

Trends in dietary carbohydrate quality during puberty from 1988 to 2007: a cause for concern?

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The extent to which the quality of dietary carbohydrates (CHO) changes throughout puberty is not known. We analysed trends in the quantity and quality of CHO intake among German adolescents by separately examining trends during puberty (pubertal trends) and trends in CHO intake from 1988 to 2007 (secular trends). Linear mixed-effects regression analyses were performed in 216 participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed Study who had provided weighed 3 d dietary records at the onset of the pubertal growth spurt (defined by age at take-off) and over the subsequent 4 years. Over the course of puberty, CHO quality changed little: added sugar intake from beverages increased in girls (0.25 (SE 0.12) % energy (% E)/year, $P=0.04$) and added sugar intake from sweets decreased in both sexes (boys: -0.22 (SE 0.11) % E/year, $P=0.049$; girls: -0.20 (SE 0.10) % E/year, $P=0.04$). For both sexes, significant upward secular trends were observed for CHO (% E), glycaemic load (g/MJ) and added sugar intakes from sources other than sweets and soft drinks (% E), while absolute fibre intake (g/d) decreased ($P\leq 0.04$). Concomitant increases in total added sugar intake (% E) and decreases in fibre and whole-grain densities (g/MJ) ($P=0.001-0.02$) were confined to boys only. The quality of dietary CHO consumed by healthy German adolescents shows notable secular declines, but does not change markedly during puberty. Public health initiatives should be tailored to improve the overall quality of CHO nutrition.

Carbohydrate intake: Dietary glycaemic index: Dietary glycaemic load: Fibre intake: Whole-grain intake: Added sugar intake: Adolescents: Pubertal trends: Secular trends

Recent studies indicate notable changes in dietary quality from childhood to adolescence. Consumption of fruits and vegetables has been found to decrease⁽¹⁾, whereas the consumption of soft drinks increased⁽¹⁾. Furthermore, as children age, they increase their fast food consumption⁽²⁾, which in turn has been found to be associated with lower intakes of fruits, vegetables and grains, and with higher sugar intakes⁽³⁾. It is thus intriguing to consider that carbohydrate (CHO) quality in particular declines as puberty commences, but this has not been investigated to date.

In addition, concern has been expressed that recent increases in relative CHO intake among European and North American children and adolescents^(4,5) may have been accompanied by a secular decline in CHO quality. In fact, prospective studies indicate that increases in CHO intake were mostly due to a higher consumption of pastries/cakes and sweets without an accompanying increase in fibre intakes^(6,7).

Considering that puberty may represent the so-called 'critical period' for the development of overweight⁽⁸⁾, it is important to disentangle pubertal and secular trends in the quality of CHO intake in order to develop preventive strategies specifically targeted at adolescents. Preferably, such investigations

should take pubertal stage into account, since individual changes in food intake may to some extent reflect adaptations to changes in physiological requirements during puberty.

Using data obtained from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, the objective of the present analysis was to analyse individual changes in CHO quality – characterised by glycaemic index (GI), glycaemic load (GL), and fibre, whole-grain and added sugar intakes – during puberty (between puberty onset and the subsequent 4 years) (pubertal trend), and to separate this trend from changes in CHO quality which may have occurred between 1988 and 2007 (secular trend) in German adolescents.

Materials and methods

Study sample

The DONALD Study is an ongoing, open cohort study that was started in 1985 in Dortmund, Germany. Details have been described elsewhere⁽⁹⁾. The study was approved by the ethics committee of the University of Bonn, and all examinations were performed with parental consent.

Abbreviations: ATO, age at take-off; CHO, carbohydrates; DONALD Study, Dortmund Nutritional and Anthropometric Longitudinally Designed Study; GI, glycaemic index; GL, glycaemic load.

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For the purpose of the present analysis, changes in dietary CHO quality during physiologically defined puberty were of interest. Chronological age may be confounded by children of the same age differing considerably in their pubertal stage. Defining puberty based on visual observation according to Tanner stage has been criticised as being subjective with considerable inter-observer variability⁽¹⁰⁾, and is commonly perceived as intrusive by healthy individuals⁽¹¹⁾. Conversely, puberty can be more objectively determined from serial height measurements, an approach chosen in several longitudinal studies^(12–14). We thus defined puberty onset as the age at take-off (ATO), i.e. the beginning of the pubertal growth spurt.

