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Associations of Prenatal and Child Sugar Intake With Child Cognition

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Abstract

Introduction—Sugar consumption among Americans is above recommended limits, and excess sugar intake may influence cognition. The aim of this study was to examine associations of pregnancy and offspring sugar consumption (sucrose, fructose) with child cognition. Additionally, associations of maternal and child consumption of sugar-sweetened beverages (SSBs), other beverages (diet soda, juice), and fruit with child cognition were examined.

Methods—Among 1,234 mother–child pairs enrolled 1999–2002 in Project Viva, a pre-birth cohort, in 2017 diet was assessed during pregnancy and early childhood, and cognitive outcomes in early and mid-childhood (median ages 3.3 and 7.7 years). Analyses used linear regression models adjusted for maternal and child characteristics.

Results—Maternal sucrose consumption (mean 49.8 grams/day [SD=12.9]) was inversely associated with mid-childhood Kaufman Brief Intelligence Test (KBIT-II) non-verbal scores (−1.5 points per 15 grams/day, 95% CI= −2.8, −0.2). Additionally, maternal SSB consumption was inversely associated with mid-childhood cognition, and diet soda was inversely associated with early and mid-childhood cognition scores. Early childhood consumption of SSBs was inversely associated with mid-childhood KBIT-II verbal scores (−2.4 points per serving/day, 95% CI= −4.3, −0.5) while fruit consumption was associated with higher cognitive scores in early and mid-childhood. Maternal and child fructose and juice consumption were not associated with cognition. After adjusting for multiple comparisons, the association between maternal diet soda consumption and mid-childhood KBIT-II verbal scores remained significant.

Conclusions—Sugar consumption, especially from SSBs, during pregnancy and childhood, and maternal diet soda consumption may adversely impact child cognition, while child fruit

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consumption may lead to improvements. Interventions and policies that promote healthier diets may prevent adverse effects on childhood cognition.

INTRODUCTION

Research is increasingly focusing on the adverse impact of sugar consumption on health outcomes, and current Dietary Guidelines for Americans emphasize the importance of reducing calories from added sugars.[1] Added sugars are incorporated into foods and beverages during preparation or processing, with sugar-sweetened beverages (SSBs) being the greatest contributor in Americans' diets.[2] Americans' added sugar consumption is on average 300 calories per day, which is substantially above recommended limits; the Dietary Guidelines for Americans advise for 10% or less of calories from added sugar, and the American Heart Association advocates less than 150 calories from added sugar per day for men and less than 100 calories for women and children.[1–5] Overconsumption may have important health implications given associations with greater risks for obesity, cardiovascular disease, and type 2 diabetes.[6–8]

Evidence is also emerging that sugar consumption may negatively impact children's cognitive development. Added sugars, especially high-fructose corn syrup (HFCS), may adversely influence hippocampal function during critical periods of development.[9] Animal studies that have examined the impact of sugar or a "Western style" diet high in both sugar and solid fats have found associations with lower cognitive functioning.[9–13] In human studies, poorer glycemic control among diabetic pregnant women, a marker of glucose exposure, was associated with poorer offspring cognitive outcomes.[14,15] There do not appear to be human studies examining the association between prenatal sugar consumption and offspring cognitive development. Additionally, only a limited number of studies have examined children's sugar consumption and cognition, and results have been inconsistent.[16]

To address these gaps in the literature, the primary aims of this study are to examine the association between prenatal sugar consumption (fructose and sucrose), as well as the offspring's sugar consumption, and child cognition in early and mid-childhood. The secondary aims are to examine the associations of maternal and child consumption of SSBs, beverages without added caloric sweeteners (e.g., diet soda and juice), and fruit (a primary food sources of fructose) with child cognition.

METHODS

Study Population

Participants were enrolled in Project Viva, a prospective observational cohort study designed to study prenatal factors, pregnancy outcomes, and child health. From 1999 to 2002, women were recruited attending their first prenatal visit at one of eight participating obstetric offices at Atrius Health, a multispecialty group medical practice in the Boston area. Study eligibility included a singleton pregnancy <22 weeks gestation at the initial clinical visit, ability to answer questions in English, and plans to stay in the area after delivery. Additional study details have been previously published.[17,18] Offspring follow-up occurred in early childhood (median age 3.3 years) and mid-childhood (median age 7.7 years). The participating institutions' IRBs approved the study. All participants provided written informed consent, and procedures were in accordance with ethical standards for human experimentation. All study instruments are publicly available (www.hms.harvard.edu/viva/index.html). Project Viva is registered on clinicaltrials.gov as NCT02820402.

