Sleep Medicine 15 (2014) 1586–1589

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Brief Communication

Delayed sleep timing is associated with low levels of free-living physical activity in normal sleeping adults

Ari Shechter, Marie-Pierre St-Onge *

New York Obesity Research Center, Columbia University, New York, NY, USA

A R T I C L E   I N F O

Article history:
Received 21 May 2014
Received in revised form 24 June 2014
Accepted 14 July 2014
Available online 2 September 2014

Keywords:
Sleep timing
Chronotype
Sleep quality
Accelerometry
Physical activity
Obesity

A B S T R A C T

Objective and Background: We and others have reported that experimentally induced short sleep does not affect resting metabolic rate and leads to increased laboratory-measured 24-h energy expenditure. Here, we aimed to determine if sleep timing and/or quality are related to physical activity (PA) levels.
Methods: Measures of PA via waist actigraphy, sleep diary, and sleep quality questionnaires were collected over a 7–18-day period in 22 adults (mean age ± standard deviation (SD): 35.8 ± 4.6 years, and mean body mass index ± SD: 23.8 ± 1.1 kg/m^2) who were on their habitual sleep–wake and activity schedules.
Results: During the recording period, mean (±SD) bedtime and wake times were 00:17 ± 1:07 h (range: 22:02–02:07 h) and 08:20 ± 1:14 h (range: 06:30–10:11 h), respectively. After controlling for sleep duration, later bedtime, wake time, and midpoint of sleep were associated with less time spent in moderate-to-vigorous PA ($p = 0.013$, $p = 0.005$, and $p = 0.007$, respectively), and increased time in sedentary PA ($p = 0.016$, $p = 0.013$, and $p = 0.013$, respectively).
Conclusions: Current results suggest that even relatively small alterations in sleep timing may influence PA. However, causality cannot be inferred from this cross-sectional study. Clinical intervention studies should be conducted to assess the relationship between sleep timing and energy balance.

1. Introduction

In attempting to explain the link between short sleep and obesity [1], we have demonstrated that experimental sleep restriction affects appetite-regulating hormones [2], increases energy intake [3], and increases in-laboratory-measured 24-h energy expenditure [4]. However, relatively little work has been done to determine how habitual sleep patterns influence physical activity (PA) levels. This is relevant as sleep–wake behavior, particularly sleep timing, is associated with food choice [5] and energy intake [6] in children/adolescents. Late bedtime and wake time are associated with lower moderate-to-vigorous PA (MVPA) levels compared to earlier sleep timing in children/adolescents [7]. The timing of the sleep episode may be an important determinant of energy balance [8]. Therefore, we aimed to determine the relationship between sleep timing and quality and PA levels, under habitual conditions in adults. We hypothesized that later sleep timing, worsened sleep quality, and greater daytime somnolence would be associated with less vigorous and more sedentary PA levels.

2. Methods

This is a retrospective analysis of baseline screening data from a previous experiment on the effects of sleep restriction on energy balance [3,9]. Participants were 30–45 years of age, with a body mass index (BMI) between 22 and 26 kg/m^2. Exclusion criteria included smoking, type 2 diabetes, history of alcohol or drug abuse, caffeine intake >300 mg/d, shift work, trans-meridian travel, and any eating, sleeping, or neurological disorders.

As part of the pre-laboratory screening procedures [3], participants had their sleep and PA tracked for 7–18 d while they were on their habitual schedules. Actigraphy was recorded with GT3x ActiGraph monitors (Actigraph LLC, Pensacola, FL, USA), a triaxial accelerometer that monitors PA and quantifies energy expenditure in step counts per minute (cpm). Participants continuously wore the actigraph at the waist level by attaching it to an elastic belt. The sampling rate was 60 Hz, and data were reintegrated into 60-s epochs for scoring. Actilife5 software (Actigraph LLC, Pensacola, FL, USA) employing Freedson cut points [10] was used to quantify PA levels. Sedentary was defined as <100 cpm, light activity was 100–1951 cpm, moderate activity was 1952–5725 cpm, and vigorous activity was ≥5725 cpm. Moderate and vigorous were combined to form the category MVPA [11].

