

Consumption of dietary salt measured by urinary sodium excretion and its association with body weight status in healthy children and adolescents

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Abstract

Objective: Highly processed foods such as convenience foods usually have a high salt content and therefore might indirectly act as adipogenic due to an increasing consumption of sugar-containing beverages (SCB). We examined the association between dietary salt and body weight status.

Design: We used data on urinary Na excretion as an indicator of dietary salt and BMI standard deviation score (BMI-SDS) and percentage body fat (%BF) of children and adolescents participating in the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study.

Setting: Dortmund, Germany.

Subjects: Children and adolescents (n 364) who had at least two 24 h urine samples and two dietary records in the observational period between 2003 and 2009 were considered in our data analysis.

Results: Repeated-measures regression models revealed that urinary Na was positively associated with BMI-SDS ($+0.202$ SDS/g Na excretion at baseline; $P < 0.001$) and %BF ($+1.303$ %BF/g Na excretion at baseline; $P < 0.01$) at baseline in boys and girls. These associations remained significant after adjustment for SCB consumption and total energy intake. Furthermore, there was a positive trend between baseline Na excretion and the individual change in %BF in the study period ($+0.364$ increase in %BF/g Na excretion at baseline), which was confirmed after inclusion of SCB consumption or total energy intake. There was no significant association between the change in Na excretion and the concurrent change of either BMI-SDS or %BF in any model.

Conclusions: Our results suggest that a high intake of processed salty foods could have a negative impact on body weight status in children and adolescents independently from their consumption of SCB.

Keywords
Sodium consumption
Convenience foods
Processed foods
Body weight
Obesity

The consumption of highly processed foods such as convenience foods (CF) is often criticised due to their supposed low nutrient and high energy density^(1,2). As a consequence, high CF consumption may lead to nutrient deficits and a poorer total diet quality in children and adolescents. Additionally, a recent analysis from the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study showed that an increase in CF intake was accompanied by an increase in body weight status in boys⁽³⁾. As this association was observed only for the subgroup of energy-dense CF it might be concluded that these products act as adipogenic because of an increase in total energy density of children's diet. However, results from the analysis may underestimate the true effect of CF on body weight because the consumption of highly processed foods could be under-reported in dietary records, especially from overweight subjects.

Another common feature of highly processed foods such as CF and snacks is their relatively high salt content^(4,5). The usage of high amounts of salt is often necessary in order to compensate for aroma losses due to storage or processing⁽⁵⁾. In an analysis from the National Diet and Nutrition Survey in Great Britain the consumption of salt predicted the intake of sugar-sweetened soft drinks in children⁽⁶⁾. In that analysis, each additional gram of salt intake daily was associated with additional consumption of 27 g of soft drinks daily. Evidence from studies on the effect of soft drinks consumption on body weight is controversial^(7,8) but, overall, the literature on this topic suggests that the replacement of these beverages by non-caloric alternatives is efficient for the prevention of weight gain in children and adolescents⁽⁹⁾. Therefore, their high salt content raises the question whether CF and possibly also other foods with a high salt content may also indirectly

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cause weight gain if the thirst that derives from the salt intake is quenched by sugar-containing beverages (SCB) such as soft drinks.

We analysed whether an increase in the consumption of foods with high salt content is associated with an increase in body weight status in healthy children and adolescents participating in the DONALD Study. The total excretion of urinary Na is a reasonable biomarker of (highly) processed salty food consumption, as more than 80% of total salt intake derives from these food products⁽⁵⁾. The individual change in salt intake was evaluated using repeated measurements of urinary Na excretion rates. In a second step, we aimed to investigate whether the association between salt consumption and body weight status is mediated by an increase in SCB consumption.

Methods

Study sample and design

The study sample consisted of a sub-cohort of participants from the DONALD Study, an ongoing open cohort study that started in 1985 in Dortmund, Germany, which investigates the relationship between nutrition, development and metabolism in subjects between infancy and early adulthood. To date, more than 1200 healthy subjects have participated in the DONALD Study and about forty are newly enrolled each year. The regular, non-invasive assessments that take place at intervals of 1 year include 3 d weighed dietary records, anthropometry and urine sampling, as well as interviews on lifestyle and medical assessments. Details of the study protocol have previously been described⁽¹⁰⁾. The DONALD Study was approved by the ethical committee of the Rheinische Friedrich-Wilhelms-Universität Bonn. All examinations and assessments are performed with parental and, later on, with the children's written consent.

