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Children's Food and Satiety Responsiveness in association with Post-Prandial Glucose following a Standardized Liquid Meal

Marissa A. Gowe, Ph.D and Paula Chandler-Laney, Ph.D.

Department of Nutrition Sciences, University of Alabama at Birmingham

Abstract

Background—Children's responsiveness to food cues and satiety may put them at greater risk for obesity; however, little is known about the physiological mechanisms underlying children's responsiveness to food and satiety.

Objectives—To examine the association between children's post-prandial glucose responses and maternal report of their eating behaviors.

Methods—A secondary data analysis was conducted using partial correlation analyses adjusted for gender in a sample of children aged 5–10 years and their mothers (N=28 dyads). Standardized liquid meal tests were administered to children and blood samples were obtained over the following 4 hours. Mothers completed the Children's Eating Behavior Questionnaire.

Results—An earlier post-prandial peak glucose concentration was associated with greater food responsiveness ($r=-0.39$, $p=0.04$) but not satiety responsiveness. The percent increase in glucose from fasting to peak also tended to be inversely associated with greater food responsiveness ($r=-0.38$, $p=0.05$).

Conclusion—Results suggest that earlier and smaller post-prandial glucose excursions may be related to children's response to food cues. Future research should use objective methods to examine whether the association of post-prandial glucose with food responsiveness prospectively contributes to weight gain.

Keywords

children; glucose; eating behavior; satiety; standardized meal

Introduction

Food responsiveness (FR) and satiety responsiveness (SR) have been associated with energy intake, body mass index (BMI), and adiposity in children.¹ Indeed, children who exhibit more FR and less SR have higher prospective BMIs and weight gain over time.^{2,3} Yet, little

Corresponding Author: Marissa A. Gowe, PhD, University of Alabama at Birmingham, 1717 11th Ave S, MT 102, Birmingham AL 35205, Phone: 205-934-3362, mgowe@uab.edu.

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is known about the mechanisms that drive FR and SR. These eating behaviors become established early in life and remain relatively consistent across childhood,⁴ which suggests that individual differences in children's underlying metabolism may contribute to FR and SR.

Glucose metabolism is frequently implicated in eating behavior. Circulating glucose increases acutely following meals that contain carbohydrate, and then in healthy individuals, the counter-regulatory actions of insulin reduce glucose back to basal concentrations. In the 1950s, Mayer hypothesized that because glucose concentrations tend to be low prior to meals and return to basal several hours after meals, low circulating glucose concentrations trigger hunger and subsequent eating.⁵ Consistent with this, several studies in adults have demonstrated that post-prandial glucose levels are inversely associated with subsequent energy intake^{6–8}, and increases in circulating glucose have been associated with better satiation following a meal.⁹ In addition, individuals with an earlier glucose peak following meals, have an earlier return of hunger following meals.⁶ Together, these data suggest that circulating glucose may be associated with FR and SR, but to our knowledge, these relationships have not been explored in children.

The goal of this study was to examine whether children's post-prandial glucose responses were associated with FR and SR.¹⁰ Based on previous research and Mayer's glucostatic theory of food intake control,^{6,11} we hypothesized that an earlier and lower percent increase in post-prandial glucose response to a standardized meal would be associated with lower SR and greater FR in children.

Methods

Secondary data analysis was conducted using data from a parent study investigating associations between maternal and child metabolic health.¹² Detailed descriptions of the methods have been published.^{12–14} The current sample included children aged 5–10 years and their mothers who completed the Children's Eating Behaviour Questionnaire (N=35).¹⁰ Children were excluded if blood samples were not obtained (n=4) or Tanner stage 2¹⁵ had been reached (n=3), resulting in a final sample of 28 child-mother dyads. Prior approval for all study procedures was obtained from the governing IRB.

Following an overnight fast, children consumed a standardized liquid meal of Carnation Instant Breakfast mixed with whole milk (1.75g of CHO/kg lean body mass) within 5 minutes. Blood samples were drawn via an intravenous catheter at –15 and –5 minutes prior to the meal, with the mean providing the fasting concentration. After the meal, samples were drawn every 5 minutes from zero (time of meal consumption) to 30 minutes, every 10 minutes from 40 to 180 minutes, and at 210 and 240 minutes. Serum glucose was measured on the SIRRUS analyzer (Stanbio Laboratory). Time to peak glucose concentration was defined as the number of minutes following meal consumption before glucose reached the first highest level before it declined. If a second peak was observed, this was not considered. The increase in glucose after the meal as compared to fasting was calculated as the percent increase [(peak glucose – fasting glucose) / fasting glucose (mg/dL) * 100]. Mothers completed the Children's Eating Behaviour Questionnaire¹⁰ domains of food responsiveness

(tendency to eat in the presence of external cues) and satiety responsiveness (tendency to stop or not start eating due to feeling full). Total fat and lean mass were determined using dual energy X-ray absorptiometry (Lunar iDXA, GE Healthcare). Height and weight were measured in light clothing and no shoes to the nearest 0.01 cm using a digital stadiometer and 0.01 kg using a digital scale, respectively. BMI was calculated using the Centers for Disease Control norms.¹⁷

Statistical analysis

Normality of key variables was visually and quantitatively assessed. Gender, age, race, and BMI percentile were examined as potential covariates of FR and SR. Gender was the only significant covariate. Replacing BMI percentile with total percent body fat or lean body mass did not substantially change the results. Pearson partial correlation analyses adjusted for gender were conducted to examine associations between children's post-prandial glucose and reported eating behavior.

