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Sucrose intake in Germany

Saccharosezufuhr in Deutschland

Summary The present investigation reevaluated the German National Food Consumption Survey in order to obtain data on sucrose intake and food sources of sucrose intake in Germany. Moreover, it focused on the effect of sucrose intake on nutrient intake.

By means of the food composition data base Bundeslebensmittelschlüssel, version II.2, 7-days dietary records of a representative sample of 15 838 persons aged 4 years and older were analyzed. The relation between sucrose and nutrients intake was investigated by variance and regression analyses. Low, moderate, and high sucrose intake categories were defined by means of sucrose density quartiles and comparisons were made for the percentages of persons meeting the German nutrient intake recommendations.

Mean daily sucrose intake ranges between 43.2 g/d (f, 51-64 years) and 82.3 g/d (m, 13-14 years). The mean contribution of sucrose to total energy intake is highest with 14 % in young age (4-6 years) and decreases to 9 % and 7 % in 51-64 year old women and men, respectively. The food groups "table sugar", "confectionery and ice cream", "biscuits, cake and pastries", "preserves", "dairy products", and "non-alcoholic beverages" are the main sucrose sources with varying importance in different age groups. The average amount of naturally occuring sucrose in the Germans' diet is estimated to 15-25 % of total sucrose intake. Sucrose contributes 80-90 % to total disaccharides intake in Germany.

With each gram of sucrose the intake of energy rises on the average by 12.5 kcal (52.4 kJ), of protein by 0.3 g (9 % of the energy increase), of fat by 0.5 g (34 %), and of carbohydrates by 1.8 g (57 %.). Consequently, the higher the sucrose content of a diet, the lower is the contribution of fat to total energy intake. In contrast, the energy-adjusted effect of sucrose was found to be negative for energy-providing nutrients (except mono- and disaccharides) as well as for all the selected micronutrients, except calcium, vitamin E, vitamin C, and dietary fiber. Accordingly, the comparison between moderate and high sucrose consumers revealed a lower percentage of persons meeting nutrient intake recommendations in the high sucrose category under the condition of a comparable energy intake. This unfavorable effect of high sucrose intake is most prominent in 4-6 year old boys and girls as the groups with the highest sucrose intake. Since from the present data no exact figure for a sucrose or sugars intake recommendation can be deduced, it is suggested to keep on the WHO recommendation for a moderate sugar intake of 10 % of energy intake.

Zusammenfassung In einer Neuauswertung der Nationalen Verzehrsstudie sollen die Höhe der Saccharosezufuhr in Deutschland, der Beitrag einzelner Lebensmittelgruppen zur Saccharosezufuhr sowie der Einfluß der Saccharosezufuhr auf die Nährstoffzufuhr untersucht werden.

Dazu wurden die 7-Tage-Ernährungsprotokolle der repräsentativen Stichprobe von 15 838 Personen im Alter ab 4 Jahren mit Hilfe des Bundeslebensmittelschlüssels, Version II.2, ausgewertet. Der Zusammenhang zwischen der Saccharose-

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zufuhr und der Nährstoffzufuhr wurde mit Varianz- und Regressionsanalysen untersucht. Gruppen mit geringer, moderater und hoher Saccharosezufuhr wurden anhand von Saccharosedichte-Quartilen festgelegt; ein Vergleich zwischen diesen Gruppen erfolgte hinsichtlich der Anzahl von Personen, die die Nährstoffzufuhrempfehlungen der DGE erfüllten.

Die mittlere tägliche Saccharosezufuhr bewegt sich zwischen 43,2 g/d (w, 51-61 Jahre) und 82,3 g/d (m, 13-14 Jahre). Mit durchschnittlich 14 % der Energiezufuhr weisen die jüngsten Teilnehmer (4-6 Jahre) den höchsten Beitrag von Saccharose an der Energiezufuhr auf, dieser sinkt auf 9 % bzw. 7 % der Energie bei 51- bis 64jährigen Frauen und Männern. Die Lebensmittelgruppen „Haushaltszucker", „Süßwaren", „Fein- und Dauerbackwaren", „Süße Brotaufstriche", „Milcherzeugnisse" sowie „nicht-alkoholische Getränke" sind die wesentlichen Saccharosequellen; deren Anteil an der Saccharosezufuhr variiert jedoch in den verschiedenen Altersgruppen. Etwa 15-25 % der aufgenommenen Saccharose kommen natürlicherweise in Lebensmitteln vor. Der Saccharosanteil an der Disaccharidzufuhr beträgt 80-90 %.

Pro Gramm Saccharose werden im Mittel 12,5 kcal (52,4 kJ) Energie, 0,3 g (9 % der zusätzlichen Energieaufnahme) Protein, 0,5 g (34 %) Fett und 1,8 g (57 %) Kohlenhydrate aufgenommen; folglich sinkt mit steigender Saccharosezufuhr der prozentuale Anteil von Fett an der Energiezufuhr. Dagegen zeigt Saccharose nach Energieadjustierung einen negativen Effekt auf die Zufuhr von allen energieliefernden Nährstoffen (außer Mono- und Disacchariden) sowie auf die Zufuhr aller betrachteten essentiellen Nährstoffe mit Ausnahme von Calcium, Vitamin E, Vitamin C und Ballaststoffen. Entsprechend finden sich unter der Voraussetzung vergleichbarer Energiezufuhr in den Gruppen mit hoher Saccharosezufuhr weniger Personen, welche die Nährstoffzufuhr-Empfehlungen erfüllen, als in den Gruppen mit moderater Saccharosezufuhr. Dieser nachteilige Effekt ist am deutlichsten bei 4-6 Jahre alten Jungen und Mädchen, den beiden Personengruppen mit der höchsten Saccharosezufuhr. Da aus den vorliegenden Daten keine exakte Empfehlung zur Saccharose- oder Zuckerzufuhr abgeleitet werden kann, wird für die Beibehaltung der WHO-Empfehlung zu einer moderaten Zuckeraufnahme in Höhe von 10 % der Energiezufuhr plädiert.

