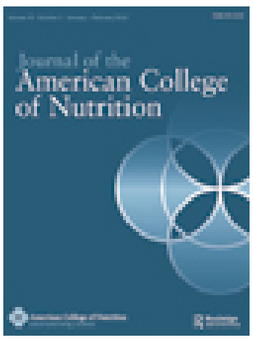

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Original Research

Alcohol Drinkers Overreport Their Energy Intake in the BIRNH Study: Evaluation by 24-Hour Urinary Excretion of Cations

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Key words: energy intake, alcohol drinkers, overreporting, 24-h urinary excretion, cations, dietary survey

Objective: Alcohol drinkers are generally considered to underreport their alcohol intake, but little is known about whether they correctly report their energy intake (EI). We assessed the validity of the reported energy intake of alcohol drinkers using the 24-hour urinary (U) excretion of potassium (K) and sodium (Na) as biomarkers.

Methods: A total of 2,124 men and 1,998 women 25 to 74 years of age with a 24-hour urine collection, a random sample of the Belgian Interuniversity Research on Nutrition and Health (BIRNH), were studied. Dietary intake (D), including alcohol consumption, was assessed by a one-day food record. Basal metabolic rate (BMR) was predicted from age, gender and weight. As a measure for the degree of reporting error, D-K/U-K, D-Na/U-Na, EI/U-K, Non-alcohol EI/U-Na (NAEI/U-Na), EI/U-Na, EI/U-creatinine and EI/BMR ratios were calculated and compared among non-, moderate and heavy drinkers in both genders.

Results: EI, NAEI and all seven ratios examined generally increased with the level of alcohol intake in both genders. After adjustment for age, body mass index, smoking and educational level, most ratios were significantly higher in moderate drinkers ($p < 0.02$ to $p < 0.0001$) and in heavy drinkers (all $p < 0.0001$) than in non-drinkers. These differences were most significant in male heavy drinkers. The exceptions were D-K/U-K, D-Na/U-Na and NAEI/U-Na in moderate and female heavy drinkers and EI/U-K in male moderate drinkers. The estimated amount of the overreporting of EI by heavy drinkers was 27.8% in men and 13.7% in women.

Conclusions: This study provides evidence that EI and NAEI obtained from the BIRNH study was overreported among alcohol drinkers, especially among male heavy drinkers. It also indicates that EI from alcohol replaced EI from food.

INTRODUCTION

An essential prerequisite for any study on the relation between diet and disease lies in the accurate assessment of dietary intake. A substantial body of evidence shows that under- and overreporting of energy intake, mainly the former, is a widespread and serious problem in dietary surveys [1–12]. If all individuals in a survey under- or overreport in the same proportion, energy intake will be systematically under- or overestimated, but the relation between diet and disease remains virtually unchanged. Under most circumstances, however, misreporting of energy intake is more likely to occur in some population subgroups, for instance in obese [1, 3, 4, 6–9, 11, 13], older [1, 3, 6, 8] or less-educated [1, 9] subjects. The non-random and non-proportional under- and overreporting of energy intake may distort the direction and strength of the diet-disease relation. Therefore, characterization of the misreporters is of crucial importance to obtain reliable data from dietary surveys. Although many studies have been conducted in this field, the majority were designed to investigate the effect of

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Abbreviations: BIRNH = the Belgian Interuniversity Research on Nutrition and Health, BMI = body mass index, BMR = basal metabolic rate, Creat = creatinine, D- = dietary, EI = energy intake, γ-GT = gamma-glutamyltranspeptidase, HDL = high density lipoprotein, K = potassium, Na = sodium, NAEI = non-alcoholic energy intake, U- = urinary.

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body mass index (BMI) on the accuracy of reported energy intake [1, 3, 4, 6–9, 11, 13, 14]. Alcohol drinking has widely become a common lifestyle habit. The present state of knowledge concerning the performance of alcohol drinkers in dietary surveys is that they tend to underreport their alcohol intake [15–18]. However, whether energy intake of alcohol drinkers is correctly assessed in dietary surveys is still unknown. Using 24-hour urinary potassium and sodium as the indirect and objective biomarkers of energy intake, we attempted to clarify this important issue in a random population sample of 2,124 men and 1,998 women who participated in the Belgian Interuniversity Research on Nutrition and Health (BIRNH).

MATERIALS AND METHODS

Study Population

The data used in the present study were obtained from the baseline survey of the BIRNH study which was conducted from 1981 to 1984. The purpose, design, methodology and results of the BIRNH study have been published previously [19, 20]. To summarize, a random sample of population stratified by age and gender was drawn from each of the 42 Belgian counties based on the voting lists. Because of the low response rate (38.6% in men and 34.4% in women), an additional sample of 10% of the non-respondents selected at random was also surveyed. No significant difference in dietary habits was found between respondents and non-respondents [21]. A total of 5,949 men and 5,353 women 25 to 74 years of age took part in the baseline survey of the BIRNH study. From all participants, a random subsample of 2,199 men and 2,064 women was drawn, and they were asked to collect their 24-hour urine. This subsample of subjects was used in the analysis of the present study. Thirty-two men and 28 women were deemed to have an incomplete collection of 24-hour urine samples and were thus excluded, because their urinary excretion of creatinine fell outside the range of the 99 percent tolerance interval. Another 43 men and 38 women were excluded because of missing values. As a result, 2,124 men and 1,998 women were available for the final analysis.

