Increased energy intake following sleep restriction in men and women: A one-size fits all conclusion?

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This is the peer reviewed version of the following article:

McNeil J, St-Onge M-P. Increased energy intake following sleep restriction in men and women: A one-size fits all conclusion? Obesity (Silver Spring), 2017, 25(6): 989-992.

which has been published in final form at https://doi.org/10.1002/oby.21831. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Use of Self-Archived Versions.

Abstract:

Objective: This study assessed the degree of interindividual responses in energy intake (EI) to an imposed sleep restriction versus habitual sleep duration protocol. It also investigated participant (age, sex, ethnicity, and BMI) and study (study site and protocol order) characteristics as potential contributors to the variance in EI responses to sleep restriction between individuals. **Methods:** Data from two randomized crossover trials were combined. All participants ($n = 43$; age: 31 ± 7 years, BMI: 23 ± 2 kg/m^2) were free of medical/sleep conditions, were nonsmokers, reported not performing shift work, and had an average sleep duration of 7 to 9 hours per night. Ad libitum, 24-hour EI was objectively assessed following sleep restriction (3.5-4 hours in bed per night) and habitual sleep (7-9 hours in bed per night) conditions. **Results:** Large interindividual variations in EI change (ΔEI) between restricted and habitual sleep conditions were noted (−813 to 1437 kcal/d). Only phase order was associated with ΔEI ($\beta = -568$ kcal/d, 95% confidence interval for $\beta = -921$ to −215 kcal/d; $P = 0.002$); participants randomized to the habitual sleep condition first had greater increases in EI when sleep was restricted ($P = 0.01$). **Conclusions:** Large interindividual variations in ΔEI following sleep restriction were noted, suggesting that not all participants were negatively impacted by the effects of sleep restriction.

Keywords: sleep restriction | energy intake

Article:

Introduction

Imposing sleep restriction up to 5 days can lead to short-term weight gain (1-4). More specifically, these studies report mean increases in energy intake (EI) of 200 to 500 kcal/d following imposed sleep restriction compared to habitual sleep duration (1-4), suggesting that increased EI may largely account for the weight gain observed following sleep restriction (5). In addition to these main effects, differences in EI responses to sleep loss according to certain participant characteristics, e.g., sex (4, 6, 7) and ethnicity (6), have been noted.

Although the abovementioned studies have consistently reported average increases in EI following imposed sleep restriction compared to habitual sleep duration, they also present large standard deviations for EI. Therefore, the range in EI responses to the same sleep restriction protocol may greatly vary between individuals.

The primary aim of this paper was to assess interindividual responses in EI to an imposed partial sleep restriction protocol. Furthermore, we investigated participants' age, sex, ethnicity, body mass index (BMI), protocol order, and study site as potential contributors to this degree of variance in EI responses to imposed sleep restriction between individuals.

Methods

Data from two randomized crossover sleep restriction interventions conducted at the University of Ottawa (Ottawa, Canada) (8) and St. Luke's-Roosevelt Hospital/Columbia University (New York, USA) (7) were combined for this secondary analysis. Study protocols were approved by their institution's ethics committees (the University of Ottawa Ethics Committee; the Institutional Review Boards of St. Luke's-Roosevelt Hospital Center and Columbia University), and participants provided informed consent. All participants were 18 to 45 years of age; free of neurological, metabolic, and sleeping disorders; nonsmokers; and nonshift workers. Participants also reported sleeping on average 7 to 9 hours per night, as verified with 2 weeks of accelerometry and sleep diary data in both studies.

