Risk Factors for Adult Overweight and Obesity in the Quebec Family Study: Have We Been Barking Up the Wrong Tree?

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The aim of this study was to determine the independent contribution of previously reported risk factors for adult overweight and obesity. A cross-sectional (n = 537) and a longitudinal (n = 283; 6-year follow-up period) analysis was performed for nine risk factors for overweight and obesity assessed in adult participants (aged 18–64 years) of the Quebec Family Study (QFS). The main outcome measure was overweight/obesity, defined as a BMI ≥25 kg/m². Using logistic regression analysis adjusted for age, sex, and socioeconomic status, short sleep duration, high disinhibition eating behavior, low dietary calcium intake, high susceptibility to hunger behavior, nonparticipation in high-intensity physical exercise, high dietary restraint behavior, nonconsumption of multivitamin and dietary supplements, high dietary lipid intake, and high alcohol intake were all significantly associated with overweight and obesity in the cross-sectional sample. The analysis of covariance adjusted for age, socioeconomic status, and all other risk factors revealed that only individuals characterized by short sleep duration, high disinhibition eating behavior, and low dietary calcium intake had significantly higher BMI compared to the reference category in both sexes. Over the 6-year follow-up period, short-duration sleepers, low calcium consumers, and those with a high disinhibition and restraint eating behavior score were significantly more likely to gain weight and develop obesity. These results show that excess body weight or weight gain results from a number of obesogenic behaviors that have received considerable attention over the past decade. They also indicate that the four factors, which have the best predictive potential of variations in BMI, be it in a cross-sectional or a longitudinal analytical design, do not have a "caloric value" *per se*.

INTRODUCTION

The positive energy balance underlying obesity is generally attributed to reduced physical activity, excessive caloric intake, and high dietary lipid intake. The influence of these factors has been largely documented and it is commonly accepted that a risk factor for obesity is one that has a direct measurable impact on components of energy balance. However, recent research has emphasized that other, less obvious factors such as short sleep duration and low micronutrient intake may also exert a considerable impact on energy balance (1). Keith *et al.* (2) recently identified 10 nontraditional putative contributors to the obesity epidemic. These other potential determinants of obesity do not have a direct substantial impact on energy intake or expenditure, but rather entrain a mismatch between energy input and output.

The identification of risk factors for obesity is the key to prevention. For instance, a recent prospective cohort study showed that eight factors in early life were independently associated with obesity risk at age 7 (ref. 3). In adults, the Quebec Family Study (QFS) has evidenced several risk factors for obesity. Thus, high lipid and alcohol intakes (4,5), low calcium and micronutrient intakes (6,7), high dietary restraint behavior (8), high disinhibition and susceptibility to hunger behaviors (9), low vigorous physical activity (10), and short sleep duration (11,12) have all been associated with obesity. However, the independent contribution of these risk factors to obesity has never been assessed. Therefore, we examined the relative contribution of these factors to the risk of being overweight or obese. The study was undertaken with the cross-sectional design cohort of QFS as well as with the 6-year follow-up sample.

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METHODS AND PROCEDURES

Subjects

The QFS was initiated at Laval University, Quebec City, in 1978 (ref. 13). The primary objective of this study was to investigate the role of genetics in the etiology of obesity, fitness, and cardiovascular and diabetes risk factors. In phase 1 of the study (1978–1981), a total of 1,650 individuals from 375 families were recruited and measured. Recruitment was conducted irrespective of body weight during phase 1, which resulted in a cohort with a wide range of BMI (in kg/m^2), 13.8–64.9. In phases 2 (1989–1994) and 3 (1995–2001), 100 families from phase 1 were retested, and an additional 123 families with at least one parent and one offspring with a BMI of ≥32 were added to the cohort. These white two-parent families were recruited through the media and were all French Canadians from the greater Quebec City area. The present analyses are based on participants in phases 2 and 3. Individuals who were between 18 and 64 years of age were selected for cross-sectional analyses (230 men and 307 women). Furthermore, 121 men and 162 women on whom follow-up data were available were retained for prospective analyses (mean duration of follow-up: 6.0 ± 0.9 years). Additional inclusion criteria were: (i) nonsmoker; (ii) not pregnant; (iii) stable body weight (±2 kg) over the 6 months preceding testing; and (iv) no metabolic disease (e.g., diabetes, hypertension) or no medication that could interfere with the outcome variable. In addition, subjects with missing data on one or more of the variables investigated in one of the two testing sessions were excluded. All subjects provided written informed consent to participate in the study. The project was approved by the Medical Ethics Committee of Laval University.

