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Glycaemic index and glycaemic load in the diet of healthy schoolchildren: trends from 1990 to 2002, contribution of different carbohydrate sources and relationships to dietary quality

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Despite intense discussion of the glycaemic index (GI) and glycaemic load (GL) concepts, data on the GI or GL levels in the diet of children are scarce. The present analysis determined trends in the levels of GI or GL of healthy children from 1990 to 2002 and examined the contribution of carbohydrate (CHO) sources to the overall GL, and the relationships of the GI and GL to the overall dietary quality. The analysis includes three cohorts of participants from the Dortmund Nutritional and Anthropometrical Longitudinally Designed study, aged 7–8 years in 1990 (*n* 53), 1996 (*n* 46) and 2002 (*n* 56). A GI value was assigned to all CHO foods recorded over three consecutive days. In comparison with 1990, 7–8-year-old children in 2002 had slightly higher GI (56·5 *v.* 55·1 %; *P*=0·03) and GL (17·5 *v.* 16·7 g/MJ; *P*=0·04) levels. In all three time periods the combined contribution of the 'tolerated food groups' (i.e. sweets, soft drinks, cakes and cookies, and salty snacks) to the overall GL exceeded that of bread and rolls (1990, 31 *v.* 24 %; 1996, 29 *v.* 31 %; 2002, 28 *v.* 25 %). Conversely, rice and fried or mashed potatoes had only a minor impact. Children in the lowest GI tertile, but not those in the lowest GL tertile, had a better nutrient profile and a more favourable food choice. In conclusion, partial replacement of high-GI 'tolerated food groups' for low-GI foods would help to reverse the slight recent increases in GI and GL, and to improve the overall dietary quality of 7–8-year-old children.

Glycaemic index: Glycaemic load: Trends: Carbohydrate sources: Children

Over the last few years, intakes of carbohydrate (CHO) have increased amongst European and North American children and adolescents, a trend resulting from a decrease in relative fat intake in response to population-wide low-fat campaigns (Nicklas *et al.* 2001; Alexy *et al.* 2002). Unfortunately, these changes are commonly characterised by an increased consumption of highly processed convenience foods and soft drinks (Troiano *et al.* 2000; Nielsen & Popkin, 2003), foods that promote a higher glycaemic response (i.e. high-glycaemic index (GI) foods). Already in 1989–1991, more than 80 % of the CHO consumed by 2–18-year-old US children had a GI equivalent to or greater than that of table sugar (Subar *et al.* 1998). These recent changes in food choice can thus be assumed to lead to a higher glycaemic load (GL) in the diet of children and adolescents, which is defined as the dietary GI multiplied by the CHO intake (Salmeron *et al.* 1997*b*).

Recent hypotheses suggest that the downstream effects of higher blood glucose and insulin levels elicited by a high-GI meal persist for 2–4 h after nutrient absorption has declined and may thus provoke reactive hypoglycaemia followed by counter-regulatory hormone secretion and elevated serum NEFA concentration (Ludwig, 2002). Over time, these physiological effects are thought to promote excessive energy intake as well as impaired β-cell function and dyslipidaemia (Brand-Miller *et al.* 2002; Ludwig, 2002; Willett *et al.* 2002). As a result, an increase in the GI and GL of the diet of children and adolescents has been proposed as one cause of the recently observed dramatic increase in the prevalences of both obesity and the metabolic syndrome in childhood and adolescence (Arbeitsgemeinschaft Adipositas im Kindes- und Jugendalter, 2002; Ogden *et al.* 2002; International Obesity Task Force, 2003; Cruz & Goran, 2004).

However, to date, information on the GI and GL of the diet of healthy children and adolescents is scarce (Ebbeling *et al.* 2003; Scaglioni *et al.* 2004) and no analyses of recent time trends are available. Data on the contribution of different CHO sources to the overall dietary GL are only available for selected adult populations (Liu & Willett, 2002). From a public health viewpoint, it is also of interest to learn about the extent to which a diet commonly consumed by children varies in its GI and GL, and how diets with a lower or higher GI or GL value are achieved in everyday life.

