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Daily sugar-sweetened beverage consumption and insulin resistance in European adolescents: the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study

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Abstract

Objective: The present study aimed to evaluate the relationship between the consumption of selected food groups and insulin resistance, with an emphasis on sugar-sweetened beverages (SSB).

Design: The present research is a large multicentre European study in adolescents, the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study).

Setting: Homeostasis model assessment–insulin resistance index (HOMA-IR) was calculated. Several anthropometric and lifestyle characteristics were recorded. Dietary assessment was conducted by using a short FFQ.

Subjects: The participants were a subset of the original sample (*n* 546) with complete data on glucose, insulin and FFQ. All participants were recruited at schools.

Results: Median (25th, 75th percentile) HOMA-IR was 0·62 (0·44, 0·87). Mean HOMA-IR was significantly higher among adolescents consuming brown bread ≤1 time/week than among those consuming 2–6 times/week ($P = 0·011$). Mean values of HOMA-IR were also higher in adolescents consuming SSB >5 times/week compared with those consuming less frequently, although a statistically significant difference was detected between those consuming SSB 5–6 times/week and 2–4 times/week ($P = 0·049$). Multiple linear regression analysis showed that only the frequency of SSB consumption was significantly associated with HOMA-IR after controlling for potential confounders. In particular, it was found that HOMA-IR levels were higher among adolescents consuming SSB 5–6 times/week and ≥1 time/d compared with those consuming ≤1 time/week by 0·281 and 0·191 units, respectively ($P = 0·009$ and 0·046, respectively).

Conclusions: The present study revealed that daily consumption of SSB was related with increased HOMA-IR in adolescents.

Keywords
Sugar-sweetened beverages
High frequence
Consumption
Homeostasis model assessment–insulin resistance

The prevalence of insulin resistance (IR) in children and adolescents is increasing around the world[1–5]. Although there is no universally accepted definition of IR, all studies evaluating the prevalence of IR indicate that more than one out of three obese children or adolescents display IR. For instance, in Greece, the prevalence of IR was found to be 9·2% (2·9% in normal-weight, 10·5% in overweight and 31·0% in obese children), using the threshold of homeostasis model assessment–insulin resistance index (HOMA-IR) > 2·10 (i.e. 97·5th percentile

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in normal-weight participants)[2]. In Italy, an IR prevalence of 3·0% in normal-weight and 40·8% in obese children (using HOMA-IR > 2·5 as the threshold) was reported[5]. In USA, the prevalence of IR was 3·1% in normal-weight, 15·0% in overweight and 52·1% in obese adolescents (using HOMA-IR > 4·39 as a threshold)[4]. Finally, a recent study conducted among Bolivian children and adolescents with obesity revealed an IR prevalence of 39·4% by using a threshold of HOMA-IR > 3·5[3].

IR in children and adolescents has been associated with CVD and metabolic disorders such as hypertension, dyslipidaemia, hepatic steatosis and endothelial dysfunction[6,7]. All of these risk factors can track into adulthood, increasing the risk of cardiovascular morbidity and mortality[8,9]. Therefore, it is important to determine factors associated with IR in order to design and implement appropriate preventive programmes.

Although our genetic background has not changed, changes in environmental parameters (such as abundance of food and sedentary lifestyle) have triggered the expression of genes towards obesity and diabetes – the same genes that once helped our ancestors survive periods of food shortage[10–12]. Unhealthy dietary patterns and lack of physical activity (PA) seem to be the most important risk factors[7,13,14]. High energy intake coming from increased consumption of simple carbohydrates and dietary fat, especially saturated and *trans* fatty acids, in conjunction with low consumption of foods rich in dietary fibre, seems to play a role in the early appearance and development of IR in childhood – even in normal-weight children[15]. The limited data available on food consumption and IR indicate that increased consumption of wholegrain cereals, dairy products (especially low-fat ones), some fish, fruits and all types of vegetables is inversely associated with IR[16–19], while consumption of sugar-sweetened beverages (SSB) and energy-dense foods such as fast foods seems to be positively associated with IR[20,21].

The aim of the present study was to evaluate the relationship between the consumption of selected food groups and IR, with an emphasis on SSB, in European adolescents.