In total, ATO could be reliably estimated for 376 subjects. Of these, 216 adolescents who had complete anthropometric and nutritional data around ATO and information on potential confounders were included in the present analysis. Plausible checks according to the age- and sex-specific cut-off points⁽¹⁵⁾ revealed implausible energy intake in 88 of the 1053 dietary records. Since the energy intakes of these eighty-eight dietary records ranged between 3347.2 kJ (800 kcal) and 9414 kJ (2250 kcal), we retained all records so as to base our intra-individual trend analyses on as many repeatedly collected diaries as possible. Due to the open cohort design of the DONALD Study, participants reached ATO between 1988 and 2003, and all of them attained their peak height velocity within 4 years of puberty onset, i.e. all our subjects reached an advanced stage of puberty within the present study period.

Anthropometry and assessment of puberty onset

Anthropometric measurements are performed at each visit by nurses who have been trained according to standard procedures⁽¹⁶⁾, with the children dressed in underwear only and barefoot. From the age of 2 years onwards, standing height is measured to the nearest 0.1 cm using a digital stadiometer (Harpenden, Crymych, UK).

ATO was estimated using the parametric Preece & Baines model 1⁽¹⁷⁾, based on height measurements from the age of 6 years onwards in boys and on height measurements from the age of 5 years onwards in girls⁽¹⁸⁾. The mean ATO in our sample of 10.3 (SD 0.9) years for boys and 8.7 (SD 0.9) years for girls was in line with mean ATO values reported from other contemporary studies conducted among American and European children^(12,19–21).

Nutrition assessment

Food consumption in the DONALD Study is assessed using 3 d weighed dietary records⁽⁹⁾. For the present analysis, each CHO-containing food recorded in the dietary record was assigned a GI. Foods were assigned either (1) a published GI⁽²²⁾; (2) the GI of a close match or (3) the GI calculated from the GI values of the foods' ingredients using recipes available in the in-house database *Lebensmitteltabelle* (LEBTAB)⁽²³⁾. 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)⁽²⁴⁾.

Dietary fibre content was calculated using the LEBTAB database. Whole-grain intake was estimated by assigning whole-grain content in grams to each CHO-containing food recorded in the dietary records using the respective recipes

and ingredient information available at the time of recording. In the present analysis, we revised the definition of whole grain used in a previous analysis⁽²⁵⁾ to only include cereal grains, which contain the same relative proportions of bran, germ and endosperm as they exist in the intact caryopsis⁽²⁶⁾.

Added sugar intake was defined as described previously⁽²⁷⁾. Since an increased soft drink consumption during adolescence^(2,28) is thought to place children at risk of excess weight gain⁽²⁹⁾, three subgroups of added sugar intakes were also examined: added sugar from beverages (i.e. from regular soft drinks and fruit juices), added sugar from sweets (i.e. from candy, chocolate, jam and ice cream) and added sugar from other sources (i.e. the remainder of food sources, e.g. breakfast cereals, pastries, milk and milk products).

The GL in the present study correlated with CHO intake (r 0.97 and 0.96 in boys and girls, respectively), GI (r 0.38 and 0.32 in boys and girls, respectively) and added sugar intake (r 0.71 and 0.69 in boys and girls, respectively). We did not assess the validity of the recorded CHO intakes, since validation of weighed dietary records – commonly considered to be the 'gold standard' method among dietary assessment methods⁽³⁰⁾ – requires the use of a widely accepted recovery biomarker, which presently does not exist for CHO intake. However, a recent analysis among DONALD participants has shown an acceptable validity of protein intake data compared with 24 h urinary nitrogen excretion in a large sample of both children and adolescents⁽³¹⁾.

Statistical analysis

To obtain the mean daily GI and GL values of each subject, we firstly multiplied the CHO content (in g) of each food consumed by the food's assigned GI. The sum of these GL values of each food corresponds to the total GL. The total GI was obtained by dividing the total GL by the total CHO intake. The mean daily added sugar, fibre or whole-grain intake was the sum of the added sugar, fibre or whole-grain content of each food consumed on each day.

SAS[®] procedures (version 9.1.3; SAS, Inc., Cary, NC, USA) were used for data analysis. Analyses indicated interactions between sex and changes in CHO quality during puberty (P value for interaction < 0.1). Thus, data obtained from girls and boys were analysed separately. A P value < 0.05 was considered to indicate statistical significance.

As suggested by Jacobs *et al.*⁽³²⁾, repeated-measures regression models (PROC MIXED), including both fixed and random effects, were used to construct longitudinal models of trends in CHO quality partitioned into pubertal trends and secular trends. The pubertal trend in our models was estimated from the pubertal age coefficient, and the time coefficient represented the secular trend. Separate models for each CHO variable (the dependent variable) regressed the respective dietary measurement at each examination on pubertal age at examination (ATO was considered the baseline pubertal age, i.e. pubertal age = 0) and the year of examination (first calendar year of the DONALD Study was considered the baseline time, i.e. time = 0).