Survey of Dietary Intake and of Anthropometric and Lifestyle Factors

The dietary intake of the subjects was assessed by a one-day food record. A standardized, structured and self-administered questionnaire was distributed to all subjects at home beforehand. This questionnaire surveyed the anthropometric, lifestyle and socioeconomic characteristics and the dietary intake of the population. All subjects were asked to record the frequency and amount of all food items consumed on their questionnaires on a specific day. The day of the dietary survey was either a weekday or a weekend day, depending largely on the availability of study participants. The amount of food items was quantified by using standardized methods (household measures) to assign weights or volumes to certain amounts of food [19]. The participants were interviewed, and all questionnaires were checked and verified by trained dietitians according to standardized methods on the first working day following the dietary survey. The conversion of food items into nutrients was based on the Paul and Southgate food composition table [22]. Because this table did not have a complete and adequate coverage of Belgian food items with regard to potassium intake, the Dutch food composition table was used for the assessment of potassium intake [23]. The discretionary salt added to the food was not considered in the survey. The frequency and quantity of all alcoholic beverages consumed (beer, wine, liquor, spirits, etc.) were recorded by the participants, and then the absolute amount of alcohol intake in grams per day was calculated according to the specific alcohol content of the beverages. Therefore, alcohol intake in this study means reported alcohol intake.

On the day of the interview, body height was measured to the nearest 1 cm and body weight to the nearest 1 kg after subjects had removed their heavy garments and their shoes.

Measurement of the 24-Hour Urinary Potassium, Sodium and Creatinine and of Serum Biochemical Parameters

Within two to five days after the day of dietary survey, a single 24-hour urine collection was performed. All seven days of a week were represented in the urine collection, but were not randomized. To ensure a complete 24-hour urine collection, special instructions on how to avoid urine loss were given to the subjects prior to urine collection. All urine specimens were analyzed in the Central Laboratory of the St. Rafaël Hospital, University of Leuven, so as to eliminate the inter-laboratory difference in biochemical measurement errors. Urinary potassium and sodium were determined by emission flame photometry [24], and urinary creatinine was measured by Jaffé's method [25]. On the day of the interview, a non-fasting blood sample was drawn from an antecubital vein with the participants in the supine position. A few hours later serum was separated and kept in a deep freezer. At weekly intervals, serum samples were transported to the same laboratory as the urine samples, and then serum gamma-glutamyltranspeptidase (γ-GT), high density lipoprotein (HDL) cholesterol and other biochemical parameters were measured.

Statistical Analysis

BMI was calculated as weight (kg) divided by height $(m)^2$. Basal metabolic rate (BMR) was estimated from the Schofield equations based on age, gender and weight [26]. Creatinine clearance was computed as an indicator of renal function [27].

The following ratios were calculated as a measure for the degree of reporting errors: dietary potassium/urinary potassium (D-K/U-K), dietary sodium/urinary sodium (D-Na/U-Na), energy intake/U-K (EI/U-K), non-alcoholic EI/U-Na (NAEI/U-Na), EI/U-Na, EI/urinary creatinine (EI/U-Creat) and EI/BMR. The ratios of D-Na to D-K (D-Na/D-K) and U-Na to U-K (U-Na/U-K) were developed as markers of different types of food intake. In all analyses, alcohol intake, smoking and educational level were treated as categorical variables. Alcohol intake was divided into three groups: non-drinkers, moderate drinkers and heavy drinkers. Gender-specific definitions for moderate and heavy drinkers were adopted. In men, moderate and heavy drinkers were defined as those who consumed 1–39 g/day and ≥40 g/day of alcohol, respectively. In women, the corresponding values were 1–19 g/day and ≥20 g/day. Smokers were classified into non-smokers, light smokers (1–19 cigarettes/day or cigar and/or pipe smokers) and heavy smokers (≥20 cigarettes/day) [28]. Three classes of educational level were created. Low, medium and high educational levels stand for incomplete or complete primary school, high school and professional higher education or university, respectively.