For the current examination, we considered only dietary and urinary data from children and adolescents between 3 and 18 years of age that were collected between January 2003 and March 2009 in order to eliminate major time trends in food intake. Children who provided either only a dietary record with no urine sample or vice versa or those who provided both but not at the same time were excluded from the analysis. Between 2003 and 2009 a total of 1683 24 h urine samples were collected from 518 children and adolescents. Three-day dietary records at the time of the urine collection were available for 498 subjects (1519 urine samples and dietary records). Sixty-four urine samples had to be excluded due to creatinine excretion rate below the cut-off value of 0.1 mmol/kg body weight per d (0.09 mmol/kg body weight per d in 3-year-old subjects) in order to minimize errors in urine collection⁽¹¹⁾. Three subjects had no information on parental BMI. Finally, we considered those 364 subjects who had at least two 24 h urine samples and two dietary records in the

observational period. The individual number of 24 h urine samples and corresponding dietary records ranged from two (ninety-four children) to seven (five children). Subjects who were younger than 10 years at their last considered dietary record and urine sampling were classified as prepubescent, those older than 10 years as pubescent.

Urine sampling and urinary variables

For the 24 h urine collection, the children and their caregivers received personal and written instructions on how to collect complete 24 h urine samples. The children were instructed to void their bladder in the morning after rising and to discard this micturition completely. The time should be noted as the start time of urine collection. For the next 24 h, all micturitions including the first void of the following morning should be collected and the time point of collection should be recorded. The samples were immediately stored in preservative-free, Extran-cleaned (Extran MA03; Merck, Darmstadt, Germany) 1-litre plastic containers at less than -12°C before transfer by a dietitian to the research institute.

In this sub-sample of the DONALD Study, the analyses of 24 h urine samples included measurements of creatinine and Na. Creatinine was quantified according to the Jaffé method using the creatinine analyser Beckman-2creatinine (Beckman Instruments, Fullerton, CA, USA). Na was measured by atom absorption flame spectrometry (Perkin Elmer 1100 Spectrometer; Perkin Elmer, Überlingen, Germany).

Variables from dietary records

In general, 3 d weighed dietary records are used for the assessment of food consumption in the DONALD Study. All foods and beverages before consumption as well as leftovers are weighed and recorded by the parents of the children or by the older subjects themselves on three consecutive days. The participants chose the first day of dietary recording within a given period of time. Semi-quantitative recording (e.g. numbers of glasses, cups) is allowed, if weighing is not possible. Our dietary records are not able to determine the small consumed amount of table salt. For the present analysis only the record day parallel to the urine collection was used.

Energy, nutrient and food group intakes at the day before the urine collection were calculated using our in-house nutrient database LEBTAB, which contains detailed data on the energy and nutrient contents of all recorded food items and is continuously updated⁽¹²⁾. The nutrient content of basic foods including milk, fruit, vegetables and meat was taken from standard nutrient tables; the content of commercial foods, e.g. bread, cheese, cold meat and ready-to-eat food, was derived from simulating recipes from labelled ingredients and nutrients. If Na was not labelled, Na content was estimated (e.g. bread, 440 mg/100 g; cheese and cold meat, 800 mg/100 g; ready-to-eat food, 400 mg/100 g).

Data from dietary records were also used to calculate the individual consumption of the following food groups.

- CF: all pre-prepared savory products, frozen, canned or instant, hot or cold (e.g. salads and soups), all-in-one-meals or courses (e.g. pizza or meat dishes), purchased in a store and eaten in the home environment. Fast food or sweet CF (dairy products, cakes, ready-to-eat cereals) were not included, because the heterogeneity of these food groups would necessitate a separate evaluation. CF consumed in day-care centres and schools, as well as frozen or canned pure vegetables, meat or fish without any other ingredients like spices, cream or crumb, were also excluded.
- Bread: bread, tortilla, wraps.
- Ready-to-eat cereals (RTEC): e.g. cornflakes.
- Cheese.
- Cold meat.
- SCB: sugar-containing soft drinks and fruit juice.
- Total beverage consumption: all beverages (e.g. SCB, water, tea) excluding milk.