Of the 2,128 women who delivered a live infant at a participating hospital, 16 with previous type 1 or type 2 diabetes mellitus, 118 with gestational diabetes, and 207 who did not complete a food frequency questionnaire (FFQ) in the first or second trimester were excluded. Of the 1,252 children who completed at least one cognitive assessment, 18 born at <34 weeks were excluded, leaving 1,234 remaining participants. Compared with the 1,234 mothers in this analysis, the 894 nonparticipants were less likely be college educated (57% vs 70%) or to have annual household income >$70,000 (56% vs 65%) and had a slightly lower average age (31.2 vs 32.3 years) and higher pre-pregnancy BMI (25.6 vs 24.4 kg/m^2). Prenatal consumption of SSBs (mean 0.7 vs 0.6 servings/day) was similar.

Measures

Maternal sugar, beverage, and fruit intake was assessed using a self-administered semi-quantitative FFQ with ≅140 items, based on a previously validated FFQ and minimally modified for use during pregnancy.[19] Women completed FFQs during the first trimester (frequency of consumption "during this pregnancy" [i.e., since the last menstrual period]), and during the second trimester ("during the past 3 months"). Associations with cognitive outcomes were similar for first trimester and second trimester maternal diet, so they were averaged for analysis of prenatal dietary exposures. The FFQ included three questions about regular soda intake, three questions about diet soda, five questions about fruit juice, one question about fruit drinks, and two questions about water. SSBs were defined as regular soda and fruit drinks (but not 100% fruit juice). The FFQ also assessed consumption for 13 fruits (excluding fruit juice), which were summed to measure total fruit intake. Fructose and sucrose were calculated based on all the food and beverage sources determined by the FFQ. Western and prudent diet scores were calculated from the FFQs as previously described but excluding fruits or SSBs.[20]

Mothers reported children's diets at the early childhood visit using a semi-quantitative FFQ previously validated among preschool-aged children.[21] This FFQ also evaluated beverages (regular soda, diet soda, fruit juice, and fruit drinks) and ten fruits (excluding fruit juice), which were summed to measure total fruit intake. To calculate sugar consumption, the Harvard nutrient composition database was used, which is based on U.S. Department of Agriculture publications, and is continuously supplemented by additional published sources, as well as personal communications with laboratories and manufacturers.[22]

Cognitive functioning was assessed at both early and mid-childhood. At the early childhood visit, trained research staff administered the Peabody Picture Vocabulary Test, third edition (PPVT-III), an evaluation of receptive language, and the Wide Range Assessment of Visual Motor Abilities (WRAVMA), including the pegboard, matching, and drawing subtests, to assess fine motor, visual spatial, and visual motor abilities, respectively. Subtest scores were combined to generate a visual motor composite score.[23,24] At the mid-childhood visit, research assistants administered the WRAVMA drawing scale, a measure of visual motor abilities; the Kaufman Brief Intelligence Test, second edition (KBIT-II), which assessed verbal and non-verbal global intelligence; and the Wide Range Assessment of Memory and Learning (WRAML) design memory and picture memory tests, measures of visual memory (results were combined for a total visual memory score).[25,26] The WRAML visual memory test is scaled to a mean score of 10 (SD=3), and the PPVT-III, KBIT-II, and WRAVMA are scaled to a mean score of 100 (SD=15).

Using a combination of self-administered questionnaires and interviews, information was collected about maternal pre-pregnancy weight and height (to calculate BMI), age, education, race/ethnicity, smoking during pregnancy, parity, household income, marital status, prenatal depression, paternal age and education, and breastfeeding duration. Birth weight and date of delivery were obtained from hospital medical records. Gestational age from the last menstrual period or from the second trimester ultrasound if the two differed by >10 days, and birth weight for gestational age *z*-score (fetal growth) were calculated.[27] Maternal intelligence was measured using PPVT-III at the early childhood visit and KBIT-II at the mid-childhood visit. Lastly, the Home Observation Measurement of the Environment short form (HOME-SF) was used to evaluate the child's home environmental for cognitive stimulation and emotional support at mid-childhood.

Statistical Analysis

Multivariable linear regression models estimated adjusted associations of maternal and child sugar consumption (fructose and sucrose), SSBs, juice, diet soda, and fruit with child cognitive outcomes. Models examining associations between maternal sugar consumption and outcomes were adjusted for variables that were associated with the outcomes or exposures or were important confounders based on previous literature, including maternal age, pre-pregnancy BMI, parity, education, smoking status during pregnancy, maternal prenatal fish intake (the mean of the first and second trimesters), household income at enrollment, and the child's sex and race/ethnicity.[28] Estimates of associations between child intake and outcomes were additionally adjusted for child's birth weight for gestational age *z*-score and the mother's corresponding intake during pregnancy. Several other potential confounding variables were initially included, namely maternal marital status, intelligence, depression during pregnancy, pre-pregnancy physical activity levels, Western or prudent dietary pattern (calculated without fruits and SSBs), breastfeeding duration, paternal age and education, and HOME-SF score.[20] Because their inclusion did not change the results, they were not included in the final models. Results focused on associations for which the 95% CI did not contain zero. Because there may have been increases in the chance of a Type I error higher than the desired 5% given multiple tests, false discovery rate adjusted *p*-values based on 36 tests were reported; comparison of these adjusted *p*-values to a cut off α (e.g., 0.05) controls the average false discovery rate (the average chance of a false positive amongst rejections) at α.[29] Given the large number of models, a uniform approach was used to model exposures as linear. As sensitivity analysis, *F*-tests comparing the original linear adjusted models to more flexible models that included exposure as a restricted cubic spline with three knots selected as quartiles of the exposure variable were also conducted. Analyses were conducted using SAS, version 9.4.