The anthropometric variables, dietary intake of energy, macronutrients and cations, urinary excretion of cations and creatinine and all ratios described above, were analyzed according to the three categories of alcohol intake. Because of significant differences in age in men and age and BMI in women among the three alcohol groups, analysis of covariance was used with age in men and age and BMI in women as covariates to calculate the adjusted means of all these variables and to compare their differences. Whenever an overall significant difference was detected among the three alcohol groups, pairwise comparisons were performed. The same analysis was also carried out for serum γ-GT and HDL cholesterol which were used as indirect biomarkers of the validity of reported alcohol intake [29, 30]. To evaluate the independent relation between alcohol intake and reported energy intake, multiple linear regression analysis was performed with the ratios used for measuring the degree of reporting error as respective dependent variables and alcohol intake, age, BMI, smoking and educational level as independent variables. All independent variables were retained in the model regardless of their significance level. Prior to the multiple regression analysis, all ratios were log-transformed due to their skewed distribution. In the multivariate models, non-drinkers, non-smokers and subjects with a low level of education were used as reference groups for categorical variables, alcohol intake, smoking and educational level, respectively. For the differences in categorical variables among the three categories of alcohol intake, a chi-square test was performed. All statistical analyses were carried out by using SAS version 6.12 (SAS institute, Inc., Cary, North Carolina). $p < 0.05$ (two-tailed) is considered to be statistically significant.

RESULTS

Anthropometric characteristics, the dietary intake of energy, macronutrients and cations, urinary excretion of cations and creatinine, and the ratios examined in relation to the level of alcohol intake are presented in Table 1 for men and Table 2 for women. Heavy drinkers were approximately five years younger than non- and moderate drinkers in both genders. No significant difference in BMI and BMR was found in men among the three groups of alcohol intake. In women, BMI was lower in heavy drinkers than in non- and moderate drinkers, whereas BMR was nearly identical among the three alcohol groups. The mean alcohol intake (g/day) of moderate and heavy drinkers was 17.7 and 78.6 in men and 8.6 and 37.5 in women. The percentages of heavy smokers and the subjects with a high educational level were higher among heavy drinkers than among non- and moderate drinkers in both genders (Table 3). The adjusted means of dietary intake of energy, non-alcoholic energy, fat, potassium and sodium in men and of energy and potassium in women increased with increasing categories of alcohol intake, whereas those of urinary excretion of potassium, sodium and creatinine did not show the same pattern and were even lower in heavy drinkers than in non-drinkers in both genders, except urinary potassium in women. Consequently, all the ratios used as a measure for the degree of reporting error were significantly higher in heavy drinkers than in non-drinkers in men (all $p < 0.0001$) and women ($p < 0.05$ to $p < 0.0001$), with the exception of D-Na/U-Na and NAEI/U-Na in women. In general, the differences in the variables examined were larger and more significant between non- and heavy drinkers than between non- and moderate drinkers (Tables 1 and 2).

The adjusted mean of the D-Na/D-K ratio did not differ significantly among the three groups of alcohol intake in both genders, but the adjusted mean of the U-Na/U-K ratio was significantly different among the three alcohol groups in men (Tables 1 and 2). Serum γ-GT and HDL cholesterol concentrations were significantly higher in alcohol drinkers than in non-drinkers in both genders except serum γ-GT in female moderate drinkers (Tables 1 and 2).

After adjustment for age, BMI, smoking and educational level, most ratios were significantly higher in moderate drinkers ($p < 0.02$ to $p < 0.0001$) and in heavy drinkers (all $p < 0.0001$) than in non-drinkers. The exceptions were D-K/U-K, D-Na/U-Na and NAEI/U-Na in moderate and female heavy drinkers and EI/U-K in male moderate drinkers. The partial regression coefficients of heavy drinkers on all ratios analyzed were greater than those of moderate drinkers in both genders. The significance levels of the partial regression coefficients of the alcohol intake categories were generally higher in heavy drinkers than in moderate drinkers and in male heavy drinkers than in female heavy drinkers (Table 4).

An additional analysis was performed by replacing alcohol intake with its indirect biomarker, serum γ-GT [30], in the

Table 1. Age-Adjusted Means[a] of Anthropometric Parameters, Dietary Intake of Energy, Macronutrients and Cations, Urinary Excretion of Cations and Creatinine, Related Ratios and Other Variables according to the Level of Alcohol Intake in 2,124 Men

