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Research paper

Sugar consumption and attention-deficit/hyperactivity disorder (ADHD): A birth cohort study



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ABSTRACT

Background: Attention-deficit/hyperactivity disorder (ADHD) is characterized by persistent symptoms of lack of attention, impulsivity and hyperactivity. The association between nutritional exposures and ADHD has been investigated and some studies have identified adverse effects from higher intake of sugar. The objective of the present study was to evaluate the association between change in sugar consumption between 6 and 11 years of age and incidence of attention-deficit/hyperactivity disorder (ADHD).

Methods: Pelotas 2004 Birth Cohort Study in Brazil. A food frequency questionnaire (FFQ) was used to estimate sugar consumption and the Development and Well-Being Assessment (DAWBA) was applied to mothers to assess the presence of ADHD.

Results: Only children without ADHD at 6 years and with complete information from FFQ and DAWBA at 6 and 11 years were included in the analyses ($n = 2924$). Odds ratios with 95% confidence intervals were calculated. Incidence of ADHD between 6 and 11 years was 4.6% (3.6–5.6%) among boys and 1.8% (1.2–2.5%) among girls. Adjusted analyses showed no association between always high sucrose consumption between 6 and 11 years and incidence of ADHD, compared with individuals who always presented low consumption, both among boys (OR = 0.66; 0.21–2.04) and girls (OR = 2.71; 0.24–30.35).

Limitations: Reflect those that are inherent to use of FFQs, such as memory bias and lack of precision in quantifying the diet.

Conclusions: The results suggest that there is no association between sucrose consumption between 6 and 11 years of age and incidence of ADHD.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is characterized by persistent symptoms of lack of attention, impulsivity and hyperactivity. It generally first appears during childhood and persists through adolescence and into adulthood, with cumulative losses over the course of development of the individuals affected (Barkley and Roizman, 2002; American Psychiatric Association, 2013). ADHD is one of the most prevalent neurobiological disorders in the world, (Polanczyk et al., 2007) and presents complex, highly inheritable etiology (Faraone et al., 2005). The association between nutritional exposures and ADHD has been investigated. Some studies have identified protective effects from higher intake of iron (Konofal et al., 2004, 2008), zinc (Akhondzadeh et al., 2004; Arnold et al., 2005) and polyunsaturated fatty acids (Sinn

and Bryan, 2007; Richardson and Montgomery, 2005; Johnson et al., 2008); and adverse effects from higher intake of food colorings (Bateman et al., 2004; Rowe and Rowe, 1994; Schab and Trinh, 2004), preservatives (McCann et al., 2007) and sugar (Wolraich et al., 1995; Azadbakht and Esmailzadeh, 2012; Lien et al., 2006; Park et al., 2012).

Sucrose, also known as table sugar or refined sugar, is a carbohydrate that, when hydrolyzed by digestive enzymes, is converted into glucose and fructose. Sucrose is rapidly metabolized by the human body and thus is a rapid energy source (Lehninger, 2002). The main source of sucrose is sugar cane (*Saccharum officinarum*). Through an industrial process, sugar cane is transformed into a solid crystalline product. Sugar is a widely commercialized product, frequently used in foods, including for children (Welsh et al., 2011).

The mechanism through which sugar consumption is a biologically

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plausible determinant of ADHD is thought to involve higher release of extracellular dopamine (a monoaminergic neurotransmitter in the catecholamine family) in the area of the striatum, and is related to the reward system (Schwartz et al., 2000). Over the long term, sugar consumption would lead to desensitization of dopaminergic receptors, which would result in the need for increased intake, as a compensatory mechanism, in order to obtain the same level of satisfaction. This would consequently lead to a progressive reduction in dopamine response after sugar consumption. This dopaminergic signaling dysfunction would promote inhibition of the control mechanisms of the frontal cortex, which is an area directly related to the neurobiology of ADHD (Johnson et al., 2011).

Several studies focusing on the association between sugar consumption and attention deficit and/or hyperactivity have been conducted. In 1995, Wolraich et al. (2016) conducted a meta-analysis that included 16 experimental studies. They concluded that sugar consumption did not pose any threat of attention deficit and/or hyperactivity among children. More recent studies have presented conflicting results: some suggested that there might be a positive association between sugar-rich food consumption or feeding patterns and ADHD (Azadbakht and Esmailzadeh, 2012; Lien et al., 2006; Park et al., 2012; Wiles et al., 2009; Howard et al., 2011), while others did not find this association (Peacock et al., 2011; Kim and Chang, 2011).

In the light of the inconsistency among the findings, the objective of the present study was to evaluate the effect of sugar consumption and the prevalence of ADHD among children aged 6 and 11 years, along with the incidence of ADHD between 6 and 11 years of age, in the 2004 Pelotas Birth Cohort.

