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REVIEW ARTICLE

Epidemiology of exercise and sleep*

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Abstract

Although exercise is widely believed to improve sleep, experimental evidence has found acute and chronic exercise to exert only modest effects on subsequent sleep. However, these studies are limited in that they have primarily used good sleepers (floor/ceiling effects). In contrast to experimental studies, epidemiologic studies have consistently reported significant positive associations between self-reported exercise habits and better self-reported sleep. This association has been confirmed across a wide range of demographics. Nonetheless, epidemiologic studies on this topic have also had limitations. They have often assessed exercise and sleep using instruments of dubious validity. Moreover, the studies have generally not included clinical diagnoses of sleep disorders. Thus, the clinical relevance of these findings is unclear. In addition, possible alternative explanations for the association of exercise and improved sleep have often not been controlled (e.g. bright light, other healthy behaviors). This review will focus on these epidemiologic studies. We will review and critique representative survey and epidemiologic studies of exercise and sleep and discuss directions for future research in this area.

Key words: epidemiology, exercise, physical activity, sleep disorders, sleep.

INTRODUCTION

In the general population, perhaps no other daytime behavior has been associated with better night-time sleep than exercise. Parents often try to get their children to run around the playground *knowing* that this will make them sleep better at night. A similar expectation about exercise for adults is apparent in our daily conversations, and can be traced back at least as far as Biblical times.[1] Acute exercise and regular exercise participation are typically recommended for better sleep in the lay literature, as well as by sleep experts.[2–4]

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Notwithstanding expectations about exercise, experimental studies have indicated that acute and chronic exercise has rather modest (albeit significant) effects on sleep.[5] However, there are numerous limitations in the experimental literature that might explain the modest effects. First, studies have focused mostly on normal sleepers who have little room for improvement (ceiling/floor effects). For good sleepers, the effects of exercise on sleep are actually quite comparable to those of hypnotic medications[6] and melatonin.[7] Second, results have often been limited by very small sample sizes. Third, studies have typically been limited to 1 or 2 exercise days and recording nights. Because sleep is sensitive to many factors, many more days of assessment might be needed to delineate the effects of exercise on sleep. Fourth, the laboratory exercise and sleep environments cannot duplicate those which might be associated with better sleep in the home environment. Theoretically, strict experimental control might better delineate the effects of exercise *per se* from those of the environment, but it is plausible that certain features of the laboratory

environment (e.g. boredom, invasive sleep recording) could inhibit usual beneficial effects of exercise on sleep.

For these reasons, epidemiologic studies of the association of exercise and sleep have some advantages over existing experimental studies, though epidemiologic studies have other limitations (as discussed below). In contrast to experimental studies, epidemiologic studies have often found quite substantial associations of exercise with better sleep. In this review, we will review and critique representative survey and epidemiologic studies of exercise and sleep and discuss directions for future research in this area.

SURVEY DATA

Exercise and better sleep

Survey studies have consistently shown a link between exercise and better sleep.[8–10] One provocative survey on this topic was that of Urponen *et al.* who assessed a random sample ($n = 1190$) of adults living in Tampere, Finland.[8] Rather than asking potentially suggestive questions about whether exercise improved their sleep, respondents were provided the open-ended statement: "please state, in their order of importance, three habits, practices, or actions which you have observed to best promote your falling asleep immediately or perceived quality of sleep." Exercise was the most commonly listed "most important habit," as indicated by 33% of the men and 30% of the women, more important than reading/listening to music (14% of men, 23% of women), taking a sauna/shower (9% of men and women), regular lifestyle (9% of men and women), and psychological factors (7% of men, 8% of women).

A similar survey of 400 randomly selected hospital patients and 400 outpatients[9] asked respondents, "can you describe any particular habit that aids you in falling asleep?" Of those who reported exercising ≥2 times per week, 83% listed exercise. Reading was the only other habit that was listed by >20% of the sample.

