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A high sugar, low fiber meal leads to higher leptin and physical activity levels in overweight Latina females as opposed to a low sugar, high fiber meal

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Abstract

Acute effects of high sugar, low fiber meals (HS) versus low sugar, high fiber meals (LS) on hormones and behavior were studied in 10 overweight Latina females, age 11-12, using a crossover design. In this exploratory pilot study, articipants arrived fasted at an observation laboratory on two occasions, and randomly received either a HS meal or a LS meal at each visit. Glucose, insulin, and leptin were assayed from serum drawn at 0, 15, 30, 60, 90 and 120 minutes. Ad-libitum snacks were provided at 120 minutes. Physical activity was measured using an observational system that provides data on time spent lying down, sitting, standing, walking, and in vigorous activity. Data was collected between March, 2005 and July, 2006. In the HS condition, glucose and leptin levels decreased more slowly, glucose levels were higher at 60 minutes (111.2 mg/dl vs 95.4 mg/dl, P = .03), leptin levels were higher at 90 minutes (49.3 vs 46.7 ng/ml, P = .017) than in the LS condition. Meals did not effect insulin or ad-libitum dietary intake. Sitting, standing, lying down and vigorous activity differed by condition, but not walking. Participants were significantly more active in the first 30-60 post-HS minutes, but after 60 minutes there was a trend for activity to be lower after the HS meal vs. the LS meal. High sugar meals sustain glucose and leptin levels longer, which may play an important role in modulating levels of physical activity in this group at high risk of obesity-related disease.

INTRODUCTION

Pediatric obesity has reached epidemic proportions, particularly among Hispanic and African American youth (1), placing them at high risk for type 2 diabetes (2) and other diseases (3,4). Physical activity is central to the prevention and treatment of obesity. Unfortunately, physical activity levels decline sharply during adolescence (5-7), particularly in girls (8). This decline is especially profound in Hispanic females (9).

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The diet of Hispanic children is particularly high in total energy and added sugar (10,11). Food consumption stimulates leptin secretion after the meal (12,13) and high carbohydrate meals result in greater leptin responses (14). Chronically augmented leptin may be an independent causal factor in the development of leptin resistance (15). Adolescent females may be at even greater risk for leptin insensitivity because of higher basal leptin concentrations compared to males (16,17).

High simple carbohydrate meals are frequently low in fiber and have been associated with poor glycemic control (18-21), poor mood, feelings of fatigue, and low levels of physical activity over time and postprandially (22,23). In adults, a simple carbohydrate breakfast resulted in higher glucose and insulin levels than after a complex carbohydrate breakfast. Subjects who consumed the complex carbohydrate breakfast reported higher satiety, better mood and lower feelings of fatigue (24). In adults, low fiber intake has been related to negative mood and depression (25). Diets rich in sucrose have been shown to increase postprandial leptin (26), however these higher postprandial leptin levels were not related postprandial satiety or food intake (14). High-sugar, low fiber meals may therefore play a dual role in the current obesity epidemic: one, by increasing energy intake and affecting leptin's ability to serve as an effective satiety signal, and two, through the possible negative effects of sugar consumption on physical activity levels.

Earlier acute feeding studies in children have examined the effect of different meals on insulin and glucose metabolism, glucagon, fatty acids, epinephrine, satiety and ad libitum food intake (27-30). To date, no studies have examined the acute effect of meal type on either physical activity or on hormones that are related to both feeding behaviors and physical activity, such as leptin (16). Therefore, in this study of the effects of High Sugar, Low Fiber (HS) versus Low Sugar, High Fiber (LS) meals in Latina females, hypotheses were that: 1) plasma levels of glucose, insulin, and leptin would be higher after the HS meals and take longer to return to baseline and 2) girls would be less physically active and consume higher amounts of food ad libitum after the HS meal.

