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Executive Functioning and Disinhibited Eating in Children and Adolescents

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Abstract

Background—Executive functioning (EF) difficulties may be associated with problems regulating eating behaviors. Few studies have evaluated this question in youth using diverse measures of EF or objective measures of energy intake.

Methods—The current study used neuropsychological tasks and a laboratory test meal to evaluate the links between EF and youth's disinhibited eating patterns. Two-hundred-five non-treatment seeking youth (*M* age=13.1±2.8y; *M* BMI*z*=0.6±1.0; 33.2% overweight; 54.1% female) completed tasks measuring decision-making; general and food-specific behavioral disinhibition; willingness to delay gratification for food and money; cognitive flexibility; and working memory. Age (children vs adolescents) was examined as a moderator. All analyses adjusted for demographic factors, pubertal status, lean mass (kg), fat mass (%), height, general intellectual functioning, and depressive symptoms.

Results—After adjusting for multiple comparisons, more general behavioral disinhibition was associated with greater total energy intake (p = .02), and poorer cognitive flexibility was

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associated with more fat intake ($p = .03$) across all ages. Poorer decision-making in children ($p = .04$), but not adolescents ($p = .24$), was associated with greater fat intake. Food-specific behavioral disinhibition, the ability to delay gratification for both food and monetary rewards, and working memory were not significantly associated with youth's disinhibited eating patterns during a single meal.

Conclusions—Most domains of EF were not associated with youth's disinhibited eating. Significant associations may highlight the need to target specific cognitive processes, particularly behavioral disinhibition, decision-making, and cognitive flexibility, in potential intervention strategies for children's disinhibited eating.

Keywords

executive functioning; cognitive; disinhibited eating; energy intake; obesity; child

Introduction

Executive functioning (EF) refers to the higher-order cognitive processes implicated in self-regulation and includes working memory, behavioral inhibition, cognitive flexibility and delayed gratification (1). Extant studies indicate that youth with obesity perform significantly worse than their peers without obesity on measures of EF, particularly tasks measuring behavioral inhibition, or the ability to inhibit or stop prepotent impulses (2–4). These data have led to the hypothesis that poorer EF may predispose youth to have excessive weight gain. These differences persist even after adjusting for confounds, such as depressive symptoms (3) and general intellectual functioning (4). The association between EF and obesity is likely bidirectional. Obesity has been linked to diseases characterized by significant cognitive decline (e.g., dementia, Alzheimer disease) (5), and poorer performance on measures of delayed gratification (6, 7), behavioral inhibition (2), and cognitive flexibility (8) are associated with excess weight gain and obesity onset.

It is theorized that poorer EF performance is associated with excess weight gain through eating-related self-regulatory difficulties. Two unique but overlapping systems, referred to as the 2-systems model, are posited to guide eating behaviors, including automatic and reflective processes (9, 10). The automatic processes capture impulsive behaviors and are thought to be the result of basic learning mechanisms, through which rewarding properties are paired with specific food items. The reflective processes include the higher-order self-regulatory (or EF) abilities that allow individuals to override automatic processes and make eating decisions based on factors such as knowledge and long-term goals. Based on this theory, a weaker EF system would contribute to a pattern of disinhibited eating behaviors, or those characterized by a lack of restraint, such as loss of control (LOC) eating, emotional eating, and overeating (11). Extant limited data offer preliminary support for these associations.

In school-age children, worse performance on measures of working memory (12) and behavioral inhibition (13) are associated with LOC eating, a predictor of excess weight gain (14). Children and adolescents with (versus without) LOC eating also demonstrate poorer behavior regulation, including difficulties inhibiting impulsive responses and adjusting to changes in task demands, as well as poorer emotional control, per their parents/caregivers' reports (15). Children with Attention-deficit/Hyperactivity Disorder (ADHD), a behavioral diagnosis characterized by decrements in EF (16), are 12 times more likely to report LOC eating (13). LOC eating has also been found to mediate the link for both ADHD and parent-reported impulsivity with increases in body mass index (BMI; kg/m^2) (13). As such, LOC eating may represent one disinhibited eating pathway through which poor EF promotes excess weight gain, although all of this research has relied on self-report of eating behaviors.