2. Methodology

The municipality of Pelotas, located in the southernmost part of Brazil, has a population of approximately 340,000 inhabitants, predominantly residing in the urban zone (93%) (Censo, 2010). In 2004, a birth cohort study was started in this municipality. It included 4231 newborns (99.2% of the births in 2004) who were children of mothers living in the urban zone of this municipality. These newborns were identified through visits to the maternity wards of the five hospitals in the municipality. Within the first 24 h postpartum, all the mothers were interviewed and their children were evaluated (perinatal study). Information on their socioeconomic, demographic and reproductive characteristics, their use of healthcare services and prenatal care and their pregnancy complications was obtained. Further methodological details of this study can be found in other published papers (Santos et al., 2010, 2014; Barros et al., 2006).

So far, the participants of the cohort have been evaluated at three months of age and at 1, 2, 4, 6 and 11 years old, and the follow-up rates obtained have been 99.2%, 95.7%, 93.5%, 92%, 90.2% and 86.6%, respectively (Santos et al., 2010, 2014). Up to the children's age of four years, interviews were conducted at their homes, and data on the mothers' health and the children's growth, development, type of diet and morbidities were sampled (Santos et al., 2010). At the children's ages of 6 and 11 years, data gathering took place in a medical clinic that had been built and equipped especially for conducting the study. At both of these follow-ups, in addition to interviews, the children underwent thorough health evaluation examinations, which included psychological, anthropometric and body composition evaluations (Santos et al., 2014).

Data from the perinatal follow-up ($N = 4231$), from the follow-up at the age of 6 years ($N = 3799$) and from the follow-up at the age of 11 years ($N = 3566$) were used in the present study. The Development and Well-Being Assessment (DAWBA) was used to evaluate the outcome of interest, ADHD. The DAWBA was applied to the mothers in the form of an interview, by trained interviewers, during the follow-ups at the ages of 6 and 11 years. The DAWBA is a structured tool consisting of questions that planned such that they would generate diagnoses based on

the classifications of the Diagnostic and Statistical Manual of Mental Disorders (DSM) and the International Classification of Diseases (ICD-10), among children and teenagers between 5 and 17 years of age (Fleitlich-Bilyk and Goodman, 2004). The ADHD module consists of 31 questions, and includes classifications of "any ADHD disorder", as well as specific subtypes (hyperactivity-impulsivity, lack of attention and combined). The DAWBA has been widely used as a diagnostic tool in psychiatric epidemiological studies during childhood and adolescence and was brought to Brazil and validated here by Fleitlich-Bilyk and Goodman (2004). In order to make the various diagnostic classifications, from the results produced by the DAWBA, a clinical rater evaluates and decides on whether symptoms are present and what losses (impacts) they have caused to the child's life, based on the diagnostic criteria of the ICD-10 or DSM. In the present study, the classifications used were DSM-IV (at 6 years of age) and DSM-V (at 11 years of age). At 6 years of age, the clinical judgment was made by a child psychiatrist, and at 11 years, by two psychologists. At both follow-ups, the raters were trained by the child psychiatrist who had translated and validated the DAWBA for the Brazilian population (Fleitlich-Bilyk and Goodman, 2004).

At the ages of 6 and 11 years, a food frequency questionnaire (FFQ) was used to investigate food consumption. The FFQ used at 6 years of age was quantitative, with 54 food items, and was answered by mothers or guardians, with a one-year recall. Food consumption was informed as the number of times (1 to 10) per day, week, month or year. For each food item, a pre-established medium portion was presented. The interviewee was then asked whether the child had consumed an amount equal to or smaller or larger than this medium portion. In order to analyze the nutritional composition, a smaller portion was calculated as half of the medium portion; a larger portion, as twice the medium portion; and an extra-large portion, as 2.5 times larger than the medium portion.

The FFQ used in the follow-up at the age of 11 years was electronic and quantitative, composed of 88 food items, with a one-year recall period. In the self-reporting questionnaire, the mothers were asked whether their children had consumed any of the food items, the frequency of consumption (daily, weekly, monthly or annually) and the size of the portion consumed. For each food item, a photo of the medium portion was presented and the interviewee was asked whether the child had consumed an equal, smaller or larger portion. For nutritional composition analyses, the smaller portion was calculated as half of the medium portion, and the larger portion, as twice the medium portion.