Anthropometric variables

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 (Model 610/612; Beckman Industrial, Scotland, UK). BMI was calculated as body weight divided by height squared (kg/m^2). These anthropometric measurements were performed according to standardized procedures recommended at the Airlie Conference (14). The main outcome measure was overweight/obesity, defined as a BMI ≥25 kg/m^2.

Potential risk factors

The aim of this article was not to explore all the potential risk factors for overweight and obesity in the QFS but rather to gather environmental risk factors that were previously found to be significantly associated with overweight/obesity in the QFS and to look at their independent effects. We thus included nine risk factors on the basis of previously reported associations with overweight and obesity by our research group (4–12). Lipid, alcohol, and calcium intake were evaluated with a 3-day food record, including 2 week days and 1 weekend day. Participants were shown how to complete this record by a dietician who provided instruction about measuring the quantities of ingested foods. This method of dietary assessment has been shown to provide a reliable measure of diet in this population (15). Mean daily intake was estimated by a dietician using the computerized version of the Canadian Nutrient File (16). In addition, a questionnaire was used to gather dietary information. One of the questions of interest for this study was as follows: "Do you consume vitamin/dietary supplements?" Because this was the only question asked to record the participants' supplement consumption habits, the dose and the type of vitamins and/or dietary supplements cannot be addressed in this study. Eating behavior traits (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)) were assessed using the Three-Factor Eating Questionnaire (17), as validated for the French population (18). The Three-Factor Eating Questionnaire has been shown to have acceptable reliability and validity (17,19). Daily physical

activity level and pattern were evaluated with a 3-day physical activity diary, as previously described (20). Briefly, subjects recorded the energy expenditure level for each 15-min period over 24 h based on activities classified on a 1–9 scale, 1 corresponding to activities of very low energy expenditure such as sleeping and 9 to activities of very high energy expenditure such as running. Participation in high-intensity physical exercise was estimated as the number of periods graded 8 and 9 over the 3 days and was used for statistical analyses. The reliability and the validity of the record have been previously reported (20). Finally, the number of hours of sleep was assessed through a question inserted in a self-administered questionnaire. The question formulation was: "On average, how many hours do you sleep a day?" Besides, the socioeconomic status of participants was obtained via a self-reported questionnaire. Employment status (student, paid employment, looking for work, home duties, retired, disabled), highest educational level (high school, college (CEGEP for Quebec), university), and total annual family income (categorized into five groups ranging from <$10,000 to $70,000 or more) were obtained. The dichotomization for each risk factor was chosen based on previous studies (4–12). Briefly, the cut-off points for the at-risk and reference groups are, respectively: ≥40 and <30% dietary fat/day (lipid intake), ≥10 and 0 g/day (alcohol intake), <600 and ≥1,000 mg/day (calcium intake), nonconsumer and consumer (consumption of vitamin/dietary supplements), ≥8 and ≤4 restraint score (cognitive dietary restraint), ≥6 and ≤3 disinhibition score (disinhibition eating behavior), ≥5 and ≤2 hunger score (susceptibility to hunger eating behavior), 0 and ≥30 min/day (high-intensity physical exercise), and <6 and ≥7 h/day (sleep duration). Tertiles have been used for the three eating behavior traits given that there is no consensus on what is considered a low or high score. All these factors were assessed at both baseline (phase 2) and year 6 (phase 3) in the longitudinal sample.

Statistical analysis

Logistic regression analysis was performed to evaluate the strength of the relationship between risk factors and adulthood overweight/obesity. Univariate logistic regression analysis was first performed separately by gender. In multivariate analysis for both sexes combined, odds ratios were adjusted for age, sex, and socioeconomic status. In an attempt to verify the independent contribution of risk factors for overweight and obesity, a one-way analysis of covariance was used to test for differences in BMI between at-risk and reference groups using age, socioeconomic status, and all other risk factors as covariates. In addition, multivariate linear regression modeling was used to estimate the mean weight gain above baseline weight over the 6-year follow-up period for individuals in the at-risk groups relative to the gain in those included in the reference category. The model was adjusted for age, sex, baseline BMI, length of follow-up, socioeconomic status, and all other risk factors. Finally, prevalence (%) of each risk factor according to lowest and highest body weight change tertiles was compared by χ^2-test. 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 (21). Statistical significance was set at a P value of <0.05. All statistical analyses were performed using the JMP version 5.1.2 program (SAS Institute, Cary, NC).