In preschool-age children, poorer behavioral inhibition is associated with greater intake of carbohydrates and sugar (17), as well as parents' report of their children's tendency to overeat in response to emotions (18). Similarly, preschoolers with low scores on a measure of delayed gratification, as well as high emotional arousal, consumed more total energy and more energy from sweets in the absence of hunger (18). Like preschool-age children, school-age children who exhibit poor general behavioral inhibition are more likely to engage in a range of disinhibited eating behaviors, including self-reported emotional and external eating (19), parent-reported food responsiveness (20), and greater consumption of energy dense food both in hungry and sated states (21). Similarly, Riggs et al. found that 4th grade children who self-reported more difficulties with EF-related processes, including general behavioral inhibition, emotional control, and working memory, also reported consuming more snack foods (22). In this same sample, strong self-reported EF also predicted greater self-reported fruit and vegetable intake one year later (23).

Importantly, not all studies have identified the expected link between EF and disinhibited eating patterns. In preschool-age children, EF performance was not associated with observed or parent-reported eating behaviors (24). However, those who performed better on a measure of delayed gratification for food items consumed more energy in the absence of hunger (24). Similarly, in a sample of school-age children, delayed gratification performance using both food and non-food items was positively associated with emotional overeating (20). The unexpected positive association between delayed gratification and disinhibited eating in children has been posited to reflect greater motivation for food (25).

In summary, the majority of research with youth supports a link between lower EF and greater disinhibited eating patterns. However, there are significant limitations to our current understanding of these associations. First, there are issues in assessment of both EF and disinhibited eating. Much of the EF literature has been narrowly focused on tests of general behavioral inhibition. Moreover, measurements of both EF and disinhibited eating patterns have frequently relied on self- and parent-reports (26). Further complicating the situation, EF is a diverse construct; some studies have even found an unexpected positive association between EF, specifically willingness to delay gratification, and disinhibited eating patterns (20, 24). Mixed findings across studies underscores the importance of evaluating multiple dimensions of EF, and of distinguishing between tasks including food and non-food items. Importantly, the link between EF and obesity appears strongest when EF has been assessed with objective tasks versus surveys (2), highlighting the importance of using neuropsychological tasks in evaluating associations with disinhibited eating patterns. Second, few studies have evaluated specific facets of EF in relation to adolescents' disinhibited eating patterns (26). Some data suggest that the link between obesity and EF is more pronounced among adolescents versus children (2). Adolescence is characterized by a period of heightened impulsivity and reward-related processing (27) which, according to the 2-systems theory, may make this a particularly vulnerable period for disinhibited eating patterns, such as LOC eating (28, 29). Finally, few studies consider potential confounding factors, like general intellectual functioning, body mass, and depressive symptoms, in their efforts to clarify whether specific domains of EF are uniquely associated with youth's disinhibited eating patterns (26).

The goal of the current study was to evaluate the association between youths' EF and their disinhibited eating patterns using neuropsychological tasks and a buffet test meal, respectively. It was hypothesized that, after adjusting for relevant demographic factors, body composition, depressive symptoms, and general intellectual functioning, poorer decision-making, general and food-specific behavioral inhibition, cognitive flexibility, and working memory, would be associated with greater total energy intake, fat intake, and sugar intake. Based on prior literature (20, 24), it was also expected that, paradoxically, greater willingness to delay gratification for food items would be positively associated with these disinhibited eating patterns. Age was examined as a potential moderator. It was hypothesized that the links between poor EF and disinhibited eating would be particularly strong among adolescents (vs children) who, because of their growth, heightened impulsivity and reward-sensitivity, and elevated risk for disinhibited eating (27–29), are expected to consume particularly large meals (30).

Methods

Participants

Boys and girls between the ages of 8–17 years were recruited to participate in a study on pediatric growth and health behaviors (Clinical Trials Identifier: NCT02390765). All participants were in good general health, as determined by a medical history and physical examination. Exclusion criteria included: 1) major medical illness or pregnancy; 2) BMI < 5^{th} percentile; 3) regular use of medication known to affect appetite or body weight; 4) significant or recent brain injury; 5) regular use of illicit substances; 6) significant weight loss (>5% of body weight) in the past three months; 7) current psychiatric disorder; and 8) full scale intelligent quotient score ≤ 70 (31). The Institutional Review Board of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development approved all study procedures.