Key words Sucrose intake – sugars – sucrose sources – nutrient intake – nutrient density – National Food Consumption Survey (NVS)

Schlüsselwörter Saccharosezufuhr – Zucker – Saccharosequellen – Nährstoffzufuhr – Nährstoffdichte, Nationale Verzehrsstudie (NVS)

Introduction

The preference for the taste quality "sweet" exists from birth on (4) and makes "sweet" foodstuffs highly palatable to many persons (10). In Germany, sucrose is the most important carbohydrate sweetener with a highly accepted sweetening profile. Therefore, it is added to a series of foods during processing and preparation. Regarding health risks of sucrose intake, both the added and the naturally occuring amounts of sucrose in the diet have to be considered. In contrast to former opinions, nowadays researchers agree that there is no evidence that the actual intake of sugars (including sucrose) is directly involved in the etiology of lifestyle-related diseases such as diabetes, cardiovascular disease or gallstones (2, 9, 17, 22, 23). The present recommendation for a moderate sugar consumption is based on the contribution of sugar intake to the formation of dental caries. However, sucrose provides energy; in combination with the high palatability of sweetened foods, diets high in added sugars were often suspected to rise energy intake and lower nutrient density (2, 29). This makes the expert commitee of the WHO/FAO recommend that "excessive intakes of sugars which compromise micronutrient density should be avoided" (17). In 1990, the WHO Study Group (33) formulated the goal of decreasing the sugar intake to 10 % of total energy intake.

The prevalence of obesity in Germany and other industrialized countries such as Great Britain or the United States is still increasing (13, 28). Since obesity is recognized as one of the most important avoidable risk factors for a number of life threatening diseases and for serious morbidity (18), the search for effective strategies to prevent and treat obesity is continuing. For several reasons experts particularly recommend diets with reduced fat content as well as a physically active life style (18, 28). With decreasing fat intake, the contribution of dietary carbohydrate intake to total energy intake increases. Epidemiologic data show that the percentage of energy derived from extrinsic sugar and from fat is reciprocally related, the so-called "fat-sugar seesaw" (3, 19, 25, 27). However, expressed in absolute amounts, extrinsic sugar intake and fat intake revealed a positive correlation (9), probably due to an increased intake of a mixed diet. Therefore, extrinsic sugar has also been postulated as a vehicle for dietary fat by making fat-containing foods more palatable (16).

Obviously, addition of extrinsic sugar to food decreases its nutrient density. However, the discussion on the consequences of an increasing extrinsic sugar proportion in the human diet on the essential micronutrient supply is still continuing. The literature provides several reports on a higher essential nutrient intake with increasing sugar intake (20, 21, 27, 29). This effect seems clear when a higher sugar intake is linked to an increase in total food consumption and in total energy intake. However, the situation may be different if energy intake is kept constant in accordance with the limited physical activity nowadays and foods high in added sugars are preferred in exchange for other foodstuffs.

Since detailed data on sucrose consumption in the German population has not been available so far, the aims of the present investigation were (a) to describe the amount and the sources of sucrose intake in Germany for different sex and age groups, and (b) to look into the effects of sucrose intake on the supply with energy and essential nutrients.

Methods

To obtain individual sucrose intake data, the German National Food Consumption Survey (NVS; source: public use file) was reevaluated. The survey was conducted between October 1985 and January 1989 in the Federal Republic of Germany. It provides intake data based on 7-day dietary records of a representative sample of more than 23,000 persons. During the data collection, the accident at Chernobyl happened (April 26, 1986) changing eating behavior to a considerable extent (11). In the present investigation this effect was eliminated in accordance with the methodological considerations in the German Nutrition Report 1996 (14) excluding all the data of the NVS that were obtained between April 26, 1986 and April 25, 1987. Therefore, a total of 15 838 dietary records was reevaluated. Average daily energy and nutrient intakes of the participants were calculated by means of the German food composition data base Bundeslebensmittelschlüssel (BLS), version II.2, providing also data on the sucrose content of each food item (7).

Sucrose intake data are given in terms of arithmetic mean and percentiles for different sex and age groups. The survey participants were grouped according to the age categories of the German dietary intake recommendations (12). In the data base BLS II.2, there is no distinction between naturally occuring sucrose and sucrose added to foods. Therefore, as a measure of sucrose sources, the contribution of different food groups to the total sucrose intake of different sex and age groups was calculated instead.

Multiple regression analysis was used to estimate the effect of sucrose intake on the intake of energy and nutrients. It was distinguished between energy-unadjusted and energy-adjusted analyses. In each case, sex and age (as logarithm to the base 10) were included as independent variables. Sucrose intake, however, was treated differently in the two analyses. In the first (unadjusted) case, the given sucrose intake was used as another independent variable. In the second case, sucrose intake was adjusted for energy intake. For this, three different models were used differing in the independent variables that were included besides sex and age. In model A, both sucrose intake and energy intake data were used, in model B sucrose intake residuals calculated from single regression analysis of the relationship between sucrose and energy intake were included (34), and in model C sucrose density values (34) were taken.

For each sex and age group, quartiles of the sucrose density distribution were calculated. They were used to distinguish between different categories of energy-adjusted sucrose intake. Low sugar consumers were defined as those in the lowest sucrose density quartile, moderate consumers fell between the 25th and 75th percentiles, and high consumers were those above the 75th percentile of sucrose density intake. The three categories were compared with respect to the percentage of persons meeting the German dietary intake recommendations (12).

Results

Mean daily sucrose intake is highest in 7-9 year old females and 13-14 year old males with 65.0 and 82.3 g/d, respectively (Table 1). With increasing age, sucrose intake decreases to about 44 g/d in both sex categories. Expressed in percent of energy intake, the highest contribution of sucrose to total energy intake (14 %) was found in the youngest age category (4-6 years) of both females and males. The given percentiles indicate a great variability between persons of the same sex and age group.

From the different food groups attributing to sucrose intake, “confectionery and ice-cream”, “dairy products” and “non-alcoholic beverages” are the dominating food groups in young people (Table 2). In adults, the food groups “table sugar” as well as “biscuits, cakes, and pastries” are of increasing importance as sources of sucrose. “Preserves” contribute in all age and sex groups to more than 10 % of sucrose intake. The contribution of any food group not listed to total sucrose intake is less than 1 %; the contribution of all these groups is summarized in “others”. The group “fresh fruit” provides considerable amounts of naturally occuring sucrose. In addition, fruit juices (included in “non-alcoholic beverages”) and fruit products like jam (in “preserves”) contain naturally occuring sucrose. The proportion of naturally occuring sucrose in the Germans‘ diet is estimated to range from 15 – 25 % of total sucrose intake within all age and sex groups.

