

## Associations between intake of added sugars and intakes of nutrients and food groups in the diets of German children and adolescents

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The aim of the present analysis was to evaluate the effect of intake of added sugars on intakes of nutrients and food groups. We used a mixed linear model (PROC MIXED) to analyse data from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study (an ongoing longitudinal cohort study between infancy and adulthood). Between July 1985 and August 2001, 3 d weighed dietary records ( $n$  4993) from 849 children and adolescents (416 male, 433 female) aged 2–18 years were collected and evaluated. Overall mean intake of added sugars was 12.4 (SD 5.3) (median 12.0) % energy. Fat intake (% energy) and intake of all analysed nutrients (as % reference values for nutrient intakes) fell across quintiles 1–5 of energy intake from added sugars ( $P < 0.001$ ). With the exception of 'Sugary foods' and 'Beverages' (significant increase,  $P < 0.0001$ ) and 'Dairy' (NS), intake of all other food groups decreased with increasing intake of added sugars ( $P < 0.0001$ ). In conclusion, we found a slight, but statistically significant, nutrient-dilution effect of added sugars and a significant reduction in intake of important nutrient-bearing food groups. However, the DONALD study gives no clear indicator on grounds of micronutrient dilution for a quantitative limit on intake of added sugars.

### Added sugars: Nutrient intake: Food intake: Children: Adolescents

The acceptable intake of sugars in a healthy diet has been widely discussed, especially for children. In recent dietary guidelines, a moderate consumption is recommended, without defining a quantitative limit (Food and Agriculture Organization/World Health Organization, 1998; Deutsche Gesellschaft für Ernährung, 2000; US Department of Agriculture, US Department of Health and Human Services, 2000). As a population goal, the Eurodiet project recommended sugary food consumption on no more than four occasions per d, based on the development of caries (Eurodiet, 2000). Previous guidelines defined an upper limit of 10 % energy (E) intake from sugars (World Health Organization, 1990). Dietary intake data from the last few decades have consistently shown intakes of sugars above this limit in the diet of children and adolescents in Germany (Linseisen *et al.* 1998), in other European countries (Gibson, 1997b; Lyhne & Ovesen, 1999) and in the USA (Krebs-Smith, 2001).

Recommendations for a limited intake of sugars are often based on the hypothesis of 'nutrient dilution'. Isolated sugars added to food provide E, but no essential nutrients. Therefore, it is often suspected that diets high in added sugars have a lower nutrient density for several vitamins and minerals. In fact, a significantly reduced nutrient density (Lyhne & Ovesen, 1999) or nutrient intake (Rugg-Gunn *et al.* 1991; Lewis *et al.* 1992;

Gibson, 1997b; Linseisen *et al.* 1998; Bowman, 1999) with increasing intake of sugars was found in several studies in children and/or adolescents. However, the nutritional significance of nutrient dilution is controversial, since these changes were only small compared with overall nutrient intakes (Gibney *et al.* 1995; Forshee & Storey, 2001).

The objectives of the present paper were to evaluate the effects of intake of added sugars on intakes of nutrients and food groups. We examined data from the ongoing Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study in a group of 2–18-year-old German children and adolescents between 1985 and 2001.

### Subjects and methods

#### Subjects and study design

The DONALD study is a longitudinal study in which detailed data on diet, metabolism, growth and development have been collected from healthy subjects between infancy and adulthood. The study started in mid 1985, with children and adolescents of different ages participating in anthropometric studies at our Institute. Since then, annual cohorts of about forty to fifty healthy infants have been enrolled. Mothers are recruited in the city of Dortmund

and surrounding communities via paediatric practices or personal contacts. Drop-out rates are small and vary by the age of the child, with the highest drop-out rate during puberty.

Participants >2 years old were examined annually. This medical examination was followed by a 3 d weighed dietary record. For this analysis, all 3 d weighed dietary records collected between July 1985 and August 2001 were considered, comprising 4993 dietary records from 849 children and adolescents (416 male, 433 female; aged 2–18 years) coming from 626 families. Between one ( $n$  142) and sixteen records ( $n$  4) per study participant were available (mean value 5.9). Mean age ranged from 6.7 (SD 4.1) to 9.6 (SD 4.7) years old per study year.

The DONALD study is an exclusively observational, non-intervening and non-invasive study and is approved by the International Scientific Committee of the Research Institute of Child Nutrition.

