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The Association between Short Sleep Duration and Weight Gain Is Dependent on Disinhibited Eating Behavior in Adults

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Study Objective: To investigate whether the relationship between short sleep duration and subsequent body weight gain is influenced by disinhibited eating behavior.

Design: Six-year longitudinal study.

Setting: Community setting.

Participants: Two hundred seventy-six adults aged 21 to 64 years from the Quebec Family Study.

Measurements and Results: Body composition measurements, self-reported sleep duration, and disinhibition eating behavior trait (Three-Factor Eating Questionnaire) were determined at both baseline and after 6 years. For each sleep-duration group (short- [≤ 6 h] average, [7-8 h], and long- [≥ 9 h] duration sleepers), differences in weight gain and waist circumference were tested by comparing the lowest (score ≤ 3) versus the highest (score ≥ 6) disinhibition eating behavior tertiles using analysis of covariance, with adjustment for potential confounding factors. Individuals having both short sleep duration and high disinhibition eating behavior were more likely to gain weight and increase their abdominal circumference over time ($P < 0.05$); however, short-duration sleepers having a low disinhibition eating behavior trait were not more likely to increase their adiposity indicators than were average-duration sleepers. Over the 6-year follow-up period, the incidence of overweight/obesity for short-duration sleepers with a high disinhibition eating behavior trait was 2.5 times more frequent than for short-duration sleepers with a low disinhibition eating behavior trait. Energy intake was significantly higher in short-duration sleepers with a high disinhibition eating behavior trait ($P < 0.05$ versus all other groups).

Conclusions: We observed that having a high disinhibition eating behavior trait significantly increased the risk of overeating and gaining weight in adults characterized by short sleep duration. This observation is novel and might explain the interindividual differences in weight gain associated with short sleep duration.

Keywords: Adiposity, appetite, body weight, eating traits, sleep deprivation

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INTRODUCTION

The evidence that short sleep duration is a determinant of obesity is growing. Prospective cohort studies have shown that short sleep duration is associated with weight gain and an increased incidence of obesity in children and adults.[1-3] Intervention studies have begun to provide a mechanistic explanation, i.e., that sleep restriction impacts the hormonal regulation of food intake.[4-6] Ultimately, reduced sleep duration must increase energy intake, reduce energy expenditure, or both increase intake and reduce expenditure to produce weight gain. However, studies are not consistent in showing an effect of short sleep duration on energy balance.[7,8] This observation highlights the need for more research aimed at elucidating the mechanisms linking short sleep duration and the risk of overweight or obesity. A better characterization of short-duration sleepers is needed at this point because of the large interindividual differences in weight gain observed among short-duration sleepers.

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Disinhibited eating behavior (tendency toward overeating and eating opportunistically) has received increased attention in the literature over the recent years because of its association not only with increased weight and obesity, but also with mediating variables, such as less healthful food choices,[9,10] which contribute to overweight and obesity. Because short sleep duration inevitably results in more time and opportunities for eating, one can hypothesize that short-duration sleepers who also have a high disinhibition eating behavior trait will eat more and gain more weight than will short-duration sleepers who have a low disinhibition eating behavior trait. However, the interaction between sleep duration and disinhibition with regard to weight gain has never been addressed. Such studies could lead to more personalized risk assessments of weight gain and obesity, particularly when one is experiencing chronic short sleep duration.

The present study examines whether disinhibition as an eating behavior trait impacts longitudinal associations between sleep duration and adiposity indexes in the Quebec Family Study. We hypothesize that short sleep duration predisposes to weight gain only in those people exhibiting a high disinhibition eating behavior trait.

