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Exploring the relationship between appetitive behaviors, executive function, and weight status among preschool children

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Abstract

Objective: The goal was to conduct exploratory analysis to determine if executive functions and food responsiveness/satiety responsiveness (appetitive behaviors that describe one's tendency to eat in the presence of food or food cues) interact to influence weight status among preschool children participating in a trial promoting self-regulation around energy-dense foods.

Methods: At baseline, parents completed the Behavior Rating Inventory of Executive Function–Preschool and the Child Eating Behavior Questionnaire. Children completed anthropometric measurements at the preschool. Spearman's correlation, linear regression, and tests of interaction were conducted. The relationship between weight status and executive functions among those who were high vs. low in food responsiveness and satiety responsiveness was examined.

Results: Children (n=92) had a mean age of 5.1 years and BMI percentile of 57.6; half (54%) were male. There were significant correlations between food responsiveness and several executive functions (emotional control, inhibitory control, working memory, and plan/organize). In the stratified analysis, children with high food responsiveness or low satiety responsiveness had higher BMI percentiles as emotional control skills worsened. BMI percentiles were not elevated among children with low food responsiveness and poor emotional control.

Conclusion: These results suggest that executive functions may be more relevant to weight status if preschool children had high levels of food responsiveness or low levels of satiety responsiveness (i.e., increased tendency to be influenced by environmental food cues). This

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analysis should be replicated with direct measures of executive function and appetitive behaviors in larger samples of young children to examine longitudinal impact on weight status.

Keywords

childhood obesity; executive functioning; appetitive behaviors; food responsiveness; eating behavior

Introduction:

The obesogenic environment is often cited as a major factor affecting current obesity rates.[1] However, there is still significant individual-level variation in weight status. Some individual-level factors that may be contributing to this variation include executive functions and appetitive trait-like behaviors.

Executive functions (EF) are a set of neurocognitive processes that help individuals make appropriate choices and guide behavioral responses during complex tasks or demands, support social-emotional skills, and achieve a goal.[2,3] The primary EFs are often identified as inhibitory control (the ability to control and regulate impulsive behaviors), working memory (the ability to hold memories in order to complete a task), and cognitive flexibility (the ability to shift thoughts in order to respond to a situation appropriately).[3-5] With regards to weight status, children with obesity have been shown to have less inhibitory control than children with normal weight.[6-8] Studies have also shown that children with lower levels of inhibitory control at the age of 3-5 years have greater weight gain or higher weight status by the age of 11-12 years.[9,10] Finally, when examining treatment seeking samples, children with low inhibitory control appear to have less weight loss during the intervention, suggesting that these cognitive processes may not only be affecting baseline obesity risk, but the ability to modify one's risk in the future.[11]

The relationship between executive dysfunction and weight status seems to occur through a greater intake of calories and disinhibited eating.[12] For example, fourth grade children who had lower EF scores had greater consumption of snack foods while those with higher EF scores had greater consumption of fruits and vegetables.[13,14] In this example, it is thought that those with lower inhibitory control scores had decreased ability to resist eating a tempting food (or decreased capacity to inhibit their response to a tempting stimuli) than those with higher levels of inhibitory control. If they have poorer working memory, they might also forget the knowledge or expectation that they should not eat high calorie foods between meals if they want to stay healthy. Similarly, they may forget the behavioral skills or plans they have learned to help them avoid eating those foods when they should not. While most of the studies around EF have focused on inhibitory control, other aspects of EF may be contributing to this relationship.[15] For example, poorer set-shifting ability, as assessed with the Wisconsin Card Sorting Test (WCST) among children (ages 8-12 years old), has been associated with greater risk for weight regain during a pediatric weight loss intervention.[16] Poorer cognitive flexibility as measured by the NIH Toolbox Dimensional Change Card Sort Test has also been associated with greater fat intake among non-treatment seeking youth (ages 8-17 years old).[17] This decreased ability to shift responses may reflect a poorer ability to switch from one behavioral strategy to another when trying to avoid eating a tempting food and the first strategy is not working.