Procedures

Individuals completed two screening visits at an outpatient pediatric clinic at the National Institutes of Health Hatfield Clinical Research Center. During the first visit, youth provided written assent and parents/guardians gave written consent. Families then completed a medical history and youth underwent a physical examination that included determination of pubertal development (32, 33). Youth then completed several surveys, including the Children's Depression Inventory (34), as well as two semi-structured psychiatric interviews to determine eligibility. During the second visit, participants arrived in a fasted state. Their height was measured in triplicate by stadiometer and their weight was measured by a calibrated scale. Participants were then asked to consume in its entirety a standard breakfast shake (21% of estimated daily energy needs; 17% protein, 16% fat, and 67% carbohydrate), the amount of which was determined using measured body weight, height, age, and an activity factor based on self-reported average physical activity during the previous week (35, 36). Participants then completed several cognitive tasks and had their fat and lean mass measured via dual-energy x-ray absorptiometry (GE Healthcare, Madison WI). At approximately 12:00PM, participants ate lunch from a large buffet test meal.

Measures – Cognitive functioning

General intellectual functioning—General intellectual functioning was evaluated with the Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II) (31). The WASI-II is a standardized brief intellectual screening tool comprised of four subtests that provides reliable, valid estimates of general cognitive ability among individuals as young as 6 years (31).

Decision-making—The Iowa Gambling Task was used to assess participants' decision-making (37). For this 15-minute computer task, participants are asked to select one of four decks of cards. Each time a deck is selected, a specified amount of play money is either awarded or lost. Two of the decks of cards – called the disadvantageous decks - produce high immediate gains and significant losses, resulting in less money over time. The other two decks are considered advantageous, as they result in small, immediate gains and losses, and thus will yield more money over time. Performance on this task is defined as the difference between the number of advantageous and disadvantageous selections across five blocks. Lower or more negative net scores are reflective of poorer decision-making characterized by a preference for immediate rewards and/or a stronger insensitivity to negative consequences. Previous studies have used the Iowa Gambling Task to assess decision making in youth with obesity (38).

General behavioral disinhibition—General behavioral disinhibition was measured with the Stop Signal Task (39). For this 15-minute computer task, participants are asked to respond as quickly as possible to a go-signal presented on a computer screen by pressing one of two corresponding buttons on the keyboard, but to inhibit their response if they hear a tone before the signal is presented (25% of items). The speed with which the tone (or stop signal) is presented changes depending on the participant's performance; it becomes increasingly closer to the go signal as participants perform better, and further away as participants fail to inhibit. Using this tracking algorithm, the stop signal delay converges on the delay at which individuals are able to stop 50% of the time. The primary indicator of performance on this task is the stop-signal reaction time (SSRT), calculated by subtracting the mean stop-signal delay from the mean reaction time. A longer SSRT represents a poorer response inhibition. The SSRT has demonstrated effectiveness in distinguishing children with overweight (40) from those without.

Food-specific behavioral disinhibition—Food-specific behavioral disinhibition was measured with the Food Go/No-Go Task (41). Participants are asked to press a button when a target "go" image (e.g., toy) is presented in the center of the screen. These "go trials" are presented on the majority (~73%) of trials to create a learned, prepotent tendency to respond to the "go" target. Youth are also instructed to withhold their learned responses in the presence of any other "no-go" stimulus (e.g., food), which are infrequently presented (~27% of all trials). Images consisted of high-calorie foods, low-calorie foods, and neutral non-food toys. Each stimulus type serves as both "go" and "no-go" targets, depending on the block. Each block has 35 "go" trials and 13 "no-go" trials. There are four randomized blocks of "go/no-go" pairs, including: high-calorie food—toy, toy—high-calorie food, low-calorie food—toy, and toy—low-calorie food. Target stimuli are presented for 500-ms with 2000–4000-ms between trials. Similar go/no-go tasks have been used with children as young as 7 years (42). The measure of interest was the number of commission errors (or responses incorrectly made to 'no-go' trials) for each pair of images; higher scores represent worse behavioral inhibition.