In the 2003 National Sleep Foundation "Sleep in America" poll,[10] older respondents (ages 55–84 year) reported on many behaviors including how often they exercised (<1, 1–2, or ≥3 times per week). Compared to those who reported exercising <1 time per week, those who exercised more frequently had fewer complaints on almost every index of disturbed sleep, including fair or poor sleep, any symptom of insomnia, difficulty falling or staying asleep, waking up feeling unrefreshed, daytime sleepiness, or any reported sleep problem. Moreover, for most of the variables assessed, a dose–response pattern was evident; respondents who exercised ≥3 times per week reported better sleep than those who reported exercising 1–2 times per week.

These surveys are consistent in showing strong associations of exercise with better sleep. However, they provide no statistical control for confounding factors, and there are numerous reasons why people might overestimate the effects of exercise on sleep in surveys. First, it is apparent that many people believe sleepiness is synonymous with physical fatigue. This is a reasonable assumption given that fatigue and sleepiness often occur simultaneously (e.g. at the end of the day). Only recently has research shown that the two constructs can often be delineated.[11] Second, exercise is one of the first optional activities that is sacrificed when one is pressed for time. Thus, if one tends to exercise on days that he/she feels less stress (e.g. on weekends), he/she might attribute better sleep to exercise rather than low stress. Third, an association between exercise and better sleep might be attributable to some external factor, such as increased light exposure.[12,13]

Late-night exercise and sleep

Evidence indicates that late-night exercise is not an uncommon practice. For example, in the 2005 "Sleep in America" Poll,[14] 4% of the respondents reported that they exercised within 1 h of bedtime almost every night, and 11% reported late-night exercise at least a few nights per week. However, in recommendations about exercise and sleep, almost invariably added is the caveat that late-night exercise (within 4–6 h of sleep) will impair sleep, especially if it is vigorous exercise. Experimental studies have failed to support this assumption.[15–17] Nevertheless, potential limitations of exercise studies – such as self-selection into studies and use of small numbers of fit participants, who might be relatively immune to sleep-impairing effects of late night exercise – might make this question more suitable for representative surveys of large samples.[18] Interestingly, the surveys support the experimental studies in showing a lack of detrimental effect of late-night exercise on sleep for most individuals. For example, Vuori *et al.* examined self-reported sleep in respondents who reported that they exercised after 8 pm ($n = 320$) and those who exercised between 4 and 8 pm ($n = 859$).[19] Among the late-night exercisers, the majority reported that after exercise they fell asleep more quickly (65%), had deeper sleep (62%), and woke up feeling better (60%). Similar percentages were reported for the early evening exercisers (70%, 66%, and 65%, respectively). Although greater

percentages of the late-night vs. early evening exercisers reported that the exercise resulted in more difficulty falling asleep (24% vs. 7%), more restless sleep (11% vs. 6%), early awakening (8% vs. 5%), and more tiredness in the morning (9% vs. 2%), it is noteworthy that the majority of respondents did not have these complaints. Similar results were reported by Hasan *et al*.[20]

EPIDEMIOLOGIC STUDIES OF EXERCISE AND INSOMNIA

Epidemiologic studies have also consistently shown associations of exercise with better sleep.[21–30] For example, Kim and colleagues conducted a study of over 3000 adults of ages 20 to 70+ year, which was representative of the population of Japan across numerous geographic regions and city sizes.[21] A structured questionnaire included questions regarding how often respondents experienced difficulties falling asleep, staying asleep, or awakening too early (never, seldom, sometimes, often or always). Insomnia was defined by experiencing any of these symptoms "often" or "always." Respondents also answered yes/no to the questions of whether they engaged in habitual exercise. Multiple logistic regression analysis revealed an insomnia odds ratio (OR) of 1.3 associated with reported no habitual exercise. This risk was comparable to that associated with reports of being unemployed (OR = 1.2) and being "unable to cope with stress" (OR = 1.4), but less than that associated with older age (>60 year; OR = 2.1), having poor perceived health (OR = 2.1), and self-reported stress (OR = 1.8).