Sucrose consumption, at both follow-ups, was evaluated through the intake of the following food items: sweet cookies, cake, sweets (candy, bubble gum and lollypops), chocolate, ice cream, chocolate milk, additional sugar (used to sweeten coffee, tea and juices), jam, sodas, artificial-flavored juices and sandwich cookies. Annual, monthly, weekly consumption frequencies were transformed into daily frequencies. The table from the United States Department of Agriculture (USDA) (USDA Agricultural Research Service, 2014) was then used to calculate the amounts of sucrose present in these foods. These values were then multiplied by the daily consumption frequencies. The sum of the daily sucrose consumption from each food item resulted in the total sucrose consumption per day.

The information regarding sucrose consumption from the follow-ups at 6 and 11 years of age was combined in order to conduct analyses. Initially, quantitative variables were categorized in terciles and then combined in order to generate five consumption categories: always low consumption (first consumption tercile at 6 and 11 years old); always medium consumption (second consumption tercile at 6 and 11 years old); always high consumption (third consumption tercile at 6 and 11 years old); increasing consumption (from the first to the second or to the third tercile; or from the second to the third tercile); and decreasing consumption (from the second to the first tercile; or from the third to the second or to the first tercile).

Potential confounding factors for the association between sugar

consumption and ADHD, for which data were gathered during the perinatal interview, were used in the following adjusted analyses: National Economic Index (NEI) (Barros and Victora, 2005); maternal educational level (number of years of schooling); mother's age (in years and categorized as <20, 20–35 or >35); marital status (mother living with or without a spouse); maternal smoking during pregnancy (at least one cigarette/day for at least one trimester of pregnancy); maternal alcohol consumption during pregnancy (yes or no); prenatal follow-up (yes or no); number of prenatal consultations; symptoms of maternal mood during pregnancy (through the question “During pregnancy, did you have depression or feel anxious?”) (yes, treated; yes, untreated; or no); pre-pregnancy body mass index (BMI), categorized into low weight (<18.5 kg/m²), eutrophic state (18.5–24.9 kg/m²), overweight (25–29.9 kg/m²) or obese (≥30 kg/m²); heavy caffeine consumption (≥300 mg/day) during pregnancy (yes or no); child's gestational age at birth; type of delivery (normal or cesarean section); and low birth weight (<2500 g) (yes or no).

Variables relating to the children, gathered at 6 years of age, were also used as potential confounding factors: number of siblings living in the same home; hours of sleep at night (≥10 or <10) (Matricciani et al., 2013); and BMI for the age (<2 Z-scores, between –2 and +2 Z-scores or >2 Z-scores). The Wechsler Intelligence Scale for Children-III (WISC-III) (Wechsler, 2002) was used for calculating the intelligence quotient (IQ), using the American standardization and conversion into Z-scores (Z-score < –1 for low IQ). Daily consumption of coffee was also assessed (yes or no). The Edinburgh Postnatal Depression Scale was used to evaluate maternal depression and was categorized as <13 (negative depression screening), and ≥13 (positive depression screening) (Santos et al., 2007), and was also investigated as a potential confounding factor.

Only children from single pregnancies were included in the analyses (*n* perinatal = 4147; *n* of the follow-up at 6 years of age = 3721; *n* of the follow-up at 11 years of age = 3497). In order to perform cross-sectional analyses (sucrose consumption at 6 and 11 years of age and prevalence of ADHD at 6 and 11 years), 3239 and 3444 children were included, respectively, considering only the children for whom exposure and outcome data were available. Mean sucrose consumption in grams per day (g/d) was calculated, with the respective standard deviation (SD), at 6 and 11 years of age, according to the food source. The *t* test was used to evaluate the difference in mean consumption between children with and without ADHD.

The prevalence of ADHD was calculated at 6 and 11 years of age, with the respective 95% confidence interval (95% CI), according to the sucrose consumption at 6 and 11 years of age, respectively (cross-sectional analysis). The cumulative incidence of ADHD between 6 and 11 years of age was evaluated according to the change in sucrose consumption within the same period (longitudinal analysis). A total of 3005 children presented complete information from the FFQ and DAWBA at 6 and 11 years old.

There was an interaction between sucrose consumption and sex (*p* = 0.029). The crude and adjusted analyses on the effect of sucrose consumption on ADHD were stratified according to sex and logistic regression was applied, with adjustment for confounding factors (variables that were associated both with exposure and with the outcome at the level of *p* ≤ 0.20) and for daily consumption of calories from sucrose-free food sources. Only children without ADHD at 6 years of age and with complete information from the FFQ and DAWBA at 6 and 11 years of age were included in these analyses (*n* = 2924), and in the calculations of cumulative ADHD incidence between 6 and 11 years old (longitudinal analyses). 95% CI values were obtained for cumulative incidences and for odds ratios (OR).

