Associations between sleep parameters and food reward

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Abstract:

This study examined the effects of acute, isocaloric aerobic and resistance exercise on different sleep parameters, and whether changes in these sleep parameters between sessions were related to next morning food reward. Fourteen men and women (age: 21.9 ± 2.7 years; body mass index: 22.7 ± 1.9 kg m^{-2}) participated in three randomized crossover sessions: aerobic exercise; resistance exercise; and sedentary control. Target exercise energy expenditure was matched at 4 kcal kg^{-1} of body weight, and performed at 70% of VO_{2peak} or 70% of 1 repetition-maximal. Sleep was measured (accelerometry) for 22 h following each session. The 'wanting' for visual food cues (validated computer task) was assessed the next morning. There were no differences in sleep parameters and food 'wanting' between conditions. Decreases in sleep duration and earlier wake-times were significantly associated with increased food 'wanting' between sessions ($P = 0.001$). However, these associations were no longer significant after controlling for elapsed time between wake-time and the food reward task. These findings suggest that shorter sleep durations and earlier wake-times are associated with increased food reward, but these associations are driven by elapsed time between awakening and completion of the food reward task.

Keywords: exercise modality | food seeking | sleep patterns

Article:

Introduction

Acute bouts of exercise may have beneficial effects on sleep by increasing sleep duration and slow-wave sleep (Bunnell *et al*., 1983; Youngstedt *et al*., 1997). However, some studies noted no significant differences in self-reported (Porter and Horne, 1981) and objectively-measured (King *et al*., 2008) sleep duration and sleep quality between exercise and non-exercise days. Passos *et al*. (2010) reported increased sleep duration and sleep efficiency following an acute bout of moderate-intensity aerobic exercise, but not following high-intensity aerobic and moderate-intensity resistance exercise, in insomniac patients. These results are, however, limited by a lack of control over exercise energy expenditure (ExEE), which is lower during resistance versus aerobic exercises per unit of time (Donnelly *et al*., 2004). Hence, the investigation of sleep following acute, isocaloric aerobic and resistance exercise is warranted.

Studies also reported greater neuronal responsiveness to food versus non-food stimuli following imposed sleep restrictions (Benedict *et al*., 2012; St-Onge *et al*., 2012). It is, however, unknown whether habitual changes in sleep parameters under free-living conditions are associated with changes in food reward.

The objective of the current study was twofold. First, we examined the effects of an acute bout of isocaloric aerobic and resistance exercise on different sleep parameters (sleep duration, sleep efficiency, sleep efficiency after sleep onset, sleep-onset latency, bedtime and wake-time). Secondly, we investigated whether changes in these sleep parameters between sessions were related to next day food ‘wanting’ through secondary analyses.

Materials and Methods

Seven men and seven women (age: 21.9 ± 2.7 years; body mass index: 22.7 ± 1.9 kg m^{-2}; body fat percentage: 21.0 ± 7.9%; VO_{2peak}: 52.6 ± 9.0 mL kg^{-1} min^{-1}) completed all required measurements. They were between 18 and 45 years old, non-smokers, weight stable (±4 kg) within the last 6 months, did not have heart problems or diabetes, and participated in <150 min of physical activity per week. Two participants had ratings ≥10 on the Pittsburgh Sleep Quality Index (PSQI), which classifies them as being poor sleepers according to this questionnaire. Only non-pregnant, premenopausal women were recruited. This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The University of Ottawa ethics committee approved all procedures involving human participants. Written informed consent was obtained from all participants.

Participants took part in three randomized crossover sessions: aerobic exercise; resistance exercise; and sedentary control. ExEE was matched at 4 kcal kg^{-1} of body weight. The mean ExEE during the aerobic and resistance exercise sessions were 274.5 ± 50.6 and 270.4 ± 56.3 kcal, respectively (P = NS; Cadieux *et al*., 2014). A washout period of at least 7 days separated each session for men, and at least 1 month for women because they were always tested between days 1 and 8 of the menstrual cycle as cortisol responses to sleep restriction (Leroux *et al*., 2014) and brain activation to food cues (Alonso-Alonso *et al*., 2011) have both been shown to vary across the menstrual cycle. For each session, participants arrived at the laboratory at 08:00 hours following a 12-h overnight fast. They were instructed not to consume alcohol or engage in structured physical activity (e.g. training and playing sports) for at least 24 h prior to each session, and during the data collection period. Participants were also instructed not to consume caffeine during the data collection period. Upon arrival, participants were weighed to the nearest 0.1 kg with a BWB-800AS digital scale and served a standard breakfast. At 10:30 hours (10:00 hours for the resistance exercise), participants completed the aerobic (running at 70% of VO_{2peak}) or resistance (supersets at 70% of 1-maximal repetition) exercise interventions, which ended when target ExEE was reached (~11:00 and 11:30 hours for the aerobic and resistance exercises, respectively), or the sedentary control session (recreational reading for 45 min). ExEE during each intervention was measured with a portable indirect calorimetry unit (model K4b^2; COSMED, Chicago, IL, USA), as previously described (Cadieux *et al*., 2014).