#### Dietary survey

Parents of the children, or the older subjects themselves, weighed and recorded all foods and fluids consumed and leftovers using electronic food scales ( $\pm 1$  g) on three consecutive days. Recipes for home-prepared meals were recorded. At the end of the 3 d record period, our dietitians visited the family and checked the record for completeness and accuracy. Product information from wrappers, cartons, etc. were kept and evaluated. If further queries turned up during the coding, the dietitians contacted the participant by telephone. Semi-quantitative recording (e.g. number of spoons, scoops) was allowed if weighing was not possible. However, in 75% of the completed records, more than 90% of the food items were weighed (Kersting *et al.* 1998b).

Record-keeping switched from the parents to the children or adolescents depending on age. Some children assisted their parents in recording from the age of 7 years. Of the 10–12-year-old children, 80% helped with the recording. In the adolescent groups, totally self-reliant records were kept by 20% of the male and 30% of the female subjects aged 13–14 years and by 70% of the male and 90% of the female subjects aged 15–18 years (Kersting *et al.* 1998b).

The first day of recording was chosen by participants. However, weekdays (71.4%) and weekend days (28.6%) were proportionally distributed in the sample.

To validate dietary recording, the reported E intake:predicted BMR ratio was used. BMR was calculated using the equations of Schofield (1985) including measured height and weight of the individuals. The mean E intake:BMR ratios of the sample were in the range of plausible dietary information (between 1.28 and 1.79 for children aged 1–5 years, between 1.39 and 2.24 for boys aged 6–18 years and between 1.30 and 2.10 for girls aged 6–18 years) according to Torun *et al.* (1996).

E and nutrient intakes were calculated using our nutrient database LEBTAB, which is continuously updated by all new recorded food items. At present, LEBTAB contains about 4900 food items (60% foods, composites and commercial products, 30% commercial infant food products

and 10% special preparations). Nutrient contents of common foods were taken from standard nutrient tables (Holland *et al.* 1992; Voorlichtingsbureau, 1993; Souci *et al.* 2000). Nutrient contents of commercial food products were determined either by using the product labels or by simulating recipes from the ingredients listed, including nutrient contents of fortified foods.

#### Definition of added sugars and food groups

Added sugars were defined as all refined sugars (e.g. sucrose, maltose, lactose, glucose, dextrin) eaten separately at the table or used as ingredients in processed or prepared foods, as done for the recent US dietary guidelines (US Department of Agriculture, US Department of Health and Human Services, 2000) and by other authors (Lewis *et al.* 1992; Lyhne & Ovesen, 1999; Forshee & Storey, 2001). Although natural intrinsic sugars and added sugars are indistinguishable with regard to chemical analysis or physiological metabolism, this separation provides consumers with useful information, especially if they are trying to limit excessive use of energy-containing sweeteners (Johnson & Frary, 2001). The definition of food groups is given in Table 1.

#### Statistical analysis

SAS® procedures (version 6.12; Statistical Analysis Systems, Cary, NC, USA) were used for data analysis (SAS Institute Inc., 1997). Intakes of nutrients and food groups were calculated as individual mean values of the three recorded days. A significance level of  $P < 0.05$  was used.

Nutrient intakes were calculated as individual percentage of recent *Reference Values for Nutrient Intakes*, jointly edited by the nutrition societies of the German-speaking countries (Deutsche Gesellschaft für Ernährung, 2000). Fat intake was given as % E. Food group intakes were calculated as individual % total food intake (TFI).

**Table 1.** Definition of food groups

Food group	Including foods
Dairy	Milk, yoghurt, dairy products, cheese
Meat, fish and eggs	Poultry, sausages, fish and egg products
Fats and oils	Discrete fats and oils from plant and animal origin, mayonnaise
Grain	Bread, breakfast cereals, cereals, flours, pasta, rice, potatoes, potato products, e.g. french fries
Fruits and vegetables	Fresh, canned and frozen products, juices
Beverages	Tap water, mineral water, coffee, tea, soft drinks, fruit juice drinks, malt beverage
Sugary foods	Table sugar, syrups, marzipan, nougat, sweets, cakes, jam, chocolate, ice cream
Miscellaneous	Spices, convenience dishes

To examine associations between added sugars and intakes of nutrients or food groups, a mixed linear model was used, in which the mean values, the covariance structure and the effect of repeated measurements were measured (PROC MIXED) (Littell *et al.* 1996). An exponential structure of covariance was specified to consider correlation of repeated measurements dependent on the absolute time interval of repeated measurements within the same subject.

