Behavioral Associations with Overweight in Low-Income Children

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Objective: Food reinforcement (relative reinforcement value [RRV]), self-control (the ability to delay gratification [ATDG]), and eating outside of homeostatic need (eating in the absence of hunger [EAH]) are associated with overweight/obesity. These constructs have typically been studied in isolation in children, and little is known about how they interrelate and whether these associations differ by sex. The objective of this study is to investigate these associations by sex.

Methods: In a low-income sample of 230 7- to 10-year-old children, RRV, ATDG, and EAH were assessed. The model showing that elevated RRV, lower ATDG, and greater EAH are each independent, direct predictors of overweight in middle childhood was separately tested by sex. It was predicted that greater RRV and less ATDG would also have indirect effects on overweight through EAH. The association between RRV and ATDG was investigated.

Results: For girls, higher RRV was indirectly associated with overweight through EAH. For boys, no associations of RRV, ATDG, or EAH with overweight were significant. Finally, for girls, RRV and ATDG were significantly positively associated.

Conclusions: In girls, higher food reinforcement appears to be an important contributor to overweight. During middle childhood, ATDG may be assessing food reinforcement rather than self-control. Future studies are needed to identify the mechanisms underlying childhood overweight in boys.

Introduction

Overweight and obesity impact 32% of children in the United States (1), and childhood overweight often continues into adulthood (2). Existing interventions have limited long-term effectiveness (3). Improved understanding of the behavioral mechanisms of overweight in children may inform the development of interventions.

Three key behavioral mechanisms theorized to underlie childhood overweight risk are food reinforcement (defined as the relative reinforcement value [RRV] of food), self-control (defined as the ability to delay gratification [ATDG]), and eating outside of homeostatic need (defined as eating in the absence of hunger [EAH]). The RRV task measures an individual's willingness to work to gain access to food when an alternative reinforcer is available (4,5). In children, higher RRV for food has been associated with greater caloric intake, higher likelihood of obesity (6), and excess future weight gain (7). ATDG measures an individual's ability to wait longer for a larger reward, as opposed to receiving a smaller reward immediately, and is typically measured with a food stimulus in children (8). Greater

ATDG has been linked to a lower risk of childhood obesity (8,9), but also to greater caloric intake (10), suggesting that ATDG may capture elements of food reinforcement. EAH measures the degree to which children consume palatable snacks following a satiating meal (11), and greater EAH has been linked to obesity (12).

The associations between RRV, ATDG, and EAH have rarely been examined. Specifically, it is unknown whether greater RRV and poorer ATDG predict greater EAH (13,14). The two prior studies testing links between ATDG and EAH have shown either a null (15) or unexpectedly positive association (10). In addition, potential sex differences in the associations of these behavioral constructs with overweight in children have rarely been examined (4,6,8), and results have been inconsistent (13,16-19).

Therefore, the objective of this study was to test the direct and indirect associations of RRV for food, ATDG, and EAH with childhood overweight, as well as to test the interrelationships among these constructs in boys and girls. We hypothesized that greater RRV for

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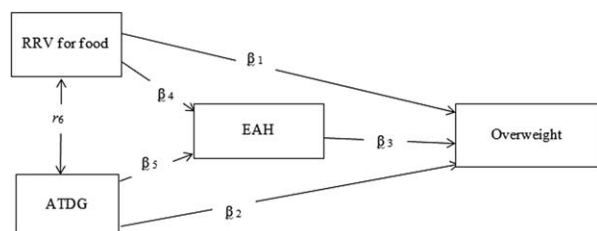
Figure 1 Conceptual model.

food, lower ATDG, and greater EAH are independent direct predictors of overweight. We also hypothesized that greater RRV for food and less ATDG are indirectly associated with overweight through EAH (Figure 1 shows the conceptual model).

Methods

Study design and participants

Participants were 7- to 10-year-old children recruited from an existing cohort participating in a multiwave longitudinal study (20). The participation rate in the current study was 91%. The parent study into which children were recruited was designed to examine obesity risk in low-income preschoolers attending Head Start. The inclusion criteria at the time of parent study enrollment were as follows: (1) primary caregiver has < 4-year college degree; (2) child is aged 3 or 4 years; (3) child was born at 36 + weeks' gestation, with no significant perinatal or neonatal complications as assessed by the study pediatrician (Dr. Lumeng). Exclusions were as follows: (1) history of food allergies or serious medical problems affecting appetite/eating; (2) nonfluency in English; (3) foster child; (4) significant developmental delay as assessed by Dr. Lumeng.