In addition to cognitive factors, basic physiologic drives like appetite can influence weight status. Appetitive trait-like behaviors characterize an individual's desire for food or tendency to eat and make up one's eating behavior profile. Two of the most commonly studied appetitive traits or behaviors are "food responsiveness" (FR) and "satiety responsiveness" (SR).[18] Those who are described as being food responsive are more likely to be influenced by food cues in the environment and tend to eat based on these external food cues, whether they are hungry or not. Those who are higher in satiety responsiveness are less influenced by external or environmental food cues and are more likely to listen to internal body cues that indicate whether they are hungry or full. Those who are high in satiety responsiveness tend to stop eating when they are full or sated. These appetitive behaviors have garnered much interest because several studies have demonstrated that children with high levels of food responsiveness or low levels of satiety responsiveness have higher weight status.[19-22] Carnell and Wardle (2008) also demonstrated that children (age 8-11 years old and 3-5 years old) with higher levels of food responsiveness had larger waist circumferences,[23] which is clinically important since waist circumference may be a better indicator of higher systolic and diastolic blood pressures, hyperlipidemia, and insulin resistance in children.[24,25]

Similar to the relationship between EF and weight status, the relationship between certain appetitive behaviors and higher weight status may be due to an increased tendency to eat when exposed to environmental food cues.[26] In the laboratory setting, several groups have shown that those with high food responsiveness have a decreased ability to compensate caloric intake after being given a preload of calories[27] and consume more snack foods when eating in the absence of hunger.[28] In some studies, children (age 4-5 years old) who were reportedly high in food responsiveness consumed more white bread, fruits, and vegetables than those who were reportedly high in satiety responsiveness,[29,30] and those who consumed more white bread and snack foods had higher BMI z-scores. These appetitive behaviors have been associated with varying weight status in children as young as 3-5 years old,[23] and shown to be associated with greater weight gain in infants from birth to 15 months.[20] In treatment seeking samples, children age 8-12 years old with high food responsiveness also had greater weight regain in the follow-up period even though they were able to lose weight during treatment.[31]

Despite the independent influence of these two domains on weight status, it is unclear how they interact to influence obesity risk. The dual-process model attempts to describe a continuous process where impulses (appetitive behaviors and drives) are tempered by higher level cognitions, such as EF.[32] The flow between these systems determines whether more basic impulses and motivations determine behavior (e.g., eating a sweet dessert after dinner even though you are full – driven by the *Impulsive system*) or whether higher level reasoning, cognitions, and goals drive the behavior (e.g., refraining from eating dessert because you are full and know that it will not be good for your health or weight – driven by the *Reflective system*). Therefore, when thinking about obesity risk, a robust reflective system (which includes EFs) could potentially decrease the impact of strong impulses or appetitive behaviors such as food responsiveness.

The goal of this project was to conduct exploratory analysis and examine the relationship between both higher-level cognitions and appetitive behaviors on weight status in a cohort of preschool age children. Using baseline data from an intervention targeting self-regulation in preschool children around the consumption of energy-dense snack foods,[33] we examined the association between EFs and child BMI percentile among preschool children who were higher in food responsiveness or satiety responsiveness compared to those who were lower in food responsiveness or satiety responsiveness. We hypothesized that EFs would play a more important role in children who were high in food responsiveness or low in satiety responsiveness and had stronger desires to eat when presented with tempting stimuli in the environment.

Materials and Methods:

Study Design and Sample:

This study is a cross-sectional secondary analysis of data collected from preschool age children who were recruited to participate in a play-based intervention targeting food-based self-regulation with the goal of decreasing consumption of energy-dense snack foods. Details regarding the intervention protocol and eligibility criteria have been previously published.[33] This protocol was approved by the Institutional Review Board of the University of California, San Diego, and registered in ClinicalTrials.gov (NCT02077387).

Briefly, children aged 4-6 years old attending one of three preschool centers were eligible to participate in the study. Children must have had a body mass index (BMI) ≥ 5th %ile and not have any developmental delay or medical condition that affected weight, eating behaviors, or cognition. At the baseline assessment, parents were asked to complete the Behavior Rating Inventory of Executive Function – Preschool[34,35] (BRIEF-P) to assess executive functioning and the Child Eating Behavior Questionnaire[18] (CEBQ) to assess appetitive behaviors. While behavioral tasks for inhibitory control and eating in the absence of hunger were used in the intervention, there were ceiling effects with those measures in our sample. Furthermore, we did not include behavioral tasks for each domain of executive functioning. Therefore, survey measures of these constructs were used in this analysis to allow us to conduct a broader exploratory analysis. These survey measures were only administered at the baseline assessment. Ninety-two children participated in the study and completed baseline measures. Only data from the baseline measures were included in this analysis.