Age (respective age of the participant), time (year of recording) and sex effects were included in each model.

In detail, we tested the following model: intake of nutrients (% reference value (RV) or % E) or food group (% TFI) = intercept +  $\beta_1$  (intake of added sugars, in fifth of % E +  $\beta_2$  (time, years) +  $\beta_3$  (age, years) +  $\beta_4$  (gender).

The coefficients for independent variables ( $\beta_1$  to  $\beta_4$ ) represent their predicted change when the reported independent variable increased by one unit. For example, the coefficient for added sugars ( $\beta_1$ ) represents the predicted change in intakes of nutrients or food groups when the reported consumption of added sugars intake ascend to the next quintile. The coefficient for time ( $\beta_2$ ) or age ( $\beta_3$ ) predicted the change in intake of nutrient or food group for a 1-year increase in study duration or age. The coefficient of the gender variable ( $\beta_4$ ) represents the predicted change of intake of nutrient or food group consumed by female compared with male subjects.

## Results

Overall intake of added sugars was 12.4 (SD 5.3) (median 12.0) % E. Quintile cut-points of added sugars intake were 7.9, 10.8, 13.3 and 16.6 % E respectively.

Table 2 shows associations between quintiles for intakes of added sugars and nutrients. Intakes of fat, vitamins and minerals were strongly inversely associated with intake of added sugars. As intake of added sugars rose, median fat intake decreased from 38 % E at the lowest quintile to 34 % E intake at the highest quintile, a decrease of 10 % (Fig. 1). Median intakes of vitamin A, C, thiamin, folate, Ca and Fe decreased by 22, 3, 3, 15, 14 and 6 % respectively (Fig. 1).

Time and age trends were heterogeneous. Intakes of fat (% E) and folate (% RV) decreased during the study period, whereas intake of vitamin C increased. Ca intake (% RV) decreased with age, whereas intakes of thiamin, folate and Fe increased.

Nutrient intakes were lower in girls than in boys; however, the differences were not significant for fat (% E) and Vitamin C (% RV).

The food groups 'Sugary foods' (55.8 (SD 22.1) % total intake of added sugars) and 'Beverages' (20.3 (SD 19.3) % total intake of added sugars) were the main contributors to intake of added sugars, followed by 'Dairy' (13.4 (SD 15.7) % total intake of added sugars), 'Grain' (6.8 (SD 10.8) % total intake of added sugars), 'Fruits and vegetables' (2.4 (SD 6.1) % total intake of added sugars) and 'Fats and oils' and 'Meat, fish and eggs' (both < 1 % total intake of added sugars).

There was no association between intake of added sugars and 'Dairy' intake (% TFI) (Table 3). Intakes of 'Meat, fish and eggs', 'Fats and oils', 'Grain' and 'Fruits and vegetables' fell with increasing added sugars intake ( $P < 0.0001$ ). Intake of 'Beverages' and 'Sugary food' increased with increasing added sugars intake ( $P < 0.0001$ ).

The greatest effect of intake of added sugars was found for 'Fruits and vegetables'. Here, a 10 % TFI difference across quintiles was found (approximately 40 %). Median intake of 'Grain', 'Fats and oils' and 'Meat, fish and eggs' decreased by 17, 15 and 4 % respectively. Median intake of 'Sugary food' (% TFI) at quintile 5 was more than doubled than in quintile 1 (+162 %) and median intake of beverages (% TFI) increased by more than one-third (+43 %) (Fig. 2).

## Discussion

Intake of added sugars in the diet of children and adolescents from the DONALD study (10–13 % E) was very similar to the values found in a representative study in Germany (12–14 % E as total sucrose in 4–18-year-olds; Linseisen *et al.* 1998) and Denmark (14 % E as added sugars in 4–14-year olds; Lyhne & Ovesen, 1999). Intakes of sugars in the UK (non-milk extrinsic sugars in preschool children (% E): boys 17.5, girls 18.2; Gibson, 1997b) and

**Table 2.** Overall intake and associations between intakes of added sugars nutrients in 2–18-year-old participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study 1985–2001\*

