. [PubMed: 23739529]
27. Lichstein, KL.; Durrence, HH.; Riedel, BW.; Taylor, DJ.; Bush, AJ. *Epidemiology of Sleep: Age, Gender, and Ethnicity*. Mahwah, New Jersey: Lawrence Erlbaum Associates; 2004. A review of epidemiological studies of insomnia and sleep; p. 9-41.
28. Minkel J, Krystal AD. Optimizing the Pharmacologic Treatment of Insomnia: Current Status and Future Horizons. *Sleep Med Clin*. 2013; 8(3):333–350. [PubMed: 24015116]
29. Muthén, LK.; Muthén, BO. *Mplus: Statistical Analysis with Latent Variables*. edition 7. Los Angeles: Muthén and Muthén; 2012. p. 1-850.(1998–2012)
30. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report. Washington, D.C: U.S. Department of Health and Human Services; 2008. p. 1-683.[cited 2014 Jun 28]. Available from: <http://www.health.gov/paguidelines/guidelines/#committee>
31. Pollock ML, Bohannon RL, Cooper KH, et al. A comparative analysis of four protocols for maximal treadmill stress testing. *Am Heart J*. 1976; 92(1):39–46. [PubMed: 961576]
32. Pollock ML, Foster C, Schmidt D, Hellman C, Linnerud AC, Ward A. Comparative analysis of physiologic responses to three different maximal graded exercise test protocols in healthy women. *Am Heart J*. 1982; 103(3):363–373. [PubMed: 7064770]
33. Proctor A, Bianchi MT. Clinical pharmacology in sleep medicine. *ISRN Pharmacol*. 2012; 914168
34. Reid KJ, Baron KG, Lu B, Naylor E, Wolfe L, Zee PC. Aerobic exercise improves self-reported sleep and quality of life in older adults with insomnia. *Sleep Med*. 2010; 11(9):934–940. [PubMed: 20813580]
35. Rosekind MR, Gregory KB. Insomnia risks and costs: health, safety, and quality of life. *American Journal of Managed Care*. 2010; 16(8):617–26. [PubMed: 20712395]
36. Roth T, Jaeger S, Jin R, et al. Sleep problems, comorbid mental disorders, and role functioning in the national comorbidity survey replication. *Biological Psychiatry*. 2006; 60(12):1364–1371. [PubMed: 16952333]
37. Singh NA, Clements KM, Fiatarone MA. A randomized controlled trial of the effects of exercise on sleep. *Sleep*. 1997; 20:40–46. [PubMed: 9130333]

38. Strand LB, Laugsand LE, Wisløff U, Nes BM, Vatten L, Janszky I. Insomnia symptoms and cardiorespiratory fitness in healthy individuals: the Nord-Trøndelag Health Study (HUNT). *Sleep*. 2013; 36(1):99–108. [PubMed: 23288976]
39. Youngstedt SD, Kline CE. Epidemiology of exercise and sleep. *Sleep and Biological Rhythms*. 2006; 4(3):215–221. [PubMed: 25374476]

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1.

Decline in cardiorespiratory fitness (i.e., reduced treadmill time) and incident sleep complaints in men adjusted for age, time between visits, body mass index, smoking, alcohol use, number of medical conditions, and complaints of depression or anxiety. Adjusted means and 95% CI at each visit are shown.

Figure 2.

Decline in cardiorespiratory fitness (i.e, reduced treadmill time) and incident sleep complaints in women adjusted for age, time between visits, body mass index, smoking, alcohol use, number of medical conditions, and complaints of depression or anxiety. Adjusted means and 95% CI at each visit are shown.

Table 1

Participants' characteristics of 1155 women and 7368 men according to follow-up visits