METHODS

Overview

An acute feeding study was used to study the effects of a High Sugar, Low Fiber (HS) meal versus a Low Sugar, High Fiber (LS) meal on plasma levels of glucose, insulin, and leptin, and objectively measured physical activity in overweight Latina girls. Participants were recruited from the Women's and Children's Hospital, surrounding sports clubs and after school venues. Inclusion criteria were: 1) female gender, 2) 11-13 yrs of age; 3) Body Mass Index (BMI) ≥95th age and gender specific percentile (23); 4) Parents and all four grandparents of Latino origin as determined by parental self-report. Participants paid two visits to an observation laboratory (crossover design) and received one of the experimental meals (order of meal visits was randomized).

Screening

Participants completed a standard oral glucose tolerance test (OGTT) to preclude diabetes (31) at the University of Southern California General Clinical Research Center (GCRC). Weight and height were measured using a beam medical scale and wall-mounted stadiometer. Body Mass Index (BMI) age- and gender-specific percentiles (32) were determined using EpiInfo (version 1.1, 2000, CDC, Atlanta, GA). Body fat was measured by dual energy x-ray absorptiometry (DEXA) using a Hologic QDR 4500 densitometer (Hologic, Inc., Bedford, MA). Parents and participants provided consent/assent after being informed that this study examined the effects of food on mood and behavior and that participants would be videotaped throughout their stay in the Observation Laboratory. Procedures were approved by the University of Southern California Institutional Review Board.

Procedures

Participants visited the Observation Laboratory after a 12-hour fast on two separate mornings with at least two weeks between visits. Participants received a HS cereal meal at one visit and a LS cereal meal at the other visit (in random order). HS meals were 488 calories, 63.66 grams of sugar (52.18%) and 0.76 grams of fiber (0.62%), 18% fat, 70% carbohydrate, and 14% protein. LS meals were 491 calories, 35.63 grams of sugar (29%), 17.66 grams of fiber (14.4%), 19% fat, 70% carbohydrate and 18% protein. The laboratory was outfitted with a treadmill, jump ropes, hula hoops, a small trampoline, Dance Dance Revolution™ active computer game, and collections of movies, music compact discs, books, magazines and comic books. A saline lock was placed on the non-dominant arm in the same location each visit, generally in the antecubital fossa. Blood was drawn at baseline (5 minutes prior to the meal). Participants were given 15 minutes to complete breakfast. Subsequent blood draws occurred at 15, 30, 60, 90, and 120 minutes from the start of the meal. After breakfast, participants were invited to choose whatever activities they preferred in the laboratory for two hours. The entire session was videotaped. The ad-libitum snack, including sandwiches, chips, cookies and a choice of drinks (sodas, juice and milk), was provided after the last blood draw. Data was collected from March, 2005 to July, 2006.

Nutrient Data System (NDS-R version 5.0_35, 2005, University of Minnesota, Minneapolis, MN.) was used to calculate nutrient intake from plate waste. Glucose was assayed using a Yellow Springs Instruments analyzer (Yellow Springs Instrument, Yellow Springs, OH). Insulin was assayed by ELISA using a Tosoh AIA 600 II Immunoassay Analyzer (Gibbco Scientific, Inc. Coon Rapids, MN), and leptin was assayed by ELISA kit from Linco, Inc (St. Charles, MO). To estimate general levels of physical activity, participants wore Walk4Life pedometers (Plainfield, IL) for 6-7 days prior to their first laboratory visit. Trained observers blinded to research condition analyzed the video tapes of each 2-hour laboratory visit using NOLDUS Observer XT software (version 5.0, Noldus Information Technology, Leesburg, PA.) programmed to score physical activity levels according to the System for Observing Fitness Instruction Time (SOFIT) (33). SOFIT scores five categories of behavior (lying down, sitting, standing, walking, and vigorous activity). For this study, SOFIT was adapted by eliminating the 20-second observe/record intervals and implementing continuous observation and real-time behavior scoring to obtain Continuous Observation scores (SOFITCO). Activity was summed over time periods between blood draws to create increments for analyses. The original five SOFIT categories were enhanced by continuous coding of fidgeting, thus including Non-Exercise Activity Thermogenesis (NEAT) using a set of conventions developed by Levine (34). NEAT includes activities other than exercise, sports and fitness-related activities. Of interest here was the inclusion of fidgeting. Inter-rater reliability for four raters using the SOFIT-CO system was 0.814 ($P<0.0001$) (35).