Delayed gratification—A 20-minute Delay Discounting Task was used to assess the ability to modulate desire for immediate gratification for the sake of long-term goals (43). Delayed gratification for both money and palatable food were examined. In the money version of the computerized task, participants are presented choices between a hypothetical monetary amount (e.g., $10) available after a specified delay (i.e., 1, 2, 7, 14, 30, 180, 365 days) and a smaller amount available immediately. Similarly, the food version presents youth with choices between one portion of their preferred palatable food (selected from a standard list before the task) available immediately and increasing portions of the food available at a delay. The Delay Discounting Task involves an adjusting amount procedure, whereby the amount of money or food portions offered increase at each delay interval. Indifference points are calculated for each participant at each delay and reflect the amount of money or food at which the immediate rewards became preferred over the delayed reward. These values were then used to calculate area-under-the-curve (AUC) values, separately for food and money, as outlined by Myerson et al (44). AUC values range from 0 to 1; smaller values indicate a steep discounting function (e.g., less willingness to wait for a larger reward as the delay increases). Previous research has identified no significant differences between real and hypothetical monetary rewards in outcomes for delayed discounting tasks (45). The Delay Discounting Task has been used successfully in children as young as 7 years of age (46).

Cognitive flexibility—Cognitive flexibility, or the ability to shift responses based on rules or contingencies, was assessed with the NIH Toolbox Dimensional Change Card Sort Test (47). For this 4-minute computer task, participants are asked to match a target visual stimulus to 1 of 2 choice stimuli according to shape or color. Performance is determined by the number of accurate responses. Normed scores are available for children as young as 3 years old and were created considering age, sex, race/ethnicity and maternal education (48).

Working memory—Working memory was assessed with the NIH Toolbox List Sorting Working Memory Test (47). For this 7-minute task, participants are placed at a computer and presented with a series of images, each for two seconds. For each item, an auditory cue accompanies the pictorial presentation. Participants are instructed to remember the stimuli and repeat them verbally to the examiner in order of size, from smallest to largest. The number and variety of objects in a series increases on successive items thereby taxing the working memory system when longer sequences need to be remembered. Performance is determined by the number of accurate responses. Normed scores are created considering age, sex, race/ethnicity and maternal education (48). This measure has demonstrated good test-retest reliability and convergent and divergent validity with children as young as 3 years (47).

Measures – Disinhibited Eating

Laboratory buffet test meal—At approximately 12:00PM, participants were escorted to a private room and exposed to a standardized buffet test meal (>10,000 kcal; 54% carbohydrate, 12% protein, 33% fat) comprised of diverse food items (49). They received tape-recorded instructions to "Let yourself go and eat as much as you want." This test meal paradigm has been shown to induce disinhibited eating patterns, including greater total energy intake and palatable food intake, in children and adolescents (50, 51). All food items were weighed on electronic balance scales in gram weights to the nearest gram; foods consumed were determined by subtracting the food weights after the participant's meal from initial weights. Food energy and macronutrient content were calculated using data from food labels. Total energy intake (kcal); percentage of energy intake from fat; and percentage of energy intake from sugar of the consumed meal were calculated with the ProNutra (Viocare Technologies, Princeton, NJ, USA) program. Total sugar intake refers to monosaccharides (glucose, fructose and galactose) and disaccharides (sucrose, lactose and maltose) and was reported as proportions of total energy consumed.

Data analysis

All analyses were conducted using IBM SPSS Statistics 24. Hierarchical multiple regression models were used to evaluate the association between youth's EF and disinhibited eating. Age (children, 8–12y, versus adolescents, 13–17y) was a proposed moderator variable. All covariates were entered into the first level of each regression model (age when not examined as a moderator; sex; race coded as 0 = non-Hispanic white and 1 = other; pubertal status; lean mass in kg; percentage fat mass (arcsine transformed); height in cm; depressive symptoms; and general intellectual functioning (3, 4, 30, 52). Main effects of the EF indicator and age were entered into the second level of their own models. In the third and final level, a two-way interaction between the EF indicator and age were included. Separate models were conducted for each measure of EF and for each energy intake variable, including total energy intake (kcal); fat intake (percentage arcsine transformed); and sugar intake (percentage adjusted for total intake; arcsine transformed). To avoid concerns associated with multicollinearity, all EF indicators were centered based on the grand mean prior to being entered into each model (53). To reduce the likelihood of type I errors associated with multiple statistical tests, the Benjamini–Hochberg correction (54) was applied within families of planned contrasts and adjusted *p*-values are presented.

