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Associations between Specific Components of Executive Control and Eating Behaviors in Adolescence: A Study Using Objective and Subjective Measures

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Abstract

A growing literature suggests that executive control (EC; also known as “executive functioning” or “EF”) in adolescence may play an important role in the development of key health behaviors, including eating behaviors. However, existing literature has significant limitations in the conceptualization and measurement of EC. The current study aims to address these limitations by employing a multidimensional approach to conceptualizing and measuring adolescent EC, including both objective and subjective measures covering multiple components of EC, and examining links with specific eating behaviors. A community sample of adolescents (N = 208; mean age = 14.5 years) completed a battery of performance-based neuropsychological tasks assessing specific components of EC (i.e., working memory, inhibitory control, flexible shifting), a norm-referenced questionnaire covering problems with specific components of EC in daily life, and a measure assessing key eating behaviors (i.e., uncontrolled eating, emotional eating, cognitive restraint). Objectively-measured adolescent working memory was significantly and uniquely associated with cognitive restraint, with stronger working memory associated with less cognitive restraint. No other associations between performance-based EC tasks and eating

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Ethics Statement: The study was approved by the Institutional Review Board (IRB) at the University of Nebraska-Lincoln. Adult participants gave written informed consent before taking part in the research, and adolescents provided written assent.

behaviors were found. In contrast, using subjective reports of EC, problems with inhibitory control were associated with greater uncontrolled eating, and problems with flexible shifting were associated with greater emotional eating. The results suggest links between specific aspects of EC and specific eating behaviors in adolescence, as well as the potential importance of context for understanding the role of EC in eating behavior. Given evidence that EC is modifiable, the findings have potential implications for novel interventions addressing eating behaviors by targeting EC.

Keywords

executive control; eating behaviors; adolescence; emotional eating; uncontrolled eating; cognitive restraint

1. Introduction

Adolescence is a key period in the development of eating behaviors with potential long-term implications for health (Lake, Adamson, Craigie, Rugg-Gunn, & Matters, 2009; Mikkilä, Räsänen, Raitakari, Pietinen, and Viikari, 2005). Many factors likely affect the emergence of eating patterns during this time, including factors within the individual adolescent, social and environmental determinants, and the interaction between the individual and environment (Ding et al., 2012; Nelson et al., 2019; Stor, Neumark-Sztainer, & French, 2002). Within the realm of individual differences, there has been increased attention in recent years to the role that specific cognitive abilities may play in the development of eating behaviors.

Specifically, a growing body of research has explored *executive control* (EC; also known as “executive functioning” or “EF”) – a set of cognitive abilities for directing attention and behavior (Espy, 2016; Garon, Bryson, & Smith, 2008) – as a possible contributor to individual eating behaviors (Egbert, Creber, Loren, & Bohnert, 2019; Liang, Matheson, Kaye, & Boutelle, 2014). Despite increased attention and emerging evidence suggesting a potentially important role for EC in developing health behaviors, the extant literature has significant limitations, particularly in the conceptualization and measurement of EC (Egbert, Creber, et al., 2019). The current study aims to address these limitations by employing a rigorous, multidimensional approach to conceptualizing and measuring adolescent EC, and examining links with specific eating behaviors.

A number of factors combine to make adolescence a critical period for developing eating patterns, including unhealthy eating behaviors such as overconsumption, uncontrolled eating, emotional eating, and poor dietary quality. Adolescence is a time of increasing autonomy, in general, and greater health behavior independence, specifically (Bassett, Chapman, & Beagan, 2008). With regard to eating, adolescents typically gain more autonomy in their food choices, although family factors are often still influential (Story et al., 2002). This rise in eating independence coincides with a developmental and environmental context that can make it challenging for adolescents to cultivate healthy eating habits (e.g., high fruit and vegetable intake and limited consumption of calorically-dense foods). Developmentally, while adolescence is a time of considerable cognitive gains, the prefrontal cortex and key regulatory systems in the brain are still maturing throughout

the teen years and into young adulthood (Luna, Padmanabhan, & O'Hearn, 2010). Adolescence can also be a time of heightened emotional turmoil, with increases in amygdala activation (Hare et al., 2008) and increasing rates of depression and anxiety (Merikangas et al., 2010), which may contribute to emotional eating behaviors (i.e., eating in response to emotional cues rather than hunger). Socially, adolescents are susceptible to peer influence and pressure to engage in a variety of unhealthy behaviors, including less healthful eating (e.g., consumption of energy-dense and nutritionally-poor foods and beverages, such as sugary drinks; Wouters, Larsen, Kremers, Dagnelie, & Geenen, 2010). Further, adolescents often encounter obesogenic food environments, with ubiquitous prompts for consumption of less healthful foods (e.g., advertisements, fast food restaurants) and barriers to healthful eating (e.g., lack of access to affordable fresh fruits/vegetables) (Shearer et al., 2015).