Hublin and colleagues assessed over 12 000 adults who were part of the Finnish Twin cohort study.[22] Insufficient sleep was defined as having an average sleep duration that was more than 1 h below the amount that the respondents reported they needed to function optimally. This study had one of the best epidemiologic metrics of leisure time exercise, which considered the intensity, duration and frequency of the exercise. The sample was divided into quartiles according to this metric. Compared with the lowest amount of exercise, exercise in the other 3 quartiles was associated with significantly less reports of insufficient sleep (OR from 0.72 to 0.82 among the men, and 0.82–0.95 among the women). However, there were much stronger associations of insufficient sleep with reported stress (OR = 6.08) and depression (OR = 3.59), which was assessed with the Beck Depression Inventory.[31]

Bazargan assessed reported sleep disturbance in 998 older African-Americans (ages 62–99 year).[23] In multiple regression analysis, exercise, quantified with a 5-point scale, was associated with significantly less reported sleep disturbance (β weight = –0.10). This association was greater than that associated with several other factors [e.g. age (β = 0.02), number or stressful life events (β = 0.04), and working status (β = –0.05)], but smaller than that associated with reported depression/anxiety (β = 0.28) or illness (β = 0.21).

Morgan conducted a study (n = 1042) of older adults ages 65–84 year.[24] A validated interview technique was used to divide the sample into 5 quintiles of exercise. Insomnia was defined as experiencing sleep problems often or always during the past week. Multiple logistic regression analysis revealed that insomnia was associated with the two lowest quintiles of exercise (OR = 2.0–2.2), but insomnia was more strongly associated with self-reported poor health (OR = 2.6) and depressed mood (OR = 2.9), which was assessed with a validated scale.

Sherrill and colleagues examined a random sample of women (n = 403) and men (n = 319) ages ≥40 year in Tucson, Arizona.[25] In multiple logistic regression analysis, numerous factors were controlled, including use of medications or alcohol to assist sleep, respiratory trouble, age and gender. Compared with less walking, reported walking >6 blocks per day at an average pace was associated with significantly fewer complaints of having any sleep problem (OR = 0.47), and difficulty maintaining sleep (OR = 0.67). Moreover, engagement in regular physical activity ≥1 time per week vs. less frequent activity was associated with less complaints of having any sleep problem (OR = 0.62), less difficulty maintaining sleep (OR = 0.71), and less reported daytime sleepiness (OR = 0.63). Participation in a regular exercise program was also associated with less difficulty maintaining sleep (OR = 0.52). However, interestingly, the largest effects of the study indicated that participating in vigorous weekend exercise in addition to a regular exercise program was associated with *more* complaints of having any sleep problem (OR = 2.15) or in difficulty maintaining sleep (OR = 2.16). However, the pattern was noted only for women. One potential interpretation of these data might be that there is a U–shaped association of exercise with sleep in which insufficient exercise and very high amounts of exercise are associated with more sleep disturbance than moderate exercise. This interpretation is supported by anecdotal reports and some experimental evidence.[32,33]

Ohida *et al*. examined a random sample (n = 31 260) of Japanese adults.[26] A written survey inquired about the sufficiency of their current sleep habits and average hours of sleep they obtained per night. The

questionnaire also identified demographic, health, and lifestyle factors that could impact sleep habits. Multiple logistic regression analysis determined that lack of habitual exercise was a predictor for subjective insufficient sleep (OR = 1.32) but not short sleep duration. Other lifestyle factors that were significantly associated with subjective insufficient sleep and short sleep duration were eating regularity, food variety, and volume of meals. However, self-reported health status of "not good" was more strongly associated with subjective insufficient sleep (OR = 3.00) and short sleep duration (OR = 1.45).

Uezu *et al*. studied the sleep and lifestyle habits of a random sample of older adults ($n = 788$) in Okinawa, Japan.[27] A validated questionnaire assessed lifestyle factors and sleep-health. From sleep-health risk factors computed from the questionnaire, individuals ranked in the top and lowest quintiles were classified as the poor and good sleep-health groups, respectively. A subset of individuals in these two groups was selected for 1 week of actigraphic recording to verify the self-report data. Those in the good sleep health group had significantly higher rates of exercise than those in the poor sleep health group. A similar study of elderly Okinawans ($n = 312$) found that those living in the suburbs had significantly better sleep habits compared to urban-dwellers.[28] Suburban residents also reported significantly more exercise and activities of daily living than those living within the city.