	Non-drinkers (n = 856) (1)	Moderate drinkers (1–39 g/day) (n = 880) (2)	Heavy drinkers (≥40 g/day) (n = 388) (3)	*p* value[b]		
				1:2	1:3	2:3
Age (years)	52.9 ± 13.8	51.8 ± 14.2	46.4 ± 12.7	NS	†	†
BMI (kg/m^2)	25.9 ± 0.12	26.0 ± 0.11	26.1 ± 0.17			
BMR (kJ/day)[c]	7006 ± 22	6990 ± 22	7017 ± 33			
CC (mL/s)[d]	1.67 ± 0.02	1.70 ± 0.02	1.59 ± 0.03	NS	**	†
Dietary (D)						
EI (kJ/day)	10983 ± 124	11773 ± 122	13660 ± 185	†	†	†
NAEI (kJ/day)	10977 ± 122	11251 ± 120	11378 ± 183			
Fat (g/day)	126 ± 1.8	133 ± 1.8	138 ± 2.8	*	***	NS
Protein (g/day)	92 ± 1.0	92 ± 1.0	91 ± 1.5			
Carbohydrate (g/day)	271 ± 3.3	273 ± 3.2	270 ± 4.9			
Alcohol (g/day)	0	17.7 ± 10.6	78.6 ± 39.3	†	†	†
K (mmol/24 hours)	94.4 ± 1.03	97.6 ± 1.01	106.6 ± 1.54	*	†	†
Na (mmol/24 hours)[e]	104.8 ± 1.76	105.9 ± 1.73	119.7 ± 2.64	NS	†	†
Urinary (U)						
K (mmol/24 hours)	72.9 ± 0.82	76.4 ± 0.80	70.8 ± 1.22	**	NS	***
Na (mmol/24 hours)	164.2 ± 2.25	163.7 ± 2.21	146.6 ± 3.36	NS	†	†
Creat (mmol/24 hours)	14.3 ± 0.13	14.6 ± 0.13	13.3 ± 0.20	NS	†	†
Ratios						
D-K/U-K	1.44 ± 0.03	1.39 ± 0.03	1.70 ± 0.04	NS	†	†
D-Na/U-Na	0.74 ± 0.02	0.74 ± 0.02	1.04 ± 0.03	NS	†	†
EI/U-K (kJ/mmol)	169.4 ± 3.43	169.4 ± 3.37	218.5 ± 5.13	NS	†	†
NAEI/U-Na (kJ/mmol)	79.2 ± 1.91	80.3 ± 1.88	96.6 ± 2.86	NS	†	†
EI/U-Na (kJ/mmol)	79.3 ± 2.13	84.0 ± 2.09	118.5 ± 3.18	NS	†	†
EI/U-Creat (kJ/mmol)	833 ± 15	864 ± 15	1143 ± 23	NS	†	†
EI/BMR	1.57 ± 0.02	1.69 ± 0.02	1.95 ± 0.03	†	†	†
D-Na/D-K (mmol/mmol)	1.16 ± 0.02	1.13 ± 0.02	1.16 ± 0.03			
U-Na/U-K (mmol/mmol)	2.40 ± 0.04	2.26 ± 0.04	2.14 ± 0.05	**	†	NS
Serum						
γ-GT (IU/L)[d]	15.0 ± 0.85	17.4 ± 0.83	29.2 ± 1.29	*	†	†
HDL-chol (mg/dL)[d]	46.3 ± 0.42	48.7 ± 0.42	52.3 ± 0.63	†	†	†

[a] Mean ± SEM, except age and alcohol intake expressed as crude mean ± SD. NS = not significant, BMI = body mass index, BMR = basal metabolic rate, CC = creatinine clearance, EI = energy intake, NAEI = non-alcoholic EI, K = potassium, Na = sodium, Creat = creatinine, γ-GT = gamma-glutamyltranspeptidase, HDL-chol = high density lipoprotein cholesterol.

[b] * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; † $p < 0.0001$. A blank space means that there was no overall significant difference among the three groups.

[c] Estimated using Schofield equations based on age, gender and weight.

[d] Due to missing values, the number of non-, moderate and heavy drinkers, respectively, was 828, 853 and 378 for CC, 644, 675 and 281 for serum γ-GT, and 828, 854 and 376 for serum HDL-chol.

[e] The discretionary salt added to diet was not measured in the survey.

multivariate models. In men, γ-GT was significantly and positively associated with D-K/U-K, EI/U-K, EI/U-Na and EI/U-Creat ($p < 0.03$ to $p < 0.0004$).

DISCUSSION

In the present study, we investigated whether moderate and heavy alcohol drinkers reported their energy intake differently from non-drinkers used as the reference group. To achieve this goal, the 24-hour urinary excretion of potassium, sodium and creatinine as well as BMR were used as objective reference parameters. For the assessment of the degree of reporting error, three kinds of ratios were calculated: dietary cations/urinary cations (D-K/U-K and D-Na/U-Na), energy intake/urinary cations (EI/U-K, NAEI/U-Na and EI/U-Na) and energy intake/energy expenditure biomarkers (EI/U-Creat and EI/BMR). An experimental study showed that 77% of dietary potassium and 86% of dietary sodium were excreted in the urine [31]. A significant positive correlation was observed between dietary intake and urinary excretion of potassium and sodium [32]. These findings indicate that the urinary excretion of potassium and sodium varies with the dietary intake so as to sustain the tightly regulated metabolism of potassium and sodium. The 24-hour urinary potassium and sodium may thus serve as objective biomarkers of their dietary intake. It is shown in food composition tables [33] that potassium is present in the majority of food items and sodium especially in processed food

Table 2. Age- and BMI-Adjusted Means[a] of Anthropometric Parameters, Dietary Intake of Energy, Macronutrients and Cations, Urinary Excretion of Cations and Creatinine, Related Ratios and Other Variables according to the Level of Alcohol Intake in 1,998 Women