All follow-ups of the 2004 Pelotas Birth Cohort were approved by the Research Ethics Committee of the Medical School of the Federal University of Pelotas.

Table 1

Socio-demographic characteristics of mothers and children belonging to the Pelotas 2004 Birth Cohort, and follow-up loss rates at 6 and 11 years of age. Pelotas 2004 Birth Cohort Study.

Variable	Perinatal study (<i>N</i> = 4147) <i>N</i> (%)	Losses at 6 years of age (<i>N</i> = 3721) %	Losses at 11 years of age (<i>N</i> = 3497) %	<i>P</i> ^a	<i>P</i> ^b
NEI in quintiles				0.03	<0.00
■ Q1 (poorest)	641	8.0	18.6		
■ Q2	659	6.2	12.4		
■ Q3	623	4.2	9.5		
■ Q4	640	6.3	8.8		
■ Q5 (richest)	639	8.1	15.0		
Maternal educational level (years)				0.04	0.00
■ 0–4	639 (15.4)	13.0	19.6		
■ 5–8	1691 (40.9)	9.6	15.3		
■ 9–11	1362 (32.9)	9.3	13.4		
■ 12 or over	446 (10.8)	11.7	18.4		
Marital status ^a				0.00	0.00
■ Without spouse	3468 (16.4)	14.0	20.2		
■ With spouse	679 (83.6)	9.5	14.9		
Maternal smoking during pregnancy ^a				0.25	0.03
■ No	3005 (72.5)	9.9	14.9		
■ Yes	1140 (27.5)	11.1	17.3		
Maternal alcohol consumption during pregnancy ^a				0.91	0.23
■ No	4007 (96.6)	10.3	15.6		
■ Yes	140 (3.4)	10.0	19.3		
Number of prenatal consultations ^a				0.00	0.00
■ <6	681 (17.5)	15.4	21.4		
■ ≥6	3219 (82.5)	8.6	13.7		
Mood symptoms during pregnancy [†]				0.01	0.00
■ No	3107	9.6	14.6		
■ Yes, untreated	898	12.9	19.7		
■ Yes, treated	140	8.6	15.0		
Sex				0.95	0.40
■ Female	2157 (52.1)	10.3	16.1		
■ Male	1990 (47.9)	10.3	15.2		

^a *P* Chi-square test comparing the follow-up at 6 years of age with the perinatal data.

^b *P* Chi-square test comparing the follow-up at 11 years of age with the perinatal data.

[†] Description of follow-up losses.

3. Results

Follow-up loss rates at 6 and 11 years of age, according to maternal characteristics during pregnancy (NEI, educational level, marital status, smoking, alcohol consumption, number of prenatal consultations, and mood symptoms) and the child's sex, are presented in Table 1. At these two follow-ups, the losses were higher among children who belonged to families at the extremes of the NEI (1st and 5th quintiles), whose mothers were less educated and without a spouse, had fewer than six prenatal consultations and had untreated mood problems during pregnancy. At 11 years of age, there was also a higher proportion of losses among children of mothers who smoked (Table 1).

The mean sucrose consumption at 6 years old was 130.81 (73.37) g/day and 108.45 (68.49) g/day, among children with and without ADHD, respectively (*p* = 0.003). At 11 years of age, the mean consumption was 186.68 (183.11) g/day and 147.77 (135.02) g/day, among children with and without ADHD, respectively (*p* < 0.001).

Table 2
Mean sucrose consumption (g/day) according to sucrose-rich food items, among children with and without ADHD at 6 and 11 years of age. Pelotas 2004 Birth Cohort.

Food item	Follow-up at 6 years of age		<i>P</i> ^a	Follow-up at 11 years of age		<i>P</i> ^a
	Without ADHD (<i>n</i> = 3153)	With ADHD (<i>n</i> = 86)		Without ADHD (<i>n</i> = 3302)	With ADHD (<i>n</i> = 142)	
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Sweet cookie	11.39 (14.78)	14.15 (16.77)	0.09	29.81 (45.49)	41.93 (59.19)	0.00
Cake	9.54 (16.53)	10.24 (11.19)	0.70	7.81 (18.79)	9.23 (20.73)	0.38
Candy	6.65 (12.08)	9.00 (11.70)	0.08	8.30 (14.84)	10.38 (16.16)	0.13
Chocolate	2.63 (4.81)	3.31 (5.26)	0.20	2.65 (6.02)	2.81 (7.31)	0.76
Ice cream	1.46 (2.86)	2.10 (4.71)	0.05	4.07 (8.90)	4.27 (2.72)	0.80
Chocolate milk	12.00 (13.05)	12.56 (12.88)	0.70	14.62 (20.68)	17.29 (23.84)	0.13
Additional sugar	23.09 (32.02)	24.67 (31.63)	0.65	21.58 (31.77)	27.12 (39.17)	0.04
Jam	2.24 (2.24)	3.73 (3.73)	0.12	11.44 (32.43)	7.67 (17.88)	0.02
Soda	17.98 (28.04)	22.47 (32.02)	0.15	39.28 (65.04)	38.25 (68.76)	0.85
Artificially flavored juice	21.72 (27.07)	29.09 (32.84)	0.01	25.13 (32.46)	32.69 (38.65)	0.08
Total	108.45 (68.49)	130.81 (73.37)	0.00	147.77 (135.02)	186.68 (183.11)	0.00

^a *t* test.