RESULTS

Characteristics of the 1,234 mother–child pairs are presented in Table 1. Among the mothers, mean age at enrollment was 32.3 (SD=5.1) years and mean pre-pregnancy BMI was 24.4 (SD=4.9) kg/m^2. They consumed on average 49.8 (SD=12.9) grams of sucrose, 32.7 (SD=10.1) grams of fructose, 0.6 (SD=0.8) servings of SSBs, 1.3 (SD=0.9) servings of juice, and 0.2 (SD=0.5) servings of diet soda per day. Compared with mothers in the lowest quartile of SSB consumption, a greater percentage of mothers who were in the highest quartile smoked during pregnancy (17.3% vs 6.7%). Mothers in the highest quartile of SSB consumption also had on average lower education levels (55.7% vs 81.6% were college graduates) and lower incomes (55.8% vs 72.5% had income levels >$70,000), compared with mothers in the lowest quartile.

Among the children, ≅32% were racial/ethnic minorities and half were female. At the early childhood assessment, they consumed on average 30.1 (SD=9.2) grams of sucrose, 27.8 (SD=11.5) grams of fructose, 0.2 (SD=0.5) servings of SSBs, 1.8 (SD=1.4) servings of juice, and 0.03 (SD=0.14) servings of diet soda per day and had mean PPVT-III score of 104.0 (SD=14.2) and total WRAVMA score of 102.6 (SD=11.2) points. At the mid-childhood assessment, children had an average KBIT-II verbal score of 112.7 (SD=14.5), KBIT-II non-verbal score of 106.8 (SD=16.6), WRAVMA drawing score of 92.2 (SD=16.7), and WRAML visual memory score of 17.0 (SD=4.4) points.

Several measures of maternal sugar consumption during pregnancy were associated with poorer child cognition in early and mid-childhood (Table 2). Maternal sucrose consumption was inversely associated with non-verbal KBIT-II scores and WRAML scores at the mid-childhood assessment; for each additional 15 grams of sucrose consumed per day, children had lower non-verbal KBIT-II scores by an average of −1.5 points (95% CI= −2.8, −0.2) and on the WRAML by −0.5 points (95% CI= −0.8, −0.1). In addition, greater prenatal SSB consumption was inversely associated with both KBIT-II verbal and non-verbal scores at the mid-childhood assessment; for each additional daily SSB serving, KBIT-II verbal scores were on average −1.2 points lower (95% CI= −2.4, 0.0) and non-verbal scores were on average −1.7 points lower (95% CI= −3.2, −0.1). Neither maternal sucrose nor SSB consumption was associated with early childhood cognition. However, diet soda consumption was inversely associated with cognition; each additional daily serving of diet soda was associated with a lower average total WRAVMA score in early childhood by 1.5 points (95% CI= −2.9, −0.1) and 3.2 points lower (95% CI= −5.0, −1.5) on the verbal KBIT-II at mid-childhood. No associations between maternal fructose or juice consumption and childhood cognition were evident.

In the models examining early childhood sugar and beverage consumption with cognitive functioning in early and mid-childhood, no associations were evident for child intake of sucrose, fruit juice, or diet soda with cognition (Table 3). Early childhood SSB consumption was inversely associated with KBIT-II verbal scores at mid-childhood; for each additional SSB serving per day, KBIT scores were on average 2.4 points lower (95% CI= −4.3, −0.5). Additionally, child fructose intake was positively associated with cognitive scores in early childhood; for each additional 15 grams of fructose consumed per day, PPVT-III scores were on average 1.5 points higher (95% CI=0.5, 2.6), although no associations were seen at mid-childhood. Fruit consumption in early childhood was also positively associated with PPVT-III as well as total WRAVMA test scores at the early childhood assessment and the verbal KBIT-II at the mid-childhood assessment.

In sensitivity analysis with *F*-tests comparing models with exposure included linearly to those including exposure as a restricted cubic spline, three of the highlighted associations above had a significant *F*-test *p*-value (KBIT-II verbal in mid childhood as well as fructose and fruit intake in childhood with PPVT-III in early childhood) suggesting the linear assumption is overly restrictive. For these three exposure–outcome associations, alternative models that replace linear exposure with indicator of quartiles of exposure in the adjusted models are presented in Appendix Table 1. The direction of the association comparing the highest to lowest quartiles in each case matches that of the slope of the main results.