Anthropometric and additional variables

In the DONALD Study anthropometric measurements are performed from the age of 2 onwards at each annual visit by trained nurses, with the children dressed in underwear only and barefoot. Standing height is measured to the nearest 0.1 cm using a Harpenden digital telescopic stadiometer (Holtain Ltd, Crymch, UK). Weight is measured to the nearest 0.1 kg using a Seca 753E electronic scale (Seca, Hamburg, Germany). Triceps and subscapular skinfolds are measured on the right side of the body to the nearest 0.1 mm using a Holtain calliper (Holtain Ltd).

Based on these data, we calculated the individual BMI as body weight (in kilograms) divided by the square of height (in metres). Sex- and age-independent BMI standard deviation scores (BMI-SDS) were computed using the German national reference data⁽¹³⁾. Body fat percentage (%BF) was estimated according to the equations of Slaughter using the sum of both skinfolds⁽¹⁴⁾.

On their child's admission on the DONALD Study, parents are interviewed about familial characteristics and are weighed and measured using the same equipment as for children. We used these data to calculate maternal BMI or parental BMI if data of the child's mother were not available. The highest maternal school education level was used as an indicator of socio-economic status.

Statistical analysis

All statistical tests were performed using the SAS[®] statistical software package version 9.1.3 (2002–2003; SAS Institute, Cary, NC, USA). A *P* value < 0.05 was considered as significant in all statistical tests.

Descriptive data are given as median and interquartile ranges. A repeated-measures regression model (PROC MIXED) which modelled the means of the data and the

covariance structure (children of the family, repeated measurements) was used to test for age and time trends in descriptive data. In a second step, we additionally included sex as a covariable in order to test for potential sex differences. Positive coefficient values for sex suggest higher values in boys.

A repeated-measures regression model was also used for testing the association of baseline urinary Na excretion with baseline values of body weight status, baseline Na excretion with change in body weight status between the individual first and last assessment, and change in urinary Na excretion with concurrent change in body weight status. Separate analyses included either BMI-SDS or %BF as the dependent variable. As initial analyses indicated no interaction of sex and puberty status with the association between Na excretion and body weight status, data were pooled for analysis.

The basic models for BMI-SDS and %BF included time (i.e. years after first individual data assessment), baseline excretion of Na (mg/d), the interaction between baseline Na excretion with time, and the change in Na excretion in the 5-year study period. The change in excretion of Na was calculated by subtracting baseline excretion from the excretion at each year of assessment. In this way, the regression coefficient of baseline Na excretion represents the slope of the dependent variable (i.e. BMI-SDS or %BF) at the first assessment on Na excretion at the first assessment. The regression coefficient of the interaction between baseline excretion and time represents the slope of the change in the dependent variable (i.e. BMI-SDS or %BF) on Na excretion at the first assessment. The regression coefficient of the change in Na excretion represents the slope of the change in the dependent variable (i.e. BMI-SDS or %BF) on the concurrent change in Na excretion.

Beside the variables in the basic model we further considered additional potential covariates (and their interactions with time) in model 2: sex, age, age × age, age × age × age, maternal BMI and maternal education. Only those variables that significantly modified the effect of Na excretion on BMI-SDS or %BF in the basic models, significantly predicted the outcome variable, or improved the fit statistic (Akaike's Information Criterion; AIC) were included in the subsequent multivariate analyses. Data on physical activity from annual questionnaires were not available for large parts of our study sample (about a third of all observations), so this variable could not be considered as a potential confounder. As we hypothesized that foods with a high salt content could indirectly act as adipogenic via an increase in consumption of SCB, we included baseline consumption of these beverages, its interaction with time and the change in SCB consumption as a potential pathway variable in our models 3a and 5a. Instead of SCB consumption the last models included total energy intake at baseline, its interaction with time and change in total energy intake.

Corresponding to the models for body weight status, the effect of Na excretion on SCB consumption was calculated in a separate model with SCB consumption as outcome variable. The basic model included baseline excretion of Na (mg/d), the interaction between baseline Na excretion and time, and the change in Na excretion in the 5-year study period. In this case, the individual effect of Na excretion on SCB consumption is represented by the association between the change in Na excretion and the concurrent change in SCB consumption.