Taken together, many adolescents face a confluence of circumstances that challenge the development of healthful eating behaviors, all at a time when their abilities to direct attention and behavior in intentional ways toward healthy decisions are still maturing. Not surprisingly given this context, adolescents abundantly consume less healthful foods (e.g., fast food, sugary drinks), with the majority of adolescents failing to meet the United States Dietary Guidelines for Americans (Banfield, Liu, Davis, Chang, & Frazier-Wood, 2016). Importantly, less healthful eating behaviors that develop in adolescence may portend significant long-term risk. Research has shown that eating patterns in adolescence often persist into adulthood (Lake et al., 2009; Lake, Mathers, Rugg-Gunn, & Adamson, 2006; Larson et al., 2008), and sustained energy-dense, nutrient-poor diets increase risk for numerous chronic conditions including obesity, Type 2 diabetes, cardiovascular disease and some cancers (Bazzano, Liu, & Serdula, 2005; Bleich, Jones-Smith, Wolfson, Zhu, & Story, 2015). Given the urgent threat that less healthful eating patterns in adolescence poses to public health, it is essential to understand the factors that affect eating behaviors at this critical point in development to inform prevention efforts.

One construct that has received increasing attention in recent years as a possible contributor to eating behavior is EC. As typically conceptualized in the developmental literature, EC is comprised of three related abilities: *working memory* (ability to hold and manipulate information), *inhibitory control* (ability to inhibit prepotent responses), and *flexible shifting* (ability to shift between changing demands) (Diamond, 2013; Espy, 2016; Miyake et al., 2000). EC follows a protracted developmental course with continued maturation from early childhood through young adulthood, tracking development of the prefrontal cortex and related brain regions that support these functions (Luna, Padmanabhan, & O'Hearn, 2010). Measurable individual differences in EC abilities emerge early in life (Espy, 2016), and these differences have been linked extensively to later educational (Clark, Sheffield, Wiebe, & Espy, 2013) and mental health (Kertz, Belden, Tillman, & Luby, 2016; Nelson et al., 2018) outcomes. EC has only more recently been explored in the context of key health behaviors, but theoretical and empirical work has begun to lay the foundation for studies explicating the interplay between EC and health.

Theoretical frameworks from developmental cognitive neuroscience and cognitive health neuroscience suggest the potentially important role of EC in key health behaviors and help to frame the current study (Hall & Marteau, 2014; Nelson et al., 2019). In particular, the

current paper builds on the conceptual framework developed by Nelson and colleagues (2019) which proposes a critical role for EC deficits in developing unhealthy behaviors – including less healthful eating behaviors – in adolescence. This framework posits that problems with specific components of EC may undermine attentional, behavioral, and emotional control in a way that increases risk for less healthful eating behavior when confronted with the environmental challenges of adolescence. For example, *inhibitory control* is critical in refraining from immediately gratifying consumption of “junk foods” (e.g., energy-dense, nutrient-poor foods) in favor of healthier options, and in directing attention away from external and internal cues to eat less healthful options (e.g., advertisements, cravings). Deficits in inhibitory control, therefore, may put the individual at risk for impulsive and uncontrolled eating. *Working memory* is essential for remembering and updating dietary goals and strategies and implementing these consistently. Individuals with working memory problems may temporarily “lose track” of dietary goals, particularly in the face of environmental cues for consumption or fluctuations in emotions, leading to emotional and/or uncontrolled eating. Finally, *flexible shifting*, is important for problem-solving strategies to meet health goals despite environmental obstacles. Deficits in shifting abilities may result in the adolescent becoming “stuck” in unhealthy patterns and unable to flexibly adapt to challenging circumstances and enact healthy behaviors. Adolescence is an ideal time for a nuanced examination of *which specific EC abilities* are most associated with eating behaviors because research suggests the three components of EC are clearly differentiated by adolescence (Lee, Bully, & Ho, 2013) but not earlier in childhood (Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, & Greenberg, 2010; Nelson et al., under review).