	Non-drinkers (n = 1,246) (1)	Moderate drinkers (1–19 g/day) (n = 550) (2)	Heavy drinkers (≥ 20 g/day) (n = 202) (3)	*p* value[b]		
				1:2	1:3	2:3
Age (years)	50.6 ± 13.6	50.8 ± 13.5	45.8 ± 12.7	NS	†	†
BMI (kg/m^2)	26.4 ± 0.12	26.0 ± 0.18	25.2 ± 0.29	NS	†	*
BMR (kJ/day)[c]	5669 ± 7	5694 ± 10	5671 ± 17	*	NS	NS
CC (mL/s)[d]	1.45 ± 0.01	1.46 ± 0.02	1.37 ± 0.03	NS	**	**
Dietary (D)						
EI (kJ/day)	8497 ± 72	9080 ± 108	9827 ± 180	†	†	***
NAEI (kJ/day)	8497 ± 71	8829 ± 108	8729 ± 179	*	NS	NS
Fat (g/day)	97 ± 1.1	104 ± 1.6	104 ± 2.7	***	*	NS
Protein (g/day)	73 ± 0.6	75 ± 0.9	73 ± 1.5	*	NS	NS
Carbohydrate (g/day)	209 ± 2.0	210 ± 3.0	206 ± 5.0			
Alcohol (g/day)	0	8.6 ± 4.8	37.5 ± 19.4	†	†	†
K (mmol/24 hours)	79.2 ± 0.64	81.8 ± 0.96	84.9 ± 1.59	*	***	NS
Na (mmol/24 hours)[e]	74.2 ± 1.02	78.1 ± 1.54	77.2 ± 2.56	*	NS	NS
Urinary (U)						
K (mmol/24 hours)	62.8 ± 0.55	64.0 ± 0.83	64.1 ± 1.39			
Na (mmol/24 hours)	130.8 ± 1.66	131.5 ± 2.50	127.2 ± 4.16			
Creat (mmol/24 hours)	10.2 ± 0.07	10.4 ± 0.10	9.8 ± 0.17	NS	*	**
Ratios						
D-K/U-K	1.37 ± 0.02	1.46 ± 0.04	NS	*	NS	
D-Na/U-Na	0.69 ± 0.02	0.74 ± 0.03	0.78 ± 0.05			
EI/U-K (kJ/mmol)	149.3 ± 1.97	155.4 ± 2.96	171.4 ± 4.92	NS	†	**
NAEI/U-Na (kJ/mmol)	80.3 ± 1.98	84.1 ± 2.98	87.7 ± 4.95			
EI/U-Na (kJ/mmol)	80.4 ± 2.08	86.8 ± 3.12	98.7 ± 5.19	NS	**	NS
EI/U-Creat (kJ/mmol)	888 ± 11	932 ± 16	1090 ± 27	*	†	†
EI/BMR	1.51 ± 0.01	1.60 ± 0.02	1.74 ± 0.03	†	†	***
D-Na/D-K (mmol/mmol)	0.98 ± 0.01	0.98 ± 0.02	0.93 ± 0.03			
U-Na/U-K (mmol/mmol)	2.19 ± 0.03	2.14 ± 0.04	2.08 ± 0.07			
Serum						
γ-GT (IU/L)[d]	10.7 ± 0.37	11.5 ± 0.55	14.5 ± 0.93	NS	†	**
HDL-chol (mg/dL)[d]	58.0 ± 0.40	59.8 ± 0.60	65.8 ± 1.00	*	†	†

[a] Mean ± SEM, except age and alcohol intake expressed as crude mean ± SD. BMI was adjusted for age only.

[d] Due to missing values, the number of non-, moderate and heavy drinkers, respectively, was 1181, 529 and 193 for CC, 966, 433 and 156 for serum γ-GT, and 1187, 531 and 192 for serum HDL-chol.

For abbreviations and other footnotes, see Table 1.

products. A greater variety of food items contain substantial amounts of potassium, as compared with nitrogen. For example, potatoes, vegetables and fruit are rich in potassium, but poor in nitrogen [33]. Therefore, it is reasonable to infer that urinary potassium is more reliable in reflecting energy intake than urinary nitrogen. However, ideally 24-hour urinary nitrogen should also be used as an indirect biomarker of energy intake. Unfortunately, the lack of data on this biomarker in the BIRNH study prevented us from doing so. The 24-hour urinary excretion of sodium (r = 0.191 for men; r = 0.189 for women) and potassium (r = 0.235 for men; r = 0.166 for women) was positively and significantly (all $p < 0.0001$) correlated with body weight in the present study. Since energy intake is subject to measurement errors, it is not an unexpected finding from our data that relatively small, but highly significant correlation coefficients were observed between energy intake and urinary sodium (r = 0.140, $p < 0.0001$ for men; r = 0.053, $p < 0.02$ for women) and potassium (r = 0.135, $p < 0.0001$ for men; r = 0.096, $p < 0.0001$ for women). If true energy intake were to be correlated with urinary excretion of sodium and potassium, the correlation coefficients would be greater. In view of aforementioned evidence and inference, it may be considered that 24-hour urinary potassium and sodium are indirect and objective biomarkers of energy intake.