METHODS

Subjects

Subjects were participants in the Quebec Family Study. Caucasian families were recruited through the media and were all

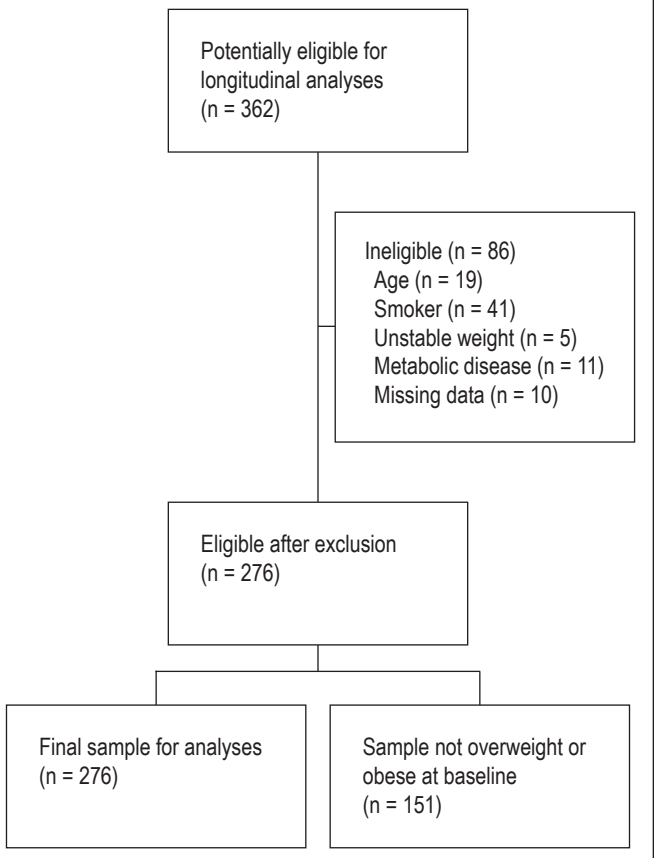

Figure 1—Flowchart diagram of subjects' selection.

French Canadians from the greater Quebec City area. Details of recruitment procedures have been published elsewhere.[11] This cohort represents a mixture of random sampling and ascertainment through obese (body mass index [BMI] ≥ 32 kg/m^2) individuals. The present analyses are based on participants in Phases 2 (1989-1994) and 3 (1995-2001) because some measurements were not available in Phase 1 (1978-1981). Adult individuals who were between 18 and 64 years of age were selected for prospective analyses (mean duration of follow-up: 6.0 ± 0.9 years). Additional inclusion criteria were (1) nonsmoker, (2) stable body weight (± 2 kg) over the 6 months preceding testing, and (3) no metabolic disease (e.g., diabetes, hypertension) or no medication that could interfere with the outcome variables. Subjects with missing data on 1 or more of the variables investigated in 1 of the 2 testing sessions (baseline and 6 year later) were excluded. The final sample consisted of 276 individuals (117 men and 159 women). Analyses were also performed with participants who were not overweight or obese at baseline (BMI < 25 kg/m^2, n = 151). The flowchart diagram of subjects' selection is presented in Figure 1. All subjects provided written informed consent to participate in the study. The project was approved by the Medical Ethics Committee of Laval University.

Anthropometric and body composition data

Height was measured to the nearest 0.1 cm using a standard stadiometer, and body weight was measured to the nearest 0.1 kg using a digital panel indicator scale (Beckman Industrial, Scotland, UK). BMI was calculated as body weight divided by height squared (kg/m^2). Waist circumference was measured at the line between the lower border of the last rib and the upper border of the iliac crest. These anthropometric measurements were performed according to standardized procedures recommended at The Airlie Conference.[12] Furthermore, body density was obtained from the mean of 6 valid measurements derived from underwater weighing.[13] Before subjects were immersed in the hydrostatic tank, the helium dilution method of Meneely and Kaltreider[14] was used to determine the pulmonary residual volume. The percentage of total body fat was determined from body density with the equation of Siri.[15] Body fat mass was estimated from body weight and the percentage of body fat. These measurements were performed in the same way at both baseline and after 6 years.