Characteristics	Visit 1	Visit 2	Visit 3	Visit 4
Women				
Age, mean (SD), y	48.8 (10.5)	51.0 (10.3)	53.3 (10.1)	55.9 (10.2)
Age, median, y	49.0	51.0	53.0	56.0
Age, lower-upper quartile range, y	41.0–56.0	43.0–58.0	46.0–61.0	49.0–63.0
BMI, mean (SD), kg/m ²	22.4 (3.4)	22.6 (3.4)	22.8 (3.4)	23.1 (3.5)
Treadmill test duration, mean (SD), min	14.4 (4.4)	14.6 (4.4)	14.2 (4.4)	13.5 (4.4)
Maximal METs, mean (SD)	10.0 (2.1)	10.1 (2.0)	9.9 (2.1)	9.6 (2.0)
% of age-predicted MHR, mean (SD)	102.3 (6.5)	103.0 (6.7)	103.3 (6.9)	103.6 (7.3)
Resting systolic blood pressure, mean (SD), mmHg	114 (15)	115 (15)	117 (16)	119 (17)
Resting diastolic blood pressure, mean (SD), mmHg	76 (9)	76 (9)	77 (9)	78 (9)
Fasting total cholesterol, mean (SD), mmol/L	5.3 (1.0)	5.3 (0.9)	5.3 (0.9)	5.3 (0.9)
Fasting triglyceride, mean (SD), mmol/L	1.1 (0.8)	1.1 (0.7)	1.1 (0.7)	1.1 (0.7)
Fasting glucose, mean (SD), mmol/L	5.7 (0.8)	5.2 (0.8)	5.2 (0.9)	5.2 (0.8)
Chronic medical conditions ^a , number (%)	424 (36.7)	454 (39.3)	508 (44.0)	586 (49.0)
Current smoker, number (%)	61 (5.3)	54 (4.7)	37 (3.2)	32 (2.8)
Alcohol use (5 drinks per week), number (%)	189 (16.4)	215 (18.6)	260 (22.5)	291 (25.2)
Sleep complaints, number (%)	0 (0)	66 (5.7)	96 (8.3)	143 (12.4)
Anxiety, number (%)	0 (0)	42 (3.6)	59 (5.1)	89 (7.7)
Depression, number (%)	0 (0)	35 (3.0)	58 (5.0)	90 (7.8)
Men				
Age, mean (SD), y	49.0 (10.5)	50.9 (10.2)	52.9 (10.0)	55.1 (10.0)
Age, median, y	49.0	51.0	52.0	55.0
Age, lower-upper quartile range, y	41.0–56.0	43.0–58.0	46.0–60.0	48.0–62.0
BMI, mean (SD), kg/m ²	25.8 (3.2)	25.9 (3.6)	26.0 (3.2)	26.3 (4.5)
Treadmill test duration, mean (SD), min	19.1 (4.7)	19.2 (4.6)	18.8 (4.7)	18.0 (4.8)
Maximal METs, mean (SD)	12.2 (2.3)	12.3 (2.3)	12.0 (2.3)	11.7 (2.3)
% of age-predicted MHR, mean (SD)	102.9 (6.8)	103.3 (6.8)	103.4 (7.1)	103.4 (7.4)
Maximal hear rate, mean (SD), bpm	176 (14)	174 (14)	173 (14)	170 (15)
Resting systolic blood pressure, mean (SD), mmHg	122 (14)	122 (14)	123 (14)	124 (15)
Resting diastolic blood pressure, mean (SD), mmHg	81 (9)	81 (9)	81 (9)	81 (9)
Fasting total cholesterol, mean (SD), mmol/L	5.3 (1.2)	5.3 (1.0)	5.2 (1.0)	5.2 (1.1)
Fasting triglyceride, mean (SD), mmol/L	1.4 (1.0)	1.4 (1.0)	1.4 (1.0)	1.4 (1.0)
Fasting glucose, mean (SD), mmol/L	5.6 (0.8)	5.5 (0.8)	5.5 (0.8)	5.6 (1.0)
Chronic medical conditions ^a , number (%)	3787 (51.4)	3887 (52.8)	4075 (55.3)	4375 (59.4)
Current smoker, number (%)	826 (11.2)	726 (9.9)	691 (9.4)	650 (8.8)
Alcohol use (5 drinks per week), number (%)	2153 (29.2)	2308 (31.3)	2449 (33.2)	2651 (36.0)
Sleep complaints, number (%)	0 (0)	251 (3.4)	389 (5.3)	532 (7.2)
Anxiety, number (%)	0 (0)	120 (1.6)	210 (2.9)	276 (3.8)
Depression, number (%)	0 (0)	108 (1.5)	185 (2.5)	261 (3.5)

Abbreviations: BMI, body mass index; ECG, electrocardiogram; MHR, maximum heart rate; SD, standard deviation;.

^aMedical conditions included heart attack, stroke, cancer, diabetes, hypertension, hyperlipidemia, and abnormal resting or exercising ECG.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 2

Participants' baseline characteristics of 1155 women and 7368 men according to incident sleep complaints (cases) or no sleep complaints (non-cases).

Characteristics	Women		Men	
	No Sleep Complaints	Sleep Complaints	No Sleep Complaints	Sleep Complaints
N	948	207	6584	784
Age, mean (SD), y	48.6 (10.5)	49.5 (10.4)	49.0 (10.5)	49.2 (10.6)
Body Mass Index, mean (SD), kg/m ²	22.3 (3.2)	22.8 (4.0)	25.8 (3.2)	25.9 (3.2)
Treadmill test duration, mean (SD), min	14.4 (4.5)	14.6 (4.4)	19.1 (4.7)	19.4 (4.6)
Maximal METs, mean (SD)	10.0 (2.1)	10.0 (2.0)	12.2 (2.3)	12.4 (2.3)
Maximal hear rate, mean (SD), bpm	175 (13)	174 (13)	176 (14)	175 (14)
Chronic medical conditions ^a , number (%)	351 (37.0)	73 (35.3)	3387 (51.4)	400 (51.0)
Current smoker, No. (%)	54 (5.7)	7 (4.4)	758 (11.5)	68 (8.7)
Alcohol use (5 drinks per week), number (%)	151 (15.9)	38 (18.4)	1899 (28.8)	254 (32.4)

Abbreviations: SD, standard deviation; ECG, electrocardiogram.

^a Medical conditions included heart attack, stroke, cancer, diabetes, hypertension, hyperlipidemia, and abnormal resting or exercising ECG.