RESULTS

Cross-sectional results

Table 1 presents the associations between risk factors and adult overweight/obesity by gender. Only high alcohol intake and nonconsumption of vitamin and dietary supplements were found not to be significantly associated with overweight and obesity in women. In particular, 20% of men and 11% of women were short-duration sleepers. Among them, 45% reported no vigorous physical activity participation and 34% were low dietary calcium consumers. In the adjusted

model, short sleep duration, high disinhibition eating behavior, low dietary calcium intake, high susceptibility to hunger behavior, nonparticipation in high-intensity physical exercise, high dietary restraint behavior, nonconsumption of multivitamin and dietary supplements, high dietary lipid intake, and high alcohol intake were all significantly associated with adult overweight and obesity (**Figure 1**).

After adjustment for age, socioeconomic status, and all other risk factors, only individuals presenting short sleep duration, high disinhibition eating behavior, and low dietary calcium intake had significantly higher BMI compared to the reference category in both sexes (**Table 2**).

Longitudinal results

Figure 2 shows the mean weight gain above baseline weight over the 6-year follow-up period for individuals in the at-risk groups relative to the gain in those included in the reference group. After adjustment for age, sex, baseline BMI, length of follow-up, socioeconomic status, and all other risk factors, short-duration sleepers gained 1.65 kg (95% confidence interval 1.05–2.31) more than those reporting sleeping >7 h a day. Furthermore, those presenting high disinhibition eating behavior, low dietary calcium intake, high susceptibility to hunger behavior, no vigorous physical activity participation, and high restraint eating behavior gained >1 kg above baseline weight relative to the gain in those in the reference group.

Over the 6-year follow-up period, 88 of the 283 subjects (31%) experienced a weight gain of ≥5 kg. Short-duration sleepers, low calcium consumers, and those with a high disinhibition and restraint eating behavior score were 35, 30, 28, and 26% more likely to experience a 5-kg weight gain, respectively, as compared with the reference category, P < 0.05 (data not shown). In addition, a total of 54 subjects were obese at baseline, defined as a BMI of ≥30 kg/m². Among the 229 subjects who were not obese at baseline, 33 new cases of obesity (14.4%) were identified over the 6-year follow-up period. The risk of developing

Table 1 Relationship between risk factors and adult overweight/obesity in the cross-sectional sample

	Men (n = 230)			Women (n = 307)		
	Nonobese (n = 107) n (%)	Overweight/obese (n = 123) n (%)	OR (95% CI)	Nonobese (n = 161) n (%)	Overweight/obese (n = 146) n (%)	OR (95% CI)
Lipid intake						
≥40% fat/day	20 (18.7)	32 (26.0)	1.77 (1.28–2.31)*	26 (16.1)	29 (19.9)	1.53 (1.05–2.04)**
<30% fat/day	30 (28.0)	27 (22.0)	1.00	48 (29.8)	35 (24.0)	1.00
Alcohol intake						
≥10 g/day	24 (22.4)	33 (26.8)	1.54 (1.12–1.98)**	22 (13.7)	23 (15.8)	1.21 (0.81–1.61)
0 g/day	55 (51.4)	49 (39.8)	1.00	87 (54.0)	75 (51.4)	1.00
Calcium intake						
<600 mg/day	17 (15.9)	34 (27.6)	2.29 (1.56–3.11)*	22 (13.7)	39 (26.7)	3.58 (2.56–4.64)*
≥1,000 mg/day	55 (51.4)	48 (39.0)	1.00	59 (36.6)	29 (19.9)	1.00
Vitamin consumption						
Nonconsumer	69 (64.5)	102 (82.9)	2.67 (1.62–3.79)*	106 (65.8)	98 (67.1)	1.07 (0.85–1.36)
Consumer	38 (35.5)	21 (17.1)	1.00	55 (34.2)	48 (32.9)	1.00
Eating behavior						
≥8 restraint score	15 (19.7)	61 (80.3)	1.99 (1.23–2.76)*	37 (36.3)	65 (63.7)	2.03 (1.21–2.89)*
≤4 restraint score	25 (32.9)	51 (67.1)	1.00	55 (53.9)	47 (46.1)	1.00
≥6 disinhibition score	16 (21.1)	60 (78.9)	3.92 (2.61–5.31)*	21 (20.6)	81 (79.4)	3.72 (2.41–5.09)*
≤3 disinhibition score	39 (51.3)	37 (48.7)	1.00	50 (49.0)	52 (51.0)	1.00
≥5 hunger score	18 (23.7)	58 (76.3)	2.01 (1.21–2.86)*	24 (23.5)	78 (76.5)	2.36 (1.38–3.32)*
≤2 hunger score	26 (34.2)	50 (65.8)	1.00	43 (42.2)	59 (57.8)	1.00
HIPE						
0 min/day	38 (35.5)	66 (53.7)	1.87 (1.19–2.58)*	85 (52.8)	99 (67.8)	2.18 (1.30–3.09)*
≥30 min/day	39 (36.4)	36 (29.3)	1.00	45 (28.0)	24 (16.4)	1.00
Sleep duration						
<6 h/day	9 (8.4)	37 (30.1)	4.66 (2.98–6.48)*	10 (6.2)	26 (17.8)	3.28 (2.06–4.65)*
≥7 h/day	98 (91.6)	86 (69.9)	1.00	151 (93.8)	120 (82.2)	1.00