Based on false discovery rate adjusted *p*-values (Tables 2 and 3), only the association between maternal diet soda consumption during pregnancy and KBIT-II verbal scores in mid-childhood was statistically significant selecting α=0.05. Results did not differ in sensitivity analyses including the 18 children born <34 weeks gestation or excluding children born after pregnancies complicated by preeclampsia.

DISCUSSION

This prospective cohort study found that greater prenatal sucrose and SBB intake by mothers was associated with poorer cognition among the offspring. Maternal sucrose consumption was associated with poorer non-verbal abilities to solve novel problems and poorer verbal memory, visual memory, and learning; whereas maternal SSB consumption was associated with poorer global intelligence associated with both verbal knowledge and non-verbal skills. Additionally, maternal diet soda consumption was associated with poorer fine motor, visual spatial, and visual motor abilities in early childhood and poorer verbal abilities in mid-childhood. Childhood SSB consumption was associated with poorer verbal intelligence at mid-childhood. Child consumption of both fructose and fruit in early childhood was associated with higher cognitive scores across several domains; both were associated with greater receptive vocabulary and fruit was additionally associated with greater visual motor abilities in early childhood and verbal intelligence in mid-childhood. Fruit juice intake was not associated with cognition.

Animal evidence supports these findings that early life exposure to excess sugar may adversely influence cognitive development. One study found that high sucrose intake in rats during periods of neurodevelopment caused impairments in hippocampus and prefrontal cortex functioning, leading to poorer executive functioning.[10] Similarly, the present study found that SSBs consumed by mothers during pregnancy and children were associated with poorer cognitive outcomes. Interestingly, child sucrose consumption was not associated with cognition, which may suggest that HFCSs are driving the inverse association between SSBs and cognition. This is consistent with a study in rats that found HFCS impacted learning and memory during periods of neurodevelopment through deleterious effects on hippocampal functioning.[9] However, the rats compensated for consuming the sugar solution by eating less food, which may have influenced the results. Similarly, another study in rats found that a Western diet high in HFCS impacted the hippocampus and negatively impacted spatial learning performance.[13] Because some of the SSBs consumed in the present study may not have been exclusively sweetened with HFCS, additional human studies should be conducted to confirm this association.

Studies examining associations of children's SSB intake with cognitive outcomes have been inconsistent. A meta-analysis that examined 16 interventions found no overall association between sugar and cognition, although the control arms in the included studies were given artificial sweeteners.[16] The present study found that greater prenatal consumption of diet soda was also associated with poorer child cognitive scores. Previous research in pregnant rats has found that aspartame consumption, the primary artificial sweetener in diet soda, resulted in poorer offspring developmental outcomes potentially because of alterations to brain neurotransmitters.[30,31] Similar to a previous study that found no association between consumption of aspartame and children's cognition,[32] this study found no association between childhood diet soda consumption and cognition, although the analyses may have been underpowered.

Fructose consumption in early childhood was also associated with higher cognitive test scores. This association appeared primarily because of fruit consumption. Fruit juice intake was not associated improved cognition, which may suggest the benefits are from other aspects of fruits, such as phytochemicals, and not fructose itself. A small number of studies examining children have previously found fruit consumption positively associated with executive functioning.[33]

Participants in the present study consumed an estimated 30 to 50 grams of sucrose daily (children and mothers, respectively), which corresponds with 120 to 200 kcal/day from sucrose. Although this is less than that of most Americans, who consume on average 77 grams (approximately 300 kcal) of added sugar daily,[2] the adverse associations seen with sucrose and SSB consumption and child cognition were at consumption levels around the Dietary Guidelines for Americans recommendations of no more than 10% of calories from added sugar.[1] However, these consumption levels were still substantially above the American Heart Association guidelines for added sugars, which recommend that children and adult women should consume on average no more than 25 grams daily.[4,5]

Limitations

This study had several potential limitations. Only a subset of the Viva cohort completed the early and mid-childhood visits, and these participants were on average a higher SES and a higher proportion were white than the overall cohort and the U.S. population, which may limit generalizability of the results. However, similar to most Americans, consumption of sugar was on average still above recommended limits and the broad range of intakes represents a relevant biological range. Additionally, this study relied on self-reported diet, although validated FFQs were used. Although there was no information on paternal intelligence quotient, paternal education was examined as a potential confounder. It is also possible that there was some reporting bias for children's dietary consumption dependent on the parents' perception of their child's development and awareness of potential associations with sugar and cognition; however, this would have biased the results towards the null, thus leading to more conservative findings.

As in any observational study in which exposures are not randomized, unmeasured confounding may explain estimated associations. The chance of a Type I error may have also been higher than desired in this study because of multiple tests. This study was strengthened by its prospective design and large sample size. Additionally, detailed dietary assessments for mothers and their children, as well as several measures of cognition at both early and mid-childhood, were performed.