As expected, sucrose intake (in absolute amounts and energy-unadjusted) is positively correlated with the intake of energy, protein, fat, and carbohydrates (Table 3) as well as many micronutrients (not shown), but it is

Table 1 Sucrose intake (mean in g/d, % of energy (% en.); percentiles in g/d) and energy intake (mean in MJ/d, kcal/d) of the participants of the German National Food Consumption Survey (NVS, n = 15,838) in different sex and age categories

Age (years)	n	Sucrose Mean (g/d)	Sucrose Mean (% en.)	Percentiles (g/d) 2.5th	5th	25th	50th	75th	95th	97.5th	Energy Mean (MJ/d)	Energy Mean (kcal/d)
Females												
4–6	341	55.6	14.3	13.6	17.5	34.5	51.8	70.8	107.3	126.1	6.5	1 555
7–9	270	65.0	13.8	17.3	22.6	44.9	61.5	82.7	119.5	140.2	7.6	1 878
10–12	224	64.1	12.8	20.0	23.4	42.6	56.7	80.5	125.1	145.2	8.4	1 997
13–14	194	61.9	12.0	11.9	19.1	38.9	56.3	81.3	122.7	134.9	8.7	2 070
15–18	519	58.6	11.9	13.9	19.0	33.9	52.5	75.4	120.0	134.7	8.2	1 962
19–24	972	58.0	11.6	10.8	14.3	35.2	53.4	75.1	119.0	134.7	8.3	1 992
25–50	3 518	45.8	9.4	7.7	11.1	25.9	41.1	60.9	96.0	107.8	8.1	1 944
51–64	1 503	43.2	8.9	9.3	12.6	26.4	39.6	55.0	84.5	102.5	8.2	1 950
> 64	898	43.5	9.0	8.5	12.0	26.2	38.2	55.7	91.2	104.9	8.1	1 930
Males												
4–6	303	60.5	14.1	16.0	20.7	40.5	57.6	77.5	107.1	122.9	7.2	1 712
7–9	294	67.1	13.4	19.2	23.3	46.5	62.7	83.5	128.0	148.2	8.4	2 007
10–12	249	71.7	12.8	14.6	23.0	50.0	68.0	89.8	125.7	153.9	9.3	2 234
13–14	185	82.3	12.7	12.8	25.5	54.1	78.2	103.0	158.7	190.8	10.9	2 602
15–18	385	74.6	10.8	16.8	22.1	47.6	69.2	98.8	140.8	160.8	11.6	2 766
19–24	748	66.8	9.9	11.5	17.2	36.6	61.1	86.3	143.8	161.3	11.3	2 694
25–50	3 278	50.3	7.8	6.9	9.8	25.4	42.9	68.1	113.7	134.6	10.8	2 578
51–64	1 218	43.8	7.0	7.5	10.3	23.7	37.6	57.9	97.3	115.9	10.5	2 505
> 64	739	43.6	7.4	8.3	10.9	25.5	39.0	56.9	91.6	105.8	9.9	2 359

Table 2 Mean contribution of important food groups (> 1 g sucrose/d) to total sucrose intake of the participants of the German National Food Consumption Survey (NVS; n = 15,838)

Age (years)	Table sugar	Confectionary and ice-cream	Biscuits, cakes, pastries	Preserves	Dairy products	Fresh fruit	Bread and rolls	Non-alcoholic beverages	Others
	(% of total sucrose intake)								
Females									
4–6	9.8	19.5	12.4	12.8	20.7	7.9	1.1	12.2	3.6
7–9	10.5	19.3	12.3	12.9	19.3	7.1	1.4	13.6	3.6
10–12	9.6	17.8	14.8	13.6	17.0	7.4	1.6	15.0	3.2
13–14	12.0	17.6	14.5	11.7	14.0	8.1	1.8	16.2	5.1
15–18	12.5	16.5	13.6	12.3	11.3	8.0	1.8	18.8	5.2
19–24	14.9	15.8	15.5	11.3	9.7	7.5	1.8	17.8	5.7
25–50	16.6	13.9	18.6	12.8	7.2	9.7	2.3	12.1	6.8
51–64	17.3	9.2	21.3	16.5	6.7	11.7	2.6	6.9	7.8
> 64	20.0	7.4	20.8	17.9	5.8	12.1	2.5	7.1	6.4
Males									
4–6	9.2	20.1	13.4	12.2	20.0	8.0	1.3	12.4	3.4
7–9	11.7	17.9	13.3	13.1	17.2	8.0	1.4	13.1	4.3
10–12	10.1	19.2	13.7	12.3	18.4	6.3	1.6	14.3	4.1
13–14	11.5	18.8	12.5	14.8	14.5	5.4	1.7	17.1	3.7
15–18	13.4	16.3	11.7	14.4	12.1	5.4	2.1	20.0	4.6
19–24	16.5	14.9	12.7	11.9	10.6	6.0	2.3	20.5	4.6
25–50	21.5	12.6	16.9	11.6	7.1	7.6	2.9	13.3	6.5
51–64	21.9	8.7	20.8	14.7	5.7	9.5	3.4	7.5	7.8
> 64	22.7	7.2	21.0	17.7	4.8	10.1	3.2	5.9	7.4

negatively correlated with alcohol intake. According to the results of the multiple regression analysis, the gross effect of 1 g sucrose intake is a rise in energy intake by 12.51 kcal (Table 3). This means that with a mixed diet, an increase of sucrose intake goes along with a considerably increased energy intake. Therefore, the energy-adjusted effects of sucrose intake were computed (Table 4). Independent of the method applied (model A, B or C), energy adjustment leads to very similar results for the effect of sucrose intake on nutrient intake (results obtained by the energy adjustment method 'sucrose density values', model C, are not shown). In particular, the signs of the regression coefficients are identical, except for magnesium, iron, and riboflavin. As given in Table 4, the multiple regression analysis with the independent variables sucrose intake, energy intake, sex, and age (log) (model A) show a statistically significant (energy-adjusted) effect of sucrose intake on the intake of all other nutrients with the exception of potassium. An inverse relationship was computed for sucrose intake and the intakes of the energy providing nutrients fat, polysaccharides, and alcohol. It is worth noting that the relationship is also found to be inverse for all the considered vitamins except vitamin E and vitamin C. Regarding minerals, negative coefficients were calculated for magnesium, iron, and zinc (model A). The strength of the relationships between the intake of sucrose and other nutrients is given by the partial R^2_{suc} (coefficient of determination). The term (R^2_{suc} * 100) represents the percentage of the variation in the dependent variable (i.e., nutrient intake) being explained by the variation in the independend variable (i.e., sucrose intake) if the covariance of both variables with the other independend variables is eliminated.