After each intervention (~14:00 hours), participants wore a biaxial accelerometer (SenseWear Pro 3 Armbands©; HealthWear Bodymedia, Pittsburgh, PA, USA) around the upper arm to assess habitual sleep parameters over 22 h. Sharif and Bahammam (2013) noted no significant differences in sleep duration, wake-time and sleep efficiency assessed with this biaxial accelerometer or polysomnography. The overall intraclass correlation between both tools was above 0.8, indicating good agreement in assessing sleep parameters (Sharif and Bahammam, 2013). These results were also verified with sleep diaries. Participants were asked to rate their sleep quality the following morning by choosing an answer on a five-point Likert scale that best described their sleep quality the preceding night (1 – much better than normal; 2 – better than normal; 3 – normal; 4 – worse than normal; and 5 – much worse than normal). Participants also rated their feelings of sleepiness on a seven-point Likert scale (1 – alert/not tired and 7 – sleep onset soon/very tired) within 15 min prior to going to bed, and within 15 min of waking up the following morning.

The following morning, between 10:00 and 12:00 hours, participants completed a validated computer-based behavioural procedure (Leeds Food Preference Questionnaire). Participants rated the extent to which they 'wanted' each randomly presented visual food cue with a 100-mm visual analogue scale. The questions and scoring methods used are described elsewhere (Finlayson *et al*., 2008).

Statistical analyses were performed using SPSS (version 17.0; SPSS, Chicago, IL, USA). One-way repeated-measures anova tests determined the effects of exercise modality on sleep parameters and next morning food 'wanting'. Bivariate Spearman correlations with Bonferroni corrections assessed the strength of relationships between sleep parameters with food 'wanting' at each session, as well as the changes in these parameters between sessions (Δcontrol – aerobic; Δcontrol – resistance; Δaerobic – resistance). Data are presented as mean ± SD. Differences with *P*-values <0.05 and ≤ 0.004 were considered statistically significant for the anova analyses and Spearman correlations, respectively.

Results

No differences were noted between sessions (Table 1), or across time for all sleep and food reward outcomes (results not shown). Sleep duration was negatively associated with food 'wanting' in the aerobic exercise session ($\rho = -0.83$; $P = 0.0001$). Changes in sleep duration ($\rho = -0.78$; $P = 0.001$) and wake-time ($\rho = -0.77$; $P = 0.001$) were negatively correlated with Δfood 'wanting' in the Δaerobic – resistance exercise condition. However, these associations were no longer significant after correcting for the time elapsed between wake-time and completion of the food reward task (results not shown).

No other significant correlations were noted between sleep parameters with food 'wanting', or between the changes in these variables (results not shown). Lastly, no significant correlations were noted between naptime (min) and PSQI scores with sleep efficiency and sleepiness measurements (results not shown).

Table 1. Objectively- and subjectively-measured sleep parameters and food 'wanting' assessed following each session

	Sedentary control		Aerobic exercise		Resistance exercise		Session effect
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Sleep parameters (accelerometry)							
Sleep duration (min)	416	88	432	59	407	83	$P = 0.62$
Sleep efficiency (%)	81.2	8.2	82.8	8.7	78.8	6.8	$P = 0.21$
Sleep efficiency after sleep onset (%)	86.7	7.7	86.9	8.4	86.6	6.7	$P = 0.99$
Sleep-onset latency (min)	13	7	9	8	19	23	$P = 0.23$
Bedtime (i.e. sleep onset)	12 :03 hours	1 h 22 min	12:22 hours	2 h 16 min	12:03 hours	1 h 12 min	$P = 0.77$
Wake-time	07:51 hours	1 h 17 min	07:47 hours	1 h 30 min	07:54 hours	1 h 43 min	$P = 0.97$
Daytime nap time (min)	24	45	11	23	22	44	$P = 0.44$
Sleep parameters (self-reported)							
Sleep quality	3.2	0.9	3.4	0.6	3.0	0.6	$P = 0.25$
Evening sleepiness rating	5.0	1.5	5.0	1.0	5.4	1.1	$P = 0.44$
Morning sleepiness rating	3.2	1.0	2.8	1.1	3.4	1.2	$P = 0.37$
Food reward measurement							
Food 'wanting' (mm)	40.6	15.7	35.7	15.9	36.3	15.2	$P = 0.34$

SD, standard deviation.