CONCLUSIONS

This large prospective study found that sucrose consumption, particularly SSB consumption, during pregnancy and childhood may adversely impact child memory and learning, whereas maternal diet soda intake also appeared harmful, and fruit consumption in childhood may be beneficial. While women should consider limiting added sugar consumption during pregnancy, diet soda may not be an ideal alternative. Interventions, policies, and programs such as the Special Supplemental Nutrition Program for Women, Infants, and Children and the National School Lunch Program that promote diets higher in fruit and lower in added sugars may prevent adverse effects on childhood cognition.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Characteristics of 1,234 Mother-Child Pairs in Project Viva by Prenatal SSB Intake[a]

Characteristics		Quartile of maternal first and second trimester SSB			
	Overall n=1,234	Q1 n=315	Q2 n=301	Q3 n=311	Q4 n=307
Maternal characteristics, N (%)					
Nulliparous, %					
No	646 (52.4)	169 (53.7)	161 (53.5)	164 (52.7)	152 (49.5)
Yes	588 (47.6)	146 (46.3)	140 (46.5)	147 (47.3)	155 (50.5)
Smoking status, %					
Never	854 (69.4)	228 (72.6)	216 (72.0)	206 (66.2)	204 (66.7)
Former	253 (20.6)	65 (20.7)	66 (22.0)	73 (23.5)	49 (16.0)
During pregnancy	124 (10.1)	21 (6.7)	18 (6.0)	32 (10.3)	53 (17.3)
College graduate, %					
No	366 (29.7)	58 (18.4)	89 (29.6)	83 (26.8)	136 (44.3)
Yes	867 (70.3)	257 (81.6)	212 (70.4)	227 (73.2)	171 (55.7)
Annual household income, %					
<$70,000	410 (35.5)	82 (27.5)	105 (36.2)	100 (34.6)	123 (44.2)
>$70,000	745 (64.5)	216 (72.5)	185 (63.8)	189 (65.4)	155 (55.8)
Age at enrollment, years, mean (SD)	32.3 (5.1)	34.0 (4.6)	32.8 (4.9)	31.9 (4.7)	30.4 (5.5)
Pre-pregnancy BMI, kg/m^2, mean (SD)	24.4 (4.9)	23.5 (4.1)	24.1 (4.3)	24.9 (5.5)	25.0 (5.6)
Maternal first-second trimester intake, mean (SD)					
Sucrose, grams/day	49.8 (12.9)	43.3 (10.6)	47.0 (10.1)	50.4 (11.3)	58.8 (13.8)
Fructose, grams/day	32.7 (10.1)	30.7 (10.7)	31.1 (9.2)	32.5 (8.7)	36.7 (10.5)
SSB, servings/day	0.6 (0.7)	0.0 (0.0)	0.2 (0.1)	0.6 (0.1)	1.7 (0.8)
Juice, servings/day	1.3 (0.9)	1.0 (0.8)	1.3 (0.8)	1.4 (0.9)	1.6 (1.2)
Diet soda, servings/day	0.2 (0.5)	0.2 (0.4)	0.2 (0.4)	0.2 (0.6)	0.2 (0.4)
Fruit, servings/day	1.8 (1.1)	2.1 (1.2)	1.8 (0.9)	1.5 (0.9)	1.6 (1.2)
Fish intake, servings/week	1.7 (1.3)	1.8 (1.5)	1.6 (1.2)	1.6 (1.2)	1.6 (1.3)
Child characteristics, N (%)					
Race/ethnicity, %					
Black	158 (12.8)	22 (7.0)	34 (11.3)	39 (12.5)	63 (20.5)