CI, confidence interval; HIPE, high-intensity physical exercise; OR, odds ratio.
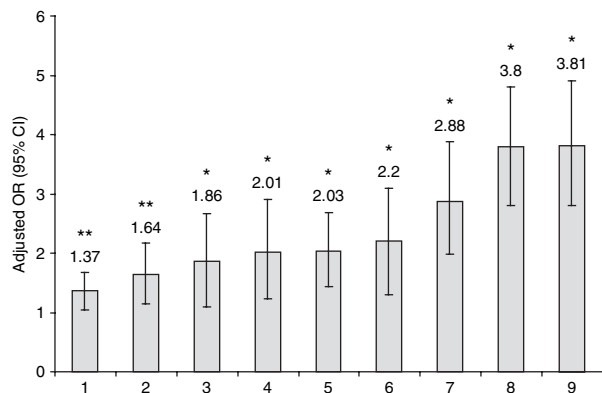*P < 0.01. **P < 0.05

Figure 1 Adjusted associations of risk factors with adult overweight/obesity in the cross-sectional sample. Model adjusted for age, sex, and socioeconomic status. Legend of the x axis: 1 = high alcohol intake (≥10 g/day), 2 = high dietary lipid intake (≥40% fat/day), 3 = nonconsumption of multivitamin and dietary supplements, 4 = high dietary restraint behavior (≥8 restraint score), 5 = nonparticipation in high-intensity physical exercise, 6 = high susceptibility to hunger behavior (≥5 hunger score), 7 = low dietary calcium intake (<600 mg/day), 8 = high disinhibition eating behavior (≥6 disinhibition score) and 9 = short sleep duration (<6 h/day). CI, confidence interval; OR, odds ratio. n = 537 (230 men and 307 women). *$P < 0.01$; **$P < 0.05$.
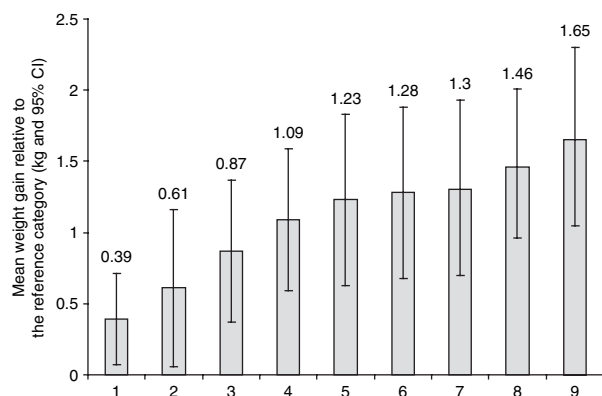

Figure 2 Mean weight gain above baseline weight over the 6-year follow-up period for individuals with the risk factor relative to the reference category. Model adjusted for age, sex, baseline BMI, length of follow-up, socioeconomic status, and all other risk factors. Legend of the x axis: 1 = high alcohol intake (≥10 g/day), 2 = high dietary lipid intake (≥40% fat/day), 3 = nonconsumption of multivitamin and dietary supplements, 4 = high dietary restraint behavior (≥8 restraint score), 5 = nonparticipation in high-intensity physical exercise, 6 = high susceptibility to hunger behavior (≥5 hunger score), 7 = low dietary calcium intake (<600 mg/day), 8 = high disinhibition eating behavior (≥6 disinhibition score) and 9 = short sleep duration (<6 h/day) (n = 283). CI, confidence interval.

obesity was elevated for short-duration sleepers, low calcium consumers, and those with a high disinhibition and restraint eating behavior score, as compared with the reference category, with 27, 22, 20, and 18% increase in risk, respectively, $P < 0.05$ (data not shown). Finally, we observed that the prevalence of individuals characterized by short sleep duration, low dietary calcium intake, high disinhibition, and restraint eating behavior scores was significantly higher for those included in the highest compared to the lowest body weight change tertile (**Table 3**).