Measures:

Anthropometrics.—Height and weight for each child was obtained at the preschool following standard protocols. Children were weighed without shoes or heavy clothing on a Tanita Digital Scale (model WB-110A). Weights were recorded twice to the nearest 0.1 kg, and the average value used for analysis. Heights were obtained using a portable Schorr height board (Schorr Inc, Olney, MD) and recorded twice to the nearest 0.1 cm. The average value was used for analysis. BMI percentile for each child was calculated based on CDC growth charts.[36] Children with a BMI > 5th percentile and < 85th percentile were categorized as having normal weight; those with a BMI ≥ 85th percentile were categorized as having overweight/obesity (OW/OB).

The Behavior Rating Inventory of Executive Function – Preschool Version[34,35] (BRIEF-P).—This parent- or teacher- report questionnaire assesses executive function behaviors in the home or preschool setting. The Preschool Version was designed for children age 2 years to 5 years and 11 months old.[34] The BRIEF-P contains 63 items that measure five areas of executive function: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize. "Inhibit" (16 items) represents the ability to control one's impulses and behaviors in different settings or contexts and at appropriate times. "Shift" (10 items) describes a child's ability to move from one activity to another in response to the situation and utilize problem solving abilities as needed. Children who are high in "shift" make transitions easily, change their focus from one topic to another, and are not overly distressed with changes in routines. "Emotional control" (10 items) represents how a child can regulate his/her emotions appropriately as the situation demands. Children who have poor emotional control are often described as having frequent emotional outbursts or overblown reactions to minor events. "Working memory" (17 items) captures how a child holds certain information or rules in his/her mind to complete a task or respond appropriately to a demand. Children with high levels of working memory can often follow complex instructions or multi-step directions and are often described as having a long attention span. "Plan/organize" (10 items) is the ability of a child to plan a series of steps to complete a task and have goals to organize and structure their behavior. The "plan" part of the scale captures whether a child can put together a series of actions or gather the appropriate tools in a timely fashion to complete the task on time. The "organize" part of the scale captures whether a child can organize all the information or materials provided to complete a task in an orderly manner. These individual scales can be combined to create 3 indexes (Inhibitory Self-Control (ISCI), Flexibility (FI), and Emergent Metacognition (EMI)) as well as a Global Executive Composite score (GEC). However, the five original scales were used in this analysis to allow us to explore each domain separately, and because Inhibit and Emotional Control loaded onto two of the higher-level indexes, thus creating greater collinearity between the indexes.

Scales were scored by providing one point for "never", two points for "sometimes", and three points for "often". Normative conversion tables were then used to obtain a t-score for each scale's raw total score. Higher t-scores indicate poorer functioning in each domain. The BRIEF-P scales are strongly correlated with scales on the Attention Deficit Hyperactivity Disorder (ADHD) Rating Scale-IV Preschool version (which measures inattention and hyperactivity-impulsivity) and the Child Behavior Checklist (1.5 – 5 years) (which measures several behavioral domains including attention problems and emotional reactivity), suggesting the BRIEF-P captures many constructs of executive functioning fairly well.[34] This scale has also been used in clinical populations of children with autism, ADHD, prematurity, and language disorders to show varying levels of executive dysfunction in several domains compared to matched control groups.[34] Alpha coefficients for the parent report of each of the five original scales ranged from 0.80 to 0.95. Test-retest stability ranged from 0.78 – 0.90.[34] The present study only utilized parent-reported executive function behaviors and found coefficient alphas to be between 0.76-0.89.

Child Eating Behavior Questionnaire [18] (CEBQ).—This 35-item questionnaire assesses children's eating behaviors, with parents being asked to report how their child responds to internal satiety cues and external food cues using a 1-5 Likert scale (1=never, 5 = always). This questionnaire specifically reports on food responsiveness, emotional over-eating, enjoyment of food, desire to drink, satiety responsiveness, slowness in eating, emotional under-eating, and food fussiness. Food Responsiveness (FR) (4 items) and Satiety Responsiveness (SR) (5 items) were the main subscales of interest, and used in the present study since these dimensions have been associated with BMI in previous studies.[20,37] Food responsiveness attempts to measure individual differences in the tendency to eat, or be responsive to external food cues (e.g., “If allowed to, my child would eat too much”, “My child is always asking for food”, “Even if my child is full up, s/he finds room to eat his/her favorite food”). Satiety responsiveness measures the individual’s ability to reduce food intake after eating and respond to internal cues of hunger and satiety (e.g., “My child leaves food on his/her plate at the end of a meal”, “My child cannot eat a meal if s/he has had a snack just before”). Means for each subscale were calculated for analysis. The CEBQ has been applied to children as young as 3 years old and has been shown to have good internal consistency, test-retest reliability, and stability over time.[18,37] These subscales have also demonstrated good internal validity and test-retest reliability.[18,38] In the present sample, scores of both food responsiveness (α = 0.81) and satiety responsiveness (α = 0.69) demonstrated adequate internal consistency.