The present analysis determined whether the dietary GI or GL of German children aged 7–8 years in 2002 (*n* 53) were higher than those of comparable samples from 1990 (*n* 46) and 1996 (*n* 56). We also examined the CHO sources contributing to the respective overall dietary GL, and whether they had changed between 1990 and 2002. Furthermore, we compared the macronutrient intake and the food choices between children with a lower dietary GI or GL and those with a higher GI or GL.

Abbreviations: CHO, carbohydrate; DONALD, Dortmund Nutritional and Anthropometrical Longitudinally Designed; GI, glycaemic index; GL, glycaemic load; SES, socio-economic status.

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Methods

Study design

The Dortmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) study is a longitudinal (open cohort) study collecting detailed data on diet, growth, development and metabolism between infancy and adulthood. Details on the subject selection procedure and the study protocol have been described elsewhere (Kroke *et al.* 2004). Briefly, the present study was initiated in 1985 with children and adolescents of different ages participating in ongoing anthropometric studies at the Research Institute of Child Nutrition (Dortmund, Germany). Since then, each year approximately forty to fifty healthy infants are recruited from the city of Dortmund and surrounding communities via personal contacts, maternity wards or paediatric practices. This recruitment procedure results in a selected, non-representative study sample, characterised by a relatively high educational and socio-economic status (SES) (Kroke *et al.* 2004).

The present study, which is exclusively observational and non-invasive, was approved by the Scientific Committee of the Research Institute of Child Nutrition, and all examinations were performed with parental consent.

Nutrition assessment

Food consumption in the DONALD study is assessed using weighed 3 d dietary records as described previously (Kersting *et al.* 1998). Parents of the children weigh and record all foods and beverages consumed, as well as leftovers, using electronic food scales (to the nearest 1 g) on three consecutive days. Recipes for meals prepared at home are recorded. The packaging of commercial food products is kept. Semi-quantitative recording (for example, number of spoons or scoops) is allowed if weighing was not possible. At the end of the 3 d record period, a dietitian visits the family and checks the record for completeness and accuracy.

Energy and nutrient intakes are calculated using the nutrient database LEBTAB, which is continuously updated to include all recorded food items. LEBTAB is based on the German standard food tables (Souci, 1994) with complementary data from other national food tables (Voorlichtingsbureau voor de Voeding, 1990; Royal Society of Chemistry, 1991; United States Department of Agriculture, 2002) and data obtained from commercial food products. Since the labels of commercial products do not usually provide information on all the nutrients included in LEBTAB, the composition of these foods is simulated. This simulation procedure includes all ingredients declared on the label. The respective amount of each ingredient is then estimated so as to match the simulated nutrient data with the available declared nutrient data (Kroke *et al.* 2004). Based on this simulation, data for all nutrients in LEBTAB can then be calculated. Furthermore, for all complex foods not included in the food tables, the food composition is calculated using the recipes provided by the study participants or local recipes. About 15 % of the food items in LEBTAB are common basic foods; 75 % are complex products.

For the present analysis a GI value had to be assigned to each of the CHO-containing foods recorded in the 3 d dietary diary. Dietary GI is defined as the incremental area under the glucose response curve following the intake of 50 g CHO from a test food compared with the area under the glucose curve induced by the same amount of CHO from ingested glucose (Jenkins *et al.* 1981). To date, GI values are available for more than 750 CHO-containing foods; however, most data are from Canadian, US or Australian foods (Chantelau, 1994; Foster-Powell *et al.* 2002). As a result, a published GI value was only available for 15 % of the foods recorded by the DONALD participants. If several GI values were available for one food item, preference was given to those values from European foods. The remaining foods were either assigned the GI of a close match (40 % of the foods) or the GI was calculated using LEBTAB recipes (40 % of the foods). For those foods assigned the GI of a closely matched food item, the following factors were taken into consideration: the food group (for example, walnuts were assigned the mean GI of cashew and groundnuts); the regional origin of the food (for example, tropical fruits were assigned the GI from other tropical fruits); the mode of preparation (for example, potato croquettes were assigned the GI of French fries); the main ingredients (for example, honey-nut loops were assigned the GI of honey snacks); the sugar content (for example, mandarin pieces in light syrup were assigned the GI of fruit cocktail in light syrup). Very few GI values are available for vegetables, since one would have to eat a large amount to ingest 50 g CHO. We therefore assigned the mean of the existing GI values for carrots (GI 47), green peas (GI 48), pumpkin (GI 75) and red beets (GI 64) to all other vegetables (mean GI 59). For the remaining foods, GI values were calculated by multiplying the CHO content (g) of each ingredient by the ingredient's GI (%) and dividing the sum of these products by the total amount of CHO consumed. Foods containing mainly fat or protein with a CHO content below 5 g/100 g were assigned a GI of 0 (for example, cold meats) (5 % of the foods).