Statistical Analyses

Means, SD and standard errors were generated. Longitudinal generalized linear mixed effects modeling (GLMM) was used to examine meal differences in hormones and behavior at specific time points and across time. GLMM allows for specification of fixed and random effects of variables on levels as well as change over time. The GLMM models were constructed to allow for the modeling of non-linear trends across the two-hour observation period. Models controlled for 'visit order' as a covariate in order to correct for possible effects of familiarity with the surroundings at second visit regardless of meal type. Analyses were conducted in SPSS (version 13.0, 2004, SPSS Inc, Chicago, IL), and type 1 error was set at $\alpha<0.05$. Because the study was not sufficiently powered to test for significant differences, the goal was to describe group differences.

Results and Discussion

Participant Characteristics

Participants were 10 Latina females aged 12.1 years (SD = 0.7), at or above the 95^{th} BMI percentile. Total body fat was 41.9% (SD = 3.3). Although guidelines for healthy percentage of body fat in children have yet to be developed, this is considered high even in adult populations (36). Fasting glucose was, 90.3 (SD = 3.6) mg/dl, fasting insulin was 16.9 (SD = 10.1) Uu/ml, and fasting leptin was 52.6 (SD = 22.1) ng/dl. Participants took an average of 5728 (SD = 3682) steps per day. Thus, this sample had considerably higher leptin levels (37) and lower physical activity levels measured by pedometer (steps per day) (38) in comparison to other samples of overweight children.

Breakfast and ad libitum snack consumption

On average, participants consumed 62% of breakfast. There were no significant differences in amount eaten between the LS and HS conditions. There were no differences in ad libitum caloric or nutrient intake at two hours after breakfast between the two conditions.

Glucose, insulin, and leptin

Blood glucose levels were equal at -5 minutes, but declined significantly more slowly in the HS condition than in the LS conditon from 30-60 minutes (P = .026) and from 60-120 minutes (P = .017). At 60 minutes, total glucose was thus significantly higher in the HS than the LS meal (mean 111.2 mg/dl (6.2 mmol/L) vs 95.4 mg/dl (5.30 mmol/L), P = .03, Figure 1 panel A). This slower glucose decline from 30-60 minutes and higher glucose levels in the HS condition at 60 minutes corresponded in time to both higher physical activity levels and higher leptin levels as discussed below.

There was no significant effect of meal type on insulin levels or in rate of change between any timepoints over the two hours (Figure 1, Panel B), which was surprising in light of earlier studies that have found meal effects on insulin levels (29). It is unclear what caused the slower decline in glucose levels in the HS group, since it was not associated with higher insulin levels. This might imply an acute change in relative insulin resistance without the expected compensatory hyperinsulinemia, following the HS meal. Alternatively, this finding could reflect an acute decrease in glucose effectiveness, the ability of glucose to lower its own concentration independent of insulin (e.g. by reducing hepatic glucose production) (39) brought on by the HS vs LS meal. Although participants were already quite insulin resistant, as indicated by baseline fasting insulin levels, it is possible that, relative to the height of the glucose after HS meal, the insulin response is inadequate or stunted. This could indicate that the beta-cell secretion has reached a “ceiling effect”, maximizing out at the observed levels. Alternatively, this could indicate a difference between the two meals in insulin secretogogues other than glucose. This might be due to the HS vs LS difference in % protein (40), or different incretin responses (e.g. GLP-1) to HS vs LS meals (41).