Nutrient§	Intercept	Added sugars†		Time‡		Age‡		Gender	
		$\beta_1$	<i>P</i>	$\beta_2$	<i>P</i>	$\beta_3$	<i>P</i>	$\beta_4$	<i>P</i>
Fat (% E)	42.71	-1.00	<0.0001	-0.28	<0.0001	0.05	0.0580	-0.26	0.2561
Vitamin A (% RV)§	105.40	-3.65	<0.0001	-0.15	0.4937	-0.04	0.8584	-4.38	0.0267
Vitamin C (% RV)	120.97	-3.07	<0.0001	1.17	0.0002	0.21	0.5190	-5.34	0.0928
Thiamin (% RV)	97.52	-0.92	0.0378	0.10	0.5428	0.58	0.0011	-5.57	0.0006
Folate (% RV)	52.68	-1.33	<0.0001	-0.18	0.0394	0.23	0.0153	-3.87	<0.0001
Calcium (% RV)	123.17	-1.37	<0.0001	0.16	0.2625	-1.47	<0.0001	-12.34	<0.0001
Iron (% RV)	105.33	-0.93	0.0002	-0.21	0.0520	0.89	<0.0001	-15.30	<0.0001

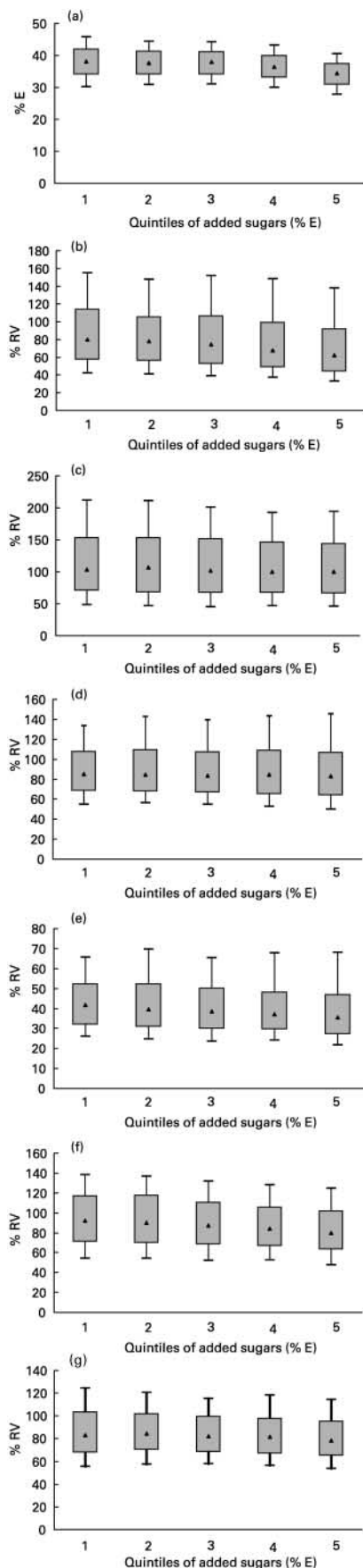
\* For details of subjects and procedures, see pp. 441–442.

E, energy; RV, reference value.

† Fifths of % E intake from added sugars.

‡ Years.

§ Reference value (RV), Deutsche Gesellschaft für Ernährung (2000).



the USA (added sugars (% E): 2–5-year-olds 16, 12–19-year-olds 20; Krebs-Smith, 2001) were somewhat higher, but definitions of sugars are not always comparable between studies. All surveys have in common that intake of sugars was above the previous limit of 10 % E.

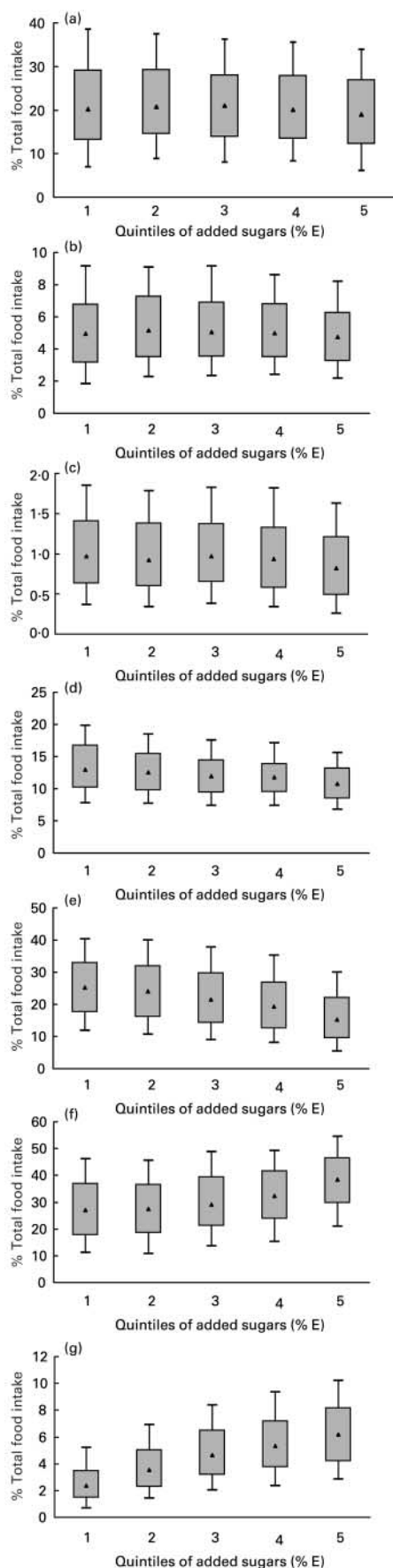
As found by others in cross-sectional surveys (Gibney *et al.* 1995; Hill & Prentice, 1995; Gibson, 1997b; Farris *et al.* 1998; Bowman, 1999), the effect of intake of added sugars on fat intake was negative ('sugar:fat seesaw' phenomenon), indicating that intake of added sugars at least partially replaced fat intake.