Results

Preliminary Analyses and Participants

Following a brief phone screen, 242 youth attended at least one of the two screening visits. Thirty-seven youth were not enrolled in the study or were deemed ineligible. The final sample for the current study included 205 participants (*M* age = 13.1±2.8y; 49.8% children 8–12y; *M* BMI*z* = 0.6±1.0; 54.1% female; 43.9% non-Hispanic white, 29.3% black/African American; 11.7% Asian/Asian American; 7.3% Hispanic/Latino/a; 7.8% multiple races). Missing data were minimal (< 5% for any variable); as such, listwise deletion was employed (55). One participant's general behavioral inhibition score was not used because it was negative, which is indicative of significantly poor effort (56). One individual's scores on the tasks measuring cognitive flexibility and working memory were winsorized (changed to three standard deviations above the mean) to reduce the effects of these outliers on the distributions. Percentage of breakfast shake consumed was considered as a covariate because 54 participants did not consume the shake in its entirety; however, this variable was not significant in any model nor did it change the significance or direction of any result and thus was excluded from all analyses. Table 1 shows bivariate correlations among the examined indicators of EF and disinhibited eating. The Supplementary table includes full results for the following hypothesis-testing analyses.

Decision-making

In fully-adjusted models, co-varying for age, sex, race/ethnicity, pubertal status, lean mass, fat mass, height, depressive symptoms, and general intellectual functioning, the links between decision-making and all energy intake variables were non-significant (all *p*s = .28). However, age moderated the link between decision-making and the percentage of energy consumed from fat (β = .001, $p = .04$). In follow-up models conducted within each age group, among children age <13y, those who performed worse on a task measuring decision-making consumed a greater percentage of food from fat (β = −.001, $p = .04$; Figure 1a), while this association was non-significant in adolescents age ≥13y ($p = .24$; Figure 1b). Moderation models for total energy ($p = .77$) and total sugar intake were non-significant ($p = .17$).

General behavioral disinhibition

In fully adjusted models, general behavioral disinhibition was positively and significantly associated with total energy consumed (β = 1.14, $p = .02$); across all ages, youth who demonstrated more disinhibition consumed more energy during the test meal. Models for fat and sugar intake were non-significant and age did not moderate any associations (*p*s = .42 – .82).

Food-specific behavioral disinhibition

Adjusting for covariates, commission errors for high energy-density images (versus toys) were not significantly associated with energy intake and age did not moderate these associations (*p*s = .12 – .99). Commission errors for low energy-density images (versus toys) were not associated with energy intake and age did not moderate this association (*p*s = .12 – .99). Commission errors for toys (versus high energy-density food) images were not significantly associated with energy intake and age did not moderate these associations (*p*s = .12 – .99). Commission errors for toys (versus low energy-density food) images was not associated with energy intake and age did not moderate these association (*p*s = .24 – .99).

Delayed gratification—In fully adjusted models, the links between delayed gratification for money and energy intake were non-significant and age was not a significant moderator of any of these associations (*p*s = .44 – .81). Similarly, the links between delayed gratification for food and energy intake were also non-significant and age was not a significant moderator of these associations (*p*s = .48 – .97).

Cognitive flexibility—Adjusting for covariates, the link between cognitive flexibility and fat intake showed an inverse, significant relationship ($\beta = -.001$, $p = .03$); across all ages, participants who demonstrated greater cognitive flexibility consumed less fat during the test meal. Models with total energy ($p = .74$) and total sugar intake were non-significant ($p = .50$). Age did not significantly moderate any of these associations (*p*s = .12 – .79).

Working memory—In fully adjusted models, the links between working memory and energy intake were all non-significant and age did not moderate these associations (all *p*s = .39).