At 6 years of age, the food items that contributed most to sucrose consumption among children without ADHD were additional sugar, artificially flavored juices, sodas and chocolate milk, representing 21.3%, 20.0%, 16.6% and 11.1% of the total sucrose consumed, respectively. Among children with ADHD, the sucrose sources most consumed were artificially flavored juices (22.2%), additional sugar (18.9%), sodas (17.2%) and sweet cookies (11.2%). Children with ADHD at 6 years of age consumed more ice cream and artificially flavored juices than those without ADHD (Table 2).

At 11 years of age, the food items that contributed most to sucrose consumption among children without ADHD were sodas (26.6%), sweet cookies (20.2%), artificially flavored juices (17.0%) and additional sugar (14.6%); and, among those with ADHD, sweet cookies (22.5%), sodas (20.5%), artificial-flavored juices (17.5%) and additional sugar (14.5%). Children with ADHD presented higher consumption of sweet cookies, additional sugar, jams and artificial-flavored juices than those without ADHD (Table 2).

Tables 3 and 4 show the association between sucrose consumption at 6 and 11 years of age and the prevalence of ADHD at 6 and 11 years, along with the association between the change in consumption between 6 and 11 years of age and the cumulative incidence of ADHD between 6 and 11 years of age, separately for boys and girls. At 6 years of age, the prevalence of ADHD among the boys became higher as the sucrose consumption increased (Table 3). In the first tertile of consumption the prevalence was 1.8 (0.7–2.9), in the second tertile 2.8 (1.5–4.2) and in the third 5.8 (3.9–7.8), and the association remained significant even after adjusting for maternal and child characteristics (*p* = 0.02) (Table 3). In girls, the association was not present, the prevalence of ADHD in the first tertile of consumption was 1.7 (0.6–2.9), in the second tertile 1.2 (0.2–2.1) and in the third 2.3 (1.0–3.6), even after adjustment (*p* = 0.88).

At 11 years of age, among the boys, the same pattern was observed, the prevalence of ADHD was 4.7 (3.1–6.6), 6.1 (3.9–7.7) and 6.7 (4.8–8.8), in the first, second and third tertiles, respectively (Table 3). However, the 95% CIs overlapped each other, thus indicating that there was no association. In addition, no association was observed among the girls, among whom the prevalence of ADHD in the first, second and third tertiles, was 1.5 (0.3–2.2), 3.1 (1.7–4.7) and 2.4 (1.1–3.6), respectively (Table 4).

After adjustment for NEI, maternal characteristics (educational level, marital status, smoking, alcohol consumption, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ, number of siblings and calorie consumption from sucrose-free sources), the incidence of ADHD between 6 and 11 years of age among boys who always presented high sucrose consumption was 5.4% (2.4–8.5%). Among boys who always presented low consumption, the incidence was 3.7% (1.3–5.9%). Among girls with decreasing consumption, the incidence of ADHD after adjustment for NEI, maternal

Table 3
Prevalence of ADHD at 6 and 11 years of age according to sucrose consumption at these ages and incidence of ADHD between 6 and 11 years of age (among boys with and without the outcome at 6 years of age), according to the change in sucrose consumption between 6 and 11 years of age. 2004 Pelotas Birth Cohort.

Boys Sucrose consumption		<i>P</i> ^a	<i>P</i> ^b
At 6 years old	Prevalence of ADHD at 6 years old (<i>n</i> = 1679)	0.00	0.02
1st tertile (4.3–74.2 g)	1.8	0.7, 2.9	
2nd tertile (74.4–125.6 g)	2.8	1.5, 4.2	
3rd tertile (125.7–524.8 g)	5.8	3.9, 7.8	
At 11 years old	Prevalence of ADHD at 11 years old (<i>n</i> = 1782)	0.32	0.30
1st tertile (0.44–80.77 g)	4.7	3.1, 6.6	
2nd tertile (80.91–163.82 g)	6.1	3.9, 7.7	
3rd tertile (163.88–1196.76 g)	6.7	4.8, 8.8	
Change between 6 and 11 years of age	Incidence of ADHD at 11 years old^c (<i>n</i> = 1489)	0.92	0.63
Always low consumption	3.7	1.3, 5.9	
Always medium consumption	5.0	1.7, 7.9	
Always high consumption	5.5	2.4, 8.6	
Increasing consumption	4.4	2.5, 6.4	
Decreasing consumption	4.5	2.7, 6.5	

Maternal characteristics (educational level, marital status, smoking during pregnancy, alcohol consumption during pregnancy, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ, number of siblings and calorie consumption from sucrose-free sources).