In order to obtain insight in the actual situation of nutrient supply, for all age and sex categories low, moderate, and high sucrose consumers (in terms of sucrose density) were identified by means of the 25th and 75th sucrose density percentiles (Table 5). The percentage of persons meeting the nutrient intake recommendations was calculated for each group (Table 6). For example, the results in women aged 19-24 years with moderate sucrose consumption in the range of 7.9-14.3 % of energy (Table 5) can be compared to those with high sucrose consumption (> 14.3 % of energy); with high sucrose intake fewer persons meet the recommendations compared to persons with moderate intake (dark grey shaded cells in Table 6), except for total carbohydrates, magnesium, and vitamin E. Comparable results can be found for most of the groups listed, including children aged 4-6 years and 7-9 years as well as adults and elderly. In females, 10-12 years and 15-18 years, and males, 13-18 years, however, more persons in the high sucrose intake category meet the dietary recommendations for most of the nutrients than in the moderate sucrose intake category. But it should be noted that these are the groups with a rather high difference in energy intake (moderate versus high consumers; statistically significant in both female groups, $p < 0.05$, Fisher's lsd test) and the groups with the smallest number of persons. In nearly all groups, mean energy intake increases from low to medium to high sucrose density categories (Table 6). This is also to be considered when comparisons were made between the sucrose intake categories "low" and "medium" revealing in most cases an advantage of the latter.

Discussion

The National Food Consumption Survey (NVS) has been the only representative study on dietary intake in Germany (1). The selected persons represented the whole population of the former FRG (before unification). A sufficient number of persons in all subgroups enables a valid statistical analysis. Until now, NVS data are only available for the intake of total disaccharides or total disaccharides minus lactose (24). Since the food composition data base BLS II.2 also provides the sucrose con-

Table 3 Effect of sucrose intake (not energy adjusted) on energy and nutrient intake calculated by means of a multiple regression analysis model for the participants of German National Food Consumption Survey (NVS, n = 15,838)

Nutrient	Unit	Sucrose		Sex		Age§		R^2_{model}
		b_{suc}	R^2_{suc}	b_{sex}	R^2_{sex}	b_{age}	R^2_{age}	
Energy	(kcal/d)	12.51***	0.357	501.82***	0.190	544.46***	0.084	0.464
	(kJ/d)	52.36***	0.357	2102.75***	0.190	2285.91***	0.084	0.464
Protein	(g/d)	0.28***	0.129	18.93***	0.153	22.76***	0.079	0.284
Fat	(g/d)	0.48***	0.182	21.27***	0.104	27.59***	0.060	0.278
Carbohydrates	(g/d)	1.80***	0.571	39.19***	0.142	27.39***	0.026	0.614
Monosaccharides	(g/d)	0.28***	0.212	0.95***	0.001	-3.90***	0.004	0.238
Disaccharides	(g/d)	1.06***	0.927	2.43***	0.017	-6.48***	0.039	0.933
Polysaccharides	(g/d)	0.48***	0.127	28.54***	0.117	31.73***	0.051	0.242
Alcohol	(g/d)	-0.04***	0.007	11.12***	0.107	13.82***	0.058	0.165

*** $p < 0.001$, unpaired t-test; § log (age) tent of foods, the NVS data set could easily be re-evaluated.

For several reasons, the data set of the present investigation was not corrected for possible underreporting. First, a better comparability to published results from the National Food Consumption Survey (e.g., 1, 14, 24) is given, where also no corrections for underreporting were made. Moreover, the most complete sugars intake estimates presented in the USA 1986 (safety evaluation of the US Food and Drug Administration) (22) and the UK 1989 (9) were not adjusted for possible underreporting of food intake (23), either. Furthermore, Voss et al. (31) showed that the energy-adjusted intake values of macronutrients obtained by the residual method (as applied in model B, Table 4) were independent of the methodological influence of underreporting. However, the problem of underreporting may be persistent in data describing sucrose intake (23). Voss and coworkers (31) considered that recent epidemiological studies tried to improve the accuracy of their data analyses by excluding subjects with implausible low energy intakes. This procedure, however, may lead to the exclusion of obese individuals (often suspected to underreport) and does not consider potential underreporting in subjects with an energy intake above the cut-off level.

The calculated amounts of sucrose intake in the present evaluation fit well with the results of other reports from Germany and Austria in children and adolescents. Schöch und Kersting (30) estimated the mean contribution of sucrose to the total energy intake at approximately 14 % in a group of German children aged 4-14 years. Also, the first Nutrition Report of Vienna (32) describing sucrose intakes of 7-18 years old pupils noted similar sucrose intake values (in % of energy) for the younger

Table 4 Effect of sucrose intake on energy and nutrient intake calculated by means of two multiple regression analysis models A (independent variables: sucrose intake, energy intake, sex, age) and B (independent variables: sucrose residuals, sex, age) for the participants of the German National Food Consumption Survey (NVS; n = 15,838)

Nutrient	Unit	Model A Sucrose effect		R^2_{model}	Model B Sucrose effect		R^2_{model}
		b_{suc}	R^2_{suc}		b_{suc}	R^2_{suc}	
Energy	(kcal/d)	–	–	1.000	2.95***	0.013	0.177
	(kJ/d)	–	–	1.000	12.30***	0.013	0.177
Protein	(g/d)	-0.16***	0.083	0.756	-0.07***	0.005	0.181
Fat	(g/d)	-0.19***	0.090	0.839	-0.04***	0.001	0.118
SFA#	(g/d)	-0.07***	0.036	0.742	-0.00n.s.	0.000	0.088
MUFA§	(g/d)	-0.08***	0.081	0.794	-0.02***	0.002	0.123
PUFA~	(g/d)	-0.03***	0.031	0.509	-0.01***	0.003	0.093
Carbohydrates	(g/d)	0.87***	0.357	0.861	1.15***	0.152	0.238
Monosaccharides	(g/d)	0.19***	0.073	0.282	0.22***	0.085	0.115
Disaccharides	(g/d)	1.00***	0.887	0.938	1.08***	0.631	0.665
Polysaccharides	(g/d)	-0.21***	0.036	0.648	-0.06***	0.001	0.134
Alcohol	(g/d)	-0.19***	0.091	0.283	-0.17***	0.069	0.217
Dietary fiber	(g/d)	0.005**	0.000	0.447	0.03***	0.008	0.082
Potassium	(g/d)	0.00n.s.	0.000	0.635	0.003***	0.008	0.132
Calcium	(mg/d)	0.91***	0.006	0.305	1.69***	0.016	0.039
Magnesium	(mg/d)	-0.09***	0.001	0.639	0.25***	0.004	0.141
Iron	(mg/d)	-0.01***	0.005	0.592	0.01***	0.001	0.114
Zinc	(mg/d)	-0.02***	0.049	0.621	-0.01***	0.004	0.138
Vitamin A	(mg RE‡/d)	-0.004***	0.005	0.064	-0.003***	0.002	0.018
Vitamin D	(µg/d)	-0.019***	0.003	0.031	-0.014***	0.002	0.016
Vitamin E	(mg TE$/d)	0.008***	0.001	0.223	0.022***	0.007	0.035
Vitamin B_1	(mg/d)	-0.003***	0.010	0.213	-0.002***	0.002	0.052
Vitamin B_2	(mg/d)	-0.001***	0.002	0.255	0.001*	0.000	0.047
Niacin	(mg/d)	-0.092***	0.122	0.686	-0.059***	0.023	0.246
Vitamin B_6	(mg/d)	-0.003***	0.018	0.335	-0.002***	0.003	0.097
Folic acid	(µg fFAE+/d)	-0.173***	0.011	0.332	-0.058***	0.001	0.085
Vitamin B_{12}	(µg/d)	-0.029***	0.007	0.056	-0.021***	0.004	0.023
Vitamin C	(mg/d)	0.266***	0.016	0.117	0.341***	0.025	0.025