Sleep Duration Assessment

The number of hours of sleep was assessed at baseline and year 6 through a question inserted in a self-administered questionnaire on physical activity participation. The question formulation was: "On average, how many hours do you sleep a day?" We then classified the participants into 3 sleep-duration groups: short-duration sleepers (≤ 6 h of sleep; 21 men and 22 women), average-duration sleepers (7-8 h of sleep; 85 men and 112 women) and long-duration sleepers (≥ 9 h of sleep; 11 men and 25 women), in agreement with our recent papers.[16,17] We decided to classify the participants into 3 sleep-duration groups because of the U-shaped association between sleep duration and overweight/obesity. The 7- to 8-hour category was associated with the lowest prevalence of overweight and obesity in this cohort, as has been previously reported.[18]

Three-Factor Eating Questionnaire

A French version of the 51-item Three-Factor Eating Questionnaire (TFEQ) was self-administered to the participants at baseline and year 6. The purpose of this questionnaire was to assess 3 factors related to cognition and eating-behavior traits. These factors are cognitive dietary restraint (intent to control food intake), disinhibition (overconsumption of food in response to cognitive or emotional cues), and susceptibility to hunger (food intake in response to feelings and perceptions of hunger). The TFEQ has been shown to have acceptable reliability and validity.[19-21] We focused exclusively on disinhibition in the present paper because of its strong association with weight gain[22] and to improve clarity. However, the interactions between sleep duration and both cognitive dietary restraint and susceptibility to hunger traits did not turn out to be significant. Tertiles of disinhibition scores (≥ 6, high disinhibition, and ≤ 3, low disinhibition) based on what was observed in this sample were used as there is no consensus on what is considered a low or high score.

Diet Assessment

Diet was evaluated with a 3-day food record, including 2 weekdays and 1 weekend day, at baseline and year 6. Participants were shown how to complete the record by a dietician, who provided instructions about measuring the quantities of ingested foods. This method of dietary assessment has been shown to provide a relatively reliable measure of diet in this popula-

tion.[23] Mean daily energy intake was estimated by a dietician using a computerized version of the Canadian Nutrient File.[24]

Covariates

Numerous covariates were measured via self-reported questionnaires at baseline and year 6. These included age, sex, employment status (student, paid employment, looking for work, home duties, retired, disabled), highest education level (high school, college [*CEGEP* for Quebec], university), total annual family income (categorized into 5 groups ranging from < $10,000 to $70,000 or more), menopause status, shift-working history (none, < 5 years, ≥ 5 years), and alcohol intake (g/day). Additionally, daily physical activity level and pattern were evaluated with a 3-day physical activity diary, as has been previously described.[25] Participation in moderate-to-vigorous physical activity over the 3 days was used for statistical analyses. The validity and reliability of the physical activity record have been previously reported.[25]

Statistical Analysis

Since there was no statistically significant sex interaction between sleep duration and the outcome variables, data for both sexes were combined to improve clarity and maximize power. Baseline characteristics of participants in the lowest and highest disinhibition eating behavior tertiles were compared by analysis of variance (continuous variables) and χ^2 tests (categorical variables). For each sleep-duration group, weight gain and change in waist circumference were computed by disinhibition eating behavior trait tertiles. An analysis of covariance was performed on the means of these variables, followed by a Tukey posthoc test to determine which groups were significantly different. The model was adjusted for age, sex, baseline body weight or baseline waist circumference, length of follow-up, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake as covariates. In addition, logistic regression analysis was used to predict the incidence of overweight/obesity (BMI ≥ 25 kg/m^2) according to sleep duration and disinhibited eating behavior. The calculations were performed among the 151 participants who were not overweight or obese at baseline. The model was adjusted for age, sex, baseline BMI, length of follow-up, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake. Odds ratios (OR) and 95% confidence intervals (95% CI) for the incidence of overweight/obesity were calculated for each combination of sleep duration and disinhibition eating behavior trait, with average sleep duration (7-8 h/day)–low disinhibition eating behavior (lowest tertile) as the reference category. Finally, we compared mean daily energy intake (kcal/kg) and moderate-to-vigorous physical activity (min/day) according to sleep duration and disinhibition eating behavior categories using an analysis of covariance followed by a Tukey posthoc test. The model was adjusted for age, sex, baseline BMI, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake as covariates. Because some individuals in this family study are biologically related, we adjusted for clustering in the analyses to avoid underestimation of standard deviations using generalized estimating equations.[26] We modeled exposure (sleep duration and disinhibition eating behavior), covariates, and outcome (development of overweight/obesity) as repeated measures at 2 time points (baseline and 6 years later). A 2-tailed P value of less than 0.05 was considered to indicate statistical significance. All statistical analyses were performed using the JMP version 8 program (SAS Institute, Cary, NC).