CHO-providing foods were grouped as follows: bread and rolls (bread, rolls, toast and crispbread); breakfast cereals and cereals (breakfast cereals, oats, cereals and sprouts); rice, pasta, cooked potatoes (boiled with or without skin); fried or mashed potatoes (pan-fried, French fries or mashed potatoes); fruits, vegetables, fruit juices, milk and milk products (milk, hot chocolate, yoghurt, buttermilk, cream, condensed milk, puddings, quark, cottage cheese and other types of cheese); 'tolerated food groups'. According to the Food Based Dietary Guidelines for German children and adolescents (Kersting *et al.* 2005), the latter are defined as food groups with a low nutrient density (i.e. the supplied micronutrient percentages are well below the supplied energy percentage). These include sweetened soft drinks (carbonated drinks and fruit drinks with less than 100 % of fruit juice content), cakes and cookies (including pastries), sweets (candies, jelly beans, chocolate bars, table sugar, ice cream, jams, honey) and salty snacks (popcorn, salty crisps, salty crackers). The consumption of these foods is tolerated, provided that they contribute at most 10 % of total energy intake, since this will enhance acceptance of dietary recommendations in children and adolescents without impairing nutrient adequacy (Kersting *et al.* 2005).

Study population

Due to the complex and time-consuming GI assignment procedure, the analyses in the present study were restricted to DONALD participants aged 7 or 8 years in 1990, 1996 and 2002. Only those children who had recorded plausible energy intakes according to criteria developed for children (Schofield, 1985; Sichert-Hellert *et al.* 1998), and had collected a 24 h urine were eligible for inclusion. Analyses of the associations between urinary C-peptide excretion and dietary GI will be presented elsewhere. Overall, 155 children met these inclusion criteria (1990, *n* 46; 1996, *n* 56; 2002, *n* 53). Even in this small sample, 1049 different CHO-containing foods were recorded in the 3 d dietary diaries.

Statistical analysis

The mean daily GI of each subject's diet was determined by multiplying the CHO content (g) of each food consumed by the food's GI (%) and dividing the sum of these products (which corresponds to the GL) by the total daily CHO intake. The dietary GL is intended to reflect the glycaemic effect of the actual amount of CHO consumed. However, in children, the total amount of CHO foods consumed is largely dependent on age and sex; thus variations of the overall GL (g) also reflect the inter-individual differences in total energy intakes. All GL data were therefore related to overall energy intake (g/MJ). Furthermore, the median CHO intake (g/d) from different CHO sources was calculated.

To analyse the potential associations between the dietary GI or GL and the nutritional intake pattern, the distributions of the GI and the GL were grouped into tertiles (T1–T3). Tests for differences were performed across the time periods (1990, 1996 and 2002) and across tertiles of GI or GL, using the Cochran–Mantel–Haenszel test, ANOVA, or the Kruskal–Wallis test, for categorical, normally distributed and not-normally distributed continuous variables, respectively. To directly compare dietary data between 1990 and 2002 or tertiles 1 and 3, *t* tests or Wilcoxon sign rank tests were used. A *P* value $<0{\cdot}05$ was considered to indicate statistical significance.

Since analyses indicated no interactions between sex and the relationships of the GI or GL to time or nutrient intake, data from girls and boys were pooled for this analysis.

All statistical analyses were carried out using SAS version 8.2 (SAS Institute, 1996).

Results

Table 1 compares the descriptive characteristics and the mean nutritional intake of the selected DONALD participants aged 7–8 years in 1990, 1996 and 2002. The SES of the parents was high in all three periods. The percentage of parents with a school education of 12 or more years increased between 1990 and 2002, while the percentage of households with smokers decreased.