There has been little research into the association between exercise and sleep in children and adolescents. Nevertheless, the available studies show exercise to be consistently associated with better sleep.[34–38]

Liu and colleagues examined a sample ($n = 1365$) of Chinese adolescents ages 12–18 year.[34] Respondents reported the frequency of experiencing difficulty initiating sleep, difficulty maintaining sleep, or awakening during the night ("never," "sometimes," or "often"). Insomnia was defined by the report of "often" for any of these complaints. Logistic multiple regression analysis revealed that, compared with more frequent exercise, exercising 1–2 nights per week and no exercise were associated with significantly more reported insomnia (OR = 2.69 and 3.29, respectively). These associations were equal or greater than several other important risks of insomnia, including self-reported fair health (OR = 1.46) or poor health (OR = 2.46) and having a high level of life stress (OR = 2.69).

In studying Taiwanese adolescents ($n = 656$; ages 13–18 year), Chen and colleagues[35] found 54% reported consistently obtaining inadequate sleep (defined as 6–8 h sleep on <3 nights/week). Adequate sleep (defined as 6–8 h sleep on >4 nights/week) was associated with a number of health-related behaviors, including stress management (OR = 7.56) healthy diet (OR = 2.99) and exercise (OR = 2.15).

EPIDEMIOLOGIC STUDIES OF EXERCISE AND SLEEP APNEA

Epidemiologic studies have shown an association of exercise with reduced symptoms and diagnoses of sleep apnea. For example, in a recent study of a large sample of truckers ($n = 10\,101$), respondents completed the Berlin Questionnaire, which divided them into high risk (26%) and low risk (74%) for obstructive sleep apnea.[39] Multiple logistic regression analysis, adjusted for age, found that occasional and regular exercise were associated with lower ORs for "high risk" classification (OR = 0.62 and 0.53, respectively), which were stronger than the associations of apnea risk with drug use (OR = 1.32), alcohol consumption (OR = 1.17), or smoking (OR = 1.16).

A polysomnographic study by Hong and Dimsdale divided a group of apnea patients into low active ($n = 20$) and sedentary ($n = 18$) categories using a median split on the Leisure Time Exercise Questionnaire.[40] Mean Respiratory Disturbance Index (RDI) values were approximately twice as high in the sedentary (53.9 ± 27.1) vs. low active patients (36.4 ± 21.7).

Previously, it was speculated that exercise might help prevent or treat sleep apnea by helping to reduce body weight. However, some epidemiologic evidence suggests that exercise might also reduce sleep apnea independent of body weight changes. As part of the Wisconsin Sleep Cohort Study, Peppard and Young investigated the association between reported exercise and sleep-disordered breathing using polysomnographic data ($n = 1104$ ages 30–60 year).[41] After adjustment for a number of covariates (e.g. age, gender, sleepiness, alcohol use), a dose–response association between exercise and sleep-disordered breathing was observed. Mean Apnea-Hypopnea Index (AHI) values for exercise of 0 h, 1–2 h, 3–6 h, and ≥7 h/week were 5.5, 3.4, 2.8, and 2.0, respectively. Importantly, following further adjustment for body type [body mass index (BMI) and skinfold thickness], the relationship persisted with mean AHI values of 5.3, 3.9, 3.2, and 2.8, respectively. Furthermore, the risk of having mild (>5 AHI) and severe sleep-disordered breathing (AHI > 15) decreased with increasing levels of exercise. For example, compared to 0 h/week of exercise, ORs for exercising 1–2 h, 3–6 h and ≥7 h/week were 0.62, 0.39, and 0.31, respectively.