Methods

Research design

The HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study) is a multicentre investigation carried out in ten European cities: Athens (Greece), Dortmund (Germany), Ghent (Belgium), Heraklion (Greece), Lille (France), Pécs (Hungary), Rome (Italy), Stockholm (Sweden), Vienna (Austria) and Zaragoza (Spain). The main aim of the HELENA-CSS was to obtain reliable and comparable data on a broad battery of relevant nutrition- and health-related parameters such as dietary intake, anthropometry, PA, fitness, haematological and biochemical indices[22]. Data collection from the HELENA-CSS took place in 2006–2007.

All participants were recruited at schools and met the general HELENA-CSS inclusion criteria: age range 12·5–17·5 years, not participating simultaneously in another clinical trial, being free of any acute infection lasting less than 1 week before inclusion and having information on weight and height[23]. The present analyses were conducted in a subset of the original sample (*n* 546) with complete data on glucose, insulin and FFQ. This subset was representative of the original sample in terms of gender, age and BMI. Ethics committees from each country approved the HELENA-CSS protocols[24].

Physical examination

The anthropometric methods followed in the HELENA-CSS were described in detail by Nagy *et al.*[25]. Weight was measured in underwear and without shoes with an electronic scale (type SECA 861) to the nearest 0·05 kg, and height was measured barefoot in the Frankfort plane with a telescopic height-measuring instrument (type SECA 225) to the nearest 0·1 cm. BMI (kg/m^2) was calculated as body weight (in kilograms) divided by the square of height (in metres). Age- and sex-standardized BMI cut-off points according to the International Obesity Task Force were used to define normal weight, overweight and obesity[26]. Pubertal stage was recorded by a researcher of the same sex as the child, after brief observation according to Tanner and Whitehouse[27].

Physical activity assessment

More details regarding PA assessment can be found in Hagstromer *et al.*[28]. In brief, PA was measured by using an accelerometer (Actigraph MTI, model GT1M; Manufacturing Technology Inc., Fort Walton Beach, FL, USA) placed on each individual for several days. The monitor was secured underneath clothing at the lower back using an elastic belt and was worn for seven consecutive days. Adolescents were also instructed to wear the accelerometer during all time awake and only to remove it during water-based activities and sleep time. It was initialized as described by the manufacturer and a 15 s epoch was used. The sum of accelerations was transformed into counts. Low PA was considered when the mean of time spent in activity was from 500 to 1999 counts. Moderate PA was considered when the mean of time spent in activity was from 2000 to 3999 counts. Vigorous PA was considered when the mean of time spent in activity was more than 4000 counts. The moderate-to-vigorous physical activity (MVPA) represents the time spent on at least 2000 counts or more for PA per d.

Dietary assessment

Food consumption

Eating habits were assessed using a mini FFQ from the Health Behaviour in School-Aged Children (HBSC) study.

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The frequency of consumption of selected food items was recorded by asking the respondent how many times weekly he/she usually eats or drinks the following: fruits, vegetables, sweets (candy or chocolate), coke or other soft drinks that contain sugar (SSB), diet coke or diet soft drinks, low-fat/semi-skimmed milk, whole-fat milk, cheese, other milk products (e.g. yoghurt, chocolate milk, pudding, quark), cereals (e.g. cornflakes, muesli, choc pops), white bread, brown bread, crisps, chips and fish. The response categories were 'never', 'less than once a week', 'once a week', '2–4 days a week', '5–6 days a week', 'once a day, every day' and 'every day, more than once'. The particular food items were selected as indicators of fat, sugar, Ca and dietary fibre intake. In a validity study performed in Belgium, comparison of the FFQ with 7 d food diaries showed no overestimation for soft drinks[29]. No specific quantities were recorded; therefore, collected data were only used for assessing the frequency of consumption.

Blood samples

Serum concentrations of glucose and insulin were measured after an overnight fast. The HOMA-IR was calculated as [fasting insulin (μIU/ml) × fasting glucose (mmol/l)]/22·5 (to convert fasting insulin values in μIU/ml to pmol/l, multiply by 6·945)[30]. A detailed description of the blood analysis has been reported elsewhere[31].