Characteristics	Quartile of maternal first and second trimester SSB				
	Overall n=1,234	Q1 n=315	Q2 n=301	Q3 n=311	Q4 n=307
Hispanic	56 (4.5)	11 (3.5)	9 (3.0)	15 (4.8)	21 (6.8)
White	843 (68.3)	233 (74.0)	212 (70.4)	211 (67.8)	187 (60.9)
Other	177 (14.3)	49 (15.6)	46 (15.3)	46 (14.8)	36 (11.7)
Sex, %					
Male	620 (50.2)	154 (48.9)	155 (51.5)	147 (47.3)	164 (53.4)
Female	614 (49.8)	161 (51.1)	146 (48.5)	164 (52.7)	143 (46.6)
Gestation length, weeks, Mean (SD)	39.7 (1.4)	39.8 (1.3)	39.7 (1.4)	39.7 (1.5)	39.5 (1.5)
Birth weight, grams, Mean (SD)	3513 (508)	3522 (472)	3544 (488)	3539 (522)	3448 (542)
Birth weight for gestational age *z*-score, Mean (SD)	0.20 (0.95)	0.19 (0.91)	0.24 (0.94)	0.27 (0.95)	0.09 (0.99)
Breastfeeding duration, months, Mean (SD)	6.5 (4.5)	7.5 (4.4)	6.8 (4.5)	6.4 (4.4)	5.1 (4.5)
Exposures early childhood,[a] Mean (SD)					
Sucrose, grams/day	30.1 (9.2)	28.8 (9.2)	30.6 (9.4)	30.5 (9.1)	30.6 (9.1)
Fructose, grams/day	27.8 (11.5)	27.9 (11.6)	28.2 (11.5)	26.8 (11.1)	28.3 (11.9)
SSB, servings/day	0.2 (0.5)	0.1 (0.4)	0.2 (0.3)	0.3 (0.5)	0.5 (0.8)
Juice, servings/day	1.8 (1.4)	1.6 (1.4)	1.6 (1.3)	1.7 (1.3)	2.2 (1.7)
Diet soda, servings/day	0.03 (0.14)	0.02 (0.07)	0.03 (0.10)	0.03 (0.12)	0.05 (0.23)
Fruit, servings/day	2.5 (1.6)	2.6 (1.7)	2.5 (1.6)	2.4 (1.5)	2.4 (1.6)
Cognitive scores early childhood,[b] Mean, (SD)					
PPVT-III	104.0 (14.2)	105.8 (13.6)	104.1 (14.2)	104.2 (14.1)	101.8 (14.7)
Total WRAVMA	102.6 (11.2)	103.7 (11.6)	102.4 (10.8)	102.6 (11.4)	101.4 (10.8)
Cognitive scores mid-childhood,[c] Mean (SD)					
KBIT-II verbal	112.7 (14.5)	116.4 (13.3)	112.4 (13.7)	112.6 (14.1)	108.8 (15.9)
KBIT-II non-verbal	106.8 (16.6)	110.8 (16.5)	104.8 (17.0)	107.1 (16.4)	104.0 (15.7)
WRAVMA drawing	92.2 (16.7)	93.3 (17.9)	90.3 (15.0)	94.3 (16.5)	90.5 (16.8)
WRAML visual memory	17.0 (4.4)	17.3 (4.4)	16.9 (4.2)	16.7 (4.3)	17.0 (4.5)

[a]Prenatal SSB intake was calculated as the average of the first and second trimesters.

[b]Early childhood dietary assessments and cognitive tests were administered median 3.3 years.

[c]Mid-childhood cognitive tests were administered at median 7.7 years.

SSB, sugar-sweetened beverage; PPVT-III, Peabody Picture Vocabulary Test, third edition; WRAVMA, Wide Range Assessment of Visual Motor Abilities; KBIT-II, Kaufman Brief Intelligence Test, second edition; WRAML, Wide Range Assessment of Memory and Learning.

Table 2

Associations of Maternal Sugar, Beverage, and Fruit Consumption With Child Cognition in Early and Mid-Childhood[a]

Dietary exposure	N	β (95% CI)[b]	*p*-value	FDR
Sucrose, per 15 grams/day				
PPVT-III, early childhood	1,114	−0.2 (−1.1, 0.8)	0.69	0.85
Total WRAVMA, early childhood	1,077	0.5 (−0.3, 1.3)	0.23	0.65
KBIT-II verbal, mid-childhood	965	−0.5 (−1.6, 0.5)	0.30	0.69
KBIT-II non-verbal, mid-childhood	974	−1.5 (−2.8, −0.2)	0.03	0.25
WRAVMA drawing, mid-childhood	967	−1.2 (−2.5, 0.2)	0.08	0.37
WRAML visual memory, mid-childhood	970	−0.5 (−0.8, −0.1)	0.01	0.18
Fructose, per 15 grams/day				
PPVT-III, early childhood	1,114	−0.4 (−1.6, 0.8)	0.53	0.85
Total WRAVMA, early childhood	1,077	0.2 (−0.8, 1.2)	0.68	0.85
KBIT-II verbal, mid-childhood	965	−0.1 (−1.4, 1.1)	0.83	0.85
KBIT-II non-verbal, mid-childhood	974	−0.5 (−2.1, 1.2)	0.58	0.85
WRAVMA drawing, mid-childhood	967	−0.8 (−2.5, 0.9)	0.34	0.69
WRAML visual memory, mid-childhood	970	−0.3 (−0.7, 0.1)	0.18	0.60
Sugar-sweetened beverages, servings/day				
PPVT-III, early childhood	1,114	−0.4 (−1.6, 0.7)	0.45	0.77
Total WRAVMA, early childhood	1,077	−0.5 (−1.5, 0.5)	0.34	0.69
KBIT-II verbal, mid-childhood	965	−1.2 (−2.4, 0.0)	0.06	0.34
KBIT-II non-verbal, mid-childhood	974	−1.7 (−3.2, −0.1)	0.03	0.25
WRAVMA drawing, mid-childhood	967	−1.0 (−2.6, 0.6)	0.23	0.65
WRAML visual memory, mid-childhood	970	−0.1 (−0.5, 0.3)	0.62	0.85
Juice, servings/day				
PPVT-III, early childhood	1,114	0.4 (−0.5, 1.2)	0.42	0.76
Total WRAVMA, early childhood	1,077	−0.4 (−1.1, 0.4)	0.32	0.69
KBIT-II verbal, mid-childhood	965	−0.4 (−1.4, 0.5)	0.37	0.71
KBIT-II non-verbal, mid-childhood	974	−0.3 (−1.4, 0.9)	0.66	0.85
WRAVMA drawing, mid-childhood	967	−0.2 (−1.4, 1.0)	0.74	0.85
WRAML visual memory, mid-childhood	970	0.0 (−0.3, 0.3)	0.96	0.96
Diet soda, servings/day				
PPVT-III, early childhood	1,114	−1.2 (−2.9, 0.5)	0.15	0.55
Total WRAVMA, early childhood	1,077	−1.5 (−2.9, −0.1)	0.03	0.25
KBIT-II verbal, mid-childhood	965	−3.2 (−5.0, −1.5)	0.0003	0.01
KBIT-II non-verbal, mid-childhood	974	−2.0 (−4.3, 0.2)	0.08	0.37
WRAVMA drawing, mid-childhood	967	−1.7 (−4.1, 0.6)	0.15	0.55
WRAML visual memory, mid-childhood	970	−0.1 (−0.7, 0.5)	0.73	0.85
Fruit, servings/day				
PPVT-III, early childhood	1,114	−0.1 (−0.8, 0.7)	0.83	0.85
Total WRAVMA, early childhood	1,077	−0.1 (−0.7, 0.6)	0.82	0.85