Of the 275 participants who enrolled in the current study, 230 had complete data for RRV, ATDG, EAH, and weight status. Because of scheduling difficulties, the 45 participants with missing data completed a partial protocol that did not include in-person behavioral tasks.

Study procedures were approved by the University of Michigan Medical School Institutional Review Board. The parents or guardians provided written informed consent, and children provided verbal assent.

Measures

Laboratory visits took place across 2 days in a private conference room at a community center near the families' homes in the late afternoon. All of the measures in the current study were assessed on the first visit day, which typically lasted between 1.5 and 2 hours (the second day included an assessment of stress reactivity; these data are not reported here). To reduce variability in hunger at the time of arrival, each child was asked to have an after-school snack. If a parent reported that a child had not eaten a snack, a packet of crackers (Pepperidge Farm Goldfish crackers, 1.5 oz, 210 kcal) was offered ($n = 103$). The tasks were administered in the following order: (1) ATDG, (2) RRV, and (3) EAH. A 5-minute break was provided between each task to reduce carry-over. Anthropometry was collected by trained study staff at the end of the protocol.

RRV for food. RRV for food was determined by measuring the number of responses on a computer task to obtain palatable food (4). Each child was provided with access to two identical computer stations that he/she could move freely between: one station where the child could work to access food (e.g., chocolate, gummy candy) and another station where the child could work to access small toys (e.g., bouncy balls, rings). The toy computer station was provided to prevent participants from working for food out of boredom. Each computer screen displayed three boxes containing different shapes. Each time either of the mouse keys on the laptop was pressed, the shapes rotated and changed. When all shapes matched, the participant received a point. In a standard RRV task, children consume the snack or play with the toy after they earn it (6). However, in the current study, the RRV protocol was modified, so that for every time a child earned five points, he/she was given a ticket to redeem a prize that corresponded to the station he/she was on (i.e., food or toy) at the end of the visit. This modification was made because variability in the amount of candy consumed during the RRV task could lead to differences in sensory-specific satiety to sweet foods, which could impact the EAH task that followed. The schedule of reinforcement for food and toys began at 10 presses to earn one point and then doubled each time a child earned a ticket (progressive ratios: 10, 20, 40, 80, 160, 320, 640, 1,280, 2,560, 5,120, and 10,240). Each child was instructed to move back and forth between the stations as many times as he/she would like and was told that the session would end when he/she no longer wanted to earn points. Food reinforcement was identified by the highest reinforcement schedule completed by each child to earn candy.

ATDG. The standard ATDG task used with preschool-aged children (12) was adjusted to be more developentally appropriate to the current age group (7- to 10-year-olds) by both increasing the number of trials (six trials in our modified task compared to one trial in the original task) and progressively increasing the waiting time to acquire food. These modifications were made to obtain sufficient variability, given that we anticiapted that all children in the cohort would be capable of waiting through the single trial in the standard task. We elected not to use the standard delay tasks employed in work with adults because of the abstract nature and cognitive demands of these tasks, which we did not feel were appropriate for this age range. The modified task was piloted prior to use in this study to confirm that it captured variablity in child behavior. Each child was asked to choose the candy option he/she preferred (a 15-g packet of M&M's chocolate candy or a 15-g packet of Skittles fruit candy). Each child was then shown two piles of candy: one with a large quantity (two packets of candy) and the other with a small quantity (one packet of candy). Each child was told that he/she would be allowed to eat the large quantity if he/she waited until the examiner returned and that this would be repeated up to five times. If a child could not or did not wish to wait, the child could ring the bell to summon the examiner, at which time the child would receive the smaller quantity of candy. The examiner would leave the room and, after 1 minute, return to ask the child if he/she would like the candy now or if he/she would like to wait longer to get more candy. If the child decided to wait longer, the researcher would add one candy packet to both the large and small piles and would tell the child again that if he/she waits, he/she may have the larger pile. This procedure was repeated up to five times, with the waiting period extended by 1 minute each time. The number of candy packets increased from one versus two, two versus three, three versus