Statistical analysis

Normally distributed continuous variables are expressed as mean values and standard deviations, while skewed variables are reported as median (25th, 75th percentile). Normality of distribution was evaluated through the Kolmogorov–Smirnov test. HOMA-IR was not normally distributed and thus log-transformed values were used. Categorical variables are summarized as relative frequencies and percentages. Associations between categorical variables were tested using the χ^2 test. The associations between the continuous and binary variables (i.e. sex) were evaluated through Student's t test or the Mann–Whitney test when the former were normally or skewed distributed, respectively. Comparisons of log-transformed HOMA-IR values among the categories of food group intake were performed by using one-way ANOVA, after testing for equality of variances. The results are presented as geometric means and 95 % confidence intervals. Bonferroni correction was used to account for increase in type I error due to multiple comparisons.

Multiple linear regression analysis was conducted in order to determine the association of selected food groups with HOMA-IR after adjusting for sex, Tanner stage, total energy intake, PA and BMI percentile. Food groups entered in the model were those found to be significantly associated with HOMA-IR at a univariate level. The results are presented as β coefficients and 95 % confidence intervals. Stratified analysis by sex was also conducted. P values $< 0{\cdot}05$ from two-sided hypotheses are considered as statistically significant. The SPSS statistical software package version 18·0 (SPSS Inc., Chicago, IL, USA) was used to conduct all statistical analyses.

Results

Table 1 presents descriptive statistics of the anthropometric parameters, fasting glucose levels, fasting insulin levels, HOMA-IR, PA, total energy intake, carbohydrate intake and fat intake for the total study population and by sex. Median (25th, 75th percentile) HOMA-IR was 0·62 (0·44, 0·87) and this was significantly higher among girls than boys. Moreover, fasting insulin levels were found to be significantly higher among girls than boys, while total energy, fat and carbohydrate intakes were found to be significantly lower in the former compared with the latter ($P < 0{\cdot}001$).

Table 2 presents the frequency of consumption of several food groups in the study population, as well as the geometric means (95 % CI) of HOMA-IR for each consumption category of the various foods selected in the present study. The most common frequency of consumption for fruits, vegetables, cheese and milk products except for whole-fat and skimmed milk was found to be 2–6 times/week, while the most common frequency of consumption for cereals, white and brown bread, whole-fat milk, skimmed milk, chips, soft drinks, sweets and fish was ≤1 time/week. It was found that HOMA-IR levels increased as the consumption of white bread increased. However, a statistically significant difference was detected only between the means of HOMA-IR in the very low (≤1 time/week) and very high (>1 time/d) consumption categories of white bread ($P < 0{\cdot}05$). Moreover, it was detected that the mean HOMA-IR was statistically significantly higher among adolescents consuming brown bread ≤1 time/week compared with those consuming 2–6 times/week ($P < 0{\cdot}01$). Finally, the analysis showed that HOMA-IR was also higher in the adolescents consuming SSB >5 times/week compared with those consuming less frequently, although a statistically significant difference was detected between those consuming SSB 5–6 times/week and 2–4 times/week ($P = 0{\cdot}049$). No other statistically significant associations were detected between HOMA-IR levels and the other food groups.

Table 3 illustrates the results of the multiple linear regression model using the log-transformed values of HOMA-IR as dependent variable and the consumption frequency of SSB, white and brown bread as independent variables, controlling for sex, Tanner stage, total energy intake, PA and BMI percentile. The results of this analysis indicate that among the three food groups included in the model, only the consumption of SSB was significantly associated with HOMA-IR. In particular, it was found that HOMA-IR levels were higher among adolescents consuming SSB 5–6 times/week and ≥1 time/d compared

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Table 1 Characteristics of the study population: adolescents aged 12·5–17·5 years, subset of the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study)

