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The effects of partial sleep restriction and altered sleep timing on appetite and food reward

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ABSTRACT

We examined the effects of partial sleep restriction (PSR) with an advanced wake-time or delayed bedtime on measures of appetite, food reward and subsequent energy intake (EI). Twelve men and 6 women (age: 23 ± 4 years, body fat: 18.8 ± 10.1%) participated in 3 randomized crossover sessions: control (habitual bed- and wake-time), 50% PSR with an advanced wake-time and 50% PSR with a delayed bedtime. Outcome variables included sleep architecture (polysomnography), *ad libitum* EI (validated food menu), appetite sensations (visual analogue scales), satiety quotient (SQ; mm/100 kcal) and food reward (Leeds Food Preference Questionnaire and the relative-reinforcing value (RRV) of preferred food task). Increased fasting and post-standard breakfast appetite ratings were noted following PSR with an advanced wake-time compared to the control and PSR with a delayed bedtime sessions (Fasting hunger ratings: 77 ± 16 *vs.* 65 ± 18 and 64 ± 16; $P = 0.01$; Post-meal hunger AUC: 5982 ± 1781 *vs.* 4508 ± 2136 and 5198 ± 2201; $P = 0.03$). Increased explicit wanting and liking for high- relative to low-fat foods were also noted during the advanced wake-time *vs.* control session (Explicit wanting: −3.5 ± 12.5 *vs.* −9.3 ± 8.9, $P = 0.01$; Explicit liking: −1.6 ± 8.5 *vs.* −7.8 ± 9.6, $P = 0.002$). No differences in the RRV of preferred food, SQ and *ad libitum* lunch intake were noted between sessions. These findings suggest that appetite sensations and food reward are increased following PSR with an advanced wake-time, rather than delayed bedtime, *vs.* control. However, this did not translate into increased EI during a test meal. Given the increasing prevalence of shift workers and incidences of sleep disorders, additional studies are needed to evaluate the prolonged effects of voluntary sleep restriction with altered sleep timing on appetite and EI measurements.

1. Introduction

Spiegel, Tasali, Penev, and Van Cauter (2004) were among the first to demonstrate increased feelings of hunger for calorie-dense foods following 2 days of 4 h *vs.* 10 h in bed/night. A recent functional magnetic resonance imaging (fMRI) study observed enhanced activation in the orbitofrontal cortex in response to visual food cues following partial sleep restriction (4 *vs.* 9 h in bed/night) (St-Onge et al., 2012). Activity in reward and food-sensitive areas of the brain was also increased in response to unhealthy *vs.* healthy food cues in these same participants following sleep restriction (St-Onge, Wolfe, Sy, Shechter, & Hirsch, 2014).

Sleep restriction protocols with differing bed- or wake-times have been shown to impact sleep architecture (Tilley & Wilkinson, 1984; Wu et al., 2010). More specifically, there is no difference in slow-wave sleep (SWS) duration when sleep was restricted to the first *vs.* second half of the night, whereas rapid eye movement (REM) sleep was greater when sleep was restricted to the second half of the night. As such, stage 2 sleep duration was reduced when sleep was restricted to the second half of the night. A recent study (Rutters et al., 2012) noted that participants with habitually lower amounts of SWS, independently of sleep duration, reported feeling hungrier and less full the following day, had increased food wanting and *ad libitum* energy intake (EI). Shechter et al. (2012) also noted a negative association between the changes in REM sleep duration and next day hunger ratings between a sleep

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restriction and control condition (4 *vs.* 9 h in bed/night). These results thus suggest that inter-individual variations in habitual sleep architecture, or changes in sleep stage durations in response to partial sleep restriction, may be linked to appetite sensations and food reward. However, it is unknown whether sleep restriction combined with altered bed or wake-times may impact appetite sensations and/or food reward differently. Additionally, it is unknown whether the changes in sleep architecture that occur in response to alterations in bed or wake-times during an imposed sleep restriction period may be associated with potential changes in these outcomes. The objective of this study was to investigate the influence of sleep timing when imposing a sleep restriction period on measures of appetite and food reward the following day with a within-subject design. Briefly, we evaluated the effects of a 50% sleep restriction during the first or second half of a habitual sleep period on appetite sensations and food reward. It was hypothesized that sleep restriction with an advanced wake-time would lead to increased appetite sensations and food reward when compared to habitual sleep duration. It was also hypothesized that these changes in appetite and food reward would be associated with changes in REM sleep duration between the control and advanced wake-time sessions.