Both the mean dietary GI and the mean dietary GL increased over time, with the difference between 1990 and 2002 reaching statistical significance. This change was accompanied by a non-significant increase in CHO intake and a non-significant decrease in fat intake from 1990 to 2002. Changes in the quality of CHO consumed are also illustrated by the fact that 7–8-year-old children in 2002 consumed less CHO from fruits, breakfast cereals and cereals and more CHO from pasta and fruit juices than their counterparts in 1990 (Table 1). Adjustment for changes in maternal education did not affect the association between the dietary GI and time, but attenuated the increase of the dietary GL over time, since children whose mothers had a higher educational level were more likely to consume a diet rich in dietary CHO (data not shown).

Fig. 1 compares the relative contribution of different CHO sources to the overall dietary GL in 1990, 1996, and 2002. Bread and rolls made a major contribution to the dietary GL in all three periods (24, 25 and 25 %, respectively). However, the combined impact of the 'tolerated food groups' (sweets, sweetened soft drinks, cakes and cookies, and salty snacks) on the dietary GL exceeded that of bread and rolls, contributing 31, 29 and 31 %, respectively. Among the 'tolerated food groups', sweetened soft drinks made the largest contribution to the overall GL in all three periods (15 *v.* 13 *v.* 15 %, respectively). Despite their relatively high GI, rice and fried or mashed potatoes had only a minor impact on the GL in all three periods since they were consumed in relatively small amounts. Furthermore, the contribution of fruits, breakfast cereals and cereals decreased and the impact of pasta and fruit juices increased, reflecting the trends observed in the consumption of total CHO (Table 1).

Table 2 and Table 3 present the associations between the dietary GI or GL and the intake of other nutrients. Children aged 7 and 8 years old with a higher dietary GI had a less favourable overall dietary pattern, characterised by a higher intake of sugar, and a lower intake of fibre (Table 2). Since the dietary GL is defined as the product of GI and CHO (g) consumed, a higher dietary GL was strongly related to a higher dietary CHO intake, a higher sugar intake and a higher dietary GI and lower intakes of dietary fat, protein and fibre (Table 3). Adjustment for time period (1990, 1996 or 2002) or maternal education did not change the results (data not shown). Neither the dietary GI nor the dietary GL were significantly associated with indices of SES.

Fig. 2 and Fig. 3 compare the median CHO intake from different sources between children consuming a diet with a low GI or GL (lowest tertile) and those consuming a diet with a high GI or GL (highest tertile). Children in the lowest GI tertile consumed significantly more CHO from fruits and fruit juice, and significantly less CHO from the 'tolerated food groups' than did children in the highest GI tertile (Fig. 2). A lower dietary GL was characterised by a significantly higher consumption of potatoes and lower intakes of 'tolerated food groups' and breakfast cereals and cereals (Fig. 3).

Discussion

The present study is the first to present detailed information on dietary GI and GL, and time trends in three samples of healthy children. The open-cohort design of the DONALD study allowed us to compare three groups of German children with a similar socio-economic background aged 7–8 years in 1990, 1996 and 2002.

In our view, the most important finding of the present study is the fact that the 'tolerated food groups' comprising sweets, sweetened soft drinks, cakes and cookies, and salty snacks had the largest impact on the overall dietary GL, even exceeding the impact of bread and rolls. We had expected bread and rolls, the most important CHO source in Germany, to contribute the most to the dietary GL. Another interesting finding is the small impact of potatoes on the overall dietary GL in all three time periods. This can firstly be attributed to the relatively low overall potato consumption among our children. In the present study and in a US study with 6–11-year-old children, potatoes contributed approximately 4 % to the total CHO intake. In contrast, in a study on European adults, potatoes provided approximately 7 % of the total CHO intake (Wirfält, 2002). Second, the German

Table 1. Descriptive characteristics and nutrient intake of Dortmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) study participants aged 7–8 years in 1990, 1996 and 2002
(Frequencies, mean values and standard deviations, or median values and 25th–75th percentiles)

