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Healthy behaviors competing for time: associations of sleep and exercise in working Americans

Christopher J. Yao, MPH, Mathias Basner, MD, PhD, MSc *

Unit for Experimental Psychiatry, Division of Sleep and Chronobiology, Department of Psychiatry, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA

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ABSTRACT

Objective: Exercise and sleep are two important health promoting behaviors, but large parts of the population do not exercise or are chronically sleep deprived. We investigated to what degree exercise and sleep compete with each other and with other waking activities for time.

Methods: Analyses are based on 2003-2016 American Time Use Survey data of a representative sample of N = 47,862 working Americans aged 18-65 years interviewed on weekdays. Models were adjusted for various sociodemographic variables and time spent working on the interview day.

Results: Long work hours and several sociodemographic variables were associated both with short sleep and low exercise rates. Respondents who exercised slept on average 15.5 min less (95% CI: -18.4 min; -12.7 min, $P < .0001$) than those who did not exercise. Sleep duration decreased with exercise duration in a dose-dependent manner. The strongest association between exercise and sleep duration was observed for exercise between 6 AM and 8 AM (ie, before work) and between 9 PM and 11 PM (ie, before bed). However, unless exercise was performed before work in the morning, exercise durations of up to 1 h were not associated with relevantly curtailed sleep.

Conclusions: These results confirm that exercise and sleep compete with each other for time. However, exercise regimens that follow current guidelines are unlikely to curtail sleep substantially, especially since exercise has been shown to positively affect sleep structure and quality. Public health efforts should nevertheless emphasize the importance of both exercise and sleep, and of not sacrificing one activity for the other.

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Introduction

Sleep is a biological imperative and plays essential roles in, eg, memory consolidation,[1] cognition,[2] mood regulation,[3] and vital metabolic processes.[4–6] Short sleep has been identified as an important risk factor for chronic illnesses[7] including obesity,[8] coronary heart disease, stroke,[9] diabetes,[10] and depression.[11] In addition to sleep duration, sleep quality is important for sleep recuperation. Several sleep disorders (eg, sleep apnea, periodic limb movements in sleep) as well as environmental stressors[12] lower sleep quality through sleep fragmentation. Similar to sleep, regular exercise is well-known to benefit both physical and mental health,[13] as well as prevent negative health outcomes including obesity, cardiovascular disease, cancer, and diabetes.[14] Worldwide, the fourth leading cause of death is physical inactivity.[15]

Thus, there is little doubt that obtaining high quality sleep of sufficient length as well as regular exercise are important for maintaining health and high levels of daytime cognitive performance. The American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) recommend that "adults should sleep 7 or more hours per night on a regular basis to promote optimal health".[16] However, despite the apparent benefits of sleep, more than a third of Americans (35.1%) report to sleep less than the recommended 7 hours.[17] Analyses based on the American Time Use Survey (ATUS) suggested that working and traveling, the bulk of which is made up of commuting, are by far the two waking activities predominantly exchanged for less sleep, and that those working multiple jobs are significantly more likely to be short sleepers compared to those not working multiple jobs.[18,19]

The American Heart Association recommends exercise durations of up to 30 min five days a week.[20] The US Department of Health and Human Services recommends that adults should participate in at least 150 min of moderate-intensity or 75 min of vigorous-

Abbreviations: AASM, American Academy of Sleep Medicine; ATUS, American Time Use Survey; min, minute(s); SRS, Sleep Research Society.

* Corresponding author at: Unit for Experimental Psychiatry, Division of Sleep and Chronobiology, Perelman School of Medicine, University of Pennsylvania, 1019 Blockley Hall, 423 Guardian Drive, Philadelphia, PA 19104-6021. Tel.: +1 215 573 5866; fax: +1 215 573 6410.

E-mail address: basner@pennmedicine.upenn.edu. (M. Basner).

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intensity aerobic physical activity per week,[21] but only about 51% of American adults meet this recommendation. Time constraints are the most frequent barriers to exercise.[22,23]

Thus, despite the well-known benefits of sleep and exercise for health and well-being, it can be challenging for individuals to achieve adequate amounts of sleep and exercise given other demands of daily life, especially work and family. In this sense, sleep and exercise are competing not only with other waking activities for time, but very likely also with each other. While recommendations to sacrifice unhealthy behaviors for more sleep or exercise make good sense, recommendations to sacrifice one healthy behavior for another healthy behavior seem more problematic. The primary goal of this analysis was therefore, on the one hand, to identify variables that are both associated with short sleep and low exercise rates and, on the other hand, to investigate the relationship between sleep and exercise duration. We hypothesized that those factors that were shown to decrease sleep duration, especially work duration, would also be associated with lower exercise participation rates and durations. Our analyses were based on the ATUS, a nationally-representative sample of non-institutionalized Americans, aged 18 to 65 years, interviewed between the years 2003 and 2016. We decided to restrict our analyses to employed respondents aged 18 to 65 years on weekdays, as these individuals were expected to struggle the most meeting sleep and exercise recommendations in the face of work and family demands.