2. Materials and methods

2.1. Participants

Twenty-two participants who corresponded to all inclusion criteria were recruited. However, only 18 completed all sessions (12 men and 6 women; age: 23 ± 4 years; BMI: 22.7 ± 2.7 kg/m^2; body fat percentage: 18.8 ± 10.1%). Study methodologies are described in more detail elsewhere (McNeil et al., 2016). Briefly, participants were between the ages of 18–45 years, non-smokers, weight stable (±4 kg) within the last 6 months, did not have heart problems or diabetes, did not take medication that could have affected appetite or sleep, and reported not performing shift work nor taking regular daytime naps. They also reported having habitual sleep duration of 7–9 h/night. Only women taking monophasic, combined estrogen-progesterone birth control pills were recruited in order to control for the effects of menstrual cycle phase and sex-steroid hormones on sleep parameters (Baker et al., 2001) and food reward (Alonso-Alonso et al., 2011). This study was conducted according to the guidelines laid down in the Declaration of Helsinki and the University of Ottawa ethics committee approved all procedures involving human participants. Written informed consent was obtained from all participants.

2.2. Study design and preliminary session measurements

This study followed a randomized crossover design, which included a preliminary session, 2 weeks of sleep-wake monitoring with accelerometry (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA, USA) and sleep diaries under free-living conditions, 2 habituation nights (1 in-lab and 1 outside of the lab) and 3 randomized experimental sessions (control with an habitual bed- and wake-time, 50% sleep restriction with an habitual bedtime and advanced wake-time, and 50% sleep restriction with a delayed bedtime and habitual wake-time). During the preliminary session, anthropometric data were collected and participants were given *ad libitum* access to a standard breakfast, which included whole-wheat toast, strawberry jam, peanut butter, cheddar cheese and orange juice. Participants were also asked to write down their favorite snack and fruit/vegetable that would be later used for the relative-reinforcing value (RRV) of a preferred food task (Temple et al., 2009), which was conducted during each of the 3 experimental conditions. Lastly, participants rated 202 food images that were divided into 4 categories according to fat content and taste (high-fat savory, low-fat savory, high-fat sweet, low-fat sweet) based on the following question: "How often do you consume this food item?". The 4 highest-rated food items within each category were then used to personalize the computer-based behavioral procedure called the Leeds Food Preference Questionnaire (LFPQ) (Finlayson, King, & Blundell, 2008) that was administered during each experimental session. Hence, the food items presented during this task may have differed between participants, but were standardized across sessions for the same participant. At the end of the preliminary session, the participants were given an accelerometer (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA, USA) and a sleep diary to measure habitual sleep-wake patterns under free-living conditions for 2 weeks. The mean bed- and wake-times measured over 2 weeks for each participant were used to prescribe the time in bed for the control session, whereas the mean sleep midpoint was used to determine the advanced wake-time or delayed bedtime in the sleep restriction conditions. Hence, the assigned bed- and wake-times, as well as the timing of measurements the following morning, differed between participants but were standardized for each participant across sessions. The 3 experimental sessions were randomly assigned to each participant. As a result, 6 participants started with each of the 3 experimental sessions. No significant order effect was noted for hunger ratings (results not shown). A washout period of at least 7 days separated each experimental session.

2.3. Evening and overnight procedures and measurements

Each experimental session began 3 h prior to the set bedtime to allow enough time to place all the electrodes (≈90 min), set up the polysomnogram (≈30 min) and allow for some downtime before going to bed (≈60 min). Electroencephalography (EEG; C3, C4, O1, O2, F3 and F4), electromyography (EMG; bipolar submental) and electrooculography (EOG) were recorded on a Medipalm 22 (Braebon Medical Corporation, Kanata, Ontario, Canada) with the Pursuit Sleep Software (Braebon Medical Corporation, Kanata, Ontario, Canada). This setting was used to assess sleep inside the lab during each experimental session. Recordings were scored independently by 2 researchers according to the AASM 2007 criteria (The American Academy of Sleep, 2007) using 30-s epochs and discrepancies were resolved by mutual agreement. When forced to remain awake during the night and the following morning, participants were allowed to take part in any type of sedentary activity (*e.g.* reading, watching movies) as long as they remained inside the lab with the evaluator.

2.4. Next morning procedures and measurements

The clock time at which all measurements were taken the next morning did differ according to each participant's habitual wake-time (range: 6 h18–8 h37), but remained the same for each participant across sessions. Upon awakening, participants were given 1 h to shower. Body weight (HR-100; BWB-800AS, Tanita Corporation, Arlington Heights, IL, USA) and fasting appetite sensations were measured 75 min after habitual wake-time each morning for each experimental session. This took place prior to breakfast consumption, which contained the exact quantity and composition of the breakfast consumed during the preliminary session for each participant. There was a difference in the elapsed time between awakening and the start of next morning measurements (*i.e.* fasting appetite measurements and standard breakfast administration) during the sleep restriction with advanced wake-time condition *vs.* the control and sleep restriction with delayed