Table 1—Baseline characteristics of participants according to lowest and highest disinhibition tertiles

	Disinhibition eating behavior score[a,b]	
Variable	Low, score ≤ 3 (n = 92)	High, score ≥ 6 (n = 92)
Age, y	42.4 ± 14.2	40.1 ± 12.7
Sex		
Men	41 (45)	45 (49)
Women	51 (55)	47 (51)
Body weight, kg	64.6 ± 12.6	78.2 ± 18.6[c]
BMI, kg/m^2	23.6 ± 3.4	28.5 ± 6.2[c]
Body fat, %	24.2 ± 8.3	30.6 ± 10.2[c]
Waist circumference, cm	79.6 ± 11.9	90.1 ± 17.4[c]
Sleep duration, h	7.6 ± 0.9	7.6 ± 1.0
Energy intake, kcal/d	2265 ± 615	2356 ± 796
MVPA, min/d	26.1 ± 40.8	22.8 ± 59.2

BMI, body mass index; MVPA, moderate-to-vigorous physical activity. [a]Values are presented as mean ± SD, except sex, which is shown as number (%). [b]Statistical significance was assessed by analysis of variance with continuous variables and by a χ^2 test with categorical variables. [c]Significantly different from low disinhibition eating behavior group (P < 0.01).

RESULTS

Baseline characteristics of participants according to disinhibition group are shown in Table 1. Those in the highest disinhibition eating behavior group had higher baseline body weight, BMI, percentage of body fat, and abdominal circumference (P < 0.01). All other characteristics, including age, sleep duration, energy intake, moderate-to-vigorous physical activity, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake were not significantly different between groups. A significantly greater proportion of the overweight and obese participants (52.4%) exhibited high disinhibition eating behavior, compared with those with a normal body weight (13.8%) (P < 0.01).

The interaction of sleep duration and disinhibition eating behavior trait with weight gain and change in waist circumference over 6 years is shown in Figure 2. Individuals with both short sleep duration and high disinhibition eating behavior were more likely to gain weight and increase their abdominal circumference over time (P < 0.05). However, short-duration sleepers with a low disinhibition eating behavior trait had increases in adiposity indicators that were similar to those of average-duration sleepers. The same pattern was observed for changes in BMI and percentage of body fat (data not shown). Further analyses also revealed that the association between sleep duration and body-fat gain was attenuated and became