Saturated fatty acids; § monounsaturated fatty acids; ~ polyunsaturated fatty acids; ‡ retinol equivalents; $ tocopherol equivalents; + free folic acid equivalents; *** p < 0.001, ** p < 0.01, * p < 0.05, n.s. not significant, unpaired t-test

age groups, but found no decrease by age. In European epidemiological studies, the term "sugar intake" is defined diversely, e.g., as intake of total sugars, simple carbohydrates, carbohydrates minus polysaccharides, mono-/disaccharides, or sugars minus lactose, and the data were obtained by various methods (20). No further studies could be found providing actual sucrose intake data. For the USA, a total mean sucrose intake of 41 g/d corresponding to 9 % of energy intake was estimated for all sex and age groups (23). In Germany unlike in the US (23), sucrose is by far the most important carbohydrate sweetener. Comparing the average sucrose intakes (Table 1) and the average disaccharide intakes in Germany (14), it can be seen that sucrose contributes approximately 80 – 90 % to the total disaccharide intake.

With the use of the BLS II.2, naturally occuring sucrose (intrinsic sucrose) and added sucrose (extrinsic sucrose) could not be distinguished. A distinction between both on a food level would have raised several problems and was omitted. Instead, the contribution of food groups to total sucrose intake was calculated. On this basis the proportion of naturally occuring sucrose was estimated. Sucrose provided by the food groups "confectionery and ice-cream", "table sugar", "biscuits, cakes, and pastries", and "bread and rolls" is considered as extrinsic (Table 2). On the other hand, "fresh fruit" provide exclusively intrinsic sucrose (approx. 5–12 % of total sucrose intake). Consequently, the critical points concerning the estimation refer to the proportion of naturally occuring sucrose in the food groups "preserves", "dairy products", "nonalcoholic beverages", and "others". Considering consumption data and usual manufacturing practise (e.g., consumption data for jam and the proportion of fruit and table sugar in jam preparations), the amount of naturally occuring sucrose can be approximated for these food groups. On this basis, it is concluded that not more than 15–25 % of total sucrose intake in Germany is naturally occuring in foods.

As expected from the well-known positive correlation between energy intake and the intake of most nutrients (9, 34), also sucrose intake was found to be positively correlated with the intake of energy and other nutrients. In Table 3, the corresponding data of the present investigation for energy and energy providing nutrients are shown. However, that data do not show the specific sucrose effect, but seem to reflect the fact that subjects with a higher energy intake consume higher amounts of a diet that provides other nutrients, too. Per gram of sucrose the nutrients protein, fat, and carbohydrates contribute 9, 34, and 57 % to the increase in energy intake (+ 12.5 kcal). Consequently, the higher the sucrose intake, the higher is the absolute amount of fat intake as well. However, the data also show that with increasing sugar intakes the contribution of fat to total energy intake decreases, well-known as fat-sugar seesaw (3, 19, 25, 27). Regarding the actual nutrition situation in Germany where up to 40 % of energy intake comes from fat (14), a high sucrose diet can be expected to turn fat intake in terms of % of energy closer to the recommended level. However, if only percentages of total energy intake are considered, one ignores the upper bound for the absolute amount of energy intake. Exceeding that bound leads to the problem of obesity. According to the literature, it is the percentage of energy derived from fat that is positively correlated with the incidence of obesity; the opposite seems to hold for the percentage of energy derived from carbohydrates or sugars (25). However, in a study on weight change in about 32 000 American women, Colditz et al. (8) found that the absolute sucrose intake (i.e., not expressed as % of energy) was positively correlated with the relative body weight (body mass index).

As suggested by Willett (34), the nutrient residual method or the nutrient density method can be employed to obtain nutrient (i.e., sucrose) intake data independent of total energy intake. Besides these two methods, a third method of energy adjustment was applied here entering absolute values for sucrose and energy intakes as two further independent variables into the regression analysis (Table 4, model A). This model is regarded superior for several reasons. The nutrient density method provided a variable that was still (even slightly, but significantly) correlated with energy intake. This is in good aggreement with Willett's (34) observations. With the residual method (Table 4, model B) the problem of misspecification due to omission of a relevant variable (i.e., energy intake) was encountered for the following reason. The included variables sex and age are correlated with the excluded variable energy intake. But the intake of most nutrients is also substantially correlated with energy intake. It can be shown that in such a case the estimates of all the regression coefficients (not merely the ones that are correlated with the omitted variable) are biased and inconsistent. One can solve this problem by including the omitted variable (i.e., energy intake) into the regression model, as was done in model A. Though this increases the problem of multicollinearity, it yields unbiased and consistent estimates. Besides, it is worth noting that the coefficients of determination as a measure of model quality are much higher for model A than for model B. Though this comparison does not allow the conclusion that model A is the true one, it gives some hints that model A is superior to the other models considered (15, 26). Finally, as can be seen in Table 4, energy adjustment is only complete in model A. Model B, however, shows (due to misspecification bias in the calculation of the residuals) a significant influence of the sucrose intake residuals on energy intake even though both variables are uncorrelated.