Table 2 Mean BMI of men and women for each risk factor in the cross-sectional sample

	Men (n = 230)	Women (n = 307)
	BMI (kg/m²)	
Lipid intake		
≥40% fat/day	27.4 ± 5.2	28.6 ± 8.1
<30% fat/day	25.8 ± 4.3	26.9 ± 7.7
Alcohol intake		
≥10 g/day	27.0 ± 4.9	27.2 ± 7.8
0 g/day	26.3 ± 6.6	25.9 ± 5.7
Calcium intake		
<600 mg/day	28.7 ± 6.5*	28.4 ± 7.6*
≥1,000 mg/day	25.9 ± 5.5	25.5 ± 8.4
Vitamin consumption		
Nonconsumer	27.1 ± 6.3	26.9 ± 6.7
Consumer	25.6 ± 5.7	26.2 ± 8.4
Eating behavior		
≥8 restraint score	29.1 ± 5.8	30.1 ± 7.9
≤4 restraint score	27.2 ± 7.1	28.2 ± 9.7
≥6 disinhibition score	29.3 ± 5.2*	29.9 ± 7.5*
≤3 disinhibition score	26.5 ± 6.9	27.1 ± 8.2
≥5 hunger score	29.3 ± 8.8	29.5 ± 8.4
≤2 hunger score	27.2 ± 7.2	27.6 ± 9.8
HIPE		
0 min/day	27.7 ± 6.7	27.7 ± 7.7
≥30 min/day	25.8 ± 5.4	25.8 ± 6.8
Sleep duration		
<6 h/day	29.4 ± 6.1*	28.8 ± 6.2*
≥7 h/day	26.3 ± 5.7	26.2 ± 7.4

Data are expressed as mean ± s.d. and are adjusted for age, socioeconomic status, and all other risk factors by analysis of covariance.
HIPE, high-intensity physical exercise.
*$P < 0.05$.

DISCUSSION

This study investigated the contributions of nine risk factors to overweight and obesity in adulthood. These risk factors were all significantly related to overweight and obesity, as previously reported (4–12). However, after statistical adjustment, only short sleep duration, low dietary calcium intake, and high disinhibition eating behavior were significantly associated with a higher BMI in both sexes in the cross-sectional sample. In the sample followed for 6 years, short sleep duration, low dietary calcium intake, and high disinhibition and restraint eating behaviors were significantly associated with a higher weight gain and a higher risk of developing obesity.

Short sleep duration has been found in this study to significantly impact body weight of adults, both cross-sectionally and longitudinally. This is concordant with the results of several other studies (11,12,22–24), including a recent one in which a total of 422 children aged between 5 and 10 years were involved (25). In the latter study, the predictability of excess body weight

Table 3 Prevalence of each risk factor according to lowest and highest body weight change tertiles

	Lowest tertile[a] (n = 94)	Highest tertile[b] (n = 94)
Lipid intake		
≥40% fat/day	17 (18.1)	21 (22.3)
Alcohol intake		
≥10 g/day	16 (17.0)	19 (20.2)
Calcium intake		
<600 mg/day	13 (13.8)	21 (22.3)**
Vitamin consumption		
Nonconsumer	61 (64.9)	67 (71.3)
Eating behavior		
≥8 restraint score	31 (33.0)	43 (45.7)**
≥6 disinhibition score	30 (31.9)	51 (54.3)**
≥5 hunger score	34 (36.2)	41 (43.6)
HIPE		
0 min/day	43 (45.7)	49 (52.1)
Sleep duration		
<6 h/day	8 (8.5)	21 (22.3)*

Data are given as n (%). Descriptive characteristics were compared by χ^2-test.
HIPE, high-intensity physical exercise.
[a]Mean body weight change of −1.9 ± 3.1 kg over the 6-year follow-up period.
[b]Mean body weight change of 9.4 ± 5.9 kg over the 6-year follow-up period.
*$P < 0.01$. **$P < 0.05$.

by short sleep duration substantially exceeded the increase in odds ratio conferred by other well-known risk factors, including parental obesity, television viewing, and physical inactivity (25). The issue of sleeping time is particularly relevant, because population statistics reveal that sleep duration has decreased on average by >1 h over the past few decades (26).