Dietary exposure	N	β (95% CI)[b]	*p*-value	FDR
KBIT-II verbal, mid-childhood	965	0.2 (−0.6, 1.0)	0.70	0.85
KBIT-II non-verbal, mid-childhood	974	−0.1 (−1.2, 0.9)	0.81	0.85
WRAVMA drawing, mid-childhood	967	−0.3 (−1.3, 0.8)	0.60	0.85
WRAML visual memory, mid-childhood	970	−0.1 (−0.4, 0.1)	0.30	0.69

Notes: Values are based on multivariable linear regression.

[a]Consumption was calculated as the mean of the first and second trimester. Early childhood cognition was assessed at a median of 3.3 years and mid-childhood cognition was assessed at a median of 7.7 years.

[b]Adjusted for maternal age, pre-pregnancy BMI, parity, college graduate, fish intake (average of first and second trimester), smoking during pregnancy, household income at enrollment >$70,000, and child sex and race/ethnicity.

FDR, False Discovery Rate adjusted *p*-value based on n=36 models; PPVT-III, Peabody Picture Vocabulary Test, third edition; WRAVMA, Wide Range Assessment of Visual Motor Abilities; KBIT-II, Kaufman Brief Intelligence Test, second edition; WRAML, Wide Range Assessment of Memory and Learning.

Table 3

Associations of Early Childhood Sugar, Beverage, and Fruit Consumption With Child Cognition in Early (Median 3.3 Years) and Mid-Childhood (Median 7.7 years)[a]