	1990		1996		2002		*P* values	
	Mean	SD	Mean	SD	Mean	SD	1990–2002	1990–2002
Descriptive characteristics								
Total (*n*)	46		56		53			
Male (*n*)	22		33		25		–	–
Female (*n*)	24		23		28		–	–
Percentage female	52		41		53			
Age (years)	7·38	0·48	7·43	0·50	7·37	0·50	0·5*	–
Parental education of at least 12 years (%)								–
Mother (*n* 153)	40·9		64·3		73·6		0·001†	–
Father (*n* 154)	45·7		63·6		75·5		0·002†	–
Maternal overweight (BMI $>$25 kg/m^2) (*n* 150)	30·2		24·1		28·3		0·9†	–
Any smokers in the household (%) (*n* 155)	52·2		37·5		9·4		0·001†	–
Nutrient intake								
Glycaemic index (%)	55·1	2·9	56·0	3·4	56·5	3·4	0·1*	0·03‡
Glycaemic load (g/MJ)	16·7	2·1	17·5	2·2	17·5	2·1	0·09*	0·04‡
Carbohydrate (% energy)	50·7	5·3	52·1	5·1	52·0	5·7	0·3*	0·2‡
Sucrose (% energy)	14·0	6·7	13·6	5·6	14·3	4·9	0·8*	0·8‡
Fibre (g/MJ)	2·6	0·8	2·5	0·5	2·5	0·6	0·2*	0·5‡
Fat (% energy)	37·1	4·4	35·6	4·9	35·6	5·1	0·9*	0·1‡
Protein (% energy)	12·3	2·1	12·4	1·9	12·5	1·8	0·4*	0·7‡
Total energy (MJ/d)	6·61	0·87	6·67	1·19	6·49	1·00	0·7*	0·5‡
Carbohydrate-contributing food groups (g/d)								
Bread and rolls								
Median	37.6		42.9		41.5		0·5§	0·5‖
25th–75th percentiles	31·1–52·6		30·3–57·8		31·8–52·1			
Breakfast cereals and cereals								
Median	11·3		12·0		6·5		0·2§	0·2‖
25th–75th percentiles	0·2–23·1		0–25·2		0–16·6			
Pasta								
Median	1·4		6·9		6·7		0·5§	0·5‖
25th–75th percentiles	0–13·0		0–13·7		0–16·6			
Rice								
Median	0		0		0		0·5§	0·5‖
25th–75th percentiles	0–4·6		0–6·5		0–3·8			
Cooked potatoes								
Median	4·5		3·9		4·0		0·6§	0·6‖
25th–75th percentiles	2·0–6·3		0–6·0		0–8·0			
Fried or mashed potatoes								
Median	1·1		2·3		0		0·6§	0·6‖
25th–75th percentiles	0–6·2		0–6·4		0–5·0			
Fruits								
Median	17·9		15·7		10·3		0·04§	0·04‖
25th–75th percentiles	10·5–22·2		7·7–21·4		3·9–18·7			
Vegetables								
Median	2·1		2·7		2·9		0·3§	0·3‖
25th–75th percentiles	1·0–5·2		1·7–4·0		2·0–6·1			
Fruit juice								
Median	9·3		17·8		14·8		0·3§	0·3‖
25th–75th percentiles	0·1–23·2		3·9–28·8		5·9–25·4			
Milk and milk products								
Median	23·2		21·0		22·6		1·0§	1·0‖
25th–75th percentiles	11·9–38·3		14·9–33·2		13·1–30·3			
‘Tolerated food groups’¶								
Median	54·0		51·7		51·3		1·0§	1·0‖
25th–75th percentiles	33·7–76·3		34·7–74·7		35·6–74·9			

* ANOVA test for differences between the three periods of time.
† Mantel–Haenzel χ^2 test for trend over the three periods of time.
‡ Unpaired *t* test for differences between 1990 and 2002.
§ Kruskall–Wallis test for differences between the three periods of time.
‖ Wilcoxon sign rank test for differences between 1990 and 2002.
¶ ‘Tolerated food groups’ comprise sweets, soft drinks, cakes and cookies, and salty snacks.