Sleep and exercise are related to each other in complex ways.[24] Due to the diverse components of exercise (chronicity, mode, duration, intensity, timing), the diversity of studies investigating the relationship between exercise and sleep is large, which complicates systematic meta-analyses on the topic. However, there is little doubt that exercise in general is beneficial for sleep and may even be effective in alleviating some of the symptoms of common sleep disorders like insomnia and sleep apnea.[25] The most recent meta-analysis on physical activity and sleep found small to medium beneficial effects of both acute and chronic exercise on total sleep time, sleep onset latency, sleep efficiency, wake time after sleep onset, stage 1 sleep, slow wave sleep, rapid eye movement sleep, and sleep quality.[26] These findings largely agree with several other systematic reviews on the effects of exercise on sleep.[24,27,28] On the other hand, sleep duration and quality were also shown to be beneficial for athletic performance and reduce injury risk while exercising.[24]

One important aspect of the effects of exercise on sleep concerns its timing relative to the sleep period. Until recently, sleep hygiene recommendations typically endorsed exercise in general with the caveat that one should avoid working out near bedtime.[29] This was based on beliefs that increased core body temperature and physiological arousal, and potentially a change in circadian rhythms could affect sleep onset latency and quality.[24,30] However, there is little evidence that this is true, and several studies investigating the effects of exercise close to sleep onset conclude that it has no negative or even positive effects on sleep quality.[26,30] Accordingly, the National Sleep Foundation has amended its sleep recommendations for "normal" sleepers to encourage exercise without any caveat to time of day as long as it is not at the expense of sleep,[31] which again stresses the conflict between exercise and sleep, both competing for time.

For the reasons stated above, we were interested on the effects of the timing and duration of exercise on sleep duration. We hypothesized that late evening or early morning exercise would be associated with greater decreases in sleep duration relative to exercise during the rest of the day.

Participants and methods

American Time Use Survey (ATUS)

The ATUS is a Bureau of Labor Statistics-sponsored continuous cross-sectional survey on time use among a nationally-representative sample of non-institutionalized Americans, aged 18 to 65 years, administered by the US Census Bureau. The ATUS uses a 15 to 20 min computer-assisted telephone interview in which participants are asked how they spent their time from 4 AM the previous day to 4 AM on the day of the interview. Activities are coded using a three-tiered activity classification system, with 17 major, or first-tier, categories, each having two additional levels (tiers) of detail. Participants are randomly selected from a subset of households that complete the eighth and final month interviews for the Current Population Survey. Detailed information about the surveying and sampling methods are available in the ATUS User Guide.[32] Weekday data from a sample of N=47,862 employed US residents aged 18-65 years surveyed during the period January 2003 to December 2016 were used in this analysis. Section 9 of Title 13, United States Code, ensures that all respondent and household information obtained via ATUS remains confidential. The ATUS advance letter also advises designated persons that this is a voluntary survey. The US Office of Management and Budget approved the survey. The ATUS response rate averaged 53.7% across survey years (range 46.8%-57.8%) and followed the general trend of declining survey response rates with a 0.85% decline in response rate per year across survey years.

Data analyses

Data were analyzed using SAS (version 9.4, SAS Institute, Cary, N. C.). Multivariate linear or logistic regression models were used to investigate the effects of several sociodemographic factors (age, sex, race/ethnicity, educational attainment, marital status, presence of spouse or partner, number of household children, family income, employment category, multiple job status), work duration (no work [0 h], >0 and ≤4 h, >4 and ≤8 h, >8 h), and variables related to survey day, year, season, and census region on sleep duration, the likelihood of exercising, and exercise duration in those who did exercise on the interview day. To investigate the association of the timing of exercise with sleep duration, we ran separate multivariable (ie, controlling for all variables listed in Table 1) linear regression models for each of forty-eight 30-min periods (ie, 12:00 AM - 12:29 AM; 12:30 AM - 12:59 AM, ..., 11:30 PM - 11:59 PM) that included an indicator variable that was set to 1 if a respondent exercised in the specific time window and to 0 otherwise. In these models, 24 h sleep duration was the dependent variable. The effects of different exercise duration categories on sleep duration were also investigated. Here we differentiated those who exercised at any time of the day (N=47,862), before work that started at or before noon (N=34,217), or after work that started at or before noon (N=32,472), respectively.

Appropriate ATUS weights and replicate weights were used to calculate representative estimates (Proc Surveyreg and Proc Surveylogistic in SAS). All confounders were entered as categorical variables to allow for non-linear effects. We used effect coding for all variables that had more than two categories (ie, age, work duration, race/ethnicity, marital status, presence of household children, education family income, employment, census region, day of the week, season, and survey year) so that each parameter estimate reflected the deviation of a given category from the mean across all categories, and a statistically significant estimate indicated that this category differed significantly from the mean across categories. For variables with two categories (ie, sex, presence of spouse or unmarried partner, and multiple job status), we used reference coding.

Results

17.1% of respondents (95% CI 16.7%, 17.6%; weighted results) exercised on the interview day. Of those who did exercise, 24.5% exercised 30 min or less, 37.4% exercised 31-60 min, 16.3% exercised 61-90 min, and 21.7% exercised more than 90 min. According to

Table 1
Effects of several sociodemographic characteristics, work duration, and variables related to survey day, year, season, and census region on sleep duration, the likelihood of exercising, and exercise duration in those who did exercise on the interview day in employed respondents on weekdays