Our present results clearly showed a general trend of declining nutrient intakes as % RV (Deutsche Gesellschaft für Ernährung, 2000) with increasing intake of added sugars. However, the nutritional significance of this effect must be considered. As also stated by Forshee & Storey (2001), Gibson (1997a), Lewis *et al.* (1992) and Lyhne & Ovesen (1999), intakes of most nutrients were adequate regardless of the level of intake of added sugars. In the diet of children and adolescents in the DONALD study, intakes of folate were well below RV. However, comparing folate intakes at different levels of intake of added sugars (Fig. 1), this borderline intake was found even at the lowest as at the highest quintile.

In the German National Food Consumption Survey (1985–9) 'Confectionery and ice cream', 'Dairy' and 'Non-alcoholic beverages' were the main food groups contributing to sucrose intake in children and adolescents (Linseisen *et al.* 1998). In the US diet, carbonated soft drinks contributed 33 % to the total intake of added sugars, reflecting the dominance of this food group on intake of added sugars in the US diet. Other considerable sources for added sugars were 'Fruit drinks' (10 % E), 'Candy' (% E) 'Cakes' (5 % E) and 'Ready-to-eat-cereals' (4 % E). In contrast to the results of the DONALD study, the importance of dairy products as a source of added sugars was only small (<4 % E) (Krebs-Smith, 2001).

Associations between intakes of food groups and added sugars found in the DONALD study are consistent with previous studies. In the Bogalusa Heart study, intakes of 'Beverages' and 'Candy' increased and those of 'Mixed meats', 'Beef' and 'Poultry' decreased with increasing intake of added sugars in 10-year-old children (Farris *et al.* 1998). Only a small negative association, without practical importance, between added sugars and 'Dairy' was found by Forshee & Storey (2001), analysing data from the 1994–6 US Continuing Survey of Food Intakes by Individuals. In this evaluation, a weak negative association between added sugars and 'Fruits and vegetables' was also found. Although this food group is the most

**Fig. 1.** Distribution of nutrients by quintiles of energy intake from added sugars in 2–18-year-old participants in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study: (a), fat (% energy (E)); (b), vitamin A (% reference value (RV, Deutsche Gesellschaft für Ernährung (2000))); (c), vitamin C (% RV); (d), thiamin (% RV); (e), folate (% RV); (f), calcium (% RV); (g) iron (% RV). For details of subjects and procedures, see pp. 441–442. Values are medians (▲), with the 25th and 75th centiles shown by the horizontal limits of the box and 10th and 90th centiles by vertical lines.



important contributor to vitamin C intake, intake of this vitamin was positively associated with intake of added sugars, whereas in the DONALD Study, a negative association was found. Obviously, the negative effect of added sugars intake on the intake of fruit and vegetables exceeded the positive effect of fortification of sweetened food products. As we have shown in a previous evaluation, nutrient fortification masks nutrient dilution by added sugars (Alexy *et al.* 2002b). In a market survey in Germany, our Institute found most fortified products among the food groups ‘Beverages’, ‘Sweets’ and ‘Cereals’ (Kersting *et al.* 1995), which are also important contributors to intake of added sugars. Thus, 56 % of all fortified food products in Germany contained additional added sugars (Kersting *et al.* 1995). As described by Sichert-Hellert *et al.* (2000) on the basis of the DONALD study between 1985 and 1996, intake of added sugars from fortified food (% TFI) increased disproportionately to E intake (% TFI). Obviously, fortification is used as a marketing instrument by the food industry to validate nutritionally unfavourable high-sugar products. However, fruits and vegetables confer a benefit beyond nutrients, since they contain many phytochemicals that are believed to be beneficial on health, although phytochemicals are not nutrients in the true sense of the word and not added back in fortification. This means that added sugars may dilute not only nutrients, but also non-nutrient food components.