An exponential spatial structure of covariance was specified to consider correlation of repeated measurements dependent on the absolute time interval of repeated measurements on the same subject. The random statement considered individual differences in body weight status at the beginning of the study.

Results

Study sample characteristics

Data on body composition and urinary Na excretion are given in Tables 1 and 2. As urine samples were available only for subjects after the age of 3 years, the number of observations was quite small in the youngest age strata. We observed no major time trends for the body composition variables or urinary Na excretion in boys or in girls. In both sexes BMI and %BF increased significantly with age. There was also a positive association between age and absolute values of Na excretion. In contrast, Na excretion in relation to body weight similarly decreased with age in both sexes. Overall, boys from our sample had significantly higher values of BMI-SDS than girls, but a lower %BF especially in higher age strata. Absolute Na excretion was higher in boys in comparison to girls, but relative values in relation to body weight did not differ. Based on urinary Na excretion, median salt intake increased from 2.4 (2.9) g/d in 3–4-year-old boys (girls) to 8.1 (6.3) g/d in 15–18-year-old boys (girls).

According to the data from dietary records there were no major time trends in the estimated Na intake and the consumption of food groups with a high salt content between 2003 and 2009 (Tables 3 and 4). The consumption of bread increased by 4.7 g/year and the consumption of RTEC decreased slightly with time in boys. In both sexes, the consumption of nearly all salt-containing foods increased with age. With the exception of cheese, boys consumed more salt-containing foods in comparison with girls. Median consumption values of some food groups were relatively small in both sexes. However, the intake of these food groups (especially CF) was substantial in the highest consumption quartile. Overall, the estimated intake of Na from the dietary records (Tables 3 and 4) was lower than urinary Na excretion (Tables 1 and 2) by about 2% in the younger age groups and by about 8% in older subjects.

Table 1 Anthropometrics and urinary sodium excretion in 3–18-year-old male participants of the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study†

	3–<4 years		4–<7 years		7–<10 years		10–<13 years		13–<15 years		15–18 years		Age (years)‡		Time (years)‡	
	n	n	n	n	n	n	n	n	n	n	n	n	β	β		
Subjects	15	66	78	74	54	66										
Observations	18	123	146	136	83	145										
Age (years)	3:1	3:0, 3:9	5:2	5:0, 6:1	8:1	7:4, 9:0	11:2	11:0, 12:1	14:0	13:1, 14:2	16:2	16:0, 17:1				
BMI (kg/m ²)	15:3	15:0, 16:0	15:3	14:8, 16:5	16:2	15:3, 17:4	17:4	16:2, 19:8	20:0	17:9, 21:9	21:7	19:5, 24:1				
BMI-SDS	-0.2	-0.4, 0.3	-0.1	-0.5, 0.6	0.0	-0.4, 0.7	-0.1	-0.6, 0.8	0.3	-0.5, 0.9	0.3	-0.5, 1.0			0.56***	> -0.01
%BF	14.0	12.7, 15.7	13.8	11.8, 16.3	15.1	12.5, 18.9	16.2	12.3, 22.5	14.3	12.1, 21.0	14.8	11.7, 21.9			0.02	0.01
Data from 24h urine samples															0.34**	0.21
Urine volume (ml/d)	394.1	297.1, 540.0	691.4	487.4, 907.1	775.9	620.5, 986.6	852.2	638.4, 1103.4	1009.5	817.0, 1520.0	1461.6	990.0, 1996.7			67.6***	13.2
Na																
mmol/d	41.8	32.3, 77.5	66.8	47.1, 84.7	90.6	68.6, 107.8	94.4	79.4, 127.5	118.3	87.8, 165.6	138.8	104.3, 183.2			7.0***	0.8
mg/d	962.0	742.7, 1782.1	1535.6	1081.8, 1948.1	2083.5	1576.4, 2478.1	2169.8	1825.4, 2930.0	2720.3	2019.4, 3807.1	3190.2	2398.5, 4211.2			161.6***	18.6
mg/kg BW per d	60.3	48.6, 110.7	69.1	54.2, 91.4	67.7	56.1, 84.9	56.3	44.9, 71.4	46.3	38.7, 65.6	44.7	35.4, 58.5			-2.4***	0.2

SDS, standard deviation score; %BF, percentage body fat; BW, body weight; Q1, quartile 1; Q3, quartile 3.