Energy intake can be divided into two sources: alcoholic and non-alcoholic. The potassium content of the majority of alcoholic beverages, especially beer and wine, is similar to that of other dietary sources, whereas the sodium content is rather low [33]. Therefore, a higher intake of alcoholic beverages, and consequently a higher energy intake, should be accompanied by a higher urinary excretion of potassium. On the contrary, the urinary excretion of sodium better reflects sodium and energy

Table 3. Smoking and Educational Level according to the Level of Alcohol Intake in 2,124 Men and 1,998 Women[a]

	Non-drinkers		Moderate drinkers[b]		Heavy drinkers[b]	
	Men (n = 856)	Women (n = 1,246)	Men (n = 880)	Women (n = 550)	Men (n = 388)	Women (n = 202)
Smoking (%)[c]						
Non-smokers	56.0	83.6	51.9	90.4	40.7	78.7
Light smokers	25.8	10.5	31.8	6.9	27.1	13.4
Heavy smokers	18.2	5.9	16.3	2.7	32.2	7.9
Educational level (%)[d]						
Low	47.0	49.4	38.9	42.0	28.6	26.2
Medium	35.7	39.5	38.0	42.2	43.8	53.0
High	17.3	11.1	23.2	15.8	27.6	20.8

[a] Distribution in smoking and educational level among the three groups is significantly different in both genders (all $p < 0.0001$).

[b] For the definitions of moderate drinkers and heavy drinkers in men and women, see Tables 1 and 2, respectively.

[c] Light smokers: 1–19 cigarettes/day; heavy smokers: ≥20 cigarettes/day. Light smokers also include cigar and/or pipe smokers (n = 171 in men; n = 2 in women).

[d] Low, medium and high educational levels designate incomplete or complete primary school, high school and professional higher education or university, respectively. Owing to rounding, the percentages of three categories in male moderate drinkers do not add up to exactly 100%.

Table 4. Multiple Regression Analysis of the Ratios Examined versus Categories of Alcohol Intake[a], Adjusting for Various Confounders[b] in 2,124 Men and 1,998 Women

Dependent variables[c]	Moderate drinkers			Heavy drinkers			Adjusted R^2
	β	SEE	p value	β	SEE	p value	
			Men				
D-K/U-K	0.004	0.020	0.84	0.172	0.026	0.0001	0.071
D-Na/U-Na	0.047	0.028	0.09	0.302	0.036	0.0001	0.106
EI/U-K (kJ/mmol)	0.036	0.021	0.08	0.268	0.027	0.0001	0.118
NAEI/U-Na (kJ/mmol)	0.028	0.024	0.23	0.181	0.031	0.0001	0.089
EI/U-Na (kJ/mmol)	0.078	0.024	0.0009	0.369	0.031	0.0001	0.141
EI/U-Creat (kJ/mmol)	0.063	0.019	0.001	0.317	0.025	0.0001	0.128
EI/BMR[d]	0.090	0.015	0.0001	0.236	0.019	0.0001	0.152
			Women				
D-K/U-K	0.020	0.019	0.30	0.046	0.028	0.10	0.037
D-Na/U-Na	0.050	0.032	0.11	0.069	0.047	0.14	0.034
EI/U-K (kJ/mmol)	0.051	0.022	0.02	0.130	0.032	0.0001	0.063
NAEI/U-Na (kJ/mmol)	0.034	0.027	0.20	0.044	0.040	0.28	0.058
EI/U-Na (kJ/mmol)	0.064	0.027	0.02	0.167	0.040	0.0001	0.069
EI/U-Creat (kJ/mmol)	0.063	0.019	0.0009	0.199	0.029	0.0001	0.116
EI/BMR	0.071	0.015	0.0001	0.151	0.023	0.0001	0.170

[a] Non-drinkers were taken as the reference group. For the definitions of moderate drinkers and heavy drinkers in men and women, see Tables 1 and 2, respectively. β = partial regression coefficient, SEE = standard error of estimate, R^2 = multiple determination coefficient, D = dietary, K = potassium, U = urinary, Na = sodium, EI = energy intake, NAEI = Non-alcoholic EI, Creat = creatinine, BMR = basal metabolic rate.

[b] Adjusting for age, BMI, smoking and educational level.

[c] All dependent variables were log-transformed prior to analysis.

[d] Estimated using Schofield equations based on age, gender and weight.

intake from all food groups other than alcoholic drinks. Thus, the D-K/U-K and EI/U-K ratios are considered to be appropriate measures for evaluating the reporting error of energy intake, while the D-Na/U-Na and NAEI/U-Na ratios are employed as parameters for assessing the reporting error of non-alcoholic energy intake. Urinary creatinine is a biomarker of muscle mass, a main component of fat-free mass [34], and thus indirectly related to energy expenditure. BMR is mainly determined by age, gender and body weight and constitutes the main proportion of energy expenditure for a sedentary lifestyle. The EI/U-Creat and EI/BMR ratios were therefore adopted as supplementary measures for examining the validity of reported energy intake.