Demographics.—Parents were asked to complete demographic information regarding their own race/ethnicity, education, and income. Race/ethnicity was categorized as non-Hispanic White, Hispanic, or Other. Education was categorized into tertiles: high school degree or less, college, or graduate school. Parents also self-reported their height and weight, and BMI was calculated using the formula BMI = kg/[m^2]. Those with a BMI ≥ 25 were considered to have overweight/obesity. Additional covariates included child age and sex.

Analysis:

Spearman correlations were used to determine associations between each BRIEF-P domain (Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize), CEBQ domain (food responsiveness and satiety responsiveness), child demographics, and parent education. Separate linear regression models were used to evaluate the relationship between executive functions and appetitive behaviors on BMI percentile. Analyses were also conducted using BMI z-score and percent from median BMI (%BMI_{p50}) as the dependent variable since this sample consisted of young children with normal weight and OW/OB.[39] Results were similar across analyses. Only BMI percentile was reported for greater ease of understanding and translation to the clinical setting.

Model 1 examined the relationship between the five executive functions and BMI percentile. Model 2 examined the relationship between food responsiveness, satiety responsiveness, and BMI percentile. Model 3 included food responsiveness, satiety responsiveness, and the five executive functions. All models included the planned covariates of child age, sex, and parent education. Since the aim of this analysis was to explore the relationship between EFs and BMI percentile among those who were higher or lower in food responsiveness and those who were higher or lower in satiety responsiveness, two-way interactions between each EF and food responsiveness or satiety responsiveness (as continuous variables) were first evaluated in individual models, including child age, sex, and parent education. Stratified models were used to describe simple relationships between EF and BMI within subgroups of children with higher and lower appetitive behaviors. Food responsiveness and satiety responsiveness were dichotomized at the median and stratified for this analysis; relationships with a p-value <0.10 were presented below. Analyses were run in R version 3.6.0.

Results:

Demographic information is presented in Table 1. Data from 92 children were included in this study. Half the sample (54%) was male, with a mean age of 5.1 years (S.D. 0.74), and a mean BMI percentile of 57.6 (S.D. 33.3). Parents had a mean age of 34.5 years (S.D. 6.1), 48% had OW/OB and 38% were Hispanic.

Spearman's correlations between all variables, as well as t-scores, means and standard deviations, are presented in Table 2. Overall, children had average EF t-scores and all domains were highly correlated with each other. Children had relatively low food responsiveness scores. Food responsiveness was inversely correlated with satiety responsiveness. Food responsiveness was significantly positively correlated with the EF domains of emotional control, inhibitory control, working memory, and plan/organize. Higher EF scores reflect worse functioning, therefore positive correlations indicated that greater food responsiveness was associated with poorer functioning in these domains.

In Model 1 of the linear regression models (examining EFs only), poorer emotional control and working memory (higher t-scores) were associated with higher BMI percentile. (Table 3) When examining the appetitive behaviors (Model 2), food responsiveness was significantly related to child BMI percentile; children with high food responsiveness had higher BMI percentiles. In the combined model (Model 3), higher food responsiveness and poorer working memory (higher t-scores) continued to be significantly associated with greater child BMI percentile. However, better plan/organize ability (lower t-score) was now related to higher BMI percentile. Model 3 explained 37% of the variance in relation to child BMI percentile.