*P < 0.05; **P < 0.01; ***P < 0.0001.

†Values are median and Q1, Q3.

‡Results from repeated-measures analyses using time since the first observation and current age as fixed effects.

Table 2 Anthropometrics and urinary sodium excretion in 3–18-year-old female participants of the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study†

	3–<4 years		4–<7 years		7–<10 years		10–<13 years		13–<15 years		15–18 years		Age (years)‡	Time (years)‡	Sex§
	<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>β</i>	<i>β</i>	<i>β</i>
Subjects	24		66		83		79		56		70				
Observations	25		112		163		145		84		144				
	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3			
Age (years)	3.2	3.1, 3.9	5.2	5.0, 6.1	8.1	7.4, 9.0	11.1	10.2, 12.0	14.0	13.1, 14.2	16.2	16.0, 17.1			
BMI (kg/m ²)	15.2	14.5, 15.5	15.4	14.5, 16.2	16.2	15.2, 17.6	17.6	15.8, 19.4	19.5	17.1, 21.7	21.0	19.3, 23.6	0.53***	-0.01	0.5
BMI-SDS	-0.1	-0.6, 0.0	0.0	-0.6, 0.5	0.0	-0.6, 0.6	-0.1	-0.7, 0.6	0.1	-1.0, 0.8	0.1	-0.6, 0.9	0.01	-0.02	0.2*
%BF	15.0	14.0, 15.9	15.6	13.1, 17.1	16.7	14.1, 21.0	18.7	15.1, 24.7	21.9	18.0, 27.7	26.4	21.8, 31.6	1.06***	0.04	-3.7***
Data from 24 h urine samples															
Urine volume (ml/d)	495.5	389.5, 744.8	591.6	480.8, 834.9	795.5	611.6, 1026.9	998.5	789.5, 1360.7	1118.7	810.7, 1504.0	1187.2	861.6, 1444.0	54.1***	6.1	37.9
Na															
mmol/d	49.1	36.0, 59.6	59.2	41.9, 76.5	80.6	64.6, 101.2	95.0	75.5, 119.5	103.8	75.4, 131.6	108.4	83.6, 138.7	4.8***	-0.9	13.2***
mg/d	1128.2	826.7, 1369.7	1361.8	962.7, 1758.3	1854.1	1484.1, 2327.6	2184.9	1735.6, 2747.5	2386.2	1732.5, 3025.3	2491.7	1921.3, 3189.0	109.5***	-21.5	302.5***
mg/kg BW per d	76.8	53.5, 86.0	68.2	50.8, 84.0	65.6	53.9, 77.4	55.3	45.2, 74.0	44.9	33.8, 56.8	44.0	31.3, 51.9	-2.5***	-1.0*	2.4

SDS, standard deviation score; %BF, percentage body fat; BW, body weight; Q1, quartile 1; Q3, quartile 3.

P* < 0.05; *P* < 0.01; ****P* = 0.0001.

†Values are median and Q1, Q3.

‡Results from repeated-measures analyses using time since the first observation and current age as fixed effects.

§Results from repeated-measures analyses on the age- and time-adjusted effect of sex; positive values indicate higher nutrient intake in boys.

Table 3 Nutrient and food group intakes according to weighed dietary records in 3–18-year-old male participants of the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study†

	3–<4 years		4–<7 years		7–<10 years		10–<13 years		13–<15 years		15–18 years		Age (years)‡	Time (years)‡
	<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>n</i>		<i>β</i>	<i>β</i>
Subjects	15		66		78		74		54		66			
Records	18		123		146		136		83		145			
	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3		
CF (g/d)	0	0, 8	0	0, 56	8.8	0, 101	10	0, 121	11	0, 150	30	0, 150	7.5***	-2.1
Bread (g/d)	55	39, 97	90	52, 133	102	69, 150	106	69, 138	131	62, 191	163	85, 224	6.1***	4.7**
RTEC (g/d)	0	0, 16	0	0, 0	0	0, 18	0	0, 0	0	0, 0	0	0, 0	0.8*	-1.6*
Cheese (g/d)	3	0, 19	3	0, 28	4	0, 39	19	0, 47	18	0, 45	18	0, 61	2.0***	1.1
Cold meat (g/d)	17	0, 32	17	0, 44	27	10, 60	27	0, 80	26	0, 59	40	0, 84	2.5***	0.6
Sweet beverages (g/d)	228	101, 281	250	27, 474	360	144, 698	504	203, 849	486	213, 889	608	294, 1185	46.3***	-8.8
Beverages (g/d)	478	422, 712	700	480, 917	922	611, 1172	988	683, 1303	1144	721, 1631	1625	1147, 2258	86.0***	-2.5
Total food consumption (g/d)	1296	1149, 1486	1633	1393, 1945	1887	1652, 2313	2126	1684, 2544	2371	1913, 3144	3019	2494, 3984	140.6***	-14.6
Total Na intake (mg/d)§	1055	984, 1449	1411	1009, 1848	1818	1432, 2406	2026	1563, 2911	2502	1997, 3129	3059	2331, 4062	163.1***	20.2