Discussion

The current study used diverse neuropsychological tasks and a validated test meal paradigm to evaluate the associations between EF and disinhibited eating in a sample of youth. General behavioral disinhibition was the only domain of EF associated with total energy intake. Across all ages, youth who demonstrated greater disinhibition consumed more total energy during a buffet test meal. Two domains of EF were associated with fat intake, and one of these associations differed by age. Across all ages, youth who demonstrated worse cognitive flexibility consumed more fat during the test meal. Moreover, children who demonstrated worse decision-making consumed a greater proportion of their food as fat; this association was not significant among adolescents. Food-specific behavioral disinhibition, the ability to delay gratification for both food and monetary rewards, and working memory were not significantly associated with youth's disinhibited eating patterns during a single test meal.

Behavioral disinhibition is the construct most consistently and robustly associated with obesity in youth (57) and it was also the only variable in the current study associated with total energy intake during the test meal across all ages. These findings are consistent with other studies linking worse general behavioral disinhibition with greater snack food intake and LOC eating in children (13, 19–22). Difficulties inhibiting a desired behavioral response, such as consuming additional portions of palatable foods, may contribute to a consistent pattern of overeating associated with excess weight gain. However, from this perspective, it is unclear why the link between food-specific behavioral disinhibition, as assessed with the Food Go/No-Go Task (41), and energy intake was non-significant in adjusted models. This pattern of findings may suggest that broad behavioral control difficulties are associated with disinhibited eating patterns when youth are presented with an array of palatable and non-palatable food options, such as in the current study's protocol. Our measure of food-specific behavioral inhibition used images that did not correspond with the same foods presented during the test meal. It is possible that greater correspondence between behavioral difficulties and disinhibited eating might have been observed if craved foods were used in both contexts. Nonetheless, in school-aged children, general behavior disinhibition is associated with more time spent in sedentary behavior as measured with accelerometers (58), while greater physical activity is associated with better behavioral inhibition (59). As such, general behavioral inhibition difficulties and unhealthy energy patterns may function to maintain one another and contribute to excess weight gain. Indeed, work from Riggs et al. (60) identified a high-risk pediatric obesity phenotype characterized by greater behavioral disinhibition, high sedentary behavior, and high energy intake. Additional studies are needed to better understand whether context-specific inhibitory difficulties have unique implications for youth's health behaviors and obesity risk.

The only additional significant associations between EF and energy intake were observed for fat consumption. Specifically, children (but not adolescents) who performed worse on a measure of decision-making consumed a greater proportion of their meal as fat during the buffet meal, as did participants who demonstrated less cognitive flexibility. The non-significant link between decision-making and fat intake in adolescents was unexpected, given the heightened impulsivity and sensitivity to rewards observed during this development period (27). According to prospective data, performance on the Iowa Gambling Task improves linearly from childhood to adulthood (61). As such, a link between decision-making and fat intake may only be evident in younger children, before significant neural improvements in decision-making occur. Additional studies are needed to determine how these changes are associated with disinhibited eating patterns over time, and whether certain developmental periods represent critical points for health risk. For instance, from adolescence to adulthood, decision-making processes appear to transition from approaching risk to avoiding it (61). In the context of dietary decision-making, individuals with poorer decision-making may consume more fat as a younger child, and then rigidly avoid it as an adult, which may inadvertently promote disinhibited eating (62) and associated weight gain. Prospective data are needed to clarify whether developments in decision-making have differential effects on disinhibited eating patterns over time.

Poorer cognitive flexibility was also associated with greater fat intake, and this association was not moderated by age. Our data suggest that it may be an important domain of EF to consider in youth's fat consumption. Given the demonstrated link between a high-fat diet and both acute and chronic declines in cognitive functioning (63), poorer cognitive flexibility and greater fat intake may reinforce one another over time. Importantly, both working memory and behavioral inhibition are considered integral components of cognitive flexibility (64). Given the non-significant link between working memory and energy intake, findings from the current study suggest that behavioral inhibition and cognitive flexibility may be particularly relevant to the disinhibited eating of youth. Concurrent difficulties inhibiting a behavioral response and greater inflexibility in thinking may contribute to a rigid pattern of responding to high-fat foods in which disinhibition inevitably occurs.

The lack of significant associations for delayed gratification and working memory with energy intake were unexpected. One possible explanation is that these domains of EF, while associated with obesity (2–4, 12, 19, 40), are less relevant to youth's disinhibited eating patterns. They may be associated with excess weight gain through other behavioral and/or physiological mechanisms, or represent consequences of poor dietary choices and/or obesity.