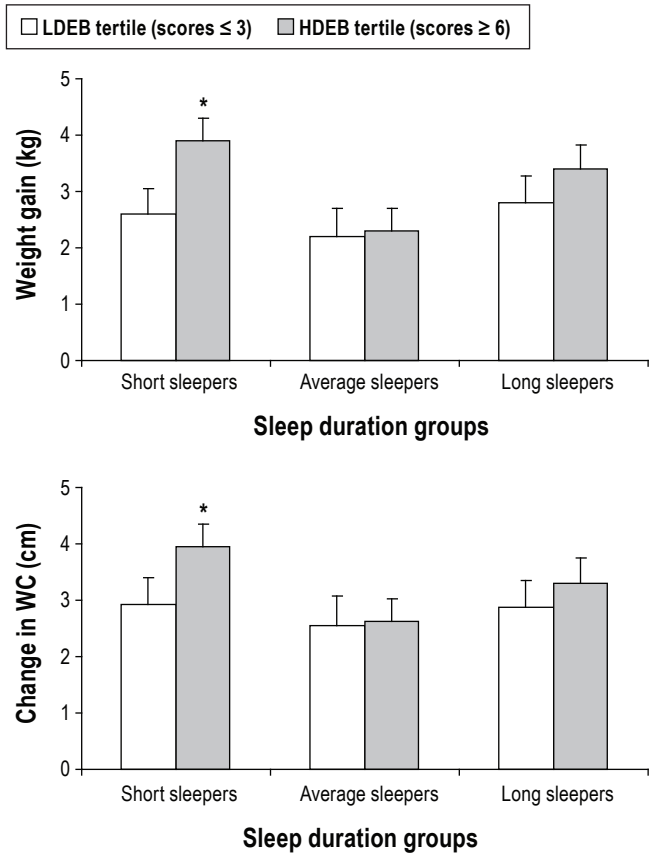

Figure 2—Joint associations between sleep duration and disinhibition eating behavior with 6-year weight gain and change in waist circumference. WC refers to waist circumference. Values are mean ± SEM. Statistical significance was assessed by analysis of covariance. The model was adjusted for age, sex, baseline body weight or baseline waist circumference, length of follow-up, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake as covariates. A Tukey posthoc test was performed to determine which groups were significantly different. n = 12 for short sleep/low disinhibition eating behavior (LDEB), n = 13 for short sleep/high disinhibition eating behavior (HDEB), n = 75 for average sleep/LDEB, n = 61 for average sleep/HDEB, n = 12 for long sleep/LDEB, and n = 11 for long sleep/HDEB. *Significantly different from all other groups (P < 0.05).

nonsignificant after adjustment for disinhibition eating behavior, again highlighting the importance of this eating behavior trait in the short-sleep–obesity connection.

A total of 125 participants (45.3% of the prospective cohort) were either overweight or obese at baseline, defined as a BMI of at least 25 kg/m^2. Among the 151 normal-weight participants, 39 new cases of overweight and obesity (25.8%) were identified over the 6-year follow-up period. As shown in Table 2, the risk of developing overweight/obesity was greater for short-duration sleepers with a high disinhibition eating behavior trait (OR: 4.49; 95% CI: 3.06-6.06). Importantly, the incidence of overweight/obesity for short-duration sleepers with a high disinhibition eating behavior score was 2.5 times more frequent than for short-duration sleepers with a low disinhibition eating behavior trait. Likewise, the incidence of overweight/obesity was best predicted when subjects with high disinhibition eating behavior trait were combined with those exhibiting long sleep

Table 2—Incidence of adult overweight/obesity according to sleep duration and disinhibition eating behavior over the 6-year follow-up period

Combination, no.[a]	OR[b]	95% CI
SSD + HDEB, n = 10	4.49[c]	3.06-6.06
LSD + HDEB, n = 14	2.19[c]	1.17-3.29
SSD + LDEB, n = 13	1.79[d]	1.15-2.49
LSD + LDEB, n = 14	1.32	0.80-1.89
ASD + HDEB, n = 27	1.18	0.71-1.72
ASD + LDEB, n = 52	1.00 (reference)	–

SSD, short sleep duration, defined as ≤ 6 h of sleep/d; HDEB, high disinhibition eating behavior, defined as a score ≥ 6; LSD, long sleep duration, defined as ≥ 9 h of sleep/d; LDEB, low disinhibition eating behavior, defined as a score ≤ 3; ASD, average sleep duration, defined as 7-8 h of sleep/d; CI, confidence interval. [a]The remaining 21 cases are in the second tertile of the DEB scale. [b]Odds ratios (OR) were calculated by logistic regression analysis. The calculations were performed among the 151 participants who were not overweight or obese at baseline. The model was adjusted for age, sex, baseline body mass index, length of follow-up, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake. [c]P < 0.01. [d]P < 0.05.

duration (as opposed to long sleep duration and low disinhibition). Overall, we observed a main effect of disinhibition on incident overweight/obesity as well as weight gain (P < 0.05).

To explain the association between sleep duration and disinhibition eating behavior score with weight gain, energy intake as well as moderate-to-vigorous physical activity were compared between groups (Figure 3). We observed that energy intake was significantly higher in short-duration sleepers with a high disinhibition eating behavior score (P < 0.05 versus all other groups). In absolute terms, energy intake of short-duration sleepers was 2816 ± 612 kcal and 2252 ± 622 kcal for those having a high and low disinhibition eating behavior trait, respectively (P < 0.05). Adjustment for energy intake in the models predicting change in adiposity indicators led to an attenuation of the coefficients, but the associations were still significant. However, moderate-to-vigorous physical activity participation did not significantly differ between groups.