The most important finding of this study is that while energy intake, its ratios with urinary biomarkers, and cation ratios (D-K/U-K and D-Na/U-Na) generally increased with increasing categories of alcohol intake, urinary potassium, sodium and creatinine did not display a similar trend and even decreased in heavy drinkers. After adjustment for various confounding factors, most of the energy-related ratios and

cation ratios were significantly higher in moderate and heavy drinkers than in non-drinkers. These differences were most significant in male heavy drinkers. Using γ-GT instead of alcohol intake in the multivariate analysis yielded similar results in men. Western populations are generally characterized by a sedentary lifestyle. The WHO recommended energy requirement, expressed as a multiple of BMR, for a sedentary lifestyle is 1.55 [35], a value that approximates to the EI/BMR ratios observed for non-drinkers in men (1.57) and women (1.51) in our study. This finding suggests that non-drinkers appeared to have an adequate reporting of their energy intake at the group level. In this study, the EI/BMR ratios in heavy drinkers were 1.95 in men and 1.74 in women which were significantly greater than those of non-drinkers (all $p < 0.0001$) and are very close to energy requirement for heavily physical activity (2.10 in men and 1.82 in women), as suggested by FAO/WHO/UNU (1985) [35]. The calculated BMR was almost identical among the three alcohol groups in both genders. No significant difference in BMI was observed among the three alcohol groups in men, and BMI was significantly lower in heavy drinkers than in non- and moderate drinkers in women. Considering our findings on BMR and BMI, the higher EI/BMR ratios in drinkers, especially in heavy drinkers, as compared with non-drinkers, can be explained by either an increased physical activity or overreporting of energy intake or both. However, as far as we know, no studies in the literature demonstrated that alcohol drinkers are generally more physically active than non-drinkers. This statement was corroborated, although indirectly, by our result that there was no significant difference in the 24-hour urinary excretion of potassium between non-drinkers and heavy drinkers in both genders, as an increase in physical activity should result in an increase in food intake, consequently in dietary intake and urinary excretion of potassium [32]. Therefore, our findings indicate that alcohol drinkers, especially male heavy drinkers, overreported their energy intake.

It can be calculated from the data in Tables 1 and 2 that, in men, the ratios of heavy drinkers to non-drinkers for energy intake and urinary potassium are 1.24 and 0.97, respectively. In women, the corresponding values are 1.16 and 1.02. This suggests that the amount of the overreporting of energy intake was 27.8% in male heavy drinkers and 13.7% in female heavy drinkers compared with non-drinkers. A similar calculation performed in moderate drinkers showed that the estimated overreporting of energy intake amounted to 1.9% in men and 4.9% in women. Underreporting of alcohol intake among drinkers is well recognized [15–18] and could result in a corresponding decrease of reported energy intake. Taking this factor into account, the actual amount of the overreporting of energy intake by alcohol drinkers would have been even greater.

Non-alcoholic energy intake, NAEI/U-Na and D-Na/U-Na were generally higher in moderate and heavy drinkers than in non-drinkers in both genders. This finding suggests the overreporting of non-alcoholic energy intake. In this study, we are unable to evaluate the validity of the reporting of alcoholic energy intake due to the lack of objective reference parameters for alcohol intake. Nevertheless, our observation provides evidence that energy intake and non-alcoholic energy intake were overreported by alcohol drinkers in this Belgian population sample.

In both genders, the 24-hour urinary excretion of creatinine was somewhat lower in heavy drinkers than in non- and moderate drinkers (Table 1 and 2). This could be due either to a lower proportion of muscle mass [36] or to an incomplete collection of 24-hour urine in heavy drinkers. Even assuming that the whole difference is attributable to a urine collection error, the EI/U-Creat ratio still remains substantially higher in heavy drinkers. A small but significant difference in creatinine clearance existed between heavy drinkers and the other two categories of alcohol intake in men and women (all $p < 0.01$) (Tables 1 and 2). This slight decline of creatinine clearance in heavy drinkers cannot have any bearing on the urinary excretion of electrolytes.

The adjusted means of fat intake in moderate and heavy drinkers were significantly higher than those in non-drinkers in both genders. No significant difference in protein and carbohydrate intake was observed among the three categories of alcohol intake except a difference in protein intake between moderate and non-drinkers in women ($p = 0.013$). These findings imply that the overreporting of dietary intake by alcohol drinkers is not neutral for all food items. This under- and overreporting of selected food items may lead to misleading conclusions on the relation between diet and disease.

The overreporting of energy intake was most marked among male heavy drinkers. The relatively lesser degree of overreporting among female drinkers may be due to a lesser amount of alcohol consumption. Heavy drinkers were younger and more likely to be heavy smokers. Compared with non-smokers, smokers appeared to overreport their energy intake in the two studies of Norwegian [1] and Dutch populations [3]. Unexpectedly, a greater proportion of subjects with a high educational level were observed in heavy drinkers than in non- and moderate drinkers. This finding may be partially explained by the fact that heavy drinkers were approximately five years younger than non- and moderate drinkers in this study and that younger individuals generally have a higher educational level than older ones [37].