All energy adjustment methods used indicate an inverse relationship between sucrose intake and the intake of protein, fat, saturated, monounsaturated, and polyun-

Table 5 25th, 50th, and 75th percentiles of sucrose density (g/MJ) and corresponding contribution of sucrose to total energy intake (% en) in the diet of the participants of the German National Food Consumption Survey (NVS, n = 15,838) in different sex and age groups

Age	n	Percentiles#					
		25th		50th		75th	
(years)		(g/MJ)	(% en)	(g/MJ)	(% en)	(g/MJ)	(% en)
Females							
4–6	341	5.95	10.0	8.28	13.9	10.71	17.9
7–9	270	6.18	10.3	8.16	13.7	10.02	16.8
10–12	224	5.82	9.7	7.36	12.3	9.30	15.6
13–14	194	5.13	8.6	6.83	11.4	8.73	14.6
15–18	519	4.94	8.3	6.59	11.0	8.63	14.4
19–24	972	4.72	7.9	6.58	11.0	8.54	14.3
25–50	3 518	3.64	6.1	5.19	8.7	7.01	11.7
51–64	1 503	3.61	6.0	4.98	8.3	6.47	10.8
> 64	898	3.61	6.0	4.89	8.2	6.51	10.9
Males							
4–6	303	5.88	9.8	8.17	13.7	10.30	17.2
7–9	294	5.84	9.8	7.40	12.4	10.07	16.9
10–12	249	5.62	9.4	7.46	12.5	9.29	15.5
13–14	185	5.70	9.5	7.41	12.4	9.00	15.1
15–18	385	4.66	7.8	6.00	10.0	7.91	13.2
19–24	748	3.76	6.3	5.49	9.2	7.53	12.6
25–50	3 278	2.69	4.5	4.17	7.0	5.96	10.0
51–64	1 218	2.52	4.2	3.77	6.3	5.33	8.9
> 64	739	2.86	4.8	4.10	6.9	5.50	9.2

Percentiles taken to define low (< 25th percentile), moderate (25th–75th percentile), and high (> 75th percentile) sucrose consumers

saturated fatty acids, polysaccharides, and alcohol. Furthermore, sucrose intake is inversely related to the intake of all selected micronutrients, except calcium, vitamin E, vitamin C, and dietary fiber (Table 4). Consequently, sucrose intake lowers the intake of most nutrients. With energy adjustment, increasing the intake of sucrose in a subject's diet means that the energy supply from the rest of the diet has to be reduced equivalently. A negative coefficient for a nutrient in Table 4 (b_{SUC}) indicates that one energy unit of sucrose intake is accompanied by a smaller amount of that nutrient than an equivalent energy unit of the rest of the diet. Therefore, increasing sucrose intake leads to decreasing intakes of other nutrients, if energy intake is restricted. This sucrose effect on nutrient intake would have been even more striking using added sucrose intake data only. The findings also indicate that there is an upper limit for sucrose intake that has to be defined.

It has been assumed that the individuals' sugars intake is a predictor of nutritional adequacy of their diet (2) because added sugars contain essentially no micronutrients ("empty calory hypothesis"). However, recent studies indicate that across the range of actual sugar intakes no meaningful variations in micronutrient intakes exist (2, 6, 20, 21, 27, 29). To obtain insight in the effect of sucrose on the actual status of nutrient supply in Germans, the percentages of persons meeting the dietary intake recommendations were calculated in three sucrose density categories. When moderate and high sucrose consumers are compared, for most minerals and vitamins the results (Table 6, shaded cells) reflect the relationship found in the regression analyses. In those sex and age groups with a small and insignificant increase in energy intake from moderate to high sucrose intake category (Fisher's lsd test), e.g., boys and girls aged 4-6 years and women aged 19-24 years or > 64 years, the expected sucrose effect is most apparent. In the moderate sucrose intake categories, there is a higher percentage of persons meeting the recommendations than in the high sucrose intake categories. On the other hand, in sucrose consumer groups with a more substantial and statistically significant difference in energy intake ($p < 0.05$, Fisher's lsd test), e.g., 10-12 years old girls or 13-14 years old boys, there is a greater chance that the sucrose effect is reversed by the energy effect resulting in a higher intake of almost all nutrients. Also, Gibson (21) stated in her study on the role of sugars in the diets of British school children that energy intake appeared to have the major influence on nutrient intake. Similar results were provided by Rugg-Gunn and coworkers (29). In agreement with Gibney (20) who applied a comparable method to estimate the effect of sugars intake on the actual nutrient intake in the UK (three sugar density categories, but no differentiation for sex and age groups) as well as other

Table 6 Percentage of Germans meeting dietary intake recommendations for energy and selected nutrients# in the groups consuming low (I, 1st quartile of sucrose density), moderate (m, 2nd and 3rd quartiles), and high (h, 4th quartile) amounts of sucrose (National Food Consumption Survey; n = 15,838; dark shaded fields: m > h; light shaded fields: m = h)

Females

Age	4 - 6 y			7 - 9 y			10 - 12 y			13 - 14 y			15 - 18 y			19 - 24 y			25 - 50 y			51 - 64 y			> 64 y		
Category	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**
Energy	11	24	31	28	35	40	27	29	57	21	31	38	11	18	33	19	33	44	31	45	54	50	60	69	56	67	72
Mean intake(MJ/d)	*6.0*	*6.7*	*6.7*	*7.5*	*7.9*	*8.2*	*8.1*	*8.0*	*9.3*	*8.0*	*8.8*	*9.1*	*7.6*	*8.1*	*9.1*	*7.6*	*8.5*	*8.7*	*7.4*	*8.3*	*8.7*	*7.8*	*8.1*	*8.6*	*7.5*	*8.2*	*8.4*
Protein	100	100	98	99	99	99	96	97	95	85	87	90	92	89	91	88	90	86	89	92	90	93	93	90	91	92	87
Fat	37	46	38	60	52	37	59	47	50	50	53	44	35	36	35	64	68	67	71	79	80	85	87	87	87	91	88
Linoleic acid	17	20	17	37	34	27	59	47	38	48	52	52	50	49	40	54	53	50	49	54	52	50	55	50	55	48	49
Carbohydrates	8	19	32	16	27	52	5	18	57	4	19	35	3	10	30	5	17	37	5	18	37	13	27	52	11	37	58
Dietary fiber	4	5	5	8	4	9	9	1	13	4	9	6	4	4	9	3	4	4	4	6	7	5	6	10	3	8	6
Potassium	81	86	87	84	88	91	82	87	96	73	75	90	57	70	81	65	81	75	69	83	83	82	86	89	75	83	84
Calcium	35	39	40	33	38	40	27	13	36	15	13	8	5	5	9	13	15	13	14	21	26	26	26	35	21	25	33
Magnesium	98	98	97	90	95	96	45	53	73	27	32	44	6	21	29	30	39	41	34	46	51	43	44	55	32	38	46
Iron	41	60	54	42	57	57	9	9	21	15	14	21	9	14	20	10	14	13	15	21	19	72	81	81	65	76	72
Zinc	11	3	3	22	13	9	14	13	16	31	25	17	16	18	19	21	18	11	21	24	18	26	19	17	18	24	15
Vitamin A (RE)	60	65	52	63	63	48	57	52	63	58	45	46	62	54	62	63	71	54	66	73	73	72	79	77	69	81	75
Vitamin D	6	4	2	3	6	2	9	5	4	6	4	2	9	10	9	24	23	20	38	32	25	36	33	31	25	34	24
Vitamin E (TE)	29	49	39	37	54	64	54	46	64	23	33	44	23	38	44	23	35	41	29	38	41	36	39	42	34	35	38
Vitamin B1	37	32	22	57	47	42	48	42	48	58	55	54	36	34	39	44	44	35	53	59	54	64	59	54	59	56	45
Vitamin B2	52	55	54	57	64	70	52	47	70	42	51	54	15	17	32	29	34	29	30	37	38	40	37	38	34	38	35
Niacin	94	88	74	96	96	94	100	96	95	92	92	98	94	90	90	96	96	91	95	97	97	98	98	98	96	97	94
Vitamin B6	37	37	22	34	35	36	34	33	50	42	37	42	15	21	24	30	33	23	33	37	33	45	41	37	35	38	35
Folic acid (fFAE)	38	46	35	34	33	27	13	12	27	13	8	10	5	9	12	9	11	10	11	13	12	14	11	10	12	11	12
Vitamin B12	99	95	87	94	99	93	96	91	95	90	87	79	89	80	72	88	84	74	89	89	82	93	88	85	90	86	79
Vitamin C	54	69	71	67	71	73	61	71	79	56	56	75	46	57	68	45	64	58	42	59	62	53	64	68	46	60	66