Variable	Observations [N] (Weighted %) N=47,862	Sleep Duration Minutes (95% CI) N=47,862	Exercise Duration Minutes (95% CI) for those who did exercise N=8,077	Odds of Exercising (95% CI) N=47,862
Work Duration+				
0 hours	5690 (12.2)	57.5 (53.4; 61.5) ****	35.3 (28.5; 42.0) ****	1.13 (1.04; 1.22) **
>0 and ≤4 hours	3344 (6.7)	23.4 (18.9; 27.9) ****	8.6 (2.1; 15.2) *	1.23 (1.12; 1.35) ****
>4 and ≤8 hours	16136 (33.6)	-25.9 (-28.3; -23.5) ****	-19.4 (-22.9; -15.9) ****	0.93 (0.88; 0.98) *
>8 hours	22692 (47.5)	-54.9 (-57.3; -52.6) ****	-24.5 (-28.0; -21.1) ****	0.77 (0.73; 0.82) ****
Age+				
18-24 years	2543 (10.3)	26.0 (20.8; 31.2)****	7.5 (-0.7; 15.7)	1.33 (1.18; 1.50) ****
25-34 years	10205 (23.0)	4.5 (2.0; 7.1)***	0.7 (-2.9; 4.3)	1.02 (0.96; 1.08)
35-44 years	14049 (24.3)	-2.1 (-4.5; 0.3)	3.8 (-0.4; 8.0)	0.95 (0.89; 1.01)
45-54 years	12495 (25.1)	-12.7 (-14.9; -10.5)****	-3.0 (-6.9; 1.0)	0.91 (0.86; 0.96)**
55-65 years	8570 (17.3)	-15.6 (-18.5; -12.8)****	-9.0 (-13.4; -4.6) ****	0.85 (0.79; 0.92)****
Sex				
Male	23824 (54.2)	Reference	Reference	Reference
Female	24038 (45.8)	2.9 (0.5; 5.2) *	-23.2 (-26.6; -19.7) ****	0.84 (0.79; 0.9) ****
Race/Ethnicity+				
White	33446 (69.6)	-2.4 (-5.7; 1.0)	-1.2 (-7.9; 5.4)	1.03 (0.96; 1.12)
Black	5572 (10.1)	-2.5 (-7.0; 1.9)	-5.2 (-13.9; 3.4)	0.88 (0.79; 0.98) *
Hispanic	6303 (14.7)	6.5 (2.4; 10.6) **	-7.4 (-14.8; -0.1) *	1.09 (0.98; 1.20)
Asian	1746 (3.9)	8.8 (3.1; 14.6) **	-9.4 (-17.0; -1.8) *	1.00 (0.86; 1.16)
Other	795 (1.7)	-10.5 (-19.8; -1.2) *	23.2 (-1.6; 48.1)	1.02 (0.81; 1.27)
Marital Status+				
Married	27921 (60.0)	2.6 (-1.7; 6.9)	-3.3 (-9.2; 2.6)	1.09 (0.97; 1.23)
Widowed	8203 (12.0)	-9.9 (-16.7; -3.1) **	2.3 (-8.1; 12.7)	0.86 (0.70; 1.04)
Divorced/Separated	1011 (1.4)	2.7 (-0.7; 6.1)	0.9 (-4.0; 5.9)	1.01 (0.92; 1.11)
Never married	10727 (26.6)	4.6 (0.9; 8.4) *	0.0 (-4.9; 5.0)	1.06 (0.95; 1.17)
Presence of spouse or unmarried partner				
No spouse or unmarried partner present	18196 (34.6)	Reference	Reference	Reference
Spouse or unmarried partner present	29666 (65.4)	-4.0 (-9.6; 1.7)	-0.4 (-3.6; 2.7)	0.92 (0.8; 1.04)
Presence of Household Children+				
No child	22436 (56.1)	9.0 (6.8; 11.3) ****	2.9 (-0.7; 6.4)	1.22 (1.15; 1.29) ****
1 child	10498 (18.2)	3.1 (0.9; 5.4) **	-2.2 (-5.6; 1.3)	0.97 (0.91; 1.02)
2 children	10085 (16.6)	0.0 (-2.0; 2.0)	0.2 (-4.2; 4.7)	0.93 (0.88; 0.98) **
3 or more children	4843 (9.0)	-12.2 (-14.7; -9.6) ****	-0.9 (-6.1; 4.2)	0.92 (0.85; 0.99) *
Education+				
Less than high school	3357 (8.6)	16.4 (12.9; 20.0) ****	11.6 (2.7; 20.5) *	0.61 (0.54; 0.68) ****
High school graduate	20299 (46.0)	-2.7 (-4.6; -0.8) **	4.6 (0.6; 8.7) *	0.77 (0.73; 0.82) ****
College graduate	17147 (32.9)	-7.7 (-9.7; -5.6) ****	-6.8 (-10.3; -3.2) ***	1.30 (1.23; 1.37) ****
Master's degree or higher	7059 (12.6)	-6.1 (-8.6; -3.5) ****	-9.5 (-13.2; -5.7) ****	1.64 (1.53; 1.76) ****
Family income+				
<$25,000	6039 (11.6)	9.6 (5.8; 13.4) ****	-3.3 (-10.1; 3.5)	0.67 (0.60; 0.74) ****
$25,000- < $50,000	10975 (21.8)	1.6 (-0.82; 4.1)	-2.3 (-6.7; 2.1)	0.82 (0.77; 0.88) ****
$50,000- < $75,000	9267 (19.1)	-2.6 (-5.3; 0.0)	-3.5 (-7.7; 0.7)	0.98 (0.92; 1.05)
$75,000- < $100,000	7037 (14.3)	0.2 (-3.0; 3.3)	-2.5 (-6.0; 1.1)	1.06 (0.99; 1.14)
$100,000- < $150,000	5009 (11.5)	-7.8 (-11.1; -4.6) ****	3.3 (-0.9; 7.6)	1.34 (1.24; 1.46) ****
≥ $150,000	3443 (8.0)	-4.0 (-7.6; -0.3) *	3.1 (-1.5; 7.7)	1.32 (1.21; 1.45) ****
No family income information available	6092 (13.7)	3.0 (0.1; 5.9) *	5.1 (-0.4; 10.6)	0.98 (0.91; 1.07)
Employment+				
Government Employee	8015 (15.2)	-4.4 (-6.6; -2.2) ***	-2.1 (-5.4; 1.3)	0.99 (0.93; 1.05)
Private Sector Employee	34620 (74.3)	-0.5 (-2.3; 1.4)	-0.8 (-3.6; 1.9)	0.97 (0.93; 1.01)
Self-employed++	5227 (10.5)	4.9 (2.4; 7.3) ***	2.9 (-1.5; 7.2)	1.04 (0.98; 1.11)
Multiple Job Status				
Not working on multiple jobs	43260 (90.4)	Reference	Reference	Reference
Working on multiple jobs	4602 (9.6)	-16.2 (-20.5; -11.9) ****	4.6 (-1.8; 10.9)	0.95 (0.86; 1.04)
Census Region+				
Northeast	16932 (35.5)	-3.2 (-5.6; -0.9) **	0.4 (-3.0; 3.8)	0.97 (0.91; 1.04)
Midwest	10428 (22.2)	0.1 (-1.9; 2.2)	1.2 (-1.8; 4.2)	0.95 (0.90; 1.01)
South	12114 (24.5)	-1.5 (-3.4; 0.5)	-0.4 (-3.7; 2.9)	0.90 (0.86; 0.95) ****
West	8388 (17.8)	4.5 (2.5; 6.6) ****	-1.1 (-4.2; 1.9)	1.2 (1.13; 1.26) ****
Day of the week+				
Monday	9545 (19.7)	6.1 (3.9; 8.4)****	-1.4 (-4.4; 1.6)	1.09 (1.02; 1.15)**
Tuesday	9754 (20.6)	3.3 (0.8; 5.8)*	2.1 (-1.8; 5.9)	1.06 (1.00; 1.12)
Wednesday	9667 (19.9)	3.8 (1.4; 6.1)**	-3.6 (-7.2; 0.0)	1.05 (0.99; 1.11)
Thursday	9381 (19.8)	2.3 (0.1; 4.5)*	-0.3 (-3.7; 3.1)	0.99 (0.93; 1.06)
Friday	9515 (20.0)	-15.5 (-17.9; -13.1)****	3.3 (-1.4; 7.9)	0.83 (0.78; 0.88)****
Season+				
Winter (Jan-Mar)	12974 (24.7)	3.0 (1.2; 4.8)**	-2.9 (-5.6; -0.2)*	0.89 (0.84; 0.94)****
Spring (Apr-Jun)	11927 (25.4)	-0.7 (-2.6; 1.2)	2.5 (-0.7; 5.8)	1.15 (1.09; 1.21)****
Summer (Jul-Sep)	11437 (24.8)	-2.0 (-4.2; 0.1)	0.2 (-2.9; 3.3)	1.23 (1.16; 1.30)****
Fall (Oct-Dec)	11524 (25.1)	-0.2 (-2.3; 1.9)	0.2 (-3.2; 3.6)	0.80 (0.75; 0.84)****