Abbreviations: ESS, Epworth Sleepiness Scale; MEQ, Morningness–Eveningness Questionnaire; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PSQI, Pittsburgh Sleep Quality Index; TST, total sleep time.

Clinical Trial Registration: Trial registration on http://www.clinicaltrials.gov/show/NCT00935402.

* Corresponding author. 622 West 168th Street, PH9E-105Q New York, NY 10032, USA. Tel.: +1 212 305 5960; fax: +1 212 305 8466.

E-mail address: ms2554@columbia.edu (M.-P. St-Onge).

http://dx.doi.org/10.1016/j.sleep.2014.07.010
1389-9457/

Table 1
Characteristics, sleep, and physical activity data of study participants.

	Range, $n = 22$	All, $n = 22$	Males, $n = 16$	Females, $n = 6$	p value
Age, years	30–45	35.8 ± 4.6	36.2 ± 5.0	34.7 ± 3.3	0.50
BMI, kg/m^2	22–25	23.8 ± 1.1	23.9 ± 1.1	23.3 ± 1.2	0.28
Recording length, days	7–18	12.5 ± 2.9	12.8 ± 2.5	11.5 ± 4.0	0.36
Bedtime, h	22:02–02:07	00:17 ± 1:07	00:12 ± 1:13	00:30 ± 0:51	0.58
Wake time, h	06:30–10:11	08:20 ± 1:14	08:15 ± 1:21	08:33 ± 0:56	0.60
Midpoint of sleep, h	02:02–06:00	04:19 ± 1:09	04:13 ± 1:15	04:32 ± 0:52	0.58
TST, min	389–556	448.8 ± 30.9	451.0 ± 36.1	442.78 ± 6.71	0.59
PSQI score	0–3	1.4 ± 1.1	1.4 ± 1.0	1.3 ± 1.0	0.94
ESS score	0–11	3.3 ± 2.7	3.3 ± 2.8	3.3 ± 2.5	0.95
MEQ score	39–73	56.9 ± 8.2	56.6 ± 8.8	57.5 ± 7.1	0.94
time in sedentary PA, %	55.8–95.9	83.2 ± 8.3	83.3 ± 8.8	82.8 ± 7.6	0.90
time in light PA, %	3.7–28.7	13.6 ± 5.8	13.5 ± 5.9	14.1 ± 6.1	0.84
time in MVPA, %	0.4–15.5	3.2 ± 3.1	3.2 ± 3.6	3.1 ± 1.8	0.96

Abbreviations: BMI, body mass index; ESS, Epworth Sleepiness Scale; MEQ, Morningness–Eveningness Questionnaire; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PSQI, Pittsburgh Sleep Quality Index; TST, total sleep time.
Data are mean ± SD.

The software was also used to determine total sleep time (TST) [12], with bedtime and wake time determined from sleep–wake logs. The midpoint of the sleep episode was calculated as wake time minus half the total time in bed. Chronotype (i.e., either having a morning or evening preference) was assessed with the Horne–Ostberg Morningness–Eveningness Questionnaire (MEQ) [13], daytime sleepiness with the Epworth Sleepiness Scale (ESS) [14], and sleep quality with the Pittsburgh Sleep Quality Index (PSQI) [15]. Procedures were approved by St. Luke's-Roosevelt Hospital and Columbia University Institutional Review Boards, and participants provided written informed consent.

Multiple regression analysis examined the associations between sleep and PA. Analyses were adjusted for sex, age, BMI, and waist-actigraphy-derived TST. Actigraphy-based estimates of TST have been validated in adults with the use of wrist-bound accelerometers and not waist-mounted actigraphs, as used here. Therefore, we utilized the observed TST metric as a proxy measure of sleep duration, and it was included in the models only as a covariate to control for approximate time spent asleep. Data showed homoscedasticity and there was no multicollinearity among variables. Analyses were performed using Statistical Package for the Social Sciences (SPSS) Version 22 (IBM, Armonk, NY, USA). Data are expressed as mean ± SD. Statistical significance was defined as $p < 0.05$.