A repeated statement was used to account for the lack of independence that exists between repeated observations on the same person, and a family variable was used as a random effect. In the unadjusted model, pubertal age and

time were the principal fixed effects. In the adjusted model, we included BMI standard deviation scores at ATO (to control for potential confounding due to a relation between CHO quality and BMI standard deviation scores at ATO⁽²⁵⁾), maternal overweight and maternal education (to account for potential confounding by an association between socio-economic status and dietary choices⁽³³⁾).

Results

Study sample characteristics at ATO by calendar year strata are presented in Table 1. Between 1988 and 1997, ATO occurred at the age of 10.2 years in boys and 8.6 years in girls, and between 1998 and 2003 at the age of 10.3 years in boys and 8.8 years in girls.

Table 2 summarises mean nutritional intakes of boys stratified by pubertal age and time. Since energy intakes increased notably throughout puberty, the absolute intakes of all measures describing CHO intake also increased during puberty apart from the intakes of whole grain and added sugar from sweets (first set of columns). With respect to relative measures of CHO intake, GL and the percentage of energy from other sources increased throughout puberty, while energy from added sugar from sweets decreased. We also observed a significant secular increase in energy intake, and absolute intakes of

all CHO quality measures increased, except for the intakes of whole grain, fibre and added sugar from sweets (second set of columns). With respect to relative intakes, we found secular increases in GL and energy from total added sugar and added sugar from other sources and CHO, and secular decreases in whole-grain and fibre intake densities.

Similarly, energy intake in girls (Table 3) also increased throughout puberty, resulting in increases of all measures describing absolute CHO intake except for the intakes of whole grain and added sugar from beverages and from sweets (first set of columns). Relative CHO intakes did not change during puberty. Secular increases were observed for GL and absolute intakes of added sugar from sweets and from other sources (second set of columns). Concurrently, absolute fibre intakes decreased, and absolute whole-grain intakes tended to decrease. With respect to relative measures of CHO intake, GI, GL and intakes of added sugar from other sources and CHO showed secular increases, while intakes of fibre and added sugar from sweets decreased.

Repeated-measures analysis confirmed upward pubertal trends in the absolute intakes of all CHO intake variables, except for added sugar from beverages in boys and whole grain and added sugar from sweets in both sexes (Table 4, first set of columns). With respect to secular trends in absolute intakes, in both sexes, fibre intake decreased and added sugar

Table 1. Characteristics* at age at take-off (ATO) for 100 boys and 116 girls from the Dortmund Nutritional and Anthropometric Longitudinally Designed Study by calendar year strata

(Mean values and standard deviations, medians (first quartile (Q1) and third quartile (Q3)) or frequencies and percentages)

Variables	Calendar year strata at ATO				
	1988–97 (n 108)		1998–03 (n 108)		P for trend
	Mean/median	SD/Q1, Q3	Mean/median	SD/Q1, Q3	
Boys		39		61	
ATO (years)	10.2	1.1	10.3	0.8	0.6
Age at PHV (years)	13.5	1.0	13.3	0.9	0.3
Body fat† (%)	13.7	11.2, 17.6	13.9	11.8, 21.7	0.3
BMI SDS	-0.08	0.88	0.15	0.97	0.2
Overweight‡	4	10.3	11	18.0	0.3
Maternal overweight§	17	43.6	17	27.9	0.1
High maternal educational level	19	48.7	36	59.0	0.3
Maternal age at ATO (years)	39.8	3.4	41.0	4.3	0.1
Maximal four-person household	35	89.7	55	90.2	0.9
Smoking in the household	17	43.6	17	27.9	0.1
Girls		69		47	
ATO (years)	8.6	0.9	8.8	0.9	0.3
Age at PHV (years)	11.5	0.9	11.8	0.9	0.1
Body fat† (%)	18.0	15.1, 23.3	16.4	14.3, 22.0	0.2
BMI SDS	0.16	0.94	-0.07	0.96	0.2
Overweight‡	15	21.7	6	12.8	0.2
Maternal overweight§	24	34.8	16	34.0	0.9
High maternal educational level	30	43.5	25	53.2	0.3
Maternal age at ATO (years)	38.0	4.8	39.8	3.0	0.03
Maximal four-person household	55	79.7	43	91.5	0.09
Smoking in the household	28	40.6	15	31.9	0.3

PHV, peak height velocity; SDS, standard deviation scores.

*P for trend was tested using ANOVA for normally distributed continuous variables, Kruskal–Wallis test for not normally distributed continuous variables and χ^2 test for categorical variables.