TABLE 1 Characteristics of the sample (*n* = 230)

	All (*n* = 230)	Male (*n* = 118)	Female (*n* = 112)
Age, y (SD)	7.84 (0.66)	7.83 (0.61)	7.85 (0.70)
Race/ethnicity, *n* (%)			
Non-Hispanic white	125 (54.35)	61 (51.69)	64 (57.14)
Black, non-Hispanic	35 (15.22)	17 (14.41)	18 (16.07)
Other, non-Hispanic	3 (1.30)	3 (2.54)	0 (0.00)
Biracial, non-Hispanic	44 (19.10)	28 (23.73)	16 (14.29)
Hispanic, any race	23 (10.00)	9 (7.63)	14 (12.50)
Weight status, *n* (%)			
Nonoverweight	115 (50.00)	67 (56.78)	48 (42.86)
Overweight	54 (23.48)	24 (20.34)	30 (26.79)
Obesity	61 (26.52)	27 (22.88)	34 (30.36)
RRV, median (IQR)	320 (80-640)	320 (80-640)	320 (80-640)
ATDG, mean (SD)	2.08 (1.22)	2.02 (1.17)	2.15 (1.28)
EAH, mean (SD)	347.71 (155.49)	370.71 (167.32)	323.48 (138.63)

The 230 participants included in this analysis did not differ from the excluded participants (*n* = 45) with regard to child sex, race/ethnicity, or overweight status. Children who were not included in the analysis were older, on average, than children who were included in the analysis (8.4 y [SD: 0.9] vs. 7.8 y [SD: 0.7], *P* = 0.001).
IQR, interquartile range.

four, four versus five, and five versus six. Each time, if the child waited the prescribed number of minutes until the examiner returned, he/she was scored as a "pass" on that trial. The number of trials (zero to five) each child passed was used to indicate ATDG, which provides additional, progressively more challenging assessments relative to versions of this task used with younger children that score children as pass/fail from one trial.

EAH. Each parent and child (plus other family members present) were served a standardized meal consisting of a 12-in deli-meat sandwich, baked potato chips, applesauce, fruit cups, condiments (mustard and mayonnaise), and water. When a child indicated that he/she was finished, the researcher then invited the child (without the parent) to a separate room. Children were provided with the following instructions: "You can have dessert. You can't take it with you, but you can eat as much as you like here for 5 minutes. If you are ready to be done before that, all you have to do is let me know. I'm going to do some work now." For 5 minutes, each child was given free access to premeasured bowls of four Little Debbie Oatmeal Creme Pies (152 g, 680 kcal), two Little Debbie Cosmic Brownies with Chocolate Chip Candy (124 g; 560 kcal), eight Nabisco/Chips Ahoy Chewy cookies (124 g; 560 kcal), eight Keebler Fudge Stripes cookies (108 g; 560 kcal), eight Little Debbie Mini Powdered Donuts (100 g, 440 kcal), and three Kellogg's Rice Krispies Treats (66 g, 270 kcal). The food that remained was weighed, and this value was subtracted from the initial weight.

BMI. Children were weighed by using a Detecto Model #DR550C portable scale and measured by using a Seca 214 portable stadiometer. BMI was calculated, and weight status was categorized as overweight (BMI ≥ 85th percentile) or not overweight (BMI < 85th percentile) based on the US Centers for Disease Control and Prevention reference growth curves for age and sex (21).

Data analysis

Data analysis was performed by using SAS 9.4 (SAS Institute Inc., Cary, North Carolina). Univariate and bivariate statistics were used to describe the sample. The distribution of RRV schedules was skewed; therefore, we log-transformed this variable before doing any modeling. Path models were conducted (by using Mplus version 6.1 [Muthen & Muthen, Los Angeles, California]) to test both the direct and indirect associations among RRV for food, ADTG, and EAH with overweight (Figure 1). To investigate for potential sex differences, path models were tested separately for boys and girls. The Bayesian estimation technique in Mplus was used to fit path models. Bayesian posterior predictive checks using χ^2 statistics and the corresponding posterior predictive *P* values were used to assess the goodness of fit for each model (22).