Males

Age	4 - 6 y			7 - 9 y			10 - 12 y			13 - 14 y			15 - 18 y			19 - 24 y			25 - 50 y			51 - 64 y			> 64 y		
Category	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**	**l**	**m**	**h**
Energy	31	44	38	45	43	52	36	46	50	39	52	67	29	31	39	33	55	58	44	57	67	59	67	76	71	78	82
Mean intake(MJ/d)	*6.7*	*7.3*	*7.4*	*8.0*	*8.4*	*8.7*	*8.7*	*9.5*	*9.7*	*9.9*	*10.9*	*11.8*	*11.1*	*11.5*	*12.1*	*10.3*	*11.5*	*11.9*	*10.0*	*10.9*	*11.4*	*10.0*	*10.4*	*11.1*	*9.7*	*9.8*	*10.2*
Protein	100	100	100	100	100	99	95	98	100	91	96	100	96	94	96	96	94	93	94	95	94	92	95	96	93	92	92
Fat	51	57	43	62	57	58	58	61	44	63	65	70	53	51	52	81	84	75	80	84	87	83	87	91	92	92	95
Linoleic acid	19	23	18	51	46	27	60	61	45	57	71	72	79	74	79	70	77	72	74	78	77	68	75	73	68	74	62
Carbohydrates	17	38	49	29	38	56	18	37	53	20	40	70	10	20	31	8	29	49	7	23	46	15	27	49	26	41	69
Dietary fiber	9	9	3	8	13	6	7	10	7	22	8	11	8	6	4	5	14	9	9	15	16	11	17	21	12	16	19
Potassium	85	93	88	82	95	96	87	90	95	80	93	98	87	91	95	88	93	93	91	92	95	90	95	96	91	93	94
Calcium	37	52	43	37	43	48	40	34	44	30	36	50	21	24	32	18	36	40	19	33	37	25	35	46	31	34	46
Magnesium	95	100	100	86	99	99	71	82	89	41	60	72	25	34	44	41	58	57	49	60	61	49	52	61	47	43	48
Iron	65	74	61	64	64	66	42	48	45	57	72	72	71	76	79	88	89	89	86	92	92	83	91	95	85	88	87
Zinc	17	15	8	28	23	15	32	22	21	26	12	20	29	31	18	18	29	20	22	25	22	22	21	19	17	17	10
Vitamin A (RE)	72	71	53	64	69	53	68	55	55	63	50	48	60	54	49	63	63	56	63	70	69	62	72	79	68	74	76
Vitamin D	4	3	3	4	3	10	15	7	3	11	13	9	13	16	9	33	26	26	35	41	33	44	42	39	42	41	39
Vitamin E (TE)	39	57	51	59	61	69	50	59	52	41	58	65	43	58	66	35	58	58	39	53	61	38	53	60	41	51	49
Vitamin B1	51	48	29	67	57	48	58	59	57	63	55	67	55	57	55	70	71	61	74	73	70	66	71	67	63	59	49
Vitamin B2	57	70	57	62	68	69	68	63	63	57	61	72	43	48	51	49	59	56	42	52	51	47	48	52	42	39	42
Niacin	92	93	84	93	97	95	95	97	95	96	97	100	96	94	97	99	98	98	98	99	98	98	99	99	97	98	95
Vitamin B6	44	50	28	51	43	34	42	40	34	50	37	44	35	32	28	60	63	52	62	62	56	62	61	60	55	48	44
Folic acid (fFAE)	45	57	37	36	36	30	19	24	26	17	11	17	22	21	23	26	30	26	28	32	29	33	28	32	30	22	22
Vitamin B12	95	98	84	96	95	92	97	98	97	91	95	87	96	96	95	99	96	93	97	97	95	98	97	95	96	95	94
Vitamin C	52	67	62	62	75	84	65	70	69	61	66	78	56	72	73	48	66	65	46	61	67	47	63	70	57	62	71

RE: retinol equivalents; TE: tocopherol equivalents; fFAE: free folic acid equivalents; # DGE 1991; fat: upper limit of recommendation in each group; carbohydrates: 50 % of total energy intake