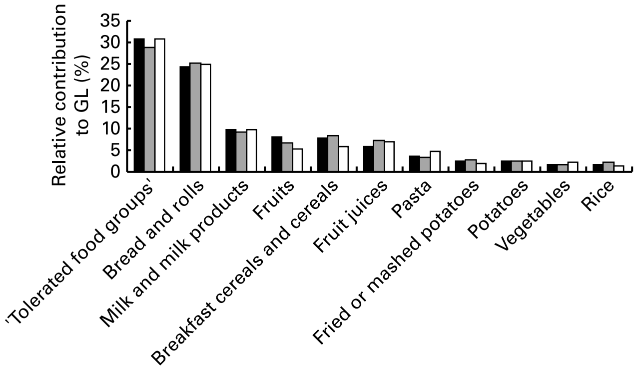

Fig. 1. Relative contribution of different carbohydrate sources to the overall dietary glycaemic load (GL) in 7–8-year-old children from the Dortmund Nutritional and Anthropometrical Longitudinally Designed Study. Comparison between samples from 1990 (■; *n* 46), 1996 (■; *n* 56) and 2002 (□; *n* 53). 'Tolerated food groups' comprise sweets, soft drinks, cakes and cookies, and salty snacks.

children in the present study consumed mainly cooked potatoes (often unpeeled), whereas fried or mashed potatoes, characterised by a high dietary GI (Foster-Powell *et al.* 2002), were eaten only occasionally.

In the present analysis sweets, sweetened soft drinks, cakes and cookies and salty snacks were combined into the entity 'tolerated food groups'. This term has been used in the Food Based Dietary Guidelines for German children and adolescents (Kersting *et al.* 2005) in order to separate these food groups from those essential for nutrient adequacy ('recommended food groups'). We are aware that other authorities have proposed a different definition for 'non-core' food groups (Bell *et al.* 2005), and that its use would produce slightly diverging results. However, our conclusion that low-nutrient-dense foods made the most significant contribution to the dietary GL would still apply, which is in line with studies in Australian and US children reporting a large contribution of 'non-core' food groups to intakes of energy and CHO (Subar *et al.* 1998; Bell *et al.* 2005).

The dominating role of the 'tolerated food groups' was seen in all three time periods and is thus not a recent development. A number of candies and jelly sweets have a relatively high dietary GI (for example, jelly beans: 78 %). Also, candies, jellies, and soft drinks are often consumed in large amounts, thereby making considerable contributions to the overall GL, which is influenced by both the GI and CHO amount consumed. Nevertheless, the soft drink consumption in the present study was lower than that observed in other studies among US children and adolescents (Morton & Guthrie, 1998; Harnack *et al.* 1999; Ludwig *et al.* 2001), and we did not observe the recent increase over time reported by others (Morton & Guthrie, 1998; Harnack *et al.* 1999; Ludwig *et al.* 2001). This may partly be due to the high overall SES of the DONALD study population. Thus, we assume that the contribution of sweets, soft drinks, cakes and cookies to the overall dietary GL is higher in 7–8-year-old German children with lower SES.

Our finding that the overall dietary GI and GL in the diet of 7-and 8-year-old children increased over the last few years should be interpreted cautiously. Given the limited precision of estimating a recorded food's dietary GI, the observed increase by just over 1 GI unit from 1990 to 2002 may not be of biological importance. The extent to which these changes are associated with increases in body weight requires the analysis of longitudinal anthropometric data and cannot be addressed by the repeated cross-sectional data used in the present analysis.

The slight increase in dietary GI from 1990 to 2002 presumably results from both the substitution of foods with a lower GI for similar foods with a higher GI, and from a shift towards other CHO sources with an overall higher GI; the intake of fruits and cereals decreased and the consumption of fruit juices increased. Generally in the present study, children in the lowest GI tertile,

Table 2. Descriptive characteristics and nutrient intake by tertiles of glycaemic index (GI) in 155 Dortmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) study participants aged 7–8 years
(Frequencies, or mean values and standard deviations)

	Tertile of GI						
	1 (GI range 50–54 %)		2 (GI range 54–57 %)		3 (GI range 57–66 %)		
	Mean	SD	Mean	SD	Mean	SD	*P* values
Descriptive characteristics							
Parental education of at least 12 years (%)							
Mother (*n* 153)	56·0		59·6		66·7		0·3*
Father (*n* 154)	54·9		62·8		69·2		0·1*
Maternal overweight (%) (BMI >25 kg/m^2) (*n* 150)	29·2		29·4		23·5		0·5*
Any smokers in the household (%) (*n* 155)	35·3		28·9		32·7		0·8*
Nutrient intake							
Glycaemic load (g/MJ)	16·0	1·8	17·0	1·4	18·8	2·3	<0·0001†
Carbohydrate (% energy)	51·2	6·1	50·9	4·3	52·8	5·4	0·1†
Sucrose (% energy)	10·9	4·1	14·0	5·5	16·9	5·8	<0·0001†
Fibre (g/MJ)	2·9	0·7	2·5	0·6	2·3	0·5	<0·0001†
Fat (% energy)	35·8	5·4	36·7	4·0	35·4	5·1	0·4†
Protein (% energy)	13·0	1·8	12·3	2·0	11·8	1·8	0·02†
Total energy (MJ/d)	6·56	0·95	6·77	1·04	6·43	1·10	0·2†