CF, convenience foods; RTEC, ready-to-eat cereals; Q1, quartile 1; Q3, quartile 3.

P* < 0.05; *P* < 0.01; ****P* < 0.0001.

†Values are median and Q1, Q3.

‡Results from repeated-measures analyses using time since the first observation and current age as fixed effects.

§Without table salt.

Table 4 Nutrient and food group intakes according to weighed dietary records in 3–18-year-old female participants of the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study†

	3-<4 years		4-<7 years		7-<10 years		10-<13 years		13-<15 years		15-18 years		Age (years)‡		Time (years)‡		Sex§	
	n	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	Median	Q1, Q3	n	Median	β	β	β	β	
Subjects	24				83				56			70						
Records	25				163				84			144						
CF (g/d)	5	0, 43	3	0, 65	10	0, 74	8	0, 101	10	0, 127	4	0, 62	1.8*	0.5	18.0**			
Bread (g/d)	64	35, 89	79	49, 105	91	57, 144	101	61, 141	111	66, 152	107	67, 169	3.6***	1.8	19.5***			
RTEC (g/d)	0	0, 0	0	0, 16	0	0, 0	0	0, 0	0	0, 0	0	0, 0	0.2	-0.6	4.2*			
Cheese (g/d)	0	0, 8	7	0, 20	11	0, 30	15	0, 38	19	0, 50	20	0, 58	1.9***	<0.1	3.3			
Cold meat (g/d)	13	0, 44	20	0, 50	24	0, 58	24	0, 61	19	0, 62	20	0, 52	0.2	0.4	7.9*			
Sweet beverages (g/d)	250	185, 357	258	97, 447	280	93, 554	313	20, 618	406	157, 755	495	103, 779	24.4***	10.3	81.9*			
Beverages (g/d)	636	455, 826	642	499, 840	800	595, 1090	980	694, 1304	1156	697, 1582	1296	932, 1691	58.6***	21.1	115.5**			
Total food consumption (g/d)	1338	1199, 1623	1502	1309, 1825	1700	1438, 2070	1998	1689, 2404	2258	1684, 2741	2333	1884, 2800	79.4***	24.5	325.1***			
Total Na intake (mg/d)	965	739, 1417	1394	992, 1762	1648	1252, 2130	1968	1464, 2484	2100	1640, 2887	2138	1625, 2720	77.2***	14.3	429.2***			

CF, convenience foods; RTEC, ready-to-eat cereals; Q1, quartile 1; Q3, quartile 3.

* $P < 0.05$; ** $P < 0.01$; *** $P = 0.0001$.

†Values are median and Q1, Q3.

‡Results from repeated-measures analyses using time since the first observation and current age as fixed effects.

§Results from repeated-measures analyses on the age- and time-adjusted effect of sex; positive values indicate higher nutrient intake in boys.

||Without table salt.

Urinary Na excretion and body weight status

Results from mixed linear regression analyses showed that baseline excretion of urinary Na was positively associated with BMI-SDS and %BF at baseline in the crude and adjusted models (Table 5; models 1 and 2, cross-sectional estimate). These associations remained significant after adjustment for SCB consumption (models 3a and 5a) and total energy intake (models 3b and 5b). Baseline Na excretion was further associated with the change in %BF in the study period in the crude model (Table 5; model 1, prospective estimate). After adjustment for several covariates in model 4 this association was no longer significant, but a positive trend remained ($P = 0.073$). This positive trend between baseline Na excretion and change in %BF was confirmed after inclusion of SCB consumption. There was no significant association between the change in Na excretion and the concurrent change of either BMI-SDS or %BF in any model.