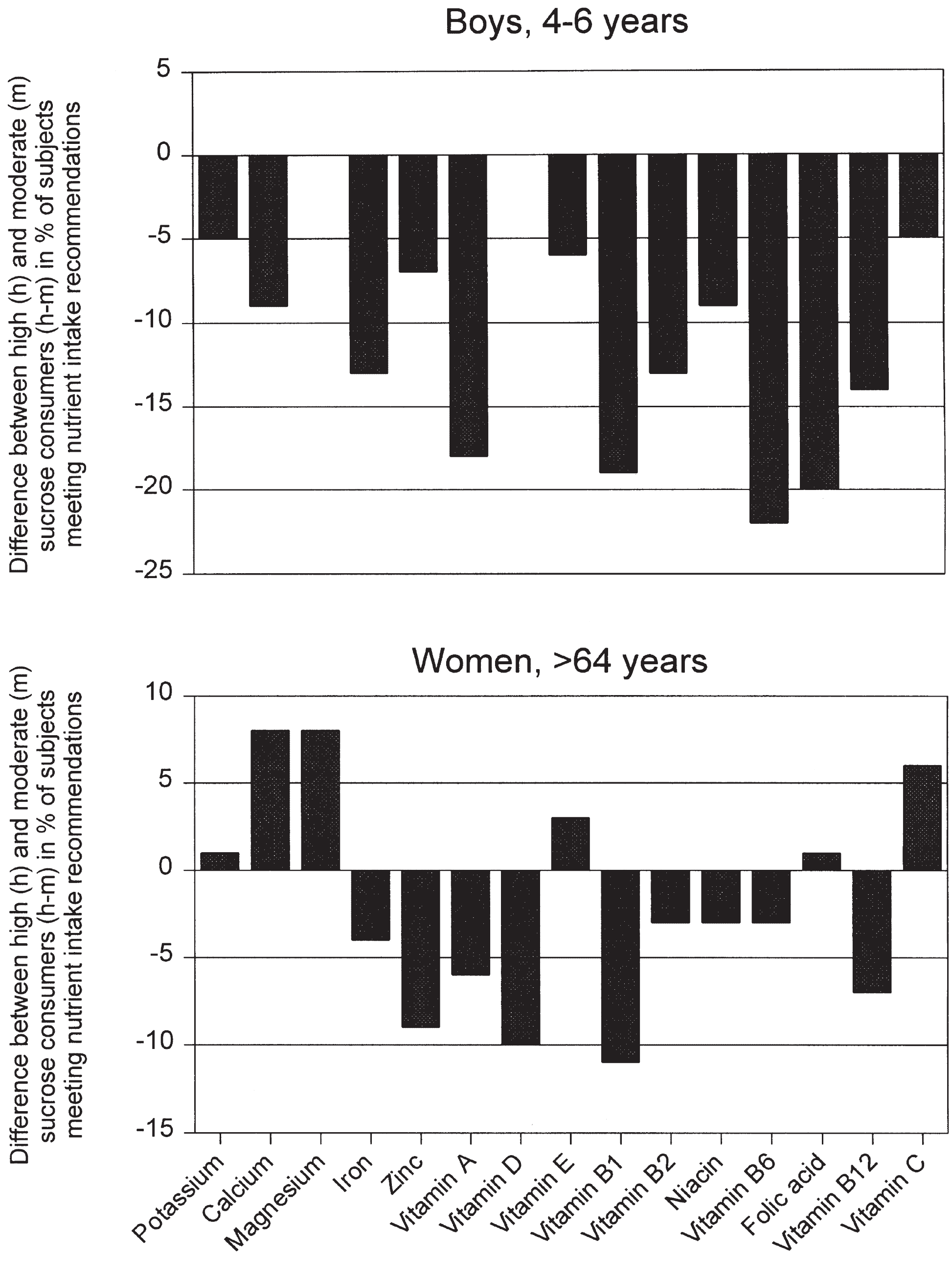

Fig. 1 Two examples for the difference between high (> 75th sucrose density quartile) and moderate (25th–75th quartile) sucrose consumers in the percentage of persons meeting German nutrient intake recommendations: A) boys, 4–6 years, with a sucrose intake of > 17.2 % of energy in the high sucrose intake category, and B) women, > 64 years, with a sucrose intake of > 10.9 % of energy. (In both examples the difference in mean energy intake between moderate and high sucrose consumers is rather low (< 0.2 MJ/d)).

investigators (21, 29), it is concluded that in general persons in the higher sucrose intake category do not reveal a distinctly worse nutrient intake situation as compared to persons in the moderate sucrose intake category. However, mean energy intakes in all sex and age groups increase from low to moderate to high sucrose density categories (Table 6). It seems that the higher the energy intake difference between categories, the less obvious is the negative effect of sucrose intake (within the here observed range) on the nutritional adequacy of the diet. On the other hand, in groups with only small differences in energy intake, a higher sucrose density is accompanied by a distinctly lower micronutrient supply. Consequently, an evaluation of the sucrose effect on the basis of absolute nutrient intakes in different sucrose intake categories also provides the same results as found in the regression analyses: the more sucrose is in a diet the worse the nutrient supply becomes if energy intake is held constant.

Since obesity is mainly a problem of energy imbalance, preventing weight gain implies limiting energy intake of each subject. This important aspect was not sufficiently considered in the many studies on the effect of sucrose on micronutrient intake (2, 6, 20, 21, 27, 29). But the call for abolition of the WHO recommendation of limiting sugar intake to < 10 % of energy (33) is based on the results of these studies (5). Obviously, a subject with a high energy requirement reaches micronutrient intake recommendations easier than one with a low energy requirement and therefore a low energy intake limit. Consequently, a maximum sucrose intake recommendation is especially reasonable for subjects with a relatively low energy intake at or below the demand level. However, it should be pointed out that this group represents the majority in Germany and other Western countries. The data of the present investigation show that a higher sucrose intake is associated with a higher energy intake by increasing the intake of all energy-providing nutrients (Tables 3 and 6). Therefore, if facing the problem of obesity, it seems in vain to argue on the basis of percentages of energy derived from either energy-providing substrate, fat or sugars. Instead, energy intake needs to be restricted. Then increasing the sucrose content of an energy-adequate diet causes an undesirable decrease in the intake of essential nutrients.

From the presented results, no exact figure for a maximally acceptable sucrose intake level can be deduced. However, to get a hint toward that objective, two groups of persons with a sucrose intake of > 10.9 % of energy (women, > 64 years) and > 17.2 % of energy (boys, 4-6 years), both defined as high sucrose consumers (Table 5), were selected as examples. The differences in the percentages of persons meeting nutrient intake recommendations in these high sucrose consumer groups compared to the corresponding moderate sucrose consumers were computed (Fig. 1). Importantly, in both groups the difference in mean energy intake between moderate and high sucrose consumers is negligible. But it can be seen that in the group with a sucrose intake > 17.2 % of energy the diet becomes nutritionally more inferior than in the group with > 10 % of energy (each compared to moderate consumers). In the group of the 4-6 year old boys, a high sucrose density of the diet is associated with a worsened intake situation for all the nutrients, except magnesium and vitamin D. Up to 22 % fewer boys in the high sucrose intake category meet the recommendations compared to boys in the moderate sucrose intake category. Because of the degree of the decrease and the kind of nutrients affected, e.g., -19 % for vitamin B1, -22 % for vitamin B6, or -20 % for folic acid (Fig. 1), the negative effects of a high sucrose intake have to be considered as very important.

These results point out the necessity of limiting sucrose intake. Since from the present data no exact figure can be deduced, we suggest the WHO recommendation of moderate sugars intake of < 10 % of energy (33) to be kept for Germans with low to moderate energy requirements. Also, a recent WHO expert consultation again recommended avoiding excessive sugars consumption that may compromise micronutrient density (17).

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