^a The analysis was adjusted for crude.

^b The analysis was adjusted for NEI.

^c The analysis was adjusted for children with ADHD at 6 years old excluded.

characteristics (educational level, marital status, smoking, alcohol consumption, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ, number of siblings and calorie consumption from sucrose-free sources) was 2.4% (0.9–3.7%), and among girls who always presented low consumption, 0.4% (0.4–1.3%). Both among the boys and the girls, the 95% CIs overlapped each other, thus indicating that there was no association in any analyses (Tables 3 and 4).

Table 5 presents crude and adjusted analyses on the association between the change in sucrose consumption between 6 and 11 years of age, and ADHD at 11 years of age. For both sexes, no association was observed in either the crude analyses or the analyses with adjustment for NEI, maternal characteristics (educational level, marital status, smoking, alcohol consumption, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ,

Table 4

Prevalence of ADHD at 6 and 11 years of age according to sucrose consumption at these ages and incidence of ADHD between 6 and 11 years of age (among girls with and without the outcome at 6 years of age), according to the change in sucrose consumption between 6 and 11 years of age. 2004 Pelotas Birth Cohort.

Girls			<i>P</i> ^a	<i>P</i> ^b
Sucrose consumption [†]				
At 6 years old	Prevalence of ADHD at 6 years old (n = 1559)	95% CI	0.37	0.88
1st tertile (2.8–68.1 g)	1.7	0.6, 2.9		
2nd tertile (68.8–115.5 g)	1.2	0.2, 2.1		
3rd tertile (498.1–115.8 g)	2.3	1.0, 3.6		
At 11 years old	Prevalence of ADHD at 11 years old (n = 1657)	95% CI	0.19	0.89
1st tertile (1.15–71.5 g)	1.5	0.3, 2.2		
2nd tertile (71.6–151.9 g)	3.1	1.7, 4.7		
3rd tertile (151.9–1352.5 g)	2.4	1.1, 3.6		
Change between 6 and 11 years of age	Incidence of ADHD at 11 years old (n = 1435)	95% CI	0.41	0.64
Always low consumption	0.4	0.4, 1.3		
Always medium consumption	1.2	0.4, 0.3		
Always high consumption	1.8	0.0, 3.5		
Increasing consumption	2.1	0.7, 3.4		
Decreasing consumption	2.4	0.9, 3.7		

Maternal characteristics (educational level, marital status, smoking during pregnancy, alcohol consumption during pregnancy, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ, number of siblings and calorie consumption from sucrose-free sources).

[†] Children with ADHD at 6 years old excluded.

^a Crude analysis.

^b Analysis with adjustment for NEI.

number of siblings and calorie consumption from sucrose-free sources). Among the boys who always presented high consumption, the adjusted OR was 0.66 (0.21–2.04) and, among girls, 2.71 (0.24–30.35), compared with their peers who always presented low consumption (taken as the reference).

4. Discussion

In the present study, sucrose consumption was associated with the prevalence of ADHD among boys at 6 years of age, in a cross-sectional analysis adjusted for confounding factors. However, subsequent cross-sectional analyses, at 11 years of age, indicated there was no association in either crude or adjusted analyses. There was also no association between sucrose consumption and the incidence of ADHD between 6 and 11 years of age. The effect of changes in sucrose consumption between 6 and 11 years of age on the incidence of ADHD over the same

Table 5

Crude and adjusted analyses on the association between the change in sucrose consumption and incidence of ADHD among 6 and 11-year-old children.

Sucrose consumption at 6 and 11 years old	Crude analysis (n = 1489) OR	95% CI	<i>P</i> ^a	Adjusted analysis ^b (n = 1109) OR	95% CI	<i>P</i> ^a
Boys						
Always low consumption	1		0.93	1		0.87
Always medium consumption	1.4	0.5, 3.5		1.1	0.4, 3.4	
Always high consumption	1.5	0.6, 3.7		0.7	0.2, 2.0	
Increasing consumption	1.2	0.6, 2.8		0.7	0.3, 2.0	
Decreasing consumption	1.2	0.5, 2.7		0.8	0.3, 2.1	
Girls						
Always low consumption	1		0.30	1		0.92
Always medium consumption	2.7	0.2, 30.0		3.1	0.3, 36.9	
Always high consumption	4.2	0.5, 38.9		2.7	0.2, 30.4	
Increasing consumption	5.0	0.6, 40.4		2.5	0.3, 23.5	
Decreasing consumption	5.5	0.7, 43.8		2.2	0.2, 21.4	

^a Logistic regression.