Results

Sample characteristics are described in Table 1. Most children were non-Hispanic, African American females with an average age between 7–8 years. Half of the children had overweight or obesity ($\geq 85^{\text{th}}$ BMI percentile).¹⁷

Table 2 displays partial correlation coefficients of the associations between FR, SR, and post-prandial glucose measures. A statistically significant correlation emerged between time to peak glucose and FR, such that an earlier glucose peak was associated with greater FR ($r = -0.39$, $p = 0.04$). There was also a trend for the percent increase from fasting glucose to be associated with FR ($r = -0.38$, $p = 0.05$), such that lower percent increase in glucose was associated with greater FR. Time to peak and the percent increase in glucose concentration were not significantly associated with SR.

Discussion

These results extend the literature by showing that an earlier post-prandial glucose peak concentration was associated with greater responsiveness to food cues in children. In addition, there were associations (near statistical significance) suggesting that children with less increase in glucose (from fasting to initial peak) following a meal may have greater FR. Together, these findings suggest that the timing and magnitude of increase in a child's glucose concentration following a meal may be related to his/her propensity to engage in food responsive behaviors (e.g. overeating and eating in the absence of hunger). Over time, these food responsive behaviors could contribute to greater weight gain as has been demonstrated in other studies.^{1,18,19} Increased experiences of hunger could be one factor contributing to the association between lower percent increase in post-prandial glucose and FR.¹¹ Additionally, post-prandial glucose response is a function of the carbohydrate content of the meal, along with the individual's insulin sensitivity, secretion, and hepatic insulin clearance. Although this particular study was not designed to examine whether these insulin parameters contributed to the association between glucose and FR, it would be useful to examine these potential mechanistic associations in a larger cohort.

Post-prandial glucose response was not associated with children's SR, which suggests that SR may not be as closely related to post-prandial glucose as FR. Moreover, SR may be more difficult for parents to infer from their children's behavior. Future work should employ objective measures such as the preload compensation test²⁰ to more robustly examine the association of glucose with SR.

Findings should be interpreted in the context of strengths and limitations. The standardized meal test provided objective glucose data which was combined with parent report of eating behavior. Future research would benefit from laboratory-based behavioral paradigms providing more objective eating behavior data. The interpretation of our findings are limited by the cross-sectional nature of the study. Thus, while we suggest that glucose metabolism may be a theoretical explanation of children's responsivity to food cues, it is also possible that children's FR contributes to their glucose metabolism. Additionally, our sample was diverse and young, but the small sample size limited statistical power (post-hoc power analyses estimated power ranged from 44–76%). However, we were able to detect effects between post-prandial glucose characteristics and food responsiveness despite being underpowered, which demonstrates the strength of these associations. It will be important to replicate these findings in a larger cohort that is adequately powered to include multiple covariates that should be adjusted for, such as children's weight status.

Future research should examine underlying physiological mechanisms and other potential mediators (e.g., executive function)²¹ of the association between children's glucose metabolism and objective measures of their eating behaviors. These findings could have implications for developing novel bio-behavioral prevention and treatment strategies for pediatric obesity.

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Abbreviations

FR	Food responsiveness
SR	Satiety responsiveness
BMI	Body mass index

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What is already known about this subject

- Responsiveness to food cues and satiety in children are associated with weight status.
- Circulating glucose is implicated in food and satiety responsiveness in adults, but little is known about these associations in children.

What this study adds

- Children with earlier post-prandial glucose peaks following an oral challenge were reported to be more responsive to food cues.
- If replicated in a larger cohort, these findings suggest that children's glucose metabolism may contribute to some eating behaviors.

Table 1

Sample child characteristics (N=28)

Sample Characteristic	M (SD) or % (n)	Min-Max
Age	7.58 (1.70)	5.17 – 10.80
% Female	60.71% (17)	-
Race/ethnicity		
% African-American	75.00% (21)	-
% White	25.00% (7)	-
BMI percentile ^a	73.92 (27.64)	19.40 – 99.90
% Healthy weight	50.00% (14)	-
% Overweight	17.86% (5)	-
% Obese	32.14% (9)	-
Peak glucose concentration (mg/dL)	148.64 (20.50)	114 – 187
Percent change from fasting to peak glucose	58.45 (19.21)	16.92 – 110.11
Time of peak glucose (min)	27.50 (6.46)	15 – 40
Food responsiveness	1.71 (1.04)	0.40 – 4.00
Satiety responsiveness	1.85 (0.60)	0.67 – 3.33

^aBMI: Body Mass Index; Healthy weight: 5th < 85th percentile BMI; Overweight 85th < 95th percentile BMI; Obese 95th percentile BMI; as defined by the Centers for Disease Control (CDC) norms

Table 2

Partial correlations between pediatric eating behaviors and post-prandial glucose characteristics (N=28)

Post-Prandial Glucose Characteristic	Food Responsiveness		Satiety Responsiveness	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Percent Increase from Fasting to Peak	−0.376	0.053	−0.063	0.756
Time to Peak (min)	−0.393	0.042	0.230	0.248

Note: analyses adjusted for gender