(continued on next page)

Table 1 *(continued)*

Variable	Observations [N] (Weighted %) N=47,862	Sleep Duration Minutes (95% CI) N=47,862	Exercise Duration Minutes (95% CI) for those who did exercise N=8,077	Odds of Exercising (95% CI) N=47,862
Survey Year+				
2003	5639 (6.9)	-7.5 (-10.5; -4.6)****	2.3 (-3.1; 7.8)	1.01 (0.93; 1.11)
2004	3645 (6.8)	-9.1 (-13.5; -4.8)****	1.7 (-5.2; 8.5)	0.98 (0.88; 1.08)
2005	3622 (7.1)	-4.2 (-8.0; -0.3)*	1.8 (-3.6; 7.2)	0.91 (0.82; 1.01)
2006	3474 (7.0)	-2.5 (-7.2; 2.2)	3.8 (-3.0; 10.5)	0.91 (0.81; 1.02)
2007	3364 (7.4)	-3.5 (-7.6; 0.6)	2.3 (-5.6; 10.2)	0.95 (0.85; 1.06)
2008	3368 (7.3)	-4.6 (-8.8; -0.5)*	-1.4 (-9.0; 6.2)	1.04 (0.94; 1.16)
2009	3411 (6.9)	-0.6 (-4.5; 3.3)	3.5 (-3.6; 10.6)	0.96 (0.86; 1.08)
2010	3445 (7.0)	-5.0 (-9.5; -0.5)*	-1.4 (-6.9; 4.1)	1.00 (0.89; 1.12)
2011	3240 (7.0)	2.0 (-2.2; 6.2)	-0.4 (-6.1; 5.3)	1.04 (0.94; 1.16)
2012	3188 (7.2)	1.4 (-2.3; 5.1)	-0.9 (-7.3; 5.6)	1.00 (0.88; 1.13)
2013	2910 (7.1)	7.0 (2.6; 11.4)**	2.3 (-6.8; 11.3)	0.98 (0.86; 1.12)
2014	2964 (7.2)	6.7 (2.6; 10.7)**	-2.8 (-8.9; 3.4)	1.02 (0.91; 1.14)
2015	2834 (7.5)	13.2 (9.3; 17.1)****	-5.0 (-11.2; 1.2)	1.14 (1.03; 1.26)*
2016	2758 (7.6)	6.8 (1.2; 11.9)**	-5.8 (-10.9; -0.6)*	1.08 (0.96; 1.22)