^b Analyses adjusted for prenatal variables: NEI, maternal characteristics (educational level, marital status, smoking during pregnancy, alcohol consumption during pregnancy, number of prenatal consultations and mood symptoms during pregnancy) and children's variables (IQ, number of siblings and calorie consumption from sucrose-free sources).

period was zero, both in crude and in adjusted analyses, for boys and girls.

The daily consumption of sugar in the children of this study was around 120 g, corresponding to about 30% of the total energetic value of the diet. In Brazil, between 1987–1988 and 2002–2003, consumption of sugar and soft drinks accounted for 13.4% of household energy availability. (Monteiro et al., 2010) According to Levy et al. (2009), household availability of high sugar content was associated with total home energy availability around 50% above the recommended value. Another more recent study with adolescents showed that consumption of fats and sugars contributed 52% of the daily caloric intake. This evidence points to consumption far above what is recommended by the WHO, which in 2015 has released a new guide to sugar consumption recommendations for adults and children (WHO, 2015). The recommendation is that the consumption is less than 10% of the calories consumed daily, and greater benefits can be achieved with a consumption below 5%, which corresponds to the consumption of 25 g of sugar per day (WHO, 2015).

Conflicting data is presented in the literature regarding the effect of sugar on the occurrence of ADHD (Wolraich et al., 1995; Azadbakht and Esmailzadeh, 2012; Lien et al., 2006; Park et al., 2012; Wiles et al., 2009; Howard et al., 2011; Peacock et al., 2011; Kim and Chang, 2011). The reasons for these divergences include differences both in the operational definition of the exposure and in the design, sample size and confounding variables considered in the analysis. Among studies found in the literature, a few investigated the consumption of sucrose or carbohydrates (Wolraich et al., 1995); others, the consumption of sugar-rich food (Lien et al., 2006, Kim and Chang, 2011); and yet others, dietary consumption patterns (Azadbakht and Esmailzadeh, 2012; Park et al., 2012; Wiles et al., 2009; Howard et al., 2011; Peacock et al., 2011). Most of the studies in which sucrose or sucrose-rich food were evaluated were double-blind experimental studies, with small numbers of participants (Wolraich et al., 1995).

More recent studies, especially cohort studies (Wiles et al., 2009; Peacock et al., 2011), evaluated the effect of dietary patterns. However, dietary pattern evaluation does not allow identification of the dietary component to which the effect should be attributed. In addition, the process of building dietary patterns is complex and involves arbitrary decisions, going from creation of food groups to retention of patterns and their interpretation (Olinto et al., 2007). Furthermore, the dietary patterns identified in a given study are specific to that population, thus impairing comparability among the findings.

The majority of cohort or cross-sectional studies, which included several hundred children and made adjustments at least for sex, age and socioeconomic conditions, found an association between higher sugar consumption and ADHD (Azadbakht and Esmailzadeh, 2012; Lien

et al., 2006; Park et al., 2012; Wiles et al., 2009; Howard et al., 2011). However, differently from the present study, they evaluated the exposure exclusively from soda consumption (Lien et al., 2006) or through construction of an indicator based only on consumption of sweet food, without taking into account the amount of sucrose present in this food. (Park et al., 2012) Longitudinal studies in which the exposure was evaluated through using dietary patterns containing only sweet food (Azadbakht and Esmailzadeh, 2012) or sweet and ultra-processed food (Wiles et al., 2009; Howard et al., 2011) found this association.

The majority of the experimental studies in which this association was investigated were conducted during the 1980s and 1990s (Wolraich et al., 1995). The experiments consisted of offering a sucrose-sweetened drink to one group, while the other group (control) was offered the same drink sweetened with aspartame or saccharin. Most of these studies did not find any association between sugar consumption and attention-deficit and/or hyperactivity (Wolraich et al., 1995).