	Total (*n* 546)		Boys (*n* 248)		Girls (*n* 298)	
	Median, mean or *n*	(P25, P75), SD or %	Median, mean or *n*	(P25, P75), SD or %	Median, mean or *n*	(P25, P75), SD or %
Age (years)†	14·5	13·5, 15·5	14·5	13·5, 15·3	14·4	13·5, 15·4
Anthropometric measures‡						
Weight (kg)	59	13	63	14	56*	10
Height (cm)	165	9	170	10	162*	7
BMI category§						
Normal weight	414	75·8	179	72·2	235*	78·9
Overweight	95	17·4	45	18·1	50	16·8
Obese	37	6·8	24	9·7	13	4·4
Tanner stage‖						
1		0·7		1·5		0·0*
2		5·4		7·2		3·9
3		18·9		18·5		19·2
4		44·0		42·4		45·5
5		31·0		30·5		31·4
MVPA†¶	55·0	40·8, 70·9	69·5	53·3, 83·7	48·8*	35·4, 62·0
Biochemical measurements						
Fasting glucose (mg/dl)‡	91	7	93	7	89	7
Fasting insulin (μIU/ml)†	8·57	6·12, 11·91	8·14	5·93, 11·59	9·00*	6·46, 12·30
HOMA-IR†	0·62	0·44, 0·87	0·60	0·43, 0·87	0·65*	0·45, 0·88
Energy and macronutrient intakes†						
Total energy intake (MJ/d)	8·05	6·31, 10·54	9·95	7·59, 12·70	7·31	5·87, 9·12
Total energy intake (kcal/d)	1925	1508, 2520	2379	1814, 3036	1748*	1403, 2180
Total carbohydrate intake (g/d)	238	187, 314	278	218, 402	222*	169, 274
Total fat intake (g/d)	75	42, 102	86	64, 128	65*	48, 91

P25, 25th percentile; P75, 75th percentile; MVPA, moderate-to-vigorous physical activity; HOMA-IR, homeostasis model assessment–insulin resistance index.
Values were significantly different compared with those for males:*$P < 0·05$.
†Data are presented as median and (P25, P75).
‡Data are presented as mean and SD.
§Data are presented as *n* and %.
‖Data are presented as %.
¶MVPA represents time spent on at least 2000 counts or more for physical activity per d.

with those consuming ≤1 time/week by 0·281 and 0·191 units, respectively ($P = 0·009$ and 0·046, respectively).

Similar findings were detected when stratified analysis by sex was conducted (Tables 4 and 5).

Discussion

Although there are plenty of studies examining the association between SSB consumption and obesity, type 2 diabetes and other CVD risk factors[32], limited data are available regarding the relationship between SSB consumption and IR[20]. To the best of our knowledge, the present work is the first large European study examining this association.

The present findings indicate that SSB consumption is significantly associated with HOMA-IR levels even after controlling for white and brown bread consumption, obesity indices (i.e. BMI percentiles), PA, total energy intake and other potential confounders. In particular, it was found that adolescents with SSB consumption equal to or higher than once daily had higher HOMA-IR than adolescents consuming SSB less than once weekly. Similar association was detected in both genders.

This result could be partly explained by the contribution of SSB consumption to weight gain[32,33]. However, the fact that the increased SSB consumption is associated with higher levels of IR-related indices, even after adjusting for BMI percentiles, indicates that an independent effect may also stem from the large quantities of rapidly absorbable carbohydrates used to flavour these beverages. In particular, it has been shown that SSB consumption raises blood glucose and insulin concentrations rapidly and dramatically[34]. Therefore, when consumed in large amounts, SSB contribute to a high dietary glycaemic load, which has been shown to induce glucose intolerance and IR[35].

Current evidence suggests that a high dietary intake of fructose that comes from either sucrose-sweetened beverages or other foods may lead individuals to develop IR and metabolic syndrome through several mechanisms[36–38]. First, it has been suggested that high intake of fructose is associated with higher concentrations of C-peptide, a marker of insulin secretion and IR[39]. It is already known that fructose does not stimulate insulin secretion and also reduces circulating leptin concentrations. The combined effects of lowered leptin and insulin concentrations could induce the likelihood of weight gain and its associated metabolic sequelae[40]. Finally, fructose seems to induce weight gain due to inadequate compensation of energy intake from solid foods when SSB are ingested[41].