† Calculated according to Slaughter *et al.*⁽⁴⁹⁾.

‡ Derived from the age- and sex-specific cut-off points proposed by the International Obesity Task Force, which are linked to the adult cut-off point of BMI of 25 kg/m²⁽⁵⁰⁾.

§ BMI \geq 25 kg/m².

|| School education for at least 12 years.

Table 2. Dietary characteristics* of boys (*n* 100, in total 486 dietary records) from the Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample during the study period (Mean values and standard deviations)

	Pubertal age†							Time						
	ATO		2 Years after ATO		4 Years after ATO		<i>P</i> for trend‡	1988–97		1998–02		2003–7		<i>P</i> for trend
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	
Number of records (<i>n</i>)	100		98		96			118		244		124		
Absolute carbohydrate intake (g/d)														
GL	132.5	29.9	144.3	37.4	173.0	41.5	< 0.0001	140.1	31.8	152.0	39.6	158.1	39.4	0.0008
Whole grain	31.5	47.4	27.1	34.1	29.6	40.9	0.9	35.6	48.3	30.6	38.5	21.0	32.1	0.01
Fibre	19.8	5.8	19.9	6.5	23.9	7.8	< 0.0001	21.9	6.1	20.6	6.5	20.4	7.7	0.2
Total added sugar	62.7	32.2	75.2	40.0	86.2	44.2	0.0002	65.2	33.5	76.0	41.0	84.1	36.7	0.0006
From beverages	18.6	20.9	20.1	26.2	30.0	32.8	0.04	17.8	20.8	26.0	28.5	23.5	24.7	0.02
From sweets	26.7	17.5	30.5	23.4	28.3	19.6	0.1	30.0	17.9	28.8	22.0	31.5	22.5	0.5
From other sources§	17.1	10.7	20.2	14.0	28.0	21.4	< 0.0001	16.8	13.3	20.7	14.4	29.0	18.6	< 0.0001
Carbohydrate	238.1	51.4	255.7	63.0	308.5	72.6	< 0.0001	250.4	55.2	269.6	67.3	279.9	66.7	0.002
Relative carbohydrate intake														
GI	55.7	3.8	56.4	3.5	56.2	4.0	0.1	55.9	3.8	56.4	3.7	56.5	3.9	0.5
GL (g/MJ)	70.5	9.6	72.1	9.7	72.9	9.8	0.01	70.3	8.8	73.3	10.3	74.5	10.5	0.003
Whole grain (g/MJ)	3.9	5.7	3.2	3.8	2.9	3.9	0.6	4.3	5.7	3.5	4.2	2.2	3.1	0.001
Fibre (g/MJ)	2.5	0.6	2.4	0.6	2.4	0.6	0.4	2.6	0.6	2.4	0.6	2.3	0.6	< 0.0001
Total added sugar (% E)¶	13.2	5.8	14.8	6.8	14.4	6.8	0.2	12.9	5.8	14.5	6.8	15.8	6.3	0.002
From beverages (% E)¶	3.8	3.9	4.8	4.9	5.1	5.4	0.4	3.6	3.9	4.9	5.1	4.5	4.6	0.049
From sweets (% E)¶	5.6	3.5	6.0	4.3	4.7	3.0	0.04	6.0	3.4	5.5	3.9	5.9	4.0	0.5
From other sources (% E)¶	3.6	2.2	4.0	2.6	4.6	3.5	0.04	3.3	2.3	4.0	2.7	5.4	3.2	< 0.0001
Carbohydrate (% E)¶	50.6	5.9	51.2	6.3	51.9	6.0	0.052	50.2	5.2	52.1	6.5	52.7	6.1	0.004
Energy (MJ/d)	7.9	1.5	8.3	1.6	9.9	1.9	< 0.0001	8.3	1.4	8.7	1.9	8.9	1.8	0.04

ATO, age at take-off; GL, glycaemic load; GI, glycaemic index; % E, % energy.

* All nutritional data represent crude values.

† Dietary records at 1 year after ATO and 3 years after ATO were not considered in the table, but all dietary records (*n* 486) were used for *P* for trend.

‡ *P* for trend was tested using PROC GLM.

§ Sugar from other sources: the difference between the total added sugar and added sugar from beverages and sweets.

|| GI was calculated using the glucose = 100 scale.

¶ Intakes of added sugar or carbohydrate (g/MJ) (% E) = 1.67.