The association between sucrose consumption and ADHD in the present study was present only in the cross-sectional analysis, and was exclusively among boys at 6 years of age. Generic and neuroimaging studies have suggested that the neurobiology of the ADHD involves dysfunction of the reward system (Blum et al., 2008; Volkow et al., 2007, 2011; Rosa et al., 2002). Knowing that certain types of food, especially those rich in sugar, trigger the reward system (Johnson et al., 2011; Wise, 2006; Lenoir et al., 2007), it is possible that the results from studies that found an effect from sugar on ADHD reflect higher sugar consumption by individuals who would develop the disorder regardless of this factor. Hyperactive/impulsive behavior might be associated with higher sucrose consumption, in which this is a consequence of rather than a determining factor for ADHD. A recently published cohort study evaluated dietary behavior in children with ADHD and found a positive association between overeating and ADHD symptoms (Leventakou et al., 2016). Another study revealed that children with ADHD presented irregular meals, ate more than five times a day and consumed many sugary drinks during the day (Ptacek et al., 2014). These results are consistent with those of other studies that showed a higher prevalence of binge eating in individuals with ADHD (Cortese et al., 2007; Docet et al., 2012; Seitz et al., 2013).

This study has limitations and strengths. Among the limitations it is important to consider the influence of uncontrolled factors on the results of this study. For instance, evidence from epidemiological and animal studies indicates that maternal diet during pregnancy plays an important role in neural programming that regulates behavior (Sullivan et al., 2014). The mechanisms by which the maternal diet influences the intrauterine environment has not yet been fully elucidated, but some studies have shown that an increase in inflammatory cytokines, nutrients such as glucose and fatty acids, and hormones such as insulin and leptin in the maternal organism directly affect the fetus (Sullivan et al., 2014). Therefore, an intrauterine environment exposed to a maternal diet rich in fats and sugars would result in the development of mental and behavioral disorders such as anxiety and depression (Bilbo and Tsang, 2010), attention deficit hyperactivity disorder (Ray et al., 2009), and autism spectrum disorders (Patterson, 2011).

Another limitation of the present study reflects those that are inherent to use of FFQs, such as memory bias and lack of precision in quantifying the diet. Use of FFQs as a tool for evaluating diets in a clinical environment leads to imprecision, especially when the objective is to quantify nutrient consumption, due to the complexity of this measurement (Willett, 1994). However, in epidemiological studies, it is the instrument most recommended, in relation to those that make spot evaluations on diets, performed during the same day or within a period of a few days. When the objective is to evaluate diets as exposure factors for health outcomes, it does not matter what a person consumes at one specific moment, but rather, over the course of time (Willett, 1994).

Among the strengths of the present study is the fact that the diet was investigated at two moments in time, which enabled evaluation of the

change in dietary consumption over the period. This approach is very important because it allows discrimination of the population according to the variation in dietary behavior. In addition, because this study used data from a birth cohort of a city in southern Brazil, the data are generalizable for a population with similar characteristics.

Other positive aspects of the present study include its investigation of the association through a longitudinal analysis, among children free from the baseline outcome (at 6 years of age), using data from a prospective cohort study, which is ideal for investigating the issue because it preserves the temporal relationship between exposure and outcome.

Another positive aspect of the present study was its investigation of the outcome (ADHD) using an instrument that had been validated and adapted for use on Brazilian populations (Fleitlich-Bilyk and Goodman, 2004). The DAWBA uses internationally acknowledged diagnostic criteria, applied by a properly trained clinical rater, and allows confirmation of the diagnosis of the disorder based on symptoms, losses and qualitative information. In addition, the percentage losses at both follow-ups were low, and adjustment for a large number of potential confounding factors could be made. Another strength of the present study was that it used a test evaluating modification of the effect of sucrose on occurrences of ADHD according to the children's sex. No other study in which the interaction between sucrose consumption and sex was evaluated was found in the literature.

The present study showed that sucrose consumption was associated with the prevalence of ADHD only among boys at 6 years of age, and that persistence of high consumption or an increase in sugar consumption between 6 and 11 years of age was not associated with higher incidence of ADHD between 6 and 11 years of age. This supports the hypothesis that the higher sugar consumption by children with ADHD is possibly a consequence rather than a determinant of the disorder.

Authors' contributions

Dr B. Del-Ponte, Dr I.S. Santos and L. Anselmi L they were responsible for designed research; Drs A. Matijasevich and I.S. Santos conducted research; Drs L. Tovo-Rodrigues L. Anselmi, M.C.F. Assunção, A. Matijasevich, T.N. Munhoz and L.A. Rohde provided essential reagents or provided essential materials; Dr B. Del-Ponte conducted analyzed data or performed statistical analysis; Drs B. Del-Ponte and I.S. Santos wrote paper; Drs B. Del-Ponte, I.S. Santos, L. Anselmi, L. Tovo-Rodrigues, M.C.F. Assunção, T.N. Munhoz and L.A. Rohde had primary responsibility for final content.

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Conflict of interest

The authors have no potential conflicts of interest to disclose.

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