+ Effect coding was used for these variables. In effect coding, each parameter estimate reflects the deviation of a given category from the mean across all categories.
++ includes those employed without pay
* $P < .05$
** $P < .01$
*** $P < .001$
**** $P < .0001$

adjusted models, ATUS sleep duration estimates of respondents who did and did not exercise on the interview day averaged 8.01 h and 8.27 h, respectively (difference -15.5 min; 95% CI -18.4 min, -12.7 min; $P < .0001$; note that ATUS sleep estimates overestimate physiological sleep; see limitations section below). Furthermore, 28.1% and 24.9% of respondents who did or did not exercise on the interview day were classified as short sleepers (defined as < 7 h sleep), respectively (difference 3.2%; 95% CI 1.9%-4.4%; $P < .0001$).

Correlates of sleep duration and exercise likelihood and duration

Table 1 shows the effects of work duration, several sociodemographic characteristics, and variables related to survey day, year, season, and census region on sleep duration, the likelihood of exercising, and exercise duration in those who did exercise on the interview day. Consistent with earlier findings,[18,19] work duration and sleep duration showed a negative association, with those respondents not working on the interview day sleeping almost 2 hours longer than those working >8 hours. Similarly, the likelihood of engaging in exercise decreased with increasing work duration and was lower in those working >4 hours compared to those working 4 hours or less. Also, in those who did engage in exercise, exercise duration decreased monotonically with increasing work duration.

Sleep duration, exercise likelihood, and exercise duration all decreased with increasing age. Males slept on average 2.9 min less than females. They were also more likely to engage in exercise and, if they did, exercised on average 23.2 min longer. Sleep duration was longest in Asian respondents and shortest in those self-classified as "other race/ethnicity." The likelihood to engage in exercise was comparable across race/ethnicity categories, but it was significantly lower for Black respondents relative to the average across all categories. Widowed respondents had significantly shorter sleep compared to the overall mean across categories, but marital status had otherwise no significant impact on sleep or exercise duration. Both sleep time and the likelihood to exercise decreased in a dose-dependent manner with the number of household children. Both exercise and sleep duration decreased with higher education levels, but those with higher levels of education were more likely to engage in exercise. While the likelihood of engaging in exercise increased with increasing family income in a dose-dependent manner, the trend of decreasing sleep duration with increasing family income was less clear. Self-employed respondents slept the longest relative to government and private sector employees, and they were also more likely to exercise, albeit statistically non-significantly. Those working multiple jobs slept significantly shorter than those working a single job, but neither the likelihood to engage in exercise nor the duration of exercise differed between those working and not working multiple jobs.

Respondents in the West Census Region slept the longest and were also most likely to engage in exercise. Both sleep duration and the likelihood to exercise decreased across the days of the workweek. Sleep duration was longest in the winter and shortest in the summer, while the likelihood of exercise was higher in the spring and summer compared to the fall and the winter. There was an increasing linear trend in sleep duration across survey years (1.40 min per year, 95% CI: 1.12; 1.68 min, $P < .0001$) as well as a small but significant increasing linear trend in the likelihood to exercise (change in OR 1.01 per year, 95% CI: 1.00; 1.02, $P = .0197$). There was, however, no linear trend in exercise duration across survey years in those who chose to exercise (0.01 min per year, 95% CI: -0.12; 0.13 min, $P = .9183$).

Association between exercise timing and sleep duration

A pronounced increase in exercise prevalence was observed between 4:30 AM and 6:00 AM before work prevalence increased, suggesting that some respondents exercised in the morning before work (Fig. 1A). Exercise prevalence had local maxima at 10:15 AM and 7:45 PM. Regardless of the time of day, those who exercised were estimated to have shorter sleep than those who did not exercise (Fig. 1B). Exercise between 12 AM and 4 AM was associated with >100 min lower sleep duration compared to those who did not exercise during the same time period. Exercise between 9 PM and 12 AM was associated with more modest decreases in sleep duration, while exercise between 10 AM and 8 PM was associated with the lowest decrease in sleep duration. The population-level association of exercise on sleep duration at a specific time of day depends both on the strength of the association (ie, how much do those who exercise sleep less) and how many respondents engage in exercise at that time of day. We thus estimated the population-level association of exercise on sleep by multiplying the decrease in sleep duration (Fig. 1B) with the prevalence of respondents exercising (Fig. 1A) for each

