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Adolescents perceive a low added sugar adequate fiber diet to be more satiating and equally palatable compared to a high added sugar low fiber diet in a randomized-crossover design controlled feeding pilot trial

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ABSTRACT

Background: High added sugar (AS) intake is associated with obesity and poor diet quality. Guidelines recommended limiting AS to 5–10% of total energy intake, but palatability and feasibility of this AS intake level is uncertain.
Objective: To compare adolescents' perceptions of hunger, fullness, and palatability in response to a low AS adequate fiber (LASAF; 5% total energy from AS and 13.5 g fiber/1000 kcal) and a high AS low fiber (HASLF; 25% total energy form AS and 8.2 g/1000 kcal) diet.
Design: Adolescents (n = 32, age: 15.3 ± 1.6 yrs., BMI percentile: 47 ± 4, 15 male) completed a randomized, crossover, controlled feeding study. Participants consumed calorie-matched LASAF and HASLF diets for 7 days, separated by a 4 week washout. Body weight was monitored daily on each diet. Hunger, fullness, and palatability were assessed via 100 mm visual analogue scales at the end of each feeding period. Differences were assessed with paired sample t-tests. Data are expressed as mean ± SD.
Results: Participants remained weight stable, and no difference in weight change between diet conditions was detected (LASAF: −0.06 ± 0.7 vs. HASLF: −0.02 ± 0.6 kg, p = 0.751). Less hunger (LASAF: 24.1 ± 14.6 vs. HASLF: 32.1 ± 17.6 mm, p = 0.024) and greater fullness (LASAF: 70.2 ± 12.3 vs. HASLF: 61.3 ± 18.1 mm, p = 0.006) were reported on the LASAF compared to the HASLF. Participants reported the diets to be equally palatable (LASAF: 39.6 ± 12.9 vs. HASLF: 37.2 ± 17.8 mm, p = 0.440).
Conclusions: Adolescents perceive a LASAF diet to be as palatable as a HASLF diet, but more satiating. LASAF diets should be investigated as a strategy for weight control in adolescents.

1. Introduction

Adolescents in the United States consume approximately 17% of total energy intake (~380 kcal/d) from added sugars (AS) (Ervin, Carroll, & Ogden, 2012). This intake level of sugars added to foods during processing, preparation, or at the table (Otten & Leyers, 2006) exceeds that of all other age groups (Ervin et al., 2012). Consumption of hypercaloric diets high in AS has been implicated in the development of obesity, cardiovascular disease, (CVD), and dental caries in children and adolescents (Vos, Kaar, Welsh, et al., 2016). Therefore, the American Heart Association recently recommended intake of AS be limited to ≤25 g/d (or 100 kcal/d) for this segment of the population (Vos et al., 2016). This is equivalent to an intake of no > 5% of total energy intake coming from AS on a 2000 kcal diet, and is consistent with recommendations from other organizations, including the World Health Organization and the Dietary Guidelines for Americans (DGA) (*2015 dietary guidelines for Americans*, 2015; *Guideline: Sugars intake for adults and children*, 2015).

Reducing AS consumption may be an effective strategy to decrease disease risk by increasing diet quality (e.g., reducing empty calories and increasing dietary fiber) (Ruottinen, Niinikoski, Lagström, et al., 2008). Analysis of National Health and Nutrition Examination Survey data shows that as AS content of the diet (as a percentage of total energy) increases, there is a reduction in nutrient adequacy (as a percentage of

Abbreviations: AS, added sugar; LASAF, low added sugar adequate fiber; HASLF, high added sugar low fiber; CVD, cardiovascular disease; DGA, Dietary Guidelines for Americans; NDS-R, Nutrition Data System for Research; g, gram; PAQ-A, Physical Activity Questionnaire for Adolescents; IOM, Institute of Medicine; VAS, visual analogue scale

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Dietary Reference Intakes) (Marriott, Olsho, Hadden, & Connor, 2010; Vos et al., 2016). Specifically, nutrient intake is lowest when AS intake exceeds 25% of total energy intake (Marriott et al., 2010). Seventeen percent of adolescent males and 20.3% of adolescent females consume a diet containing > 25% of total energy from AS, which is more than any other life stage group (Marriott et al., 2010). It is well established that the atherosclerotic progression leading to CVD starts in childhood, and is heavily influenced by lifestyle factors such as dietary intake and body weight (Vos et al., 2016). In addition to improving dietary quality, it has also been suggested that a reduction in AS intake to recommended levels could have significant impact on weight management strategies over the lifespan by promoting a decrease in total energy intake (*2015 dietary guidelines for Americans*, 2015; *Dietary Guidelines for Americans*, 2010; Drewnowski, 1998; Ebbeling, Feldman, Chomitz, et al., 2012). Therefore, adolescence may be a critical period for adherence to AS guidelines in order to establish healthy dietary habits to reduce risk of weight gain and chronic diseases.

Decreasing AS intake is challenging due to their widespread incorporation in the food supply (Basu & Lewis, 2014; Guthrie & Morton, 2000; Reedy & Krebs-Smith, 2010). The addition of sugar to food products acts to enhance texture, add body to improve mouthfeel, extend shelf life, and perhaps most importantly, increase palatability (Erickson & Slavin, 2015; Goldfein & Slavin, 2015). Based on 2016 and previous consumer surveys conducted by the International Food Information Council, the majority of respondents cite 'taste' as the biggest influencer of their food and beverage purchasing decisions (http://www.foodinsight.org/sites/default/files/2016_executivesummary_final_web.pdf, 2016). Thus, it makes sense that food manufacturers would add extrinsic sugar sources to their products in order to increase consumption and sales. However, to date, no randomized controlled trials have evaluated adolescents' hunger and satiety ratings of low vs high AS diets, making it difficult to determine the feasibility and palatability of AS intake guidelines.