Table 3. Dietary characteristics* of girls (*n* 116, in total 567 dietary records) from the Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample during the study period (Mean values and standard deviations)

	Pubertal age†							Time						<i>P</i> for trend‡
	ATO		2 Years after ATO		4 Years after ATO		1988–97		1998–02		2003–7			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Number of records (<i>n</i>)	116		114		114			241		231		95		
Absolute carbohydrate intake (g/d)														
GL	109.2	24.7	119.0	27.2	134.4	35.5	< 0.0001	116.4	27.8	123.8	31.2	124.2	32.5	0.01
Whole grain	28.2	37.7	25.8	32.4	46.5	160.7	0.3	39.5	114.6	27.5	45.3	22.8	52.9	0.1
Fibre	16.9	4.3	17.1	4.8	19.3	5.6	0.0005	18.4	5.2	17.2	5.2	17.9	4.4	0.02
Total added sugar	53.7	24.8	62.1	29.4	68.1	35.6	0.005	58.7	29.2	64.1	32.2	61.8	31.6	0.2
From beverages	14.0	15.5	18.2	21.8	21.3	25.9	0.06	16.8	19.1	19.1	20.6	17.0	23.8	0.4
From sweets	25.0	14.1	27.5	17.4	27.3	19.3	0.7	26.8	17.3	28.3	18.3	22.2	14.8	0.02
From other sources§	14.2	9.5	16.0	12.3	19.1	13.0	0.001	14.8	10.0	16.2	12.2	21.9	12.5	< 0.0001
Carbohydrate	195.8	40.7	211.3	44.1	237.0	59.2	< 0.0001	209.6	47.2	218.2	51.0	218.8	53.6	0.1
Relative carbohydrate intake														
GI	55.7	3.1	56.2	3.4	56.6	3.4	0.3	55.5	3.1	56.6	3.4	56.7	3.5	0.0003
GL (g/MJ)	71.6	8.8	72.4	9.9	74.2	11.1	0.3	70.1	9.2	74.6	10.4	73.3	10.2	< 0.0001
Whole grain (g/MJ)	4.7	7.0	3.8	4.7	7.1	28.7	0.4	6.0	20.1	4.1	6.7	3.5	8.6	0.2
Fibre (g/MJ)	2.7	0.6	2.5	0.6	2.6	0.7	0.4	2.7	0.7	2.5	0.7	2.6	0.6	0.02
Total added sugar (% E)¶	13.9	5.5	14.8	6.0	14.7	6.4	0.8	13.9	5.8	15.2	6.4	14.2	5.4	0.07
From beverages (% E)¶	3.5	3.7	4.3	4.9	4.5	5.2	0.5	3.8	4.1	4.5	4.7	3.7	4.7	0.2
From sweets (% E)¶	6.6	3.3	6.6	4.1	5.9	3.7	0.06	6.4	3.8	6.8	4.0	5.2	3.1	0.003
From other sources (% E)¶	3.7	2.4	3.9	2.7	4.2	2.7	0.3	3.6	2.4	3.8	2.6	5.1	2.6	< 0.0001
Carbohydrate (% E)¶	51.4	5.4	51.5	6.1	52.4	6.7	0.6	50.5	5.7	52.6	5.9	51.7	6.2	0.0003
Energy (MJ/d)	6.4	1.1	6.9	1.3	7.6	1.6	< 0.0001	7.0	1.4	6.9	1.4	7.1	1.4	0.7

Trends in carbohydrate quality during puberty

ATO, age at take-off; GL, glycaemic load; GI, glycaemic index; % E, % energy.

* All nutritional data represent crude values.

† Dietary records at 1 year after ATO and 3 years after ATO were not considered in the table, but all dietary records (*n* 567) were used for *P* for trend.

‡ *P* for trend was tested using PROC GLM.

§ Sugar from other sources: the difference between the total added sugar and added sugar from beverages and sweets.

|| GI was calculated using the glucose = 100 scale.

¶ Intakes of added sugar or carbohydrate (g/MJ) (% E) = 1.67.

Table 4. Pubertal and secular trends* (per year) in carbohydrate quality (absolute intake) in 216 participants from the Dortmund Nutritional and Anthropometric Longitudinally Designed Study analysed by repeated-measures regression analysis (β coefficients with their standard errors)