Next, we explored differences in association between the EF domains and BMI percentile among those with higher or lower levels of food responsiveness or satiety responsiveness by entering two-way interaction terms into each model. Among the EF domains, emotional control had the strongest two-way interactions. The interaction term between emotional control and food responsiveness (p=0.21) and satiety responsiveness (p=0.10) prompted further exploration. P-values for all other tests of interaction ranged from 0.23 – 0.60. Relationships between emotional control and BMI percentile were examined within subgroups stratified by high (i.e., above the median) or low (i.e., at or below the median) scores on food responsiveness and satiety responsiveness. (Table 4; Figure 1) Among those with High food responsiveness and Low satiety responsiveness, poorer emotional control (i.e., higher t-score) was associated with higher BMI percentiles; for every one point increase in emotional control t-score, there was an increase in child BMI percentile by 1.04 (S.E. 0.58) or 1.11 (S.E. 0.45) points respectively. The relationship to BMI percentile was the opposite among those with Low food responsiveness; increases in emotional control t-score (indicating poorer functioning) were associated with lower BMI percentiles. Similar trends were seen among those with High satiety responsiveness.

Discussion:

This is one of the few reports to examine the association between executive functions and appetitive behaviors on child weight status, particularly in the preschool period. Many of the executive functions were significantly correlated with food responsiveness, suggesting that even at this young age, we are starting to see a correlation between poor cognitive control (higher t-scores) and higher responsiveness to food cues. This relationship has also been found in studies examining grade school children.[40,41] However, the interaction of these two domains on weight status is not typically studied. Our analysis demonstrated that as early as preschool, cognitive functions may play an important role in the relationship to weight status, particularly among children with high levels of food responsiveness or low levels of satiety responsiveness. Interestingly, poor emotional control did not have the same relationship to weight status among those with low food responsiveness. This suggests that EF may not be as critical to weight status among those who do not have strong tendencies to eat around food, and any challenges they are facing due to poorer emotional control are likely not manifesting with greater food intake. However, if children had high levels of food responsiveness (or stronger impulsive reactions to food cues in the environment) and poor executive functioning, particularly emotional control (manifested as higher t-scores), they were at risk of having a higher BMI percentile. Thus, having a robust reflective system, or EF skills, may be more critical when someone has strong impulsive drives to eat.

We should note that when examining the relationship between EFs and BMI percentile alone in Model 1 of the linear regression models, we found that poorer working memory and emotional control were associated with higher BMI percentiles. Other groups examining preschool and grade school children have found similar associations, particularly with lower emotion regulation, inhibitory control,[42] and self-regulation.[10] These studies used behavioral tasks to assess EF, which may have allowed for more robust and accurate measurement of the child's abilities. Unfortunately, we were reliant on parent report of child EFs and did not find a relationship between inhibitory control and BMI percentile. This may be due to the fact that working memory (e.g., the ability to follow multi-step directions) and emotional control (e.g., the ability to control an emotional response during a stressful or frustrating event) may be more outwardly noticeable, and therefore more easily recognized by parents. Parents may find it difficult to know whether their child is using set-shifting abilities (e.g., using different strategies while trying to problem-solve) or inhibitory control skills, since these are cognitive processes that are less easily observed. Therefore, the variability in EF reporting in our analysis may be less robust than that of other studies, thus limiting our ability to find a relationship between a wider range of EFs and food responsiveness as it relates to weight status.

While both EF and appetitive behaviors are not commonly analyzed together, recently Groppe and Elsner [40] examined the relationship between appetitive behaviors and a broad range of executive functions in grade school children (7-11 years old). Using several different tasks to assess executive functions and the same parent report of child food approach behavior (Children's Eating Behavior Questionnaire[18]), they found that among girls, poorer inhibition, attention shifting (or set shifting), and updating ability (a component of working memory) was associated with eating behaviors such as food responsiveness, desire to drink, and restrained eating.[40] Their results are similar to the relationships we found in our study between food responsiveness and several EFs, namely inhibitory control, working memory, plan/organize, and emotional control. They were also able to follow their sample of children for one year and found that those with lower EF had a greater increase in food approach behaviors, including food responsiveness, during the following year.[41] If these relationships prove to be true in younger age groups, the combined effect of having low EFs and high food responsiveness during the preschool years may lead to greater risk of obesity as children enter grade school and beyond.