The purpose of this investigation was to compare adolescents' perceptions of hunger, fullness, and palatability in response to diets of low (5% total energy) and high (25% total energy) AS content. These levels were selected for comparison due to their public health relevance. The 5% of total energy low AS diet is in line with current recommendations (Vos et al., 2016), and the 25% of total energy high AS diet is associated with a high risk of nutrient inadequacy, when consumed chronically (Marriott et al., 2010). The low AS diet also had adequate fiber content (LASAF; 13.5 g fiber/1000 kcal) and the high AS diet had low fiber content (HASLF; 8.2 g fiber/1000 kcal) according to IOM guidelines (*Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients)*, 2005), as occurred naturally when creating diets comprised of similar foods and matched macronutrient intake.

2. Materials and methods

2.1. Participants

Non-obese (BMI < 95th percentile for age and sex) adolescents (12–18 years) without food allergies/intolerances were eligible for enrollment in this randomized, crossover, controlled feeding study. The Virginia Tech Institutional Review Board approved the study protocol. All participants provided written informed assent and a parent/legal guardian provided written informed consent prior to participation.

2.2. Study design

This investigation was a sub-study of a trial designed to determine the validity and sensitivity of a fingerstick blood δ^{13}C AS biomarker (Clinical Trials ID: NCT02455388) (Davy & Jahren, 2016; Moore et al., 2017). Following baseline assessments, participants completed two 7-day controlled feeding periods, consisting of a LASAF (5% total energy from AS and 13.5 g fiber/1000 kcal) and a HASLF (25% total energy from AS and 8.2 g fiber/1000 kcal) diet, in a randomized, counter-balanced order (e.g. Sequence A: LASAF first and HASLF second or Sequence B: HASLF first and LASAF second), stratified by sex. A washout period of at least 4 weeks separated each feeding period. Diets were created using Nutrition Data System for Research (NDS-R) software, version 2013 (*Nutrition data systems for research [computer program]*, 2015) and consisted of 3-day rotating menus at five energy levels (2000, 2500, 3000, 3500 and 4500 kcals) for both the LASAF and HASLF conditions. The LASAF and HASLF diets were matched for macronutrient composition (55% carbohydrate, 15% protein, and 30% fat), percentage of AS from solid (67%) and liquid (33%) sources (Guthrie & Morton, 2000), percentage of protein from animal (42%), dairy (20%), and vegetable/egg (38%) sources (Smit, Nieto, Crespo, & Mitchell, n.d.), and were designed to consist of similar foods [see Table 1 for sample menu]. Unavoidably, in addition to differences in fiber content, the diets also differed in energy density (LASAF: 0.97 kcals/g; HASLF: 1.30 kcals/g) and Healthy Eating Index (HEI)-2010 scores (a measure of diet quality based on adherence to US Dietary Guidelines; LASAF: 74; HASLF: 52) (Guenther, Casavale, Kirkpatrick, et al., 2013) [see Supplemental Table 1 for subgroup HEI scores]. Participants were provided two optional 150 kcal snack modules daily. The snack modules matched the composition of the base diets for each AS level (5% vs 25%), macronutrient composition, percentage of AS from liquid vs solid sources, and protein sources. Lastly, three optional sucralose (Splenda®) packets were included with each day's food intake for participants to use at their discretion. This was done in order to increase adherence to the diets. Trained metabolic kitchen research assistants prepared diets under the supervision of a doctoral-level Research Registered Dietitian Nutritionist.

Participants reported to the Metabolic Kitchen and Dining Laboratory each morning of the 7-day feeding period, following an overnight fast. Breakfast was consumed on-site and the remainder of the day's food and beverages were packed into a cooler. Participants were instructed to consume all foods provided and to report deviations from study protocol to research staff. Coolers were returned the following morning and compliance was assessed via weigh-back methodology using a digital benchtop scale (Practum 5101-1S, Sartorius; Goettingen, Germany), query of participants regarding adherence, and daily measurement of body weight on a digital scale. Actual nutrient intake per participant was calculated in NDS-R by subtracting food returned (e.g., residue in food containers) from food provided.

2.3. Measurements

At baseline, participants' height and body weight were determined without shoes, in light clothing to the nearest 0.1 cm and 0.1 kg, respectively using a wall-mounted stadiometer (Seca Model 216, Seca; Chino, CA) and digital scale (Scale-Tronix 5002, Welch Allyn; Skaneateles Falls, NY). Body weight was also measured daily during each of the 7-day feeding periods in order to ensure compliance and weight stability. Habitual energy intake was assessed with four 24-h record-assisted dietary recalls collected by trained research assistants using the multi-pass method (National Health and Nutrition Examination Survey (NHANES), 2010) on non-consecutive days, including one weekend day (Burrows, Martin, & Collins, 2010; Thompson & Subar, 2013). Intake was reported by the participant, with a parent/guardian serving as a proxy respondent as needed. Recalls were analyzed using NDS-R (version 2013) software. Usual physical activity was assessed via the Physical Activity Questionnaire for Adolescents (PAQ-A) (Kowalski & CPR, 1997). The assigned energy level of the provided diets was estimated using the 2005 Institute of Medicine (IOM) equations for pediatric populations (*Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients)*, 2005), with an appropriate activity level according to the PAQ-A.