	Pubertal trend						Secular trend					
	Boys			Girls			Boys			Girls		
	β	SE	P	β	SE	P	β	P	SE	β	SE	P
GL (g/d)												
Unadjusted model	8.903	1.164	<0.0001	5.805	0.856	<0.0001	1.189	0.678	0.08	0.216	0.447	0.6
Adjusted model†	8.903	1.163	<0.0001	5.796	0.856	<0.0001	1.188	0.678	0.08	0.225	0.448	0.6
Fibre (g/d)												
Unadjusted model	0.984	0.198	<0.0001	0.772	0.138	<0.0001	-0.190	0.133	0.2	-0.181	0.079	0.02
Adjusted model†	0.151	0.195	<0.0001	0.807	0.140	<0.0001	-0.358	0.129	0.006	-0.216	0.081	0.008
Whole grain (g/d)												
Unadjusted model	0.300	1.255	0.8	0.204	1.493	0.9	-0.922	0.609	0.1	-0.760	0.555	0.2
Adjusted model†	0.554	1.242	0.7	0.400	1.493	0.8	-1.186	0.580	0.04	-0.962	0.554	0.08
Total added sugar (g/d)												
Unadjusted model	4.274	1.267	0.0008	3.397	0.809	<0.0001	1.880	0.730	0.01	0.177	0.487	0.7
Adjusted model†	4.239	1.263	0.001	3.469	0.801	<0.0001	1.923	0.724	0.008	0.079	0.477	0.8
From beverage												
Unadjusted model	1.617	0.844	0.06	1.771	0.539	0.001	0.800	0.486	0.1	0.042	0.323	0.9
Adjusted model†	1.582	0.830	0.06	1.831	0.535	0.001	0.849	0.462	0.07	-0.019	0.316	0.9
From sweets												
Unadjusted model	0.957	0.633	0.1	0.503	0.488	0.3	-0.159	0.369	0.7	-0.285	0.231	0.2
Adjusted model†	0.941	0.630	0.1	0.524	0.486	0.3	-0.136	0.365	0.7	-0.304	0.228	0.2
From other sources												
Unadjusted model	1.400	0.534	0.01	1.038	0.372	0.006	0.911	0.224	<0.0001	0.349	0.146	0.02
Adjusted model†	1.385	0.533	0.01	1.004	0.371	0.007	0.927	0.222	<0.0001	0.385	0.144	0.01
Carbohydrate (g/d)												
Unadjusted model	14.58	1.950	<0.0001	10.23	1.422	<0.0001	1.989	1.197	0.09	-0.048	0.735	0.9
Adjusted model†	14.59	1.948	<0.0001	10.16	1.422	<0.0001	1.980	1.193	0.1	-0.024	0.735	0.9
Energy (MJ/d)												
Unadjusted model	0.444	0.052	<0.0001	0.340	0.039	<0.0001	0.019	0.033	0.6	-0.030	0.020	0.1
Adjusted model†	0.447	0.053	<0.0001	0.337	0.039	<0.0001	0.016	0.033	0.6	-0.027	0.020	0.2

GL, glycaemic load; ATO, age at take-off; SDS, standard deviation scores.

*Pubertal trend, directly from ATO and over the subsequent 4 years; secular trend, from year 1988 to year 2007.

†BMI SDS at ATO, maternal education and maternal overweight were included in the adjusted model, since they significantly affected the pubertal and secular trends of the carbohydrate quality in the basic models. Models of fibre intake and whole-grain intake were adjusted additionally for BMI SDS at ATO, maternal education and maternal overweight; models of total added sugar and its subgroups, dietary GL and carbohydrate intake were adjusted additionally for BMI SDS at ATO; energy model was adjusted additionally for BMI SDS at ATO and maternal overweight.

from other sources increased between 1988 and 2007 (Table 4, second set of columns). In boys, the absolute whole-grain intake decreased, and added sugar intake increased over time.

The only pubertal trends for relative CHO intakes were an increase in added sugar intake from beverages in girls and a decrease in added sugar intake from sweets in both sexes (Table 5, first set of columns). With respect to secular trends, the relative intakes of CHO, GL and added sugar from other sources increased over time (Table 5, second set of columns). Downward secular trends in fibre and whole-grain intake densities and upward secular trends in total added sugar were only observed in boys.

Discussion

The present study suggests that in the population of healthy adolescents, the CHO quality did not change considerably over the course of puberty. However, CHO quality declined over the last 20 years, i.e. absolute fibre intake decreased and the contribution of added sugar from sources other than beverages and sweets to total energy intake increased. These adverse 20-year secular trends were most pronounced in boys, with an additional increase in total added sugar intake and decreases in fibre and whole-grain intakes.

During puberty, adolescents increase their self-awareness and are exposed to a changing lifestyle, all of which may affect their eating behaviours⁽³⁴⁾, e.g. fast food and soft drink consumption increases⁽²⁾. In the present study, girls increased their energy intake from added sugar provided by beverages during puberty, corresponding to an increase of 1% in energy over 5 years. Excess consumption of soft drinks is considered a risk factor influencing body composition^(35,36). However, girls concomitantly decreased their energy intake from added sugar provided by sweets, hence compensating for their increase in added sugar from beverages. Therefore, increases in soft drink consumption during puberty may be less important than commonly assumed.