Additionally, prospective data suggest that the association between EF and disinhibited eating patterns may become more evident later in life. Specifically, there is a significant interaction between body mass and age for EF performance, indicating that the inverse association between EF and body mass increases with age (65). Finally, the fact that the majority of indicators of EF were not associated with disinhibited eating may be an artifact of measurement limitations. A single observation of disinhibited eating was used in the current study. Likewise, different domains of EF may only be relevant to youth's disinhibited eating behaviors in certain contexts. For instance, the potential negative effects of weaker EF systems on disinhibited eating risk may only become evident in stressful situations, when youth's cognitive and coping systems are further taxed (66). Including methods such as ecological momentary assessments in longitudinal studies would enhance our understanding of how EF abilities interact with environmental and state-level psychological changes to affect eating decisions.

Strengths of the current study address significant limitations of prior work by using an extensive neuropsychological battery to assess distinct domains of EF, as well as the inclusion of a buffet test meal to capture youth's disinhibited eating. Although there are limitations to generalizing the findings from a single test meal to youths' daily eating habits, intake patterns during this meal are correlated with body mass, adiposity, eating in the absence of hunger (67), binge eating, and emotional eating (68), suggesting these results may have implications for youths' broader disinhibited eating habits and health risk. The current study also adjusted for confounding factors rarely considered in prior work, including body composition (so that the potential impact of obesity itself was mitigated), general intellectual functioning, and depressive symptoms. The primary limitations of the current study include its use of a convenience sample and cross-sectional design. This approach may limit our understanding of the link between EF and disinhibited eating in higher risk samples. EF and eating patterns also change over time and in different contexts. Results from the current study only represent correlations between performance on several EF tasks and energy intake at a single meal. Longitudinal studies with multiple assessments of both EF and disinhibited eating would greatly clarify optimal targets for obesity prevention in youth.

Our pattern of findings highlights the need to be clear about which EF domain is being studied when discussing EF in the context of health and health behaviors, particularly because prior work has spurred the development of interventions targeting EF as a means of reducing obesity risk in children (69). Our data suggest a rationale for studies targeting general behavioral inhibition, decision-making, and cognitive flexibility, to determine if improvements in these domains of EF can reduce disinhibited eating patterns and chronic disease risk in youth. The need to take a targeted approach to intervening with EF is reinforced by the lack of significant correlations between most of the indicators of EF that we evaluated (other than those stemming from the same task; see Table 1). Consistent with prior investigations (70), these findings indicate that EF is comprised of various related but distinct cognitive processes. Future research needs to determine whether modifying these cognitive processes has specific consequences for youth's disinhibited eating patterns. For instance, some data suggest that targeting behavioral inhibition may be more relevant to reducing palatable food consumption versus promoting healthy food consumption (71).

Although research related to targeting specific EF domains to improve youth's eating habits is in its infancy, intervening early may prove to be prudent to minimize the potential harmful consequences of disinhibited eating on immediate and long-term cognitive functioning. Although the optimal strategies for strengthening decision-making, behavioral inhibition, and cognitive flexibility are unclear, these particular domains of EF continue to improve through adulthood (72), suggesting intervention approaches likely need to be developmentally tailored. Prospective studies are needed to determine if intervening with youth's EF can serve as a means of reducing their disinhibited eating.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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NRK, MTK and JAY contributed to study design; all authors contributed to data collection; NRK conducted data analysis and interpretation, completed the literature search, generated the figures and together with MTK and JAY wrote the first draft of the manuscript. All authors were involved in writing the paper and had final approval of the submitted and published versions. This work was supported by Intramural Research Program (NICHD grant number ZIA-HD00641; Yanovski); Supplemental funding (OBSSR, NIH; Yanovski); National Research Service Award (grant number 1F32HD082982; NICHD, NIH; Kelly)