Dietary exposure	N	β (95% CI)[b]	*p*-value	FDR
Sucrose, per 15 grams/day				
PPVT-III, early childhood	1,002	0.1 (−1.2, 1.4)	0.88	0.93
Total WRAVMA, early childhood	965	0.0 (−1.1, 1.2)	0.96	0.99
KBIT-II verbal, mid-childhood	850	−0.2 (−1.6, 1.3)	0.79	0.90
KBIT-II non-verbal, mid-childhood	856	−0.4 (−2.2, 1.5)	0.71	0.88
WRAVMA drawing, mid-childhood	850	−0.4 (−2.3, 1.6)	0.72	0.88
WRAML visual memory, mid-childhood	853	−0.1 (−0.6, 0.4)	0.73	0.88
Fructose, per 15 grams/day				
PPVT-III, early childhood	1,002	1.5 (0.5, 2.6)	0.005	0.14
Total WRAVMA, early childhood	965	0.7 (−0.2, 1.6)	0.13	0.78
KBIT-II verbal, mid-childhood	850	0.4 (−0.8, 1.5)	0.53	0.87
KBIT-II non-verbal, mid-childhood	856	0.8 (−0.7, 2.2)	0.29	0.85
WRAVMA drawing, mid-childhood	850	0.6 (−0.9, 2.1)	0.44	0.85
WRAML visual memory, mid-childhood	853	0.3 (−0.1, 0.6)	0.20	0.85
Sugar-sweetened beverages, servings/day				
PPVT-III, early childhood	1,031	−0.8 (−2.7, 1.0)	0.38	0.85
Total WRAVMA, early childhood	994	−0.4 (−2.0, 1.2)	0.60	0.88
KBIT-II verbal, mid-childhood	877	−2.4 (−4.3, −0.5)	0.01	0.14
KBIT-II non-verbal, mid-childhood	884	0.8 (−1.6, 3.2)	0.52	0.87
WRAVMA drawing, mid-childhood	878	−1.0 (−3.6, 1.5)	0.42	0.85
WRAML visual memory, mid-childhood	881	−0.1 (−0.7, 0.6)	0.84	0.92
Juice, servings/day				
PPVT-III, early childhood	1,032	0.2 (−0.4, 0.8)	0.47	0.85
Total WRAVMA, early childhood	996	0.1 (−0.4, 0.7)	0.56	0.88
KBIT-II verbal, mid-childhood	878	−0.3 (−0.9, 0.3)	0.30	0.85
KBIT-II non-verbal, mid-childhood	885	0.0 (−0.8, 0.8)	0.99	0.99
WRAVMA drawing, mid-childhood	879	0.3 (−0.5, 1.1)	0.43	0.85
WRAML visual memory, mid-childhood	882	0.1 (−0.2, 0.3)	0.61	0.88
Diet soda, servings/day				
PPVT-III, early childhood	1,028	−1.6 (−9.0, 5.9)	0.68	0.88
Total WRAVMA, early childhood	991	0.8 (−5.7, 7.4)	0.80	0.90
KBIT-II verbal, mid-childhood	874	2.1 (−7.1, 11.3)	0.65	0.88
KBIT-II non-verbal, mid-childhood	881	−4.6 (−16.6, 7.3)	0.45	0.85
WRAVMA drawing, mid-childhood	875	6.8 (−5.5, 19.0)	0.28	0.85
WRAML visual memory, mid-childhood	878	1.2 (−1.9, 4.4)	0.45	0.85
Fruit intake, servings/day				
PPVT-III, early childhood	1,033	0.6 (0.1, 1.1)	0.03	0.24
Total WRAVMA, early childhood	996	0.6 (0.1, 1.1)	0.009	0.14

Dietary exposure	N	β (95% CI)[b]	*p*-value	FDR
KBIT-II verbal, mid-childhood	878	0.5 (0.0, 1.1)	0.06	0.40
KBIT-II non-verbal, mid-childhood	885	0.4 (−0.3, 1.1)	0.31	0.85
WRAVMA drawing, mid-childhood	879	0.4 (−0.3, 1.2)	0.24	0.85
WRAML visual memory, mid-childhood	882	0.1 (−0.1, 0.3)	0.34	0.85

Notes: Values are based on multivariable linear regression.

[a]Early childhood cognition was assessed at a median of 3.3 years and mid-childhood cognition was assessed at a median of 7.7 years.

[b]Adjusted for maternal age, pre-pregnancy BMI, parity, college graduate, fish intake (average of first and second trimester), smoking during pregnancy, household income at enrollment >$70,000, and corresponding intake during pregnancy (i.e., sucrose, fructose, sugar-sweetened beverages, fruit juice, or diet soda) and child sex, race/ethnicity, and birth weight for gestational age *z*-score.

FDR, False Discovery Rate adjusted *p*-value based on n=36 models; PPVT-III, Peabody Picture Vocabulary Test, third edition; WRAVMA, Wide Range Assessment of Visual Motor Abilities; KBIT-II, Kaufman Brief Intelligence Test, second edition; WRAML, Wide Range Assessment of Memory and Learning.

Appendix Table 1

Associations of Maternal Diet Soda Consumption (Mean First and Second Trimester) and Child Fructose and Fruit Consumption With Child Cognition in Early (Median 3.3 Years) and Mid-Childhood (Median 7.7 Years) Alternatively Modeled as Quartiles

Consumption quartiles	β (95% CI)[a]
Maternal diet soda consumption	
KBIT-II verbal, mid-childhood	
Q1	0.0 (ref)
Q2	−0.9 (−3.0, 1.1)
Q3	−2.7 (−5.0, −0.3)
Q4	−6.5 (−9.8, −3.2)
Child fructose consumption	
PPVT-III, early childhood	
Q1	0.0 (ref)
Q2	1.0 (−1.3, 3.3)
Q3	2.7 (0.4, 5.0)
Q4	2.6 (0.3, 4.8)
Child fruit consumption	
PPVT-III, early childhood	
Q1	0.0 (ref)
Q2	1.4 (−0.9, 3.7)
Q3	2.4 (0.1, 4.7)
Q4	2.9 (0.5, 5.3)

KBIT-II, Kaufman Brief Intelligence Test, second edition; PPVT-III, Peabody Picture Vocabulary Test, third edition; Q, quartile

[a]Adjusted for maternal age, pre-pregnancy BMI, parity, college graduate, fish intake (average of first and second trimester), smoking during pregnancy, household income at enrollment >$70,000, and child sex and race/ethnicity. Child exposures additionally adjusted for birth weight for gestational age *z*-score and corresponding intake during pregnancy.