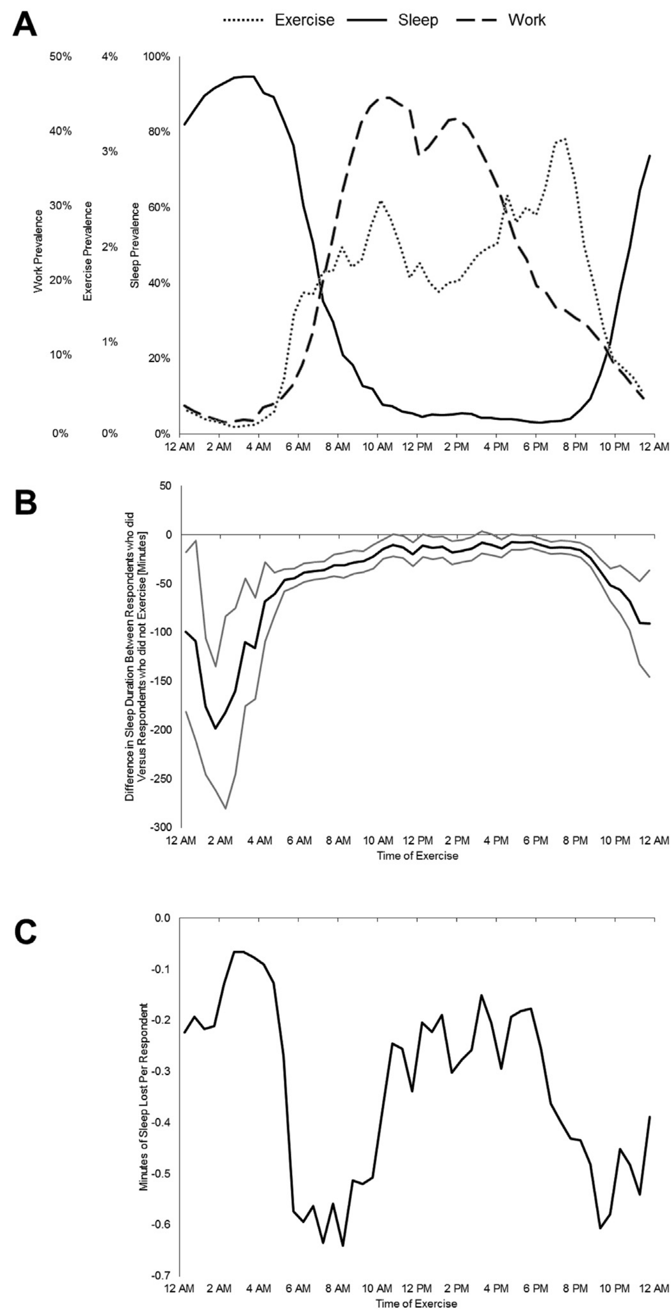

Fig. 1. Panel A shows the prevalence of exercise, work, and sleep depending on time of day. A pronounced increase in exercise prevalence was observed between 4:30 AM and 6:00 AM before work prevalence increased. Exercise prevalence had local maxima at 10:15 AM and 7:45 PM. Please note the difference in ordinate scales for the three activities. Panel B shows changes in sleep duration depending on the timing of exercise. Separate analyses were performed for forty-eight 30-min time windows, contrasting those who exercised during the specific time window to those who did not. Gray lines reflect the 95% confidence interval around the point estimate (black line). Panel C shows the population-level impact of exercise on sleep duration depending on time of day. The impact of exercise on sleep loss increases (a) the greater the change in sleep duration if respondents exercise at a certain time of day (Panel B) and (b) the more people exercise at that time (Panel A). Point estimates of Panel B were thus multiplied with the prevalence of exercise shown in Panel A. The highest population-level impact of exercise on sleep was observed between 6 AM and 8 AM and between 9 PM and 11 PM.

of the forty-eight 30-min time periods. Fig. 1C shows that the highest population level association between exercise on sleep was observed between 6 AM and 8 AM (ie, before work) and between 9 PM and 11 PM (ie, before bed).

Association between exercise duration and sleep duration

Sleep duration decreased with exercise duration in a dose-dependent manner (Fig. 2A). Likewise, the percentage of respondents classified as short sleepers (<7 h) increased in a dose-dependent manner with increasing exercise duration. Focusing on all respondents regardless of when they exercised, sleep duration did not differ significantly in those who exercised up to 30 min and the percentage of respondents classified as short sleepers did not differ significantly for exercise durations up to 60 min, respectively, relative to those who did not exercise at all. Those who exercised more than 90 min slept on average 30.6 min less than those who did not exercise ($P < .0001$). As work start time and commute time are usually fixed, we hypothesized that exercise in the morning before work would be especially detrimental to