* Mantel–Haenzel χ^2 test for trend over the tertiles.
† Test for linear associations between nutrient intakes and GI.

Table 3. Nutritional intake and descriptive characteristics by tertiles of the glycaemic load (GL) in 155 Dortmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) study participants aged 7–8 years
(Frequencies, or mean values and standard deviations)

	Tertiles of GL						
	1 (GL range 11·6–16·2 g/MJ)		2 (GL range 16·2–17·9 g/MJ)		3 (GL range 17·9–24·1 g/MJ)		
	Mean	SD	Mean	SD	Mean	SD	*P* values
Descriptive characteristics							
Parental education of at least 12 years (%)							
Mother (*n* 153)	50·0		56·9		75·0		0·01*
Father (*n* 154)	56·0		65·4		65·4		0·3*
Maternal overweight (%) (BMI >25 kg/m^2) (*n* 150)	31·9		21·2		29·4		0·8*
Any smokers in the household (%) (*n* 155)	31·4		26·9		38·5		0·4*
Nutrient intake							
Glycaemic index (%)	54·0	2·3	55·5	2·6	58·1	3·4	<0·0001†
Carbohydrate (% energy)	46·9	3·4	51·0	2·8	57·0	3·9	<0·0001†
Sucrose (% energy)	10·6	4·3	13·2	4·3	17·9	5·7	<0·0001†
Fibre (g/MJ)	2·7	0·7	2·6	0·7	2·4	0·6	0·004†
Fat (% energy)	39·9	3·6	36·6	3·0	31·5	3·5	<0·0001†
Protein (% energy)	13·2	1·8	12·4	1·3	11·5	2·1	<0·0001†
Total energy (MJ/d)	6·83	1·09	6·61	0·98	6·33	0·99	0·01†

* Mantel–Haenzel χ^2 test for trend over the tertiles.
† Test for linear associations between nutrient intakes and GL.

but not those in the lowest GL tertile, had a more favourable consumption that agreed more closely with current dietary recommendations; children with a lower dietary GI (<55 %) consumed more fibre, less sucrose, more fruits, fruit juices and milk and less ‘tolerated food groups’ than children with a high dietary GI. This finding is in line with two other studies in middle-aged men and women with and without diabetes (Buyken *et al.* 2001; Schulz *et al.* 2004). In the IRAS study, total intake of fruits and low-fat milk was inversely associated with the dietary GI (Schulz *et al.* 2004). In individuals with type 1 diabetes from Southern Europe, a lower GI was related to higher intakes of fruits and pasta and a lower intake of white bread. Whereas in those with type 1 diabetes from Northern, Western, and Eastern Europe a lower GI was associated with consumption of more wholegrain bread and fruits and less potatoes (Buyken *et al.* 2001).

As previously mentioned, extrapolation of the present results to the general population of 7–8-year-old German children is hampered by the fact that the parents of the DONALD study participants are characterised by higher educational attainment and a higher SES than average (Kroke *et al.* 2004). Within this homogeneous sample, associations between the dietary GI or GL and SES were not discernible. However, a number of other studies have reported associations between a higher dietary GI or GL and indicators of lower SES in adult samples (van Dam *et al.* 2000; Stevens *et al.* 2002; Jonas *et al.* 2003), but these were also less pronounced in two populations of highly educated health professionals (Salmeron *et al.* 1997*a*; Michaud *et al.* 2002).