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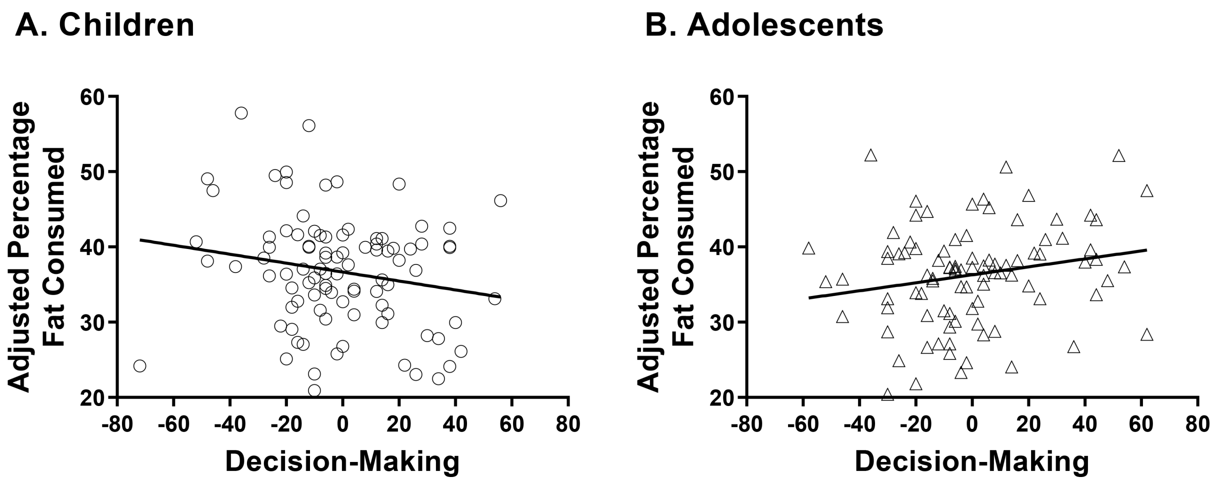

Figure 1.

In fully-adjusted models, co-varying for age, sex, race/ethnicity, pubertal status, fat-free mass, fat mass, height, general intellectual functioning, and depressive symptoms, age moderated the link between decision-making and the percentage of calories consumed from fat ($\beta = .001$, $p = .04$). In a follow-up model conducted within each age group, children who performed worse on a task measuring decision-making consumed more food from fat ($\beta = -.001$, $p = .04$; Figure 1a) while this association was non-significant in adolescents ($p = .24$; Figure 1b).

Table 1.

Correlations among Indicators of Executive Functioning and Disinhibited Eating

	M (SD)	1	2	3	4	5	6	7	8	9	10	11	12
1 Decision-Making	0.82 (25.52)												
2 General Behavioral Disinhibition	284.32 (73.13)	−0.08											
3 Delayed Gratification for Money	0.46 (0.36)	0.13	−0.05										
4 Delayed Gratification for Food	0.42 (0.37)	0.10	0.00	**0.79									
5 Cognitive Flexibility	47.89 (14.72)	0.01	−0.10	−0.08	−0.14								
6 Working Memory	51.19 (10.09)	0.10	−0.05	0.04	0.03	**0.24							
7 High Calorie Foods vs Objects	0.34 (0.23)	−0.05	**0.21	*−0.15	−0.14	*−0.15	−0.06						
8 Low Calorie Foods vs Objects	0.33 (0.22)	**−0.25	**0.23	−0.13	−0.03	*−0.17	−0.08	**0.44					
9 Objects vs High Calorie Foods	0.40 (0.23)	−0.11	*0.16	−0.13	−0.04	*−0.17	−0.01	**0.42	**0.50				
10 Objects vs Low Calorie Foods	0.43 (0.25)	−0.07	**0.19	0.00	−0.02	−0.09	−0.04	**0.67	**0.37	**0.45			
11 Total Calories Consumed	972.89 (420.56)	*−0.15	0.10	−0.10	−0.10	−0.04	−0.01	*0.19	*0.22	*0.23	*0.15		
12 Total Fat Consumed (%)	0.65 (.08)	−0.10	0.02	0.03	0.00	*−0.21	−0.13	0.03	0.10	0.08	0.09	**0.18	
13 Total Sugar Consumed (%)	0.46 (.11)	0.07	0.11	0.08	0.10	0.03	−0.02	−0.11	−0.04	−0.07	−0.07	−0.13	**−0.53

Note.

** $p<.01$

* $p<.05$