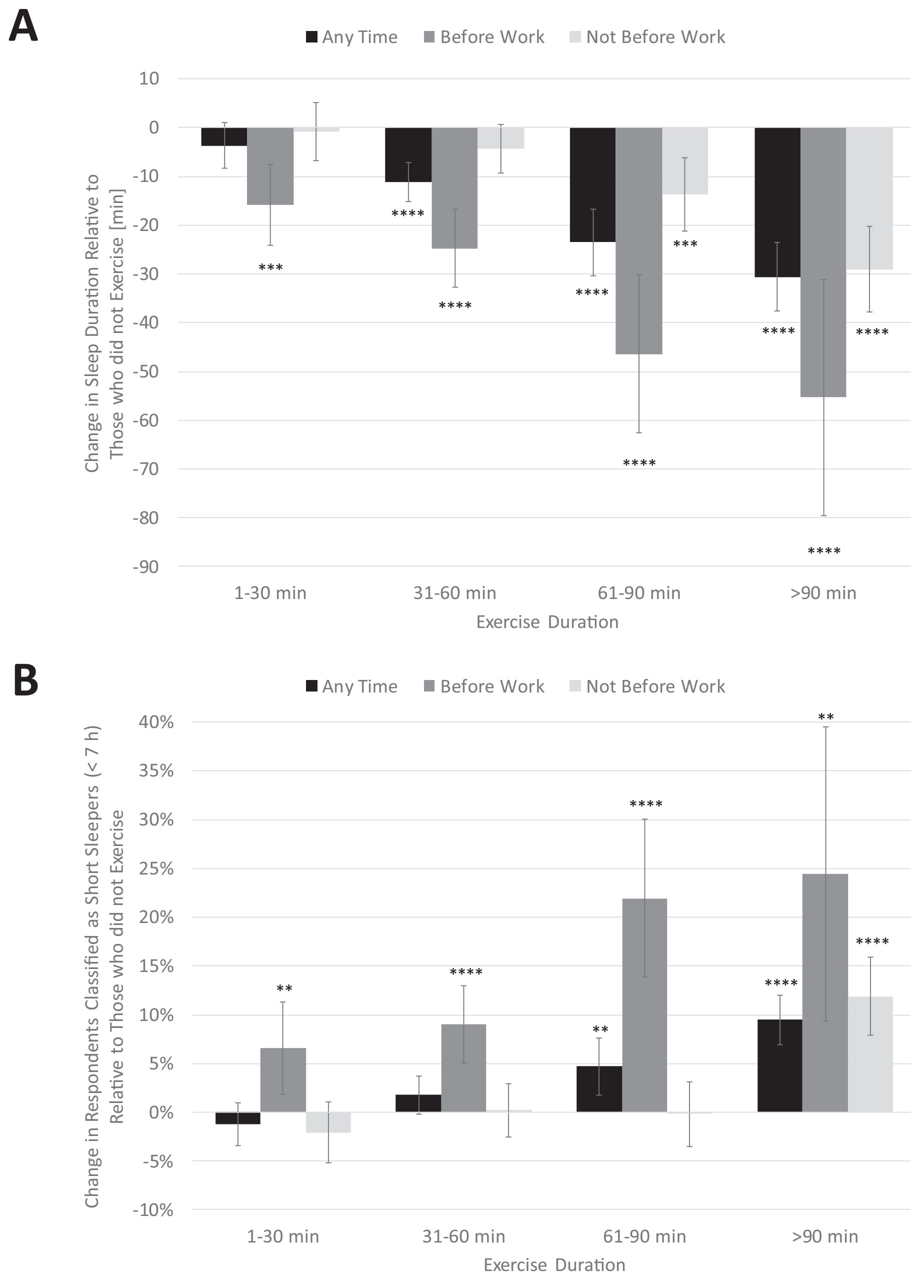

Fig. 2. Change in sleep duration (Panel A) and the percentage of respondents classified as short sleepers (<7 h; Panel B) depending on exercise duration during any time of the day, after getting up in the morning and before work start, or after work start relative to those who did not exercise on the interview day, respectively. Analyses are based on weekdays and employed respondents. 70.1% of respondents started a work period before noon. Of those, 4.8% exercised before work start. Error bars reflect 95% confidence intervals. *** $P < .001$, **** $P < .0001$

sleep duration. Indeed, at the same exercise duration, sleep duration of respondents who exercised before work start was shorter relative to those who exercised after starting work or at any time during the day (the latter including those who exercised before work; Fig. 2). In those who exercised before work, even short exercise durations of up to 30 min were associated with a significant 15.8 min drop in sleep duration relative to those who did not exercise, and significantly more respondents were classified as short sleepers. In contrast, even exercise durations of up to 60 min were not associated with a significant drop in sleep duration in those who exercised after work start, and exercise durations up to 90 min did not affect the percentage of respondents classified as short sleepers.

Discussion

To our knowledge, this is the first study to investigate the relationship between sleep and exercise based on time use surveys in a population of 18- to 65-year-old working respondents representative for the US. The findings largely corroborate our first hypothesis that those factors that were shown to decrease sleep duration were also associated with lower exercise rates. The lowest sleep durations as well as the lowest exercise rates were observed for 55- to 65-year-old respondents, working >8 h on the interview day, on multiple jobs, not self-employed, with 3 or more children, a spouse or domestic partner present, and on Fridays. This is strong evidence for the notion that activities related to work, family, and socializing are in fact competing with both sleep and exercise for time. Some variables did, however, affect sleep and exercise differentially. In addition to seasonal and regional effects, the most striking differences were found for family income and educational attainment. High levels of income and educational attainment were associated with less sleep and a higher likelihood of exercising, which suggests that wealthy, well-educated subjects likely emphasize the importance of exercise over the importance of adequate sleep.

Our analyses also demonstrate that sleep and exercise are in fact competing for time. Respondents who exercised on the interview day slept on average 15.5 min less than those who did not exercise. Also, sleep duration decreased in a dose-dependent manner with increasing exercise duration, while the percentage of respondents classified as short sleepers increased. Exercise durations of up to 30 min were associated with a small and statistically non-significant decrease in sleep duration relative to those who did not exercise, while longer exercise periods were associated with more pronounced (>10 min) and statistically significant decreases in sleep duration, as well as increases in the percentage of respondents classified as short sleepers.

The analyses showed that not only the duration, but also the timing of exercise mattered for sleep, as exercise in periods adjacent to the sleep period, ie, between 6 AM and 8 AM and between 8 PM and 11 PM was associated with shorter sleep durations. A sub-analysis demonstrated that sleep duration was shorter in respondents who exercised in the morning before work compared to those who exercised for the same duration at any time during the day or after work start. If work start and commute times are fixed, those findings are plausible, because exercise before work must be at the expense of sleep duration. Increasing the flexibility of work start times may thus be one avenue for allowing exercise before work without significantly curtailing sleep.[19] Also, these findings highlight that exercise recommendations should probably take circadian preference into account. For example, exercise in the morning before work would exacerbate social jet lag in night owls, but it would likely be less problematic for larks.[33] Similarly, late evening exercise should have little effects on subjects with a late circadian preference compared to those with an early circadian preference. Several recent studies contradict common sleep hygiene recommendations that exercise late at night should be discouraged. If this is corroborated in future studies, there is no reason to discourage late evening exercise in those with a late circadian preference.[26,30,34]