The adjusted models for examination of the effect of Na excretion on SCB consumption included baseline Na excretion, baseline Na excretion \times time, time, age \times age, maternal BMI and maternal education as covariates (data not shown). The individual change in Na excretion was significantly associated with a concurrent change in SCB consumption ($\beta = +30.5$, $P = 0.027$). Accordingly, each additional gram of salt intake daily was associated with consumption of an additional 12 g SCB daily.

Discussion

The main findings of the present study were the positive associations of baseline Na excretion and accordingly the baseline consumption of salt-containing foods with both BMI-SDS and %BF at baseline. Furthermore, children with a high urinary Na excretion at baseline tended to increase %BF in the study period. However, we observed no association between an individual increase in Na excretion and the concurrent change in body weight status.

Until now, studies on consequences of a high intake of dietary salt have primarily focused on the effect on blood pressure. Indeed, a meta-analysis of controlled trials showed that dietary salt intake affects blood pressure even in children and adolescents⁽¹⁵⁾. So far, the association between habitual salt intake and body weight was examined only in two cross-sectional analyses. Findings from these studies confirm our results: Hoffmann and Cubeddu observed increasing values of body weight and BMI across quartiles of urinary Na excretion in 766 adults⁽¹⁶⁾; and rising values for body weight and BMI were recently also observed in 18–20-year-old Swedish men across quartiles of Na excretion⁽¹⁷⁾. Furthermore, the present examination supports the results from a previous DONALD analysis of dietary records, in which we found a positive association between baseline consumption of

Table 5 Results of the mixed linear model of the association between absolute sodium excretion and body weight status of 364 children and adolescents from the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study

	Baseline Na excretion (g/d) (cross-sectional estimate)		Baseline Na excretion (g/d) × time (prospective estimate)		Change in Na excretion (g/d) (concurrent estimate)		AIC
	β	<i>P</i>	β	<i>P</i>	β	<i>P</i>	
BMI-SDS							
Model 1	0.243	<0.0001	0.084	0.251	0.0031	0.749	1539.8
Model 2	0.202	0.0008	0.034	0.602	0.0007	0.945	1507.8
Model 3a	0.313	0.0007	0.146	0.704	-0.002	0.983	1517.3
Model 3b	0.215	0.001	0.046	0.845	-0.0002	0.982	1507.5
%BF							
Model 1	2.641	<0.0001	0.594	0.014	0.056	0.617	7787.7
Model 4	1.303	0.007	0.364	0.073	0.021	0.854	7722.3
Model 5a	1.570	0.008	0.610	0.056	0.050	0.661	7728.8
Model 5b	1.598	0.0009	0.476	0.044	0.075	0.529	7729.0

AIC, Akaike's Information Criterion (smaller AIC values are better); SDS, standard deviation score; %BF, percentage body fat.

Model 1 adjusted for time.

Model 2 adjusted for time, age, age × age and parental BMI.

Model 3a adjusted for time, age, age × age, parental BMI, baseline consumption of sweet beverages, baseline consumption of sweet beverages × time and change in sweet beverage consumption.

Model 3b adjusted for time, age, age × age, parental BMI, baseline energy intake, baseline energy intake × time and change in energy.

Model 4 adjusted for time, age, age × age, age × age × age and parental BMI.

Model 5a adjusted for time, age, age × age, age × age × age, parental BMI, baseline consumption of sweet beverages, baseline consumption of sweet beverages × time and change in sweet beverage consumption.

Model 5b adjusted for time, age, age × age, age × age × age, parental BMI, baseline energy intake, baseline energy × time and change in energy.

CF with high energy density and the change in %BF in children and adolescents within a study period of 5 years⁽³⁾. In contrast to the present examination the association between high-energy CF and %BF was significant only for boys. One reason for the missing significance for girls could be a gender-specific under-reporting of highly processed foods in dietary records. In the present study the intake of salt was underestimated in dietary records, especially from older subjects, by about 8%. Therefore, the consideration of urinary Na excretion is more appropriate to evaluate the overall effect of foods with a high salt content on body weight status.