The study conducted at St. Luke's-Roosevelt Hospital/Columbia University included two sessions of five nights each: sleep restriction (4 hours in bed per night) and habitual sleep duration (9 hours in bed per night). At least 4 weeks separated each session. EI was standardized over the first 4 days of each session, and ad libitum, 24-hour EI was assessed on day 5. Participants were able to self-select foods inside the research facility or purchase foods outside of the facility with a monetary allowance. All consumed food items were weighed and recorded by study staff. The study conducted at the University of Ottawa included three sessions of one night each: sleep restriction with advanced wake time (3.5-4 hours in bed per night, remained awake during the second part of the night), sleep restriction with delayed bedtime (3.5-4 hours in bed per night, remained awake during the first part of the night), and habitual sleep duration (7-9 hours in bed per night). Advancing wake time leads to selective reductions in rapid eye movement sleep (9); therefore, data from the sleep restriction with delayed bedtime condition were included as the "sleep restriction condition" in the present analysis. There was also no statistically significant difference in EI change (ΔEI) when comparing both sleep restriction conditions in this study (results not shown). At least 7 days separated each session. Participants self-selected foods from a validated menu, which were served in ad libitum quantities. Study staff weighed and recorded all consumed food items. Despite differences in study protocol/intervention lengths between study sites, no statistically significant differences in ΔEI between studies were noted (Ottawa: 157 ± 443 vs. New York: 282 ± 630 kcal/d; $P = 0.48$).

ΔEI for each participant was calculated by subtracting EI during the habitual sleep duration condition from EI during the sleep restriction condition. A multivariable, stepwise linear regression analysis was used to examine the strength of the associations between the participants' age, sex (man or woman), ethnicity (white or other), BMI, protocol order (sleep restriction or habitual sleep duration first), and study site (New York or Ottawa) with ΔEI. A sample size of 43 participants with a predetermined power of 0.80 and two-tailed alpha of 0.05 is estimated to provide a large effect size (Cohen's $f^2 = 0.41$) to detect significant associations with this regression model. Stratified analysis with an independent *t* test was conducted if significant associations were noted with this regression model. Statistical analyses were performed using SPSS Statistics® (version 19.0; IBM Corp., Armonk, New York Illinois). Statistical significance was set at $P < 0.05$.

Results

Details on mean differences in EI between sleep duration conditions for the studies presented herein are presented elsewhere (7, 8). Table 1 presents baseline characteristics for all participants and according to phase order and study site.

Table 1. Baseline characteristics for all participants and according to phase order and study site

		Study site		**Phase order**	
	All participants (*n* = 43)	**Ottawa (*n* = 17)**	**New York (*n* = 26)**	**Habitual sleep first (*n* = 17)**	**Sleep restriction first (*n* = 26)**
Age (y), mean ± SD	31 ± 7	23 ± 4	35 ± 5	33 ± 7	29 ± 7
BMI (kg/m^2), mean ± SD	23 ± 2	23 ± 3	24 ± 1	24 ± 2	23 ± 2
Sex, *n* (%)					
Men	24 (55.8%)	11 (64.7%)	13 (50%)	8 (47.1%)	16 (61.5%)
Women	19 (44.2%)	6 (35.3%)	13 (50%)	9 (52.9%)	10 (38.5)
Ethnicity, *n* (%)					
White	27 (62.8%)	15 (88.2%)	12 (46.2%)	11 (64.7%)	16 (61.5%)
Other	16 (37.2%)	2 (11.8%)	14 (53.8%)	6 (35.3%)	10 (38.5%)

SD, standard deviation.

The range in ΔEI was large (−813 to 1437 kcal/d; Figure 1). In all participants, 41.9% had a > 300 kcal/d increase in EI during sleep restriction versus habitual sleep duration conditions, 39.5% had a ≤ 300 kcal/d difference in EI between conditions, and 18.6% had a > 300 kcal/d decrease in EI following sleep restriction versus habitual sleep duration.

Figure 2 presents interindividual variations in ΔEI according to sex, ethnicity, phase order, and study site. Only phase order was significantly associated with ΔEI ($\beta = -568$ kcal/d, 95% confidence interval for $\beta = -921$ to -215 kcal/d; $P = 0.002$) in the multivariable regression model. Post hoc analysis revealed that participants randomized to the habitual sleep duration condition first had greater increases in EI when sleep was restricted versus habitual sleep duration (506 ± 494 vs. 54 ± 537 kcal/d; $P = 0.01$).