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Table 2 Association between the frequency of consumption of selected foods and HOMA-IR†: adolescents aged 12·5–17·5 years (*n* 546), subset of the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study)

	≤1 time/week			2–6 times/week			1 time/d			>1 time/d		
Food group	*n*	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI
Fruits	111	0·625	0·590, 0·713	214	0·617	0·570, 0·668	102	0·620	0·563, 0·683	92	0·588	0·518, 0·666
Vegetables	123	0·667	0·608, 0·731	244	0·638	0·593, 0·686	96	0·562	0·506, 0·623	49	0·569	0·487, 0·665
Cereals	255	0·614	0·572, 0·658	143	0·604	0·551, 0·661	76	0·655	0·586, 0·730	41	0·614	0·512, 0·737
White bread	188	0·587	0·541, 0·636	161	0·607	0·558, 0·660	91	0·645	0·532, 0·732	71	0·720	0·645, 0·803
Brown bread	229	0·670**	0·627, 0·715	176	0·559**	0·516, 0·607	63	0·581	0·489, 0·690	43	0·675	0·560, 0·813
Cheese	180	0·592	0·549, 0·639	230	0·618	0·575, 0·663	60	0·613	0·518, 0·726	39	0·721	0·604, 0·861
Whole-fat milk	240	0·592	0·578, 0·668	99	0·592	0·546, 0·706	90	0·592	0·553, 0·687	80	0·592	0·533, 0·677
Skimmed milk	250	0·636	0·596, 0·679	96	0·584	0·520, 0·655	89	0·624	0·548, 0·710	76	0·607	0·535, 0·688
Other milk products	146	0·627	0·576, 0·682	225	0·611	0·568, 0·658	86	0·641	0·574, 0·717	56	0·588	0·495, 0·699
	≤1 time/week			2–4 times/week			5–6 times/week			≥1 time/d		
	n	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI	*n*	Geometric mean	95 % CI
SSB	258	0·606	0·565, 0·650	115	0·578*	0·523, 0·639	57	0·746*	0·578, 0·947	85	0·636	0·578, 0·647
Soft drinks, light	401	0·606	0·565, 0·650	55	0·659	0·588, 0·739	25	0·691	0·563, 0·848	33	0·662	0·548, 0·801
Chips	404	0·611	0·578, 0·647	58	0·604	0·533, 0·686	24	0·656	0·572, 0·753	28	0·683	0·558, 0·837
Sweets	183	0·605	0·555, 0·659	161	0·614	0·563, 0·670	65	0·670	0·591, 0·761	100	0·621	0·562, 0·686
Fish	211	0·605	0·562, 0·650	200	0·626	0·600, 0·653	87	0·667	0·583, 0·764	48	0·647	0·559, 0·748

HOMA-IR, homeostasis model assessment–insulin resistance index; SSB, sugar-sweetened beverages.
†Log-transformed values.
Association between frequency of consumption of selected food and HOMA-IR was significant, based on one-way ANOVA after Bonferroni correction to account for increase in type I error due to multiple comparisons: *$P \leq 0{\cdot}05$, **$P < 0{\cdot}01$.

Table 3 Association between frequency of consumption of selected foods and HOMA-IR† in the total sample (*n* 546); results from multiple linear regression‡ among adolescents aged 12·5–17·5 years, subset of the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study)

Independent variable	Category	β coefficient	95 % CI	*P* value
SSB	≤1 time/week	Reference	Reference	Reference
	2–4 times/week	0·080	−0·084, 0·245	0·338
	5–6 times/week	0·281	0·070, 0·493	0·009
	≥1 time/d	0·191	0·003, 0·380	0·046
White bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	−0·088	−0·254, 0·079	0·300
	1 time/d	0·023	−0·169, 0·214	0·814
	>1 time/d	0·038	−0·158, 0·234	0·701
Brown bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	0·008	−0·155, 0·172	0·921
	1 time/d	0·036	−0·168, 0·241	0·726
	>1 time/d	−0·028	−0·247, 0·191	0·801

HOMA-IR, homeostasis model assessment–insulin resistance index; SSB, sugar-sweetened beverages.
†Log-transformed values.
‡After controlling for sex, Tanner stage, total energy intake, physical activity and BMI percentile.