Changes in plasma leptin followed a different timecourse during the first 90 minutes between conditions. There was a neglible post-prandial decline in plasma leptin following the HS meal, whereas the LS meal was accompanied by a significant decrease in leptin compared to the HS meal (Figure 1 panel C), (slope -5 to 90 min, P = .026). There was also a significant difference in leptin levels at 90 mins (LS vs HS, mean 46.7 vs 49.31 ng/ml, P = .017). During the last 30 mintues, there were no significant differences between the 2 meals. Post-prandial suppression of leptin was diminished following HS meal, leading to higher leptin levels at 90 minutes, but there were no differences in subsequent ad libitum food intake. It has been suggested that overweight children may have a deficient satiety signaling or be less responsive to satiety signals (37). Baseline leptin was also quite high in this group of overweight girls. Elevated leptin concentrations may be critical in the development of leptin resistance. Both rodent and human models of obesity demonstrate increased leptin levels that rise proportionally with increased adiposity, yet fail to halt the progression of obesity (42-44).

Physical Activity

Girls in the LS condition spent more time sitting during the 30-60 minute block post meal (P = .016), but time spent sitting in this condition declined from 60-90 minutes while time spent sitting increased in the HS condition, resulting in a significant interaction in condition (meal) by time at 120 minutes (P = 0.049) (Figure 2, panel A). Minutes spent standing post-HS was significantly higher during the 30-60 minute block (P = .025, HS vs LS). However, between 60-120 minutes, minutes spent standing decreased in post-HS, while increasing in post-LS (P = .040 for slope over 60-120 minutes in HS vs LS) (Figure 2, Panel B). There were no meal effects on walking. Time spent in lying down differed only at the 90-120 minute block, where girls in the LS condition spent more time lying down (P = .019) (data not shown). In the 30-60 minute block, girls exhibited more vigorous activity in the high sugar condition (P = 0.05). Although not significant, it appears in Figure 2, panel C that vigorous behavior decreased in the high sugar condition and increased in the low sugar condition after the 60 minute mark.

Participants were more active after a high sugar/low fiber meal (HS) in the first 30-60 post-meal minutes, as indicated by increased standing and very active activity and decreased sitting. However, after 60-90 minutes, there was a trend for activity to be lower after the HS meal vs. the LS meal. Concurrent with the HS activity burst during the first 30-60 minutes, glucose and leptin levels were elevated in HS vs LS. This finding is in agreement with some studies, but not with others. For instance, in one study of 123 5-year-old Pima Indian children (67 males/76 females), fasting leptin concentrations were positively related to physical activity levels ($r = 0.26$, $P < 0.01$) (46). However, in another study a sample of 253 healthy girls and 257 healthy boys aged 8–18 years, fasting leptin was higher in girls compared to boys, negatively correlated to number of steps/day as measured by the Yamax Digiwalker pedometer in girls (P < 0.001), and unrelated to physical activity in boys (16).

A limitation to this study was the short (2-hour) time period during which physical activity and hormones were measured, which may be too short to access the effect of meal type on ad libitum food consumption (29). Although other micronutrients were comparable between the two meals, the LS meal had a higher percentage of protein, which may have influenced outcomes. Participants had been informed as to the purposes of the research and knew that they were being filmed. This may have influenced their behavior, but the randomization of the meal type and statistical control for visit order should account for any systematic variation. However, the fact that participants were being filmed in a laboratory environment limits generalizability. Another limitation was the small sample size. Therefore, this study is currently being replicated in large sample including multiple ethnicities, different age groups, both genders and a 5-hour post-meal observation period.

Conclusions

A recent study in 707 female (46) and 567 male (47) students, aged 13–18 years, attending Los Angeles schools found that one of the main reasons that adolescents drank sugar-laden sodas was to experience what they identified as a highly valued ‘sugar rush’. This study suggests that there might be a relative 'sugar rush' in physical activity levels, followed by a 'crash'. This is the first study to examine the difference between 2 types of meals, high and low in sugar, on spontaneous physical activity and hormones that play a role in the regulation of both food intake and physical activity. This data suggest that meal composition influences glucose, leptin and physical activity in preadolescent overweight Latinas. Meal composition may thus have an important role in modulating levels of physical activity in this group at high risk of obesity-related disease.