Results

Sample characteristics

Sample characteristics are shown in Table 1. The sample was 45.6% Hispanic or not white and 48.7% female; 50.0% of participants were classified as having overweight/obesity. The age range that was the focus of recruitment was 7 to 8 years old, and 95% of the sample was within this age range. Eleven children were slightly older (9 to 10 years old). The median food reinforcement schedule completed was a progressive ratio of 320 (range: 0-5,120). The average number of trials passed in the ATDG task was 2.08 (SD = 1.22; range: 0-5). The mean total number of kilocalories consumed in the EAH task was 347.71 (SD = 155.49; range: 0.00-768.60).

Model fit

All of the models showed good fit, with posterior predictive *P* values ranging from 0.583 to 0.667, well within the 0.05 to 0.95 range. Model fit was optimized by separating boys and girls into two

TABLE 2 Path estimates

Pathway code	Pathway description	Girls			Boys		
		Estimate (posterior SD)	95% CI	P	Estimate (posterior SD)	95% CI	P
B_1	RRV for food → overweight	0.15 (0.10)	−0.01 to 0.36	0.06	−0.17 (0.12)	−0.43 to 0.07	0.12
B_2	ATDG → overweight	−0.10 (0.11)	−0.27 to 0.11	0.46	0.004 (0.13)	−0.23 to 0.29	0.98
B_3	EAH → overweight	0.54 (0.10)	0.33 to 0.70	< 0.0001	0.12 (0.11)	−0.09 to 0.36	0.24
B_4	RRV for food → EAH	0.21 (0.09)	0.02 to 0.41	< 0.0001	−0.09 (0.09)	−0.25 to 0.08	0.24
B_5	ATDG → EAH	0.14 (0.10)	−0.06 to 0.34	0.18	0.04 (0.09)	−0.12 to 0.25	0.68
R_1	Correlation of RRV for food with ATDG	0.26 (0.08)	0.09 to 0.42	< 0.0001	0.20 (0.09)	0.00 to 0.34	0.06

distinct models. Two sample t tests were used to confirm that the beta estimates from the girl and boy models were different by a statistically significant measure (all models: $P < 0.0001$).

Path estimates for girls. Path estimates for girls are shown in Table 2. There was a trend-level direct effect of RRV ($P = 0.06$) and a direct effect of higher EAH ($P < 0.0001$) on overweight, but there was no direct effect of ATDG ($P = 0.46$). There was an indirect effect of higher RRV for food through higher EAH on overweight ($P < 0.0001$), but there was no indirect effect of ATDG ($P = 0.18$). RRV for food and ATDG were positively correlated ($P < 0.0001$).

Path estimates for boys. Path estimates for boys are shown in Table 2. There were no direct effects of RRV, ATDG, or EAH on overweight (all $P > 0.12$). There were no indirect effects of RRV for food or ATDG through EAH on overweight (all $P > 0.24$). There was a trend-level positive association between RRV for food and ATDG ($P = 0.06$).

Discussion

The hypothesized conceptual model was partially supported, particularly in girls. In girls, higher RRV was indirectly associated with overweight through EAH, and EAH was directly associated with overweight. Additionally, for girls, there was a trend-level direct association of RRV with overweight. Thus, for girls, this pattern is consistent with EAH potentially mediating the association between RRV and overweight. In contrast, for boys, there were no associations of RRV, ATDG, or EAH with overweight. Finally, for girls, RRV and ATDG were positively associated; for boys, there was a trend-level positive association.

The current study suggests that higher food reinforcement may be an important pathway to overweight in girls through greater EAH during middle childhood. Prior research has found that higher RRV is associated with elevated BMI in preschoolers, children, and adults (14,23). Differences in RRV for food may be related to differences in the functioning of the mesolimbic dopamine system (24), which is implicated in motivational processes (25). RRV for food can even be assessed in the first year of life (23), and there is evidence that RRV for food may be malleable. In infants, repeated exposure to an alternative reinforcer (i.e., a music enrichment program) resulted in reduced RRV for food (26). Future research is needed to investigate to what degree RRV for

food may be modified in middle childhood and whether this may be protective against future weight gain.