Table 4 Association between frequency of consumption of selected foods and HOMA-IR† in girls (*n* 298); results from multiple linear regression‡ among adolescents aged 12·5–17·5 years, subset of the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study)

Independent variable	Category	β coefficient	95 % CI	*P* value
SSB	≤1 time/week	Reference	Reference	Reference
	2–4 times/week	0·156	−0·056, 0·368	0·147
	5–6 times/week	0·256	−0·032, 0·543	0·081
	≥1 time/d	0·276	0·025, 0·527	0·031
White bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	−0·070	−0·276, 0·136	0·504
	1 time/d	−0·045	−0·289, 0·199	0·716
	>1 time/d	0·079	−0·179, 0·337	0·547
Brown bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	−0·016	−0·222, 0·190	0·880
	1 time/d	−0·183	−0·432, 0·067	0·151
	>1 time/d	−0·076	−0·369, 0·218	0·612

HOMA-IR, homeostasis model assessment–insulin resistance index; SSB, sugar-sweetened beverages.
†Log-transformed values.
‡After controlling for sex, Tanner stage, total energy intake, physical activity and BMI percentile.

Table 5 Association between frequency of consumption of selected foods and HOMA-IR† in boys (*n* 248); results from multiple linear regression‡ among adolescents aged 12·5–17·5 years, subset of the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study)

Independent variable	Category	β coefficient	95 % CI	*P* value
SSB	≤1 time/week	Reference	Reference	Reference
	2–4 times/week	−0·012	−0·291, 0·266	0·931
	5–6 times/week	0·356	0·019, 0·692	0·039
	≥1 time/d	0·044	−0·285, 0·374	0·790
White bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	−0·194	−0·512, 0·123	0·227
	1 time/d	−0·034	−0·380, 0·312	0·846
	>1 time/d	−0·048	−0·377, 0·281	0·774
Brown bread	≤1 time/week	Reference	Reference	Reference
	2–6 times/week	−0·034	−0·356, 0·287	0·833
	1 time/d	0·434	0·055, 0·813	0·025
	>1 time/d	−0·042	−0·389, 0·305	0·810

HOMA-IR, homeostasis model assessment–insulin resistance index; SSB, sugar-sweetened beverages.
†Log-transformed values.
‡After controlling for sex, Tanner stage, total energy intake, physical activity and BMI percentile.

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Although our findings indicate a low consumption of SSB in European adolescents compared with other similar populations (i.e. US), these findings are in accordance with those reported from a similar study carried out in the USA among 3831 students in 6th to 12th grade[20]. Bremer *et al.* observed that increased SSB consumption was independently associated with increased HOMA-IR, LDL and TAG concentrations and decreased HDL concentrations. The innovative finding of that study was that the increased SSB consumption was related to increased HOMA-IR and TAG concentrations in boys but to BMI and waist circumference in girls[20]. Moreover, a recent meta-analysis revealed that adults consuming more than one serving of SSB daily had higher risk of developing type 2 diabetes than those consuming less than one serving monthly, indicating that high SSB consumption is a risk factor for metabolic disorders not only in childhood but also in adulthood[42].

The current study is cross-sectional and hence no causal relationship between SSB consumption and IR can be extracted. Recent study has shown that the amount of fructose and/or glucose additives in beverages is associated with IR development[37]. However, this association was not evaluated in the current study due to lack of related data. In addition, in the current study SSB included only coke or other soft drinks that contain sugar, while in general SSB is a wider group including additionally fruit drinks, sweetened teas, sport drinks, etc. Therefore, the effect of SSB on IR may have been underestimated. Finally, an important limitation of the analysis is that food frequency consumption data were collected by a simple FFQ, even though more detailed 24 h recall data are available in the present study. However, the use of standardized methodologies and tools for the collection of dietary data within HELENA-CSS strengthens the value of our findings. At this point it should be highlighted that this is an exploratory analysis only, and these associations should be further explored using more detailed dietary data.

Conclusions

Frequent consumption of SSB of more than once daily seems to increase fasting glucose and HOMA-IR levels, which could lead to an increased risk for early development of type 2 diabetes in adolescents. If further research findings on the potential effect of SSB are consistent with those of the current study, then it is important that educational programmes aiming to improve adolescents' dietary habits, including the reduction of SSB consumption, are designed and implemented in European adolescent populations in order to prevent the increment in type 2 diabetes prevalence.

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