Research over the past decade has suggested an effect of calcium on energy and fat balance and has emphasized the importance of an adequate intake of dairy foods, particularly skimmed and partly skimmed milk (27). Observational studies have also shown that a suboptimal intake of other micronutrients predicts an increased propensity to being overweight. In a large cohort of overweight subjects, Nachtigal *et al.* (28) found that long-term users of multivitamins, vitamins B_6 and B_{12}, and chromium experienced less weight gain than individuals who did not use the supplements. This is concordant with other results showing that zinc, magnesium, and vitamins C and E deficiencies were risk factors for higher percent body fat and central obesity (29). More recently, Major *et al.* (7) investigated the impact of a multivitamin and mineral supplementation on the response to a weight-reducing program. Their results showed that micronutrient supplementation significantly attenuated the expected increase in hunger and desire to eat in obese women experiencing weight loss. Results of this study add support to the currently available literature suggesting that low micronutrient intake, particularly calcium, accentuates the risk of being overweight. However, after statistical adjustment, our results suggest that the risk of being overweight/obese in nonconsumers of vitamin and dietary supplements could be confounded by other factors.

Our unadjusted results also support previous reports showing that a high percentage of lipids in the diet and no vigorous physical activity participation are associated with higher adiposity (4,10,30–32). In addition, our results concur with studies reporting higher adiposity indices in individuals who consume high levels of alcohol (5,33). However, our study reveals that the relationships between physical exercise intensity, lipid, and alcohol intake with body weight are confounded by other factors as we lost significance in the adjusted model. The same pattern applies for susceptibility to hunger and restraint eating traits in the cross-sectional sample. On the other hand, a high dietary restraint trait seems to be associated with weight gain over time, as previously reported (8). Having a high disinhibition and susceptibility to hunger eating behavior seems also counterproductive on the long run. This is concordant with previous studies showing that these two eating behavioral traits were positively associated with the level of obesity and energy intake (9,34) and that disinhibition was reported to be a major determinant of weight gain or weight regain after weight loss (35,36).

It is a truism that the positive energy balance underlying obesity is generally attributed to factors exerting a direct measurable impact on energy intake or expenditure. Indeed, the traditional risk factors for obesity are reduced physical activity, excessive caloric intake, and high dietary lipid intake. However, our attempts to prevent and/or manage obesity based on these traditional risk factors have been unsuccessful and the prevalence of obesity continues to rise. Most systematic reviews and meta-analyses of reduction in dietary fat suggest that a weight loss of ~3–5 kg can be expected with a reduction in the proportion of energy from dietary fat of 10 percentage points (e.g., from 40 to 30%) (refs. 37–39). Estimates of the impact of training and physical activity on body weight do not really show any major effect (40,41). Accordingly, it becomes obvious for many researchers that the excess weight gain seen in many individuals is not entirely explained by these traditional risk factors and a growing body of evidence reveal that other, less obvious or nontraditional factors, can also promote a positive energy balance and weight gain (1,2). Our results are concordant with these emerging data since the four more important risk factors for overweight/obesity and weight gain found in this study do not have a "caloric value" *per se*. More research will nevertheless be needed to better understand the actual impact of these putative contributors to obesity and to prove causal relationships.

Strengths of this study include the use of both cross-sectional and longitudinal designs and the simultaneous testing of several risk factors for overweight and obesity. Furthermore, data were obtained from both men and women, and we used an approach that should serve to minimize confounding with repeated measures of risk factors. However, although cohort studies are well suited for the identification of associations, they cannot establish causality. Furthermore, QFS was originally designed to explore the role of genetics in the etiology of obesity, fitness, and cardiovascular and diabetes risk factors.

Future work that is similar in design is needed on a larger sample that is more representative of Canadians from across the country for a better generalizability of the results obtained. Finally, it is likely that the risk factors for overweight and obesity are broader than the nine considered in this study.

In summary, adults who sleep fewer hours, consume less dietary calcium and present a high disinhibition eating behavior are more likely to be overweight or obese. Over a 6-year follow-up period, those who slept fewer hours, consumed less calcium and had a high disinhibition and restraint eating score gained more weight. Hence, health practitioners and clinicians may need to address a broader range of influential factors to more adequately address the obesity epidemic.

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