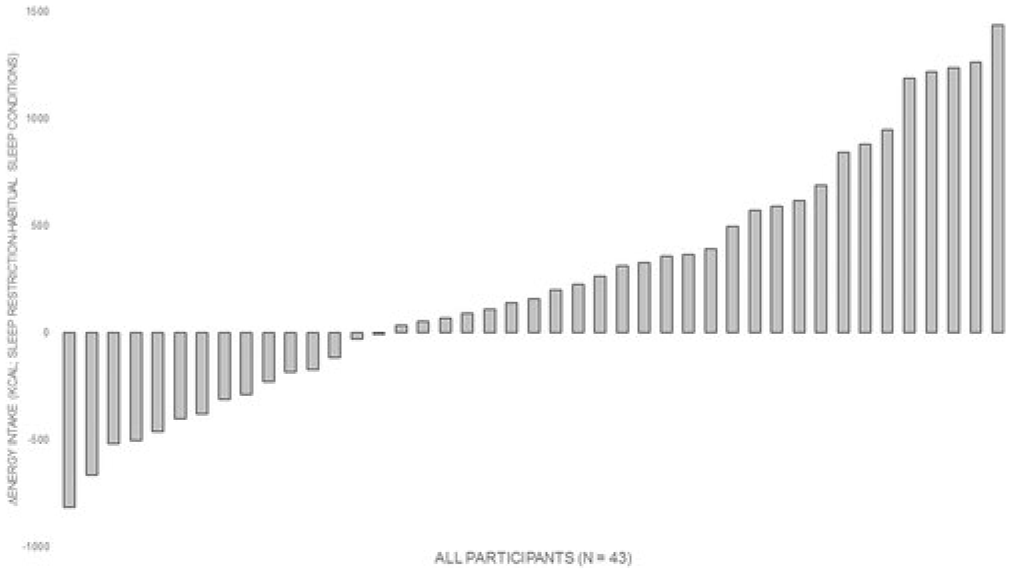

Figure 1. Distribution of energy intake (EI) responses (ΔEI) to sleep restriction. ΔEI for each participant was calculated by subtracting EI during the habitual sleep duration condition from EI during the sleep restriction condition.

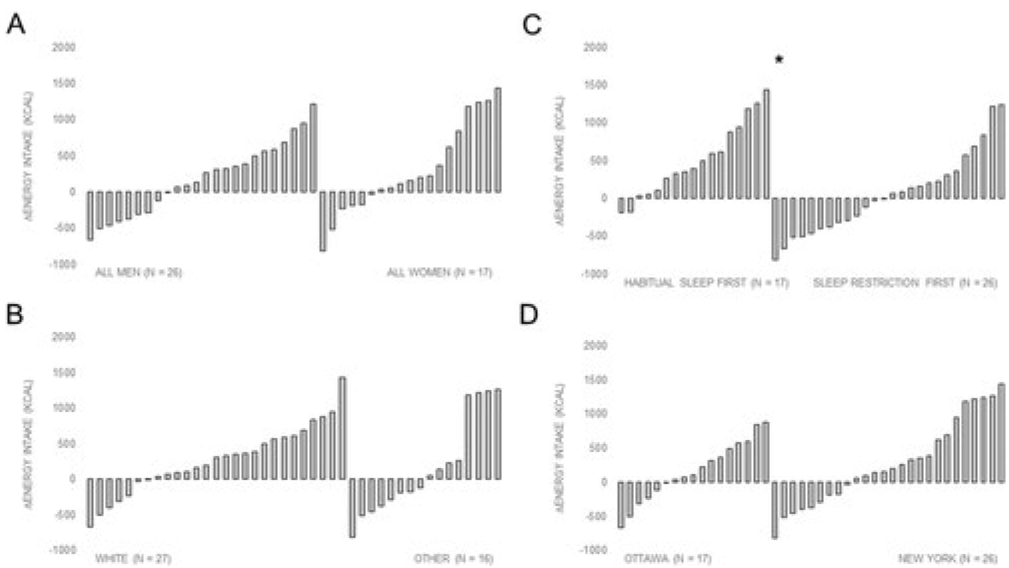

Figure 2. Distribution of energy intake responses (ΔEI) according to (**A**) sex (man or woman), (**B**) ethnicity (white or other), (**C**) phase order (habitual sleep or sleep restriction conditions first), and (**D**) study site (Ottawa or New York). ΔEI for each participant was calculated by subtracting EI during the habitual sleep duration condition from EI during the sleep restriction condition. $*P = 0.01$.