Given these emerging relationships between appetitive behaviors, EF, and weight status, policy changes that limit obesogenic temptations in the environment may help to decrease stimulation of impulsive behaviors and excessive caloric intake. However, we cannot simply rely on these changes to make an impact on obesity trends. More immediate solutions that cultivate a child's reflective system or executive functions, particularly emotional control skills, may be useful to assist children in combating the constant barrage of hedonic stimuli that prompt unhealthy choices. Programs that foster a child's executive functioning around eating may offer such a solution.[43] These programs could foster the development of higher level cognitive processes and allow children to develop greater capacity to overcome impulses to eat unhealthily. This work is particularly apropos for young preschool-age children as they are easily distracted and prone to react to novel, highly rewarding stimuli such as sweets and fatty foods. They are also developing higher level executive functions [44,45] and eating behaviors [46] at this time, and may be more amenable to training efforts than when they are older.[47] Programs that promote executive function in preschool-age children exist,[48] but are not frequently adapted to address food stimuli.[33] Efforts to increase inhibitory control or emotional control skills in children would target another skill set currently not addressed in many treatment/prevention programs, and may be particularly useful for those with higher levels of food responsiveness or lower levels of satiety responsiveness.

While the results of our study expand our current understanding of the importance of executive functions within the context of certain appetitive behaviors and how they relate to weight status during early childhood, there were some limitations to consider. First, this study relied on parent report of child appetitive behaviors and EF. Objective measures of appetitive behaviors and EF would have removed any parental bias in reporting on these domains particularly among children with obesity. Furthermore, use of tasks to assess eating behaviors and EFs would add greater validity to these findings and allow us to outline a potential mechanism between appetitive behaviors and BMI. Nevertheless, the BRIEF-P has been found to have high internal consistency (ranging from 0.80 to 0.95) and test-retest stability (mean of 0.86 over 1 to 9.5 weeks) in normative parent samples.[34] Furthermore, the BRIEF-P scales are strongly correlated with scales on the ADHD-IV-P and the Child Behavior Checklist, suggesting that the BRIEF-P captures many constructs of executive functioning fairly well.[34] Finally, given the cross-sectional nature of the analysis, we were unable to comment on the direction of influence between EFs, food responsiveness, and weight status, and whether lower EF skills increase one's risk of food responsiveness or vice versa. Longitudinal analyses could elucidate the direction of these relationships and help to identify which area (the impulsive or reflective system) should be more heavily targeted for intervention.

Conclusion:

In this study, we found that EFs, particularly emotional control, may be more salient among preschool children with higher levels of food responsiveness or lower levels of satiety responsiveness when considering the relationship to weight status. Poor emotional control among those with lower levels of food responsiveness did not have the same relationship to weight status, and child BMI percentile was not elevated. These results highlight the importance of appetitive behaviors in relation to weight status and suggest that EFs may be more critical to address among children who have a strong tendency to eat when tempted by environmental food cues. This type of analysis should be replicated in larger samples, over longer periods of time, and with more objective measures or behavioral tasks of eating and executive function to better understand the strength and direction of these relationships. If these findings continue to hold true in longitudinal studies, interventions to promote executive functions in at-risk populations could be explored as a means of obesity prevention or treatment.

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Upon request, individual participant data will be made available, including data dictionaries and study protocols. Only deidentified data that underlie the results reported in this article will be made available beginning 6 months and ending 5 years after the publication of this article. Researchers must provide a methodologically sound proposal and submit requests to k1rhee@health.ucsd.edu. The study executive team will review all requests and must approve all analyses prior to any release of data. Data sharing agreements will need to be signed before data is released on a secure website managed by UC San Diego Health.

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Abbreviations:

EF	Executive functions
BMI	body mass index
OW/OB	overweight/obese

BRIEF-P	Behavior Rating Inventory of Executive Function – Preschool Version
CEBQ	Child Eating Behavior Questionnaire