DISCUSSION

This study provides a first test of the hypothesis of whether the relationship between short sleep duration and subsequent body weight gain is influenced by disinhibition eating behavior score. We observed that having a high disinhibition eating behavior trait significantly increases the risk of overeating and gaining weight in those with short sleep duration. This observation is of high clinical relevance because it could contribute to explaining some of the interindividual differences in weight gain when people are experiencing chronic short sleep duration. Furthermore, our results highlight the fact that short sleep duration alone may not be sufficient in and of itself to predict weight and adiposity gain.

Increased energy intake is commonly considered the most plausible explanation for why short-duration sleepers have a higher risk of becoming obese. This concept is supported by

recent intervention studies showing that sleep restriction increases the intake of calories from snacks[5] and overall energy intake in adults.[4] However, epidemiologic studies have failed to associate short sleep duration with increased energy intake.[7,18,27] This is potentially due to the imprecision of the measure, i.e., small differences in chronic energy intake associated with short sleep duration cannot be adequately captured in dietary recalls. Another possible explanation could be that the population of short-duration sleepers was not fully characterized in previous observation studies. In the present study, we were able to find individuals characterized by short sleep duration with an increased energy intake but only when they exhibited a high disinhibition eating behavior score. This observation supports the hypothesis that increased food intake is an important mechanism linking short sleep duration to weight gain. However, our results suggest that the effect of short sleep duration on food intake is dependent on the disinhibition eating behavior trait.

Disinhibition emerges as an important eating behavior trait in the literature, with influences that extend beyond eating behavior and touch upon other behaviors that contribute to obesity.[9] Examples of disinhibition include eating in response to negative affect, overeating when others are eating, not being able to resist eating, and overeating in response to the palatability of food. In particular, individuals characterized by a high disinhibition eating behavior score have a higher liking for sweet and high-fat foods.[9] This observation supports the hypothesis that the hedonic value of food intake is associated with short sleep duration.[28,29] Because bedtime restriction inevitably results in extended exposure to readily available, energy-dense, palatable foods, it might be difficult for short-duration sleepers to resist consuming more food. As recently proposed, increased snacking and consumption of energy-dense foods may reflect the effects of short sleep duration on stress responses and reward-seeking behaviors.[30] Interestingly, a recent study in adolescents reported that impaired sleep was associated with less reactivity of reward-related brain systems, suggesting that more exciting rewards are required to create the same level of neural activation.[31] In this context, the orexin system could be an important therapeutic target for the management of obesity because it is a critical regulator of sleep/wake states and of feeding behavior and reward processes.[32] In the present study, the relationship between higher energy intake and high disinhibition eating behavior was only observed in short-duration sleepers and not in average- and long-duration sleepers (Figure 3). Because long-duration sleepers who had high disinhibition eating behavior scores also experienced weight gain with less "exposure" time to foods, the hedonic drive for food intake does not seem to be the main explanation in long-duration sleepers. Long sleep duration is generally associated with other health problems that can predispose to weight gain through different mechanisms.

In addition to the nonhomeostatic, reward-driven regulation of feeding, lack of sleep has been reported to decrease plasma leptin levels, increase plasma ghrelin and cortisol levels, and alter glucose homeostasis, all of which impact the regulation of food intake.[33-35] Furthermore, the increased fatigue and tiredness associated with lack of sufficient sleep may impact overall participation in physical activity. In particular, results from a recent intervention study have shown that short-term sleep restriction (2 nights of 4 hours in bed) was accompanied by a decrease in daytime spontaneous physical activity in healthy men.[8] Interestingly, the reduction in overall physical activity was explained by a shift toward less-intense activities under free-living conditions. In the present observation study, physical activity was associated neither with sleep duration nor with disinhibition eating behavior score. Although these results agree with those of other studies,[5,36,37] we have more to learn about the relationship between sleep duration and daily physical activity because subtle changes could result in weight gain over time. In particular, future studies should measure non-exercise activity thermogenesis in relationship to lack of sleep to improve our understanding of the contribution of this energy-expenditure component.