Most investigations conducted so far among alcohol drinkers focused on whether alcohol intake *per se* was misreported [15–17]. To our knowledge, no previous studies revealed that energy intake is overreported in alcohol drinkers. The amount of alcohol intake was compared between the overreporters and adequate reporters of energy intake in some studies. Alcohol consumption was higher in overreporters than in adequate

reporters in a Norwegian population sample [1], but the opposite result was found in a Swedish study [38]. The differences in both studies, however, did not attain the significance level.

The controversy remains on whether alcoholic energy replaces or adds to non-alcoholic energy from diet. An increase in alcohol intake was associated with a decrease in food intake in 10,428 American men and women [39] and in 164 middle-aged Scottish men [40]. This indicates that energy derived from alcohol substituted for energy from non-alcoholic sources. However, alcoholic energy intake was not compensated for by lower intake of other nutrients in the Dutch National Food Consumption Study [41] and in a study performed in 499 middle-aged Italian women [42]. The results from two American cohort studies showed that alcoholic energy was added to energy intake from food in men, but energy from alcohol displaced carbohydrate intake in women [43]. A common drawback of these studies is that no objective reference parameters were used to validate reported energy intake. In the present study, reported energy intake was significantly higher in moderate and heavy drinkers than in non-drinkers in both genders. However, using 24-hour urinary sodium and potassium as indirect and objective biomarkers of energy intake, we demonstrated that the above-mentioned finding was an artifact that occurred due to the overreporting of energy intake in alcohol drinkers. Therefore, our study suggests that alcoholic energy replaces energy from diet. The observation from some studies that energy from alcohol was added to energy from other sources may be explained partly by the overreporting of energy intake in alcohol drinkers.

Why alcohol drinkers overreport their energy intake remains obscure. Drinking alcoholic beverages may increase the volume of gastric content and enhance the sensation of satiety [44]. The social disapproval of heavy drinking may induce drinkers to underreport alcohol intake and to overreport food intake, leading to an overall overreporting of energy intake.

The question arises of whether the food intake of alcohol drinkers could be qualitatively different from that of non-drinkers. The sodium and potassium content of various food products can be quite different [33]. For example, cheese and meat products are high in sodium and low in potassium, and fruit and vegetables are high in potassium and low in sodium [33]. Therefore, the D-Na/D-K and U-Na/U-K ratios were used as markers of different types of reported and actual food intake. The D-Na/D-K ratio did not differ among the three alcohol groups in both genders. This increases the value of cations as indirect biomarkers of energy intake. The U-Na/U-K ratio was significantly lower in moderate and heavy drinkers than in non-drinkers in men, which can be explained by the low sodium content of most alcoholic beverages.

In the BIRNH study, highly significant correlations were found between dietary fat intake and serum lipid levels [29]. The analysis of the present study showed elevated concentrations of serum γ-GT and HDL cholesterol in alcohol drinkers, especially in heavy drinkers, as compared with non-drinkers. These results indirectly validated the methodology of the dietary survey, including the assessment of alcohol intake. The BIRNH study also has some potential limitations, which have been discussed in detail elsewhere [6]. A time gap of two to five days existed between the dietary survey and the 24-hour urine collection. However, several studies demonstrated that daily variation in group mean values of the 24-hour urinary excretion of potassium, sodium and creatinine was very small [45, 46]. A one-day food record was used to assess the dietary habits, including alcohol intake, of the participants. Thus, non-drinkers defined in this study may not necessarily be teetotalers. The data from a Dutch population sample of 1,145 men and 1,171 women showed that alcohol intake was higher on weekends than on weekdays [41]. Another limitation of the present study is that heavy drinkers are less likely to participate in nutritional studies [47]. The above limitations may give rise to misclassification of the subjects with regard to their drinking level or the underestimation of the prevalence of heavy drinkers, resulting in the attenuation of, rather than the enhancement of, the real degree of the overreporting of energy intake among alcohol drinkers [48]. It is still unknown to what extent the results of the BIRNH study can be extrapolated to other dietary surveys.

CONCLUSIONS

This is the first study to demonstrate that reported energy intake and non-alcoholic energy intake obtained from dietary surveys was likely to be overestimated among alcohol drinkers, which was especially pronounced among male heavy drinkers. This finding remained materially unchanged even after adjustment for various confounders. The estimated amount of overreporting of energy intake by heavy drinkers was 27.8% in men and 13.7% in women. In view of the fact that alcohol-derived energy intake is usually underreported in dietary surveys, the actual magnitude of the overreporting of energy intake would have been even higher. In this Belgian population, 18.3% of men and 10.1% of women were defined as heavy alcohol drinkers. Therefore, our observation has important implications for nutritional epidemiology. More studies are warranted to confirm the overreporting of energy intake by alcohol drinkers using objective reference parameters.

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