American Journal of
Preventive Medicine

RESEARCH ARTICLE

Associations of Prenatal and Child Sugar Intake With Child Cognition

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

Am J Prev Med 2018;▮(▮):▮▮▮–▮▮▮. *© 2018 American Journal of Preventive Medicine. Published by Elsevier Inc. All rights reserved.*

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

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0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2018.02.020

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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

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