Under consideration of the previous analysis of the DONALD study mentioned above⁽³⁾, it might be hypothesized that not only the high energy density of CF could be responsible for their association with body weight status. CF and other foods with a high salt content may also indirectly act as adipogenic due to an induced higher intake of SCB. Indeed, He *et al.* observed that salt intake predicted the intake of sugar-sweetened soft drinks among children in a cross-sectional analysis of a dietary survey in Great Britain⁽⁶⁾. Accordingly, the authors suggested that the higher soft drinks consumption could be a causal link between salt intake and obesity. However, findings from the present examination of the DONALD Study do not support this hypothesis. Although SCB consumption was also predicted by salt intake in the present longitudinal analysis, the results for Na excretion and body weight status remained significant after consideration of SCB consumption.

It is reasonable to assume that a potential effect of salt intake on body weight status is based on a high intake of high-energy salty foods like cheese. However, also the

inclusion of total energy intake did not change the observed associations. This is in line with results from Hulthén *et al.* who observed no association between urinary Na excretion and total energy intake in young Swedish men⁽¹⁷⁾. Accordingly, the high energy density of salty foods may also not fully explain the link between dietary Na and body weight. Therefore, the mechanism of a potential adipogenic effect of dietary Na remains unclear. A high Na intake could also be an indicator of an overall unhealthy lifestyle characterized by dysbalances between energy intake and expenditure.

From the age of 13 years onwards Na excretion rates in our sample exceeded the recommended upper limit of 100 mmol/d for adults, which corresponds to a salt intake of 5.8 g⁽⁴⁾. Excretion rates in younger children cannot easily be classified as there is no unique definition of an upper limit of salt intake in children⁽⁵⁾. However, in all age strata median Na intake clearly exceeded the recommended minimum requirements from the latest German reference values⁽¹⁸⁾.

Results from dietary records indicated no major changes in the consumption of processed salty foods in our study sample for the time between 2003 and 2009. Urinary Na excretion rates approved this missing time trend. In contrast, per capita consumption of highly processed foods in the form of CF has increased in recent years in Germany. Additionally, mean urinary Na excretion rates in the two abovementioned studies on the association between Na excretion and body weight were 198 mmol/d⁽¹⁷⁾ and 143 mmol/d⁽¹⁶⁾ and therefore higher even in comparison with our oldest age strata. In general participants of the DONALD Study are characterized by a higher socioeconomic status than the overall German population⁽¹⁰⁾

and probably do not represent extremes of Na consumption or body weight status. Thus, our results may even underestimate the true relationship between salty food consumption and body weight status. Another weakness of our study was the missing consideration of physical activity because of the large number of missing data. However, the consideration of the available information on physical activity did not lead to major modifications of our results (results not shown).

Beside these limitations there are also some advantages of the present study. First, the longitudinal character of our study with repeated, precise measurements of exposure and outcome variables and also potential confounders allow a detailed analysis of inter-individual effects on body weight. Accordingly, a previous analysis of the DONALD Study using the same statistical models was recently assessed as 'quasi-experimental'⁽¹⁹⁾. Second, the consideration of urinary Na excretion may be more appropriate than data from dietary records to evaluate the intake of dietary Na and its effect on body weight. Third, the repeated assessment of skinfold thicknesses offers an accurate assessment of the individual development of %BF. As an excess fat mass is regarded as the most relevant factor for the development of obesity-related health problems^(20,21) the consideration of %BF beside BMI-SDS is another advantage of our study.

Conclusions

In our sample of healthy German children and adolescents the consumption of salty foods was not only cross-sectionally associated with baseline body weight status; there was also a trend between high baseline consumption of salty foods and increasing individual %BF in the study period. This association was not fully mediated by a higher consumption of SCB or a higher total energy intake, although an increase in salt intake was associated with an increase in SCB consumption. A reduction in the consumption of salty foods could therefore have a beneficial effect on body weight status independently from changes in beverage consumption. However, more studies on the relationship of salt consumption and body weight regulation are needed to support the present findings.

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conceived the project and performed initial statistical analyses; L.L. conducted further analyses and wrote the manuscript; U.A. and M.K. provided critical input on the data analyses and on the early versions of the manuscript; U.A. supervised the study. All authors contributed to interpretation of the data and revision of the manuscript. The authors are very grateful to the staff of the Research Institute of Child Nutrition for carrying out the anthropometric measurements and for collecting and coding the dietary records.

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