Although findings have been mixed, an emerging body of research has explored links between EC and eating, with numerous studies reporting significant associations between deficits in aspects of EC (or closely related constructs) and specific eating behaviors. A substantial literature has found deficits in components of objectively-measured EC – typically inhibitory control – significantly predict emotional eating and weight gain in young adults (e.g., Jasinska et al, 2012; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Among children and adolescents, findings generally point to an association between EC deficits (assessed using either objective or subjective measures) and less healthful eating patterns (Egbert, Creber, et al., 2019). For example, in a series of cross-sectional and short-term longitudinal studies with fourth graders, Riggs and colleagues reported associations between EC problems (as measured by a subjective norm-referenced questionnaire) and greater snack food intake (Riggs et al 2010a; Riggs, Spruijt-Metz, Chou, & Pentz, 2012) and lower fruit and vegetable intake (Riggs et al., 2010b; Riggs et al., 2012). In a cross-sectional study of adolescents ages 14–17, Ames and colleagues (2014) found that poorer performance on an objective inhibitory control task was associated with more binge eating behavior in females and greater intake of sweet snacks and sugary beverages in males. In a cross-sectional study of early adolescent girls (ages 9–13), Egbert and colleagues found associations between poorer inhibition (using a performance-based task and questionnaire) and aspects of eating in the summer, including higher caloric intake and sugar-sweetened beverages (Egbert, Bohnert, et al., 2019). Similar patterns of findings have been reported among samples of youth with obesity, including links between subjective reports of EC

problems and problematic eating behaviors such as overeating and binge eating (e.g., Gowey et al., 2018). Finally, Stautz and colleagues (2016) reported results from a rare large-scale longitudinal study of over 6000 youth, with objective performance-based measures of inhibitory control and working memory in childhood (ages 8–10) and dietary behaviors in early adolescence (age 13), finding a significant positive bivariate association between working memory (but not inhibitory control) and fruit/vegetable intake; however, working memory was no longer a significant predictor of intake after controlling for intelligence.

While the extant literature alludes to links between deficits in EC and key eating behaviors, important limitations in the conceptualization and measurement of EC undermine our understanding of these associations and ability to inform interventions. This literature has been plagued by an overly-narrow conceptualization of EC, with many studies viewing EC as limited to inhibitory control, and thus overlooking the potential role of other aspects of EC (e.g., working memory, flexible shifting) (Egbert, Creber, et al., 2019). Studies that employ a broader, richer conceptualization of EC as a multidimensional construct comprised of three related yet distinct components are needed but currently lacking from the literature. Related to the problems with EC conceptualization, the extant literature on EC and eating behaviors has important limitations in the measurement of EC. Specifically, there has been an over-reliance on exclusively subjective (typically self- or parent-report) measures of EC. Studies using objective, performance-based measures, such as neuropsychological tasks, are relatively rare. Even when such tasks are utilized, studies typically include only one or two tasks, often covering only inhibitory control. Task batteries with more comprehensive coverage of the EC construct – including tasks measuring not only inhibitory control but also working memory and flexible shifting – are needed, both to more fully represent EC and to begin to distinguish *which aspects* of EC are most associated with eating behaviors. Further, studies that employ *both* subjective and objective measures of EC are exceptionally rare and could provide additional insight into the role of EC. While objective EC tasks are likely best for capturing individual EC abilities, subjective questionnaires can provide additional information about the deployment of those abilities in the context of daily life (Gioia, Isquith, Guy, & Kenworthy, 2015). Finally, there is a relative lack of studies exploring EC-eating associations at key developmental periods like adolescence.

The current study addresses the limitations noted above by examining associations between different aspects of EC (measured using both a multidimensional objective task battery and scales from a subjective norm-referenced questionnaire) and key eating behaviors in a community sample of adolescents. Based on our theoretical framework and previous literature, we developed specific a priori hypotheses regarding associations between aspects of EC and eating behaviors. Specifically, we first hypothesized that the different aspects of EC (i.e., inhibitory control, working memory, flexible shifting) would each show unique associations with uncontrolled eating, with poorer EC abilities/more EC problems associated with greater uncontrolled eating behaviors. Similarly, we hypothesized poorer EC/more EC problems to be associated with greater emotional eating behaviors. We also explore associations between specific aspects of EC and cognitive restraint in eating, although existing theory and literature were insufficient to make a priori directional hypotheses regarding these analyses. This study promises to build on previous EC-eating literature by improving the conceptualization and measurement of EC, and facilitating a more in-depth

examination of which aspects of EC are most associated with specific eating behaviors. Explicating the specific aspects of EC that are most critical will inform prevention efforts by identifying priority targets for novel interventions. Given accumulating evidence that EC is modifiable (Diamond & Lee, 2011; Diamond & Ling, 2016; Hillman et al