Food 'wanting' scores were measured with a 100-mm visual analogue scale. Self-reported sleep quality was measured with a five-point Likert scale (i.e. score of 3 is indicative of an habitual or 'normal', sleep quality), and sleepiness ratings were measured with a seven-point Likert scale. Sleep efficiency (%) is defined as sleep duration/time lying down in bed, and sleep efficiency after sleep onset (%) is defined as sleep efficiency (%) after sleep onset and before wake-time.

Discussion

This is the first study to investigate acute effects of isocaloric aerobic and resistance exercise on sleep parameters, and whether habitual changes in sleep parameters are associated with next morning food reward.

Our results indicated no significant effects of exercise modality on sleep, which supports studies that subjectively (Porter and Horne, 1981) and objectively (King *et al.*, 2008) assessed sleep parameters on exercise and non-exercise days. A study that noted increases in sleep duration and slow-wave sleep did so following acute aerobic exercise to exhaustion (Bunnell *et al.*, 1983). The latter is further supported by a meta-analysis (Youngstedt *et al.*, 1997), which reported significant median increases in sleep duration and slow-wave sleep of 10 and 1.4 min, respectively, following an acute bout of aerobic exercise; with effects being greatest for aerobic exercises that exceeded 1 h. Hence, the shorter aerobic exercise session (mean duration of 24 min) sustained at 70% of VO_{2peak} in the present study may not be sufficient to alter sleep. Conversely, the resistance exercise lasted on average 86 min, and had no significant impact on sleep. It may be hypothesized that ExEE, which was matched in this study, may have a greater impact on sleep rather than exercise duration *per se*. Future studies are needed to evaluate this hypothesis, and assess the effects of exercise modality performed at different times of day on sleep, as advancements in melatonin release following evening exercise (Buxton *et al*., 2003) may affect sleep differently.

Secondary analyses revealed that decreases in sleep duration and earlier wake-times were associated with increased food reward. These results add to studies reporting greater neuronal responsiveness to food versus non-food stimuli following imposed sleep restriction (Benedict *et al*., 2012; St-Onge *et al*., 2012). Although other cross-sectional studies reported associations between later sleep timing midpoints with poorer diet qualities (e.g. higher fast food and lower fruit/vegetable intakes; Baron *et al*., 2011; Sato-Mito *et al*., 2011), this is the first study to suggest that an earlier wake-time is associated with increased food reward. An important cofounding factor in the present study is the elapsed time between wake-time and completion of the food reward task (between 10:00 and 12:00 hours), as participants with an earlier wake-time may express greater drives towards food in the morning because of greater elapsed time spent awake prior to completing the task, comparatively to individuals who usually wake later.

The present findings are limited by a small sample size of normal-weight men and women. Only 1-day assessments of outcomes, and acute exercise interventions, were performed, which may not account for normal day-to-day variability or potential additive effects. The food reward task represents a proxy of actual food intake. Differences in exposures to environmental factors in the evening and/or overnight between conditions were not evaluated and may alter sleep (e.g. exposure to blue-light from technological devices). The strength of associations noted in women may be in part influenced by the menstrual cycle, as all women were tested between days 1 and 8 of the follicular phase. Lastly, correlations cannot infer causality. However, the temporal order of events (i.e. sleep preceding food reward measurements) reinforces current results.

These findings suggest that exercise modality does not acutely alter sleep. Shorter sleep durations and earlier wake-times were associated with increased food reward, but these associations were driven by elapsed time between awakening and completion of the food reward task. Future studies are needed to confirm these preliminary findings and further assess the effects of sleep timing, or individual circadian rhythms, on food reward. Future studies should also consider the elapsed time between awakening and completion of food reward measurements, as this may be an important cofounder driving food-seeking behaviour.

Author Contributions

J. M., S. C. and É. D. formulated the research questions, designed the study and carried out the experiment. J. M., G. F. and É. D. analysed the data. All authors were involved in writing the paper, and had final approval of the submitted and published version.

Conflict of Interest Disclosure

The authors of this paper declare no conflict of interest.

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