There was limited support in the current study for the association of ATDG with overweight in middle childhood. ATDG is typically considered a marker of self-control (27), and in many studies with preschool-aged children, lower ATDG was associated with a greater risk for future weight gain (8,9,16). However, Hughes and colleagues (10) found that greater ATDG (interpreted as more self-control) was associated with greater caloric intake and was unrelated to other measures of self-control in Hispanic preschoolers. In the current study, ATDG was positively associated with RRV for girls, and there was a trend-level positive association for boys, suggesting that ATDG may be capturing some aspect of reinforcement for food in middle childhood. There are similarities between the assessment of RRV for food (willingness to work for larger quantities of food) and ATDG (willingness to wait for larger quantities of food). As self-control increases with age, older children who find food particularly reinforcing may be more capable of waiting for food rewards. With older children, other paradigms may be needed to more precisely assess self-control related to food, such as the cued go/no-go task (i.e., inhibiting one's response to unhealthy food cues).

Current findings are consistent with prior research that highlights EAH as an important factor associated with overweight (12,13). Little is known about factors that may contribute to greater EAH. It is possible that children who are more prone to EAH are less sensitive to signals of hunger and satiety; however, interventions designed to increase awareness of hunger and satiety were not effective in reducing EAH (28). The current study highlights the role of food reinforcement as an important factor in EAH, as girls with higher RRV for food have higher EAH. Prior research has found that children with higher EAH are also more likely to have alleles (AA and AT) of the FTO gene that have been implicated in risk for overweight (29). The same FTO alleles associated with EAH are also implicated in greater activation of neural regions related to food motivation in response to food cues (30). Future research should investigate whether reducing food reinforcement may also diminish EAH and risk for overweight.

Results also revealed marked sex differences. For girls only, higher RRV was indirectly associated with overweight through higher EAH. Thus, for girls, higher food reinforcement may be an important target for intervention. In contrast, in boys, there was not a significant association of RRV with EAH or overweight. Prior research has found limited sex differences regarding the association of RRV

with risk for overweight in children (4,6,8). The current study also found an association of EAH with overweight for girls only. This is consistent with prior research that EAH is associated with elevated BMI in girls (but not boys) (17) but inconsistent with other research that this association is present for boys only (18,19). Prior research that failed to detect an association between EAH and overweight for girls was conducted in settings where the participant's food consumption could be observed by others (i.e., in school or at home), which may have altered eating behavior (18,19). However, the lack of EAH-overweight associations for boys in the current study highlights the importance of identifying factors (e.g., physical inactivity, satiety responsiveness) that may underlie a risk for overweight in boys and developing more individualized treatments that address potential sex differences.

There are limitations to consider. First, the current study is cross-sectional and, therefore, causality cannot be inferred. Second, the current study sample included low-income participants, and it is possible that these results may not generalize to more well-resourced populations. Environmental drivers of obesity (e.g., less access to healthy foods, fewer safe spaces for physical activity) may account for a larger portion of the variance in BMI among low-income samples, which may reduce the effect size of individual differences. Third, the RRV task was modified to have participants work to earn tickets for food/toys (rather than consuming candy or playing with toys during the task). This was done to prevent performance on the RRV task from impacting the EAH task. Altering the RRV task in this manner required the children to wait to receive the reinforcer, which added an element of delay of gratification to the standard RRV task. This may have increased the similarities between ATDG and RRV. Future research is needed that utilizes the standard RRV task that provides food reinforcers contingent upon responding to remove ambiguity between reinforcement value and self-control. Finally, the ATDG, RRV, and EAH protocols were always administered in the same order; thus, the potential contribution of order effects cannot be ruled out. Future research would benefit from counterbalancing the order of tasks or conducting assessments on separate days to rule out potential carryover effects.

In summary, the current study has several important implications. First, for girls, RRV was indirectly through EAH associated with overweight. This suggests that girls with higher reinforcement for food are more prone to eat palatable food even when not calorically deprived. Second, ATDG was associated with reinforcement for food rather than self-control in middle childhood for girls, which suggests that other approaches are needed to assess self-control related to food in this developmental stage. Third, for girls, EAH was associated with overweight, which suggests that approaches to reducing food reinforcement through attention modification training or food cue extinction (28,31) may be important for reducing EAH and overweight. Finally, the current study highlights the need to identify the mechanisms underlying overweight in boys and the potential need to consider sex differences in developing obesity interventions for children.O

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