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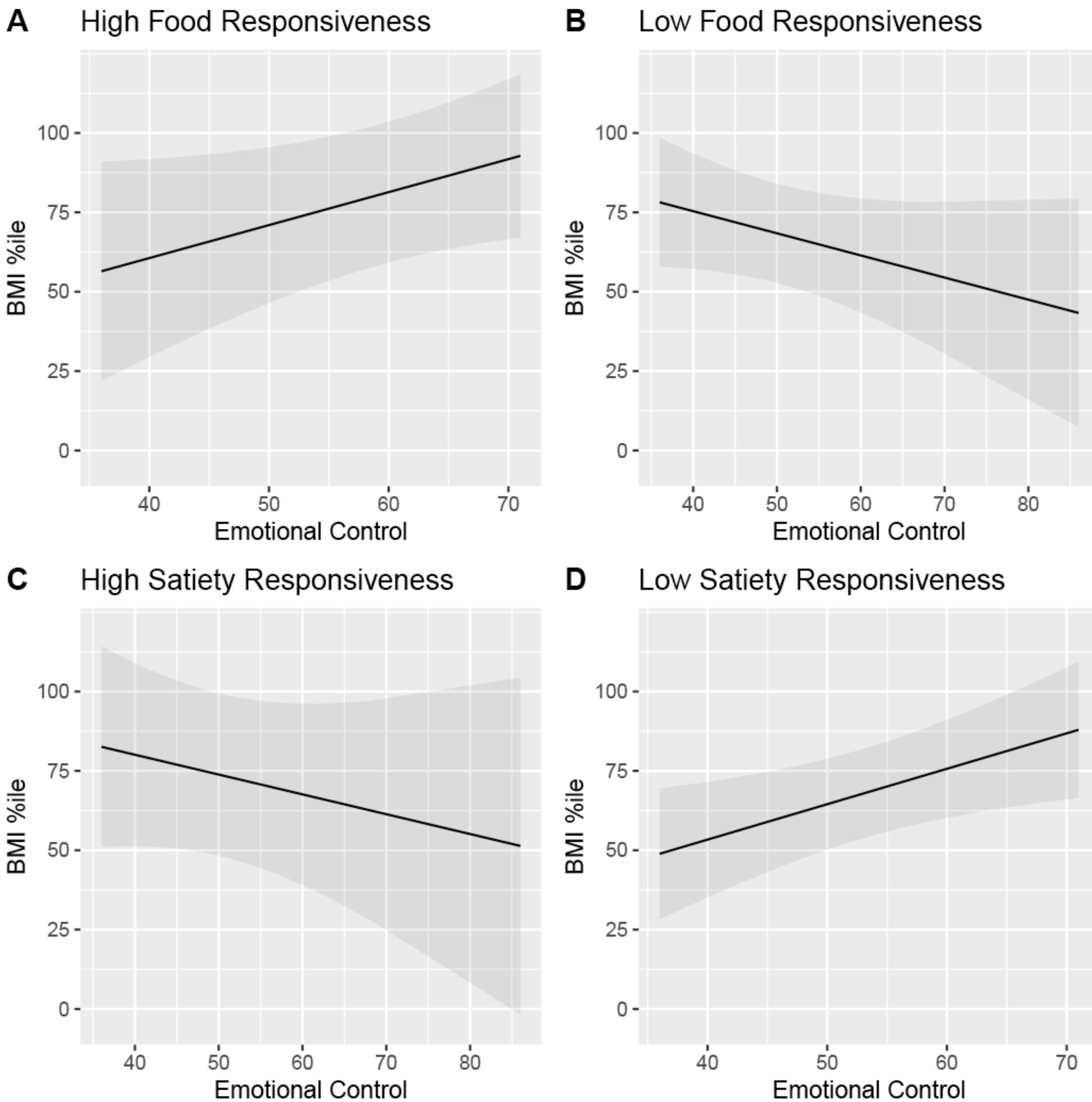

Figure 1: Relationship between emotional control and child BMI percentile among those with high or low food responsiveness or satiety responsiveness

Food responsiveness and satiety responsiveness were stratified at the median and emotional control t-scores used to examine the relationship to BMI percentile among children age 4-6 years old. Poorer emotional control (higher t-score) was associated with greater BMI percentiles among those children with high levels of food responsiveness (Panel A, p=0.083, cohen's d=0.32) and low levels of satiety responsiveness (Panel D, p=0.029, cohen's d=0.35). Those with low levels of food responsiveness (Panel B, p=0.054, cohen's d= −0.21) did not have higher BMI percentiles when emotional control t-scores were high (indicating worse functioning). The relationship among those with high levels of satiety responsiveness (Panel C, p=0.19, cohen's d= −0.18) was similar to that seen among those with low food responsiveness.

Table 1:

Sample Characteristics at Baseline

No. (%)	Total (n=92)
Child Age (years), Mean (SD)	5.1 (0.74)
Sex	
Girls	42 (46%)
Boys	50 (54%)
Race/ Ethnicity	
Hispanic	41 (45%)
Non-Hispanic White	22 (24%)
Other	29 (31%)
Weight status, Mean (SD)	
BMI	16.5 (2.5)
BMI Percentile	57.6 (33.3)
Overweight/Obese	30 (34%)
Parent Age (years), Mean (SD)	34.5 (6.1)
Sex	
Women	79 (87%)
Men	12 (13%)
Race/ Ethnicity	
Hispanic	35 (38%)
Non-Hispanic White	26 (28%)
Other	31 (34%)
Weight	
Overweight/Obese	44 (48%)
Household Income ($100,000+)	35 (38%)
Marital Status (Married)	61 (67%)
Parent Education[1]	
High School or less	34 (43%)
Undergraduate Degree	24 (30%)
Graduate Degree	21 (27%)

[1]Note: Missing data for parent education were present for 13 families.