Although our findings highlight that long exercise bouts, especially before work in the morning, have the potential to significantly decrease sleep duration, this does not mean that exercise should be discouraged. Exercise durations up to 1 h, unless performed prior to work, were associated with minor reductions in sleep duration, and did not significantly increase the number of respondents classified as short sleepers. Thus, following the exercise recommendations of the American Heart Association[20] (up to 30 min five days a week) or the US Department of Health and Human Services[21] (150 min of moderate-intensity or 75 min of vigorous-intensity aerobic physical activity per week) is not in conflict with obtaining sleep of sufficient duration. Also, minor reductions in sleep duration should be tolerable, as the beneficial effects of exercise on multiple aspects of sleep, including onset latency, quality and efficiency, should more than outweigh minor reductions in time in bed.[24,26–28,30] Also, the duration of exercise bouts was identified as a significant moderator of the beneficial effects of exercise on sleep, suggesting sleep quality benefits increase with exercise duration.[26]

People can exercise while doing other things, and this may be one avenue for promoting exercise without risking sleep curtailment, eg, riding a bike for the commute to work, or using a treadmill while watching TV. Some workplaces now offer treadmill desks, and they have been shown to be acceptable and improve cardiometabolic risk markers without decreasing workplace performance.[35–37] The 2010 New York City *Active Design Guidelines* encouraged building designers and city planners to encourage physical activity into people's already tightly-constrained schedules.[38] The guidelines called for more bike lanes that were clearly marked or physically separated from vehicular traffic, public art, public bike-sharing programs, and additional bike racks and shelters to encourage biking to work. Unfortunately, secondary activities (performed at the same time as the primary activity) are not coded in the ATUS.

Strengths and Limitations

The study has several strengths and limitations.[39] Strengths of this study include the timeliness of the data, the consistency of the ATUS across survey years, the data's representativeness for the US population, the large number of relevant confounders available for adjustment, and the large number of respondents.

The study also has several limitations. First, due to the cross-sectional nature of the data, the findings reflect associations and do not imply causality. Some of the potential causal mechanisms discussed above warrant further investigation and confirmation. Second, self-reported sleep duration and exercise duration can be correlated due to self-report bias.[40]

Third, information on secondary activities is not collected in the ATUS. We were thus not able to distinguish whether, eg, a respondent's commute to work involved physical activity or not. Also, due to a 2011 change in occupation coding, and due to the difficulty of assigning activity levels to broad job categories, we refrained from classifying physical activity levels while on the job.

Fourth, the following examples are provided in the ATUS coding lexicon for the sleep category (coded as tier 010101): sleeping, falling asleep, dozing off, napping, getting up, waking up, dreaming, cat napping, getting some shut eye, dozing. Some of these examples describe rest or transitions in or out of sleep rather than sleep itself. Also, the ATUS sleep category covers 24-hour sleep (including naps), not nighttime sleep or, in case of subjects working the night shift, the dominant sleep period (importantly, a category "sleeplessness" does exist). Thus, ATUS sleep time estimates are not directly comparable with those derived from a single question asking, eg, about average sleep duration on weekday nights. For these reasons, readers should refrain from translating ATUS sleep time estimates to objectively assessed sleep time in a 1:1 fashion (even single-question estimates of sleep time have been shown to overestimate physiological sleep).[41,42] A comparison of ATUS sleep time estimates with self-reported sleep time data for weekdays/workdays from the 2005-2008 National Health and Nutrition Examination Survey (NHANES) indicated that ATUS sleep time overestimates self-reported sleep time by approximately 1 h on average.[19]

Fifth, ATUS participants are interviewed only once and contribute information of a single 24-hour day. The interview day may thus not necessarily be representative for any given respondent. However, averaging across a large number of respondents representative of the population of interest reduces the risk of bias.

Sixth, we had no detailed information on the respondents' health status or on the content of some behaviors that may act as confounders and be associated with sleep duration or exercise participation/duration. Finally, we had no information on exercise intensity. However, a recent meta-analysis did not find a moderating effect of exercise intensity on any of the investigated sleep outcomes.[26]

Clearly, sleep and exercise are interrelated in complex ways. As evidenced by the long list of limitations above, a single study can only shed so much light on this complex relationship, stressing the importance of consistency among different types of studies for inferring causality. Our analyses emphasize that behavioral interventions are rarely restricted to the behavior of interest, and that potential negative influences on other behaviors need to be taken into account.

Conclusions

Our results suggest that exercise and sleep are competing for time in US workers on weekdays and that sleep duration decreases with exercise duration in a dose-dependent manner. Daily exercise durations of up to 1 h were associated with minor decreases in sleep duration, though, unless respondents chose to exercise before work in the morning. In light of the positive effects of exercise on sleep structure and quality and on health in general a slight decrease in time in bed due to exercise should be acceptable. Our findings suggest that following exercise recommendations by the American Heart Association and the US Department of Health and Human Services are not expected to relevantly curtail sleep. Ways to increase exercise participation rates beyond the 17.1% observed in our sample without curtailing sleep include exercising while doing other activities (eg, commuting, watching television). Flexible work start times could help increase sleep time in those who choose to exercise before work. Based on the importance of the timing of exercise on sleep duration, circadian preference should be one factor in the choice of when to exercise. Public health efforts should emphasize the importance of both exercise and sleep for health, as well as the necessity of a healthy balance that avoids sacrificing one activity for the other.

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