The strengths of this study include its longitudinal design and the use of objective measures of adiposity. Furthermore, data were obtained on both men and women, and we used an approach that tends to minimize confounding, as we incorporated

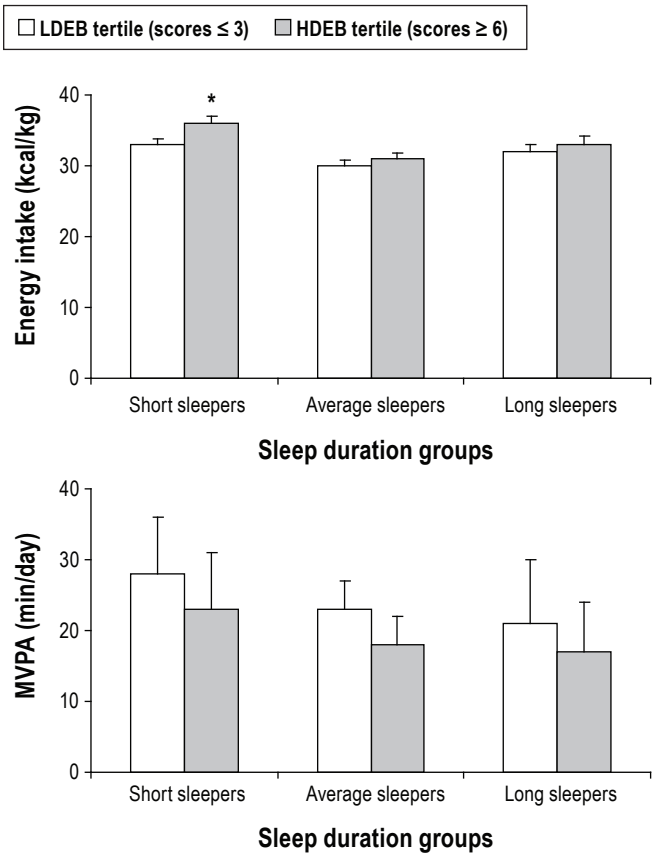

Figure 3—Energy intake and moderate-to-vigorous physical activity according to sleep duration and disinhibition eating behavior. MVPA refers to moderate-to-vigorous physical activity. Values are mean ± SEM. Statistical significance was assessed by analysis of covariance. The model was adjusted for age, sex, baseline body mass index, employment status, highest education level, total annual family income, menopause status, shift-working history, and alcohol intake as covariates. A Tukey posthoc test was performed to determine which groups were significantly different. n = 12 for short sleep/low disinhibition eating behavior (LDEB), n = 13 for short sleep/high disinhibition eating behavior (HDEB), n = 75 for average sleep/LDEB, n = 61 for average sleep/HDEB, n = 12 for long sleep/LDEB, and n = 11 for long sleep/HDEB. *Significantly different from all other groups ($P < 0.05$).

repeated measures of exposure, covariates, and outcome. However, although observation cohort studies are well suited for the identification of associations, they cannot establish causality. Additionally, the Quebec Family Study was originally designed to explore the role of genetics in the etiology of obesity, fitness, and cardiovascular and diabetes risk factors. Future research based on a prospective design and a larger sample more representative of the population is warranted. Finally, we also have to keep in mind the limitations of self-reported measures (e.g., sleep duration, energy intake, and physical activity), as well as the possibility of residual confounding.

In summary, the present study provides support for the hypothesis that the association between short sleep duration and weight gain may be dependent on disinhibition eating behavior score in adults. Specifically, we observed that short-duration sleepers with a high disinhibition eating behavior trait had higher energy intake. These results are novel and emphasize the need to include a disinhibition eating behavior score in the personalized risk assessment of weight gain and obesity of short-duration sleepers.

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Dr. Chaput designed the study, conducted the analyses, and wrote the manuscript; Drs. Bouchard and Tremblay designed and created the Quebec Family Study; and Drs. Bouchard, Tremblay, and Després helped revise the manuscript.

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DISCLOSURE STATEMENT

This was not an industry supported study. **Dr. Després** has received research support from Eli Lilly Canada; is on the advisory board of Novartis, Theratechnologies, Torrent Pharmaceuticals Ltd., and Sanofi-Aventis; and has participated in speaking engagements for Abbott Laboratories, AstraZeneca, Solvay Pharma, GlaxoSmithKline, and Pfizer Canada. **Dr. Bouchard** is on the advisory board of Weight Watchers. The other authors have indicated no financial conflicts of interest

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