It is plausible that individuals with lower levels of sleep apnea might be more inclined to exercise due to lower levels of sleepiness and fatigue. However, some evidence from these epidemiologic studies contradicts this obvious explanation. The Peppard and Young study controlled for sleepiness.[41] Within the sample of apneic patients of Hong and Dimsdale, physical activity, but not RDI, was significantly correlated with measures of vitality and energy.[40] Moreover, these correlations persisted after controlling for RDI. The results of Peppard and Young are also consistent with two non-controlled chronic exercise studies which found decreases in sleep apnea that were apparently independent of changes in body weight or composition.[42,43]

Giebelhaus and colleagues have speculated that strengthening respiratory muscles with regular exercise might make the muscles less susceptible to collapse resulting in apnea.[42] Another mechanism by which exercise could reduce sleep apnea is via its anxiolytic effects.[44] Whereas sleep apnea had previously been attributed strictly to biological mechanisms, recent evidence indicates that anxiety can also precipitate apnea.[45]

EPIDEMIOLOGIC STUDIES OF EXERCISE AND RESTLESS LEGS SYNDROME

There are abundant anecdotal accounts that moderate daytime exercise can help prevent symptoms of restless legs syndrome (RLS), though very vigorous or prolonged exercise can exacerbate the symptoms.[46] Moreover, RLS patients report that acute symptoms can often be relieved only getting out of bed and moving the legs.[47] Further rationale for expecting beneficial effects of exercise is that dopaminergic drugs are the primary treatment for RLS,[46] and exercise has strong dopaminergic effects.[48] Phillips *et al*. conducted a random telephone survey ($n = 1803$) of RLS symptoms and predictors.[49] In multiple logistic regression analysis, the adjusted risk of RLS symptoms associated with low level of exercise (<3 h vs. ≥3 h/mo) (OR = 3.3) was second only to diabetes (OR = 4.4), and exceeded that associated with BMI (OR = 1.3), age (OR = 1.1), and smoking >1 pack/day (OR = 2.1). Experimental studies have found that exercise and L-dopa have comparable efficacy for reducing RLS and periodic limb movements during sleep, though this research has been limited to patients with spinal cord injury.[50,51] Clearly, there is a need for more epidemiological and experimental studies of this topic.

SUMMARY AND FUTURE DIRECTIONS

In epidemiologic studies, exercise has been consistently associated with better sleep. This association has been observed across multiple age groups and demographics. Although the epidemiologic association of exercise with better sleep has generally been modest compared with other predictors (e.g. depression, stress), the association has been more consistently established for exercise than perhaps any other behavior.

Notwithstanding these results, there are a number of limitations and potential confounds in the literature. First, with few exceptions, epidemiologic studies have relied on self-report measures of exercise and sleep, and these measures have often been of unknown validity. The use of invalid questionnaires could either overestimate or underestimate the association of exercise with better sleep. Second, as discussed for the survey data, causality cannot be inferred from epidemiologic associations. People who sleep more or better and feel less fatigue and sleepiness are more inclined to exercise. Conversely, less sleep may lead to more fatigue and less energy to exercise.[52] Epidemiologic studies of exercise and sleep have generally not controlled for sleepiness or fatigue, and none has controlled for both of these separate constructs. Third, better sleep in physically active individuals compared with sedentary individuals could also be attributed to better physical and mental health and greater engagement in other healthy behaviors that are conducive to sleep (e.g. less smoking and alcohol consumption). Epidemiologic studies have not adequately controlled for all of these variables. Fourth, the association of exercise with better sleep might be explained by an external factor, such as light exposure. Indeed, the limited available experimental evidence linking bright light with better sleep is more compelling than that for exercise.[12] However, epidemiologic studies have not adequately controlled for bright light. Fifth, epidemiologic studies might also underestimate the efficacy of exercise if respondents with disturbed sleep are already exercising. Finally, there are no prospective epidemiologic studies of exercise and sleep.

Future epidemiologic studies of exercise and sleep should attempt to assess large, representative samples across all age groups. Moreover, they should include both cross-sectional as well as prospective assessments of exercise and sleep. Validated measures of exercise and sleep would be ideal. Polysomnographic assessment is possible for large-scale epidemiologic studies, such as the Wisconsin Sleep Cohort Study.[41] Moreover, there should be greater attempts to include validated

assessments of physical and mental health, other healthy habits, and a host of other factors that are associated with sleep, such as BMI,[53] socioeconomic status,[54] light exposure,[55] and education level.[56]

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