3. Results

Twenty-two participants were included (Table 1). Bedtime and wake time were 00:17 ± 1:07 h (range: 22:02–02:07 h) and 08:20 ± 1:14 h (range: 06:30–10:11 h), respectively. The midpoint of sleep was 04:19 h ± 1:09 h (range: 02:02–06:00 h). The participants were good sleepers (PSQI: 1.4 ± 1.1, range: 0–3) with minimal daytime sleepiness (ESS: 3.3 ± 2.7, range: 0–11). The MEQ score was 56.9 ± 8.2 (range: 39–73), indicative of an intermediate chronotype. Two participants were definite morning types (scores: 70, 73), six were moderate morning types (range: 61–68), 13 were intermediate types (range: 46–57), and one was a moderate evening type (score: 39). Having a later chronotype, reflected by lower score on the MEQ, was associated with later bedtime ($r = -0.74$, $p < 0.001$), wake time ($r = -0.73$; $p < 0.001$), and midpoint of sleep ($r = -0.75$, $p < 0.001$).

TST was 448.8 ± 30.9 min (range: 389–556 min). The participants spent 83.2 ± 8.3% (range: 55.8–95.9%) of their time in the sedentary state, 13.6 ± 5.8% (range: 3.7–28.7%) in light PA, and 3.2 ± 3.1% (range: 0.4–15.5%) in MVPA. TST was not associated with bedtime ($r = -0.09$, $p = 0.70$), wake time ($r = 0.26$, $p = 0.24$), or midpoint of sleep ($r = 0.10$, $p = 0.66$).

After controlling for age, sex, BMI, and TST, the timing of the sleep schedule showed significant relationships with PA (Table 2). Bedtime and wake time were positively associated with percent time spent in sedentary PA (coefficient = 3.94, $p = 0.016$ and coefficient = 3.81, $p = 0.013$, respectively). Bedtime and wake time showed significant negative associations with percent time spent in light (coefficient = –2.32, $p = 0.041$ and coefficient = –2.13, $p = 0.048$, respectively) and MVPA (coefficient = –1.62, $p = 0.013$ and coefficient = –1.68, $p = 0.005$, respectively). The midpoint of sleep showed a significant positive association with percent time spent sedentary (coefficient = 3.99, $p = 0.013$) and significant negative

Table 2
Multiple regression analyses showing associations between sleep measures and physical activity levels in healthy, free-living adults after adjusting for age, sex, body mass index, and TST.

Predictor	Sedentary			Light			MVPA		
	Coefficient	Standard error	p value	Coefficient	Standard error	p value	Coefficient	Standard error	p value
Bedtime	3.94	1.46	**0.016**[a]	–2.32	1.05	**0.041**[b]	–1.62	0.58	**0.013**
Wake time	3.81	1.36	**0.013**[a,c]	–2.13	1.00	**0.048**[b]	–1.68	0.52	**0.005**[d]
Midpoint of sleep	3.99	1.42	**0.013**[a]	–2.29	1.03	**0.041**[b]	–1.70	0.55	**0.007**
MEQ score	0.31	0.22	0.17	0.17	0.15	0.28	0.14	0.09	0.11
ESS score	0.28	0.83	0.74	0.05	0.56	0.94	–0.32	0.32	0.34
PSQI score	–1.03	1.78	0.57	0.95	1.20	0.44	0.08	0.72	0.91

Abbreviations: MEQ, Morningness–Eveningness Questionnaire; MVPA, moderate-to-vigorous physical activity; ESS, Epworth Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index; TST, total sleep time.
Significant results ($p < 0.05$) are indicated in bold.
[a] Indicates significant effect of age covariate (coefficients = –0.83 to –0.85, p values < 0.04).
[b] Indicates significant effect of age covariate (coefficients = 0.58–0.59, p values < 0.05).
[c] Indicates significant effect of TST covariate (coefficient = –0.13, $p = 0.027$).
[d] Indicates significant effect of TST covariate (coefficient = 0.05, $p = 0.032$).