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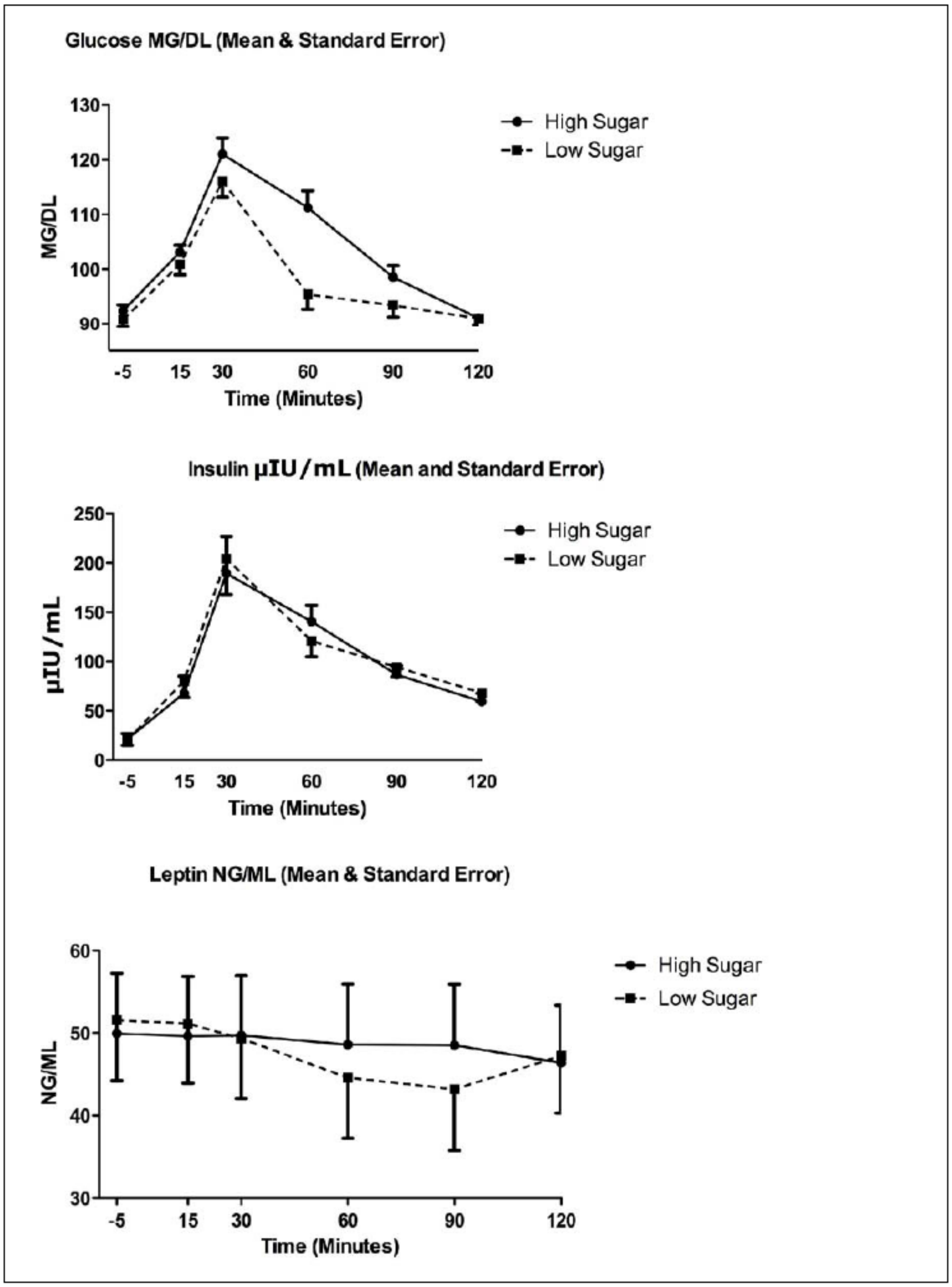
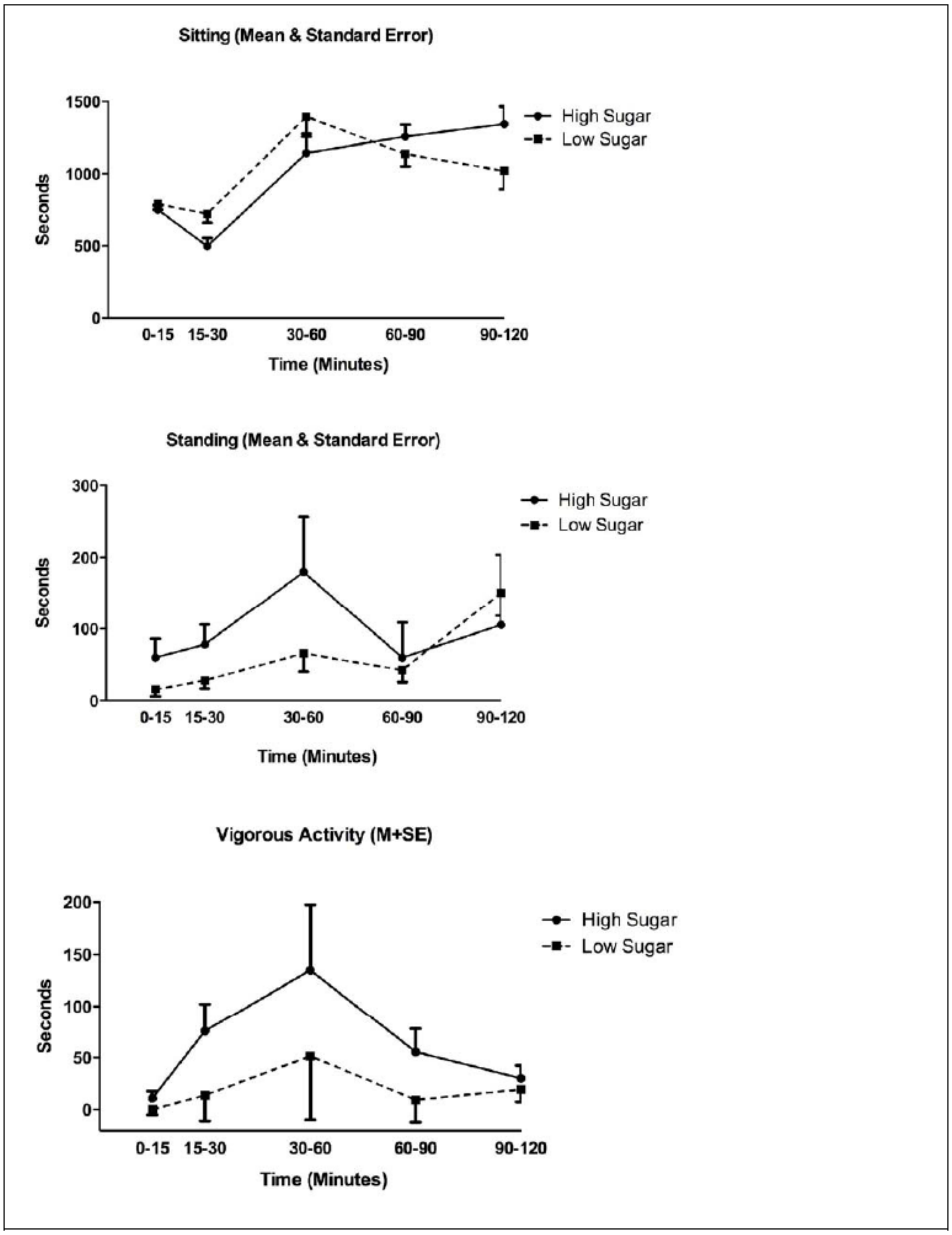


*effect of meal over 120 minutes controlling for visit

Figure 1.

Overweight Latina girls show higher Glucose levels and slower clearance (Panel A), no differences in Insulin levels (Panel B), and higher Leptin levels and slower clearance (Panel C)* after a sugar meal as opposed to a low sugar meal.



*effect of meal over 120 minutes controlling for visit

Figure 2.

Overweight Latina girls sit less (Panel A), stand more (Panel B) and show more vigorous activity (Panel C) for the first 30-60 minutes after a high sugar meal than after a low sugar meal