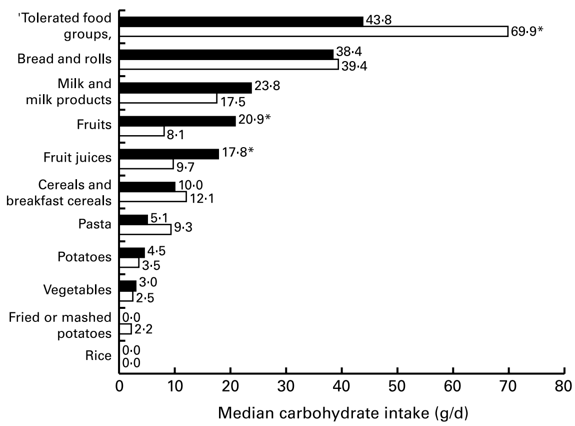

Fig. 2. Median carbohydrate intake from different carbohydrate sources in 7–8-year-old children with a low (lowest tertile; ■), or a high (highest tertile; □) dietary glycaemic index. * Median value of the lowest tertile was significantly different from that of the highest tertile according to the Wilcoxon sign rank test (*P*<0·05). ‘Tolerated food groups’ comprise sweets, soft drinks, cakes and cookies, and salty snacks.

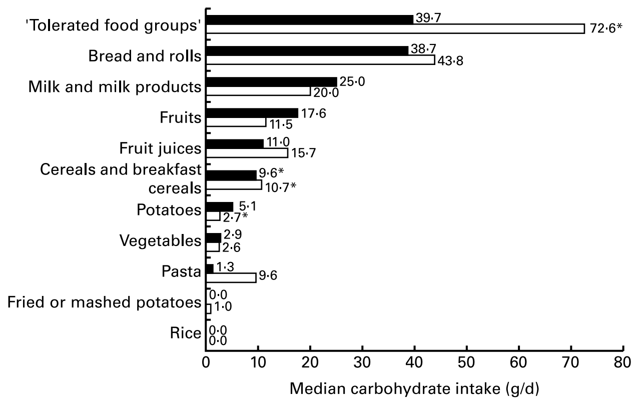

Fig. 3. Median carbohydrate intake from different carbohydrate sources in 7–8-year-old children with a low (lowest tertile; ■), or a high (highest tertile; □) dietary glycaemic load. * Median value of the lowest tertile was significantly different from that of the highest tertile according to the Wilcoxon sign rank test (*P*<0·05). ‘Tolerated food groups’ comprise sweets, soft drinks, cakes and cookies, and salty snacks.

The complex GI assignment procedure may represent another limitation of the present study. However, the weighed 3 d dietary record used here allowed us to directly assign a GI value to each CHO-containing food, instead of estimating mean dietary GI values for food groups as is the case in most other epidemiological studies that use food-frequency questionnaires (Salmeron *et al.* 1997*a*; Liu & Willett, 2002; Stevens *et al.* 2002; Scaglioni *et al.* 2004). Due to the limited amount of information on values of GI for many complex foods commonly consumed in Germany (for example, German wholemeal breads) (Foster-Powell *et al.* 2002), we had to calculate the GI of 40 % of the foods from the ingredients. We are aware of the controversies surrounding the applicability of the GI to mixed meals (Wolever & Jenkins, 1986; Bornet *et al.* 1987; Chew *et al.* 1988; Hollenbeck & Coulston, 1991; Flint *et al.* 2004; Sheard *et al.* 2004). However, whenever no GI is available for a food, its calculation from the ingredients is at present the only feasible approach for epidemiological studies.

In conclusion, the present results have major implications for the current discussion as to whether the dietary GL can best be lowered by consuming less CHO ('low-carb' diet; for example, Atkins diet), by reducing the overall dietary GI (low-GI diet; for example, by Ludwig (2000) or Wolever (2003)) or a combination of both (for example, food pyramids proposed by Willett (2001) or Ludwig (2000)). Among German children, high-GI foods such as fried and mashed potatoes or rice had little influence on their overall dietary GL due to their low consumption. Instead, the 'tolerated food groups' (sweets, sweetened soft drinks, cakes and cookies, and salty snacks) had the largest impact on the overall GL. Thus, partial replacement of high-GI 'tolerated food groups' for foods with a low dietary GI, especially fruits and vegetables, may help to reverse the observed slight increases in the GI and GL since 1990, and to enhance the overall dietary quality in children.

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