Some limitations of the present study should be considered in interpreting the findings. First, the DONALD study sample is not representative, upper social class families are over-represented (Kersting *et al.* 1998b). However, several evaluations showed no or only minor differences in dietary habits in our sample compared with the previous German National Food Consumption Survey (Alexy *et al.* 1998, 1999; Kersting *et al.* 1998a,b). Time trends of dietary habits are also comparable, for example, with findings of the MONICA study in German adults (Alexy *et al.* 2002a).

Second, potential under-reporters were not excluded from analysis. In a longitudinally designed study such as the DONALD study, direct estimation of under-reporting, for example by doubly-labelled water, is usually not feasible. By an indirect identification of under-reporting, e.g. by cut-offs for the E intake:BMR ratio, as suggested by Goldberg (1991), a distinction between real under-reporters and those with an habitual low-E intake is not possible. In addition, after excluding implausible records (5 %) from 4–18-year-old females (E intake: BMR ratio below cut-offs suggested by Sichert-Hellert *et al.* (1998) for children and adolescents), results were very similar to those of the total sample (results not shown).

**Fig. 2.** Distribution (% total food intake) of food groups by quintiles of energy intake from added sugars in 2–18-year-old participants in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study: (a), dairy; (b), meat, fish and eggs; (c), fats and oils; (d), grain; (e), fruits and vegetables; (f), beverages; (g), sugary foods. For details of subjects and procedures, see pp. 441–442 and for details of food groups, see Table 1. Values are medians (▲), with the 25th and 75th centiles shown by the horizontal limits of the box and 10th and 90th centiles by vertical lines.

**Table 3.** Overall intake and associations between intakes of added sugars and food groups in 2–18-year-old participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study 1985–2001\*

Nutrient (% total food intake)	Intercept	Added sugars†		Time‡		Age‡		Gender	
		$\beta$ 1	<i>P</i>	$\beta$ 2	<i>P</i>	$\beta$ 3	<i>P</i>	$\beta$ 4	<i>P</i>
Dairy	32.49	-0.01	0.9302	-0.29	<0.0001	-0.72	<0.0001	-1.82	0.0001
Meat, fish and eggs	7.05	-0.18	<0.0001	-0.12	<0.0001	0.06	<0.0001	-0.27	0.0292
Fats and oils	1.37	-0.04	<0.0001	-0.04	<0.0001	0.02	<0.0001	0.00	0.9430
Grain	13.10	-0.46	<0.0001	-0.04	0.0207	0.19	<0.0001	-0.38	0.0609
Fruits and vegetables	28.73	-2.25	<0.0001	0.02	0.6272	-0.40	<0.0001	1.88	0.0002
Beverages	13.94	2.12	<0.0001	0.50	<0.0001	0.85	<0.0001	-0.06	0.9198
Sugary foods	2.47	0.83	<0.0001	-0.05	<0.0001	0.03	0.0095	0.33	0.0008

\* For details of subjects and procedures, see pp. 441–442.

† Fifths of % energy intake from added sugars.

‡ Years.

In summary, analysis of dietary data from the DONALD study gives no clear indicator of micronutrient dilution for a quantitative limit of intake of added sugars. Obviously, an adequate nutrient intake is still possible within a wide range of added sugars intake (Gibson, 1997a; Ruxton *et al.* 1999). Others authors found no compromised nutrient intakes for non-milk extrinsic sugars intakes up to about 16% E intake in children (Gibson, 1997b) and non-milk extrinsic sugars up to 20% E intake in adults (Gibson, 1997a), values well above the mean intake of added sugars in children and adolescents of the DONALD study. In addition, Ruxton *et al.* (1999) concluded, after reviewing published literature, that consuming average amounts of sugars (14–20% E) had no detrimental effects on micronutrient intakes, even in children. However, a negative association between added sugars and intakes of all vitamins and minerals was found, so that added sugars intake should not be fully liberal.

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