Table 2:

Spearman correlations between executive functions and child appetitive behaviors

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1. Shift											
2. Emotional Control	0.62***										
3. Inhibit	0.33**	0.57***									
4. Working Memory	0.36**	0.54***	0.74***								
5. Plan/Organize	0.40***	0.51***	0.73***	0.82***							
6. Food Responsiveness	0.15	0.23*	0.24**	0.33***	0.30**						
7. Satiety Responsiveness	0.24*	0.07	0.00	−0.14	−0.07	−0.17**					
8. BMI %ile	−0.06	0.04	0.04	0.12	0.04	0.23	−0.24				
9. Child Age	−0.12	−0.07	0.10	0.01	0.09	0.08	−0.18	0.16			
10. Child Gender	−0.12	−0.16	−0.08	−0.16	−0.14	0.13	0.03	0.07	0.13		
11. Parent Education	0.14	0.13	−0.06	−0.03	−0.11	0.16	0.29*	−0.35	0.50***	−0.09	
T-scores and Means	51.03	51.57	53.01	53.26	50.60	2.11	3.06	57.62	5.09	//	//
Std. Dev.	8.34	10.16	10.08	10.80	9.92	0.77	0.61	33.29	0.74	//	//

*p<0.05

**p<0.01

***p<0.001

For the BRIEF-P domains, t-scores are presented above and were used for analysis. Higher t-scores represent poorer functioning. Food responsiveness (4 items) and satiety responsiveness (5 items) were scored using a 5-point likert scale. Higher scores indicate greater food responsiveness or satiety responsiveness. Means for each scale are presented above and were used for analysis.

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Table 3:

Linear regression models of the relationship between executive functioning and appetitive behaviors on child BMI percentile.

	Model 1	Model 2	Model 3
Emotional Control	0.99 * [0.01, 1.96]		0.81 [−0.15, 1.76]
Inhibit	−1.09 [−2.21, 0.02]		−1.04 [−2.12, 0.05]
Plan/Organize	−1.12 [−2.38, 0.14]		−1.24 * [−2.47, −0.01]
Shift	−0.71 [−1.77, 0.35]		−0.75 [−1.81, 0.32]
Working Memory	1.83 ** [0.60, 3.05]		1.58 * [0.36, 2.80]
Food Responsiveness		12.39 * [2.12, 22.65]	13.96 * [2.76, 25.16]
Satiety Responsiveness		0.09 [−12.20, 12.37]	4.91 [−7.80, 17.63]

* $p < 0.05$

** $p < 0.01$; Table displays unstandardized beta coefficients and 95% confidence intervals.

R^2 for each model was 0.31, 0.26, and 0.37 respectively.

Note: Model 1 examined the relationship between the five executive functions and BMI percentile. Model 2 examined the relationship between food responsiveness, satiety responsiveness, and BMI percentile. Model 3 included food responsiveness, satiety responsiveness, and the five executive functions. All models include the planned covariates of child age, child sex, and parent education. Parent education was a significant predictor of child BMI percentile (p<0.001) in all models.

Table 4:

Relationship between emotional control and child BMI percentile among those who have high or low food responsiveness or satiety responsiveness

	High FR (SE)	Low FR (SE)	High SR (SE)	Low SR (SE)
Emotional Control	1.04 (0.58)	−0.70 (0.46)	−0.62 (0.66)	1.11 (0.45)
p-value	p=0.083	p=0.054	p=0.19	p=0.029
Cohen’s d	0.32	−0.21	−0.18	0.35

FR = Food responsiveness

SR = Satiety responsiveness

SE = standard error

Table displays standardized beta coefficients and standard errors. Increases in emotional control t-scores (indicating worse functioning) were associated with higher BMI percentiles among those with High food responsiveness and Low satiety responsiveness. However, increases in emotional control t-scores among those with Low food responsiveness were associated with lower BMI percentiles. Similar trends were seen in those with High satiety responsiveness. All models included the planned covariates of child age, child sex, and parent education. Parent education was a significant predictor of child BMI percentile ($p<0.05$) in all models.