Discussion

Our findings indicated large interindividual variations in ΔEI in response to sleep restriction, suggesting that EI following similar degrees of imposed sleep restriction was highly variable between participants. Large interindividual variations in weight loss following diet and/or exercise interventions have also been reported (10-12). Even though the trials presented herein used objective and precise methods to assess EI, accuracy and validity issues often arise as a result of large day-to-day variability in EI (11).

Spaeth et al. (13) also reported interindividual differences in EI (−501 to 1178 kcal/d) and large differences in body weight change (−2.3 to 6.5 kg) between participants who took part in two identical sleep restriction conditions. There is evidence to suggest that trait-like differences between individuals may impact the degree of sensitivity to the adverse cognitive effects of sleep loss (14-17). Van Dongen et al. (14) were among the first to investigate interindividual differences in sleepiness ratings and responses to psychomotor and cognitive tasks following total sleep deprivation, demonstrating large inter-, but not intra-, individual responses to sleep loss. Killgore et al. (15) later demonstrated that an extraversive personality trait was associated with greater declines in alertness and psychomotor vigilance following total sleep deprivation. Furthermore, individuals with lower cortical activity when rested (17) and/or greater ventrolateral prefrontal cortex activation following sleep loss (16) have been classified as being "resistant" to the effects of sleep loss.

No baseline participant characteristics (age, sex, ethnicity, and BMI) included in our regression model were significantly associated with ΔEI between sleep conditions. Spaeth et al. (13) reported greater consistency in EI and body weight changes to consecutive sleep restriction interventions in men versus women but no differences in body weight change to the sleep restriction intervention between individuals with normal weight and overweight. Only phase order was significantly associated with ΔEI in the present study, with participants randomized to the habitual sleep condition first having greater increases in EI when sleep was restricted versus habitual sleep duration. A similar order effect was previously reported by Markwald et al. (4), noting a reduction in EI and weight loss when participants transitioned from the sleep restriction to adequate sleep condition. Although a mere hypothesis, it is possible that participants were more cautious during the first sleep condition as a result of not knowing the randomization order and/or less familiarity with the laboratory settings and measurement procedures, compared to the second session. Conversely, the novelty associated with ad libitum access to food may lead to greater EI in some participants during the first session, independently of the study condition. Studies are needed to explore this hypothesis within the contexts of EI research.

Strengths of this paper include the combination of data from two different sleep restriction trials to increase the number of participants and better illustrate interindividual variability in EI responses to imposed sleep restriction. Additionally, these studies included objective measurements of sleep and EI under strict laboratory conditions. Limitations include the measurement of EI over a single 24-hour period and the recruitment of healthy, young individuals with good sleep quality only, which limits generalizability of study findings to other populations (e.g., individuals with sleep disorders). Although no statistical difference in ΔEI was noted between study sites, additive effects of sleep restriction on EI may have occurred in one study imposing five nights of sleep restriction, but not the other, which only imposed one night of sleep restriction for each condition.

In conclusion, we demonstrated large interindividual variations in EI responses to imposed sleep restriction, suggesting that not all individuals may be negatively impacted by the effects of sleep restriction. Future studies are needed to identify contributing behavioral (e.g., physical activity participation) and physiological (e.g., resting metabolic rate, [an]orexigenic hormonal variations) factors to the interindividual responses in EI to imposed sleep restriction in order to better characterize those individuals who are "resistant" to the effects of partial sleep restriction on EI.

Acknowledgments

We would like to thank the participants for taking part in these studies, as well as students for their involvement in data collection. We would also like to thank Amy Roberts for conducting the research at St. Luke's-Roosevelt Hospital/Columbia University. Lastly, we thank Dr. Éric Doucet and Dr. Geneviève Forest for their involvement in the design and conduct of the study at the University of Ottawa.

Funding agencies: This study was supported in part by R01 HL091352 (St-Onge), P30 DK26687, and Columbia University's CTSA grant No. UL1 TR000040 from NCAT/NIH.

Disclosure: The authors declared no conflict of interest.

Clinical trial registration: ClinicalTrials.gov identifier NCT00935402.

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