In the present study, relative CHO intakes increased over the 20-year observational period. The concomitant increase in GL was primarily driven by this increase in total CHO and to a lesser extent by an upward secular trend in GL. The present results for adolescents confirm and extend a previous analysis in 7- to 8-year-old DONALD participants, where the GI and GL increased moderately between 1990 and 2002⁽²⁴⁾.

The present study indicates that CHO quality declined remarkably over the past 20 years. Between 1988 and 2007, absolute fibre intakes decreased considerably in both sexes, corresponding to a 10–15% decrease over a 10-year

Table 5. Pubertal and secular trends* (per year) in carbohydrate quality (relative intake) in 216 participants from the Dortmund Nutritional and Anthropometric Longitudinally Designed Study analysed by repeated-measures regression analysis(β coefficients with their standard errors)

	Pubertal trend						Secular trend					
	Boys			Girls			Boys			Girls		
	β	SE	P	β	SE	P	β	SE	P	β	SE	P
GI												
Unadjusted model	0.123	0.114	0.3	0.103	0.097	0.3	0.079	0.071	0.3	0.102	0.051	0.049
Adjusted model†	0.066	0.119	0.6	0.076	0.096	0.4	0.115	0.073	0.1	0.097	0.052	0.06
GL (g/MJ)												
Unadjusted model	0.102	0.077	0.2	0.011	0.073	0.9	0.115	0.040	0.004	0.102	0.037	0.006
Adjusted model†	0.101	0.077	0.2	0.012	0.073	0.9	0.115	0.040	0.004	0.100	0.037	0.007
Fibre (g/MJ)												
Unadjusted model	0.001	0.018	0.9	-0.008	0.018	0.7	-0.033	0.013	0.01	-0.012	0.011	0.3
Adjusted model†	0.008	0.018	0.6	-0.007	0.018	0.7	-0.040	0.012	0.001	-0.012	0.011	0.2
Whole grain (g/MJ)												
Unadjusted model	-0.111	0.144	0.4	-0.219	0.253	0.4	-0.122	0.064	0.06	-0.106	0.078	0.2
Adjusted model†	-0.094	0.142	0.5	-0.184	0.253	0.5	-0.141	0.059	0.02	-0.140	0.077	0.07
Total added sugar (% E)‡												
Unadjusted model	0.154	0.220	0.5	0.097	0.163	0.6	0.308	0.128	0.02	0.063	0.100	0.5
Adjusted model†	0.145	0.219	0.5	0.122	0.161	0.4	0.320	0.124	0.01	0.039	0.097	0.7
From beverages (% E)‡												
Unadjusted model	0.164	0.151	0.3	0.235	0.121	0.05	0.125	0.089	0.2	0.004	0.074	0.9
Adjusted model†	0.133	0.147	0.4	0.247	0.119	0.04	0.157	0.083	0.06	0.009	0.072	0.9
From sweets (% E)‡												
Unadjusted model	-0.219	0.114	0.06	-0.200	0.098	0.04	-0.018	0.067	0.8	-0.043	0.042	0.3
Adjusted model†	-0.222	0.113	0.049	-0.200	0.098	0.04	-0.013	0.066	0.8	-0.040	0.041	0.3
From other sources (% E)‡												
Unadjusted model	0.051	0.096	0.6	0.052	0.084	0.5	0.191	0.044	<0.0001	0.106	0.034	0.002
Adjusted model†	0.048	0.096	0.6	0.046	0.084	0.6	0.194	0.044	<0.0001	0.113	0.034	0.001
Carbohydrate (% E)‡												
Unadjusted model	0.241	0.206	0.2	-0.059	0.184	0.8	0.230	0.110	0.03	0.199	0.093	0.03
Adjusted model†	0.241	0.206	0.2	-0.064	0.184	0.7	0.230	0.111	0.04	0.204	0.099	0.03

GI, glycaemic index; GL, glycaemic load; % E, % energy; ATO, age at take-off; SDS, standard deviation scores.

*Pubertal trend, directly from ATO and over the subsequent 4 years; secular trend, from year 1988 to year 2007.

†BMI SDS at ATO, maternal education and maternal overweight were included in the adjusted model, since they significantly affected the pubertal and secular trends of the carbohydrate quality in the basic models. Models of dietary GI and intakes of fibre and whole grain were adjusted additionally for BMI SDS at ATO, maternal education and maternal overweight; models of total added sugar and its subgroups, dietary GL and carbohydrate intake were adjusted additionally for BMI SDS at ATO.

‡Intakes of added sugar or carbohydrate (g/MJ) (% E) = 1.67.

time period. This decline was more pronounced in boys who concomitantly decreased their fibre and whole-grain densities by -0.4 and -1.4 g/MJ, respectively, in 10 years. Some^(6,37), but not all^(38,39), previous trend analyses of CHO intakes in adolescents support a reduction in fibre intake: daily fibre intakes decreased by 1.15 g/d in 12- to 18-year-old US boys between 1977–8 and 1987–8⁽³⁷⁾, and fibre intakes decreased by 0.18 g/d in German girls aged 9–13 years between 1990 and 2004⁽⁶⁾. In view of the numerous recognised health benefits associated with higher intakes of fibre and whole grains⁽⁴⁰⁾, these marked downward secular trends in adolescents are a cause for concern, since they may result in an increased risk for diabetes mellitus, CVD and cancer in adulthood.

In the present study, boys presented with an upward secular trend in added sugar intake, amounting to 3% more energy intake in 10 years. High consumption of added sugars is thought to be associated with a decrease in micronutrient density in children and teenagers⁽⁷⁾. Furthermore, we observed secular upward trends in the consumption of added sugar from sources other than beverages and sweets for both sexes. Further analysis revealed that this category consisted mainly of breakfast cereals and pastries (data not shown).

Interestingly, the adverse secular trends were less pronounced in girls. Females have been suggested to commonly give greater

relevance to healthy eating and to make healthier food choices, e.g. they consume more fibre and less fat⁽⁴¹⁾. In addition, attention to weight control is more prominent in adolescent girls, and they are more likely to diet or restrain their eating behaviour⁽⁴²⁾. Furthermore, females are more likely to under-report their dietary intake⁽⁴³⁾. However, in the present study, neither exclusion of dietary records with potentially under-reported energy levels (3% of the observations in our girls were under-reported according to age-specific cut-off points⁽¹⁵⁾) nor adjustment for the ratio of reported energy intake to estimated BMR appreciably altered the findings. Nevertheless, selective under-reporting of socially undesirable foods such as sweets and soft drinks or selective over-reporting of healthy foods such as fruits and vegetables might have attenuated the secular and pubertal trends in CHO intake, particularly among girls.

The fact that GI values had to be calculated for approximately 35% of the CHO-containing foods is a limitation of the present study. While this procedure has been controversially discussed⁽⁴⁴⁾, several reports suggest that the GI of a whole diet or mixed meal can be accurately estimated from the GI values of its ingredients^(45,46). Furthermore, whenever no GI or a close match is available for a food, its calculation from the ingredients is the only feasible approach for epidemiological studies. In addition, the high correlation between

GL and CHO is in line with the previously expressed concern that GL estimates are largely ‘surrogates’ for CHO intake⁽⁴⁷⁾. Theoretically, a validation of GI and GL values could provide further insights in this regard; however, validation of estimates obtained from weighed dietary records would require repeated measurements of postprandial blood glucose levels, an approach which is not feasible particularly in an observational study with children and adolescents.

Given the relatively small study sample, the possibility of chance findings cannot be excluded. The elaborate design of the DONALD Study resulting in a study sample with a relatively high socio-economic status represents a further limitation of the study. While non-representativeness is less relevant for the interpretation of the pubertal trends since each individual acts as his or her own control, it does limit the generalisability of our secular trends. However, the CHO intake of our participants (49–52% energy) was similar to the values observed in other studies in adolescents^(5,38), and the added sugar intake (13–15% energy) was in line with the values found in a representative German study⁽⁴⁸⁾. The fact that our adolescents consumed more fibre than adolescents in other studies^(5,38) suggests that our secular trends may underestimate the ‘true’ decline in CHO quality over the past 20 years in the general population of European adolescents.

The present study has several strengths, including its comprehensive analysis of various aspects of CHO quality and the use of an innovative statistical approach⁽³²⁾ to simultaneously address independent trends during puberty and over the time. The prospectively collected, repeated and detailed measurements of anthropometric and dietary data for each participant allowed us to align the present analysis to a physiological marker of early puberty so as to reliably estimate individual pubertal trends in CHO quality. A further advantage lies in the constantly updated nutritional database, Lebensmitteltabelle (LEBTAB), which is a prerequisite for a precise evaluation of 20-year secular trends.

In conclusion, the quality of dietary CHO consumed by healthy German adolescents did not change considerably over the course of puberty. However, public health initiatives should be tailored at improving the overall quality of CHO nutrition, which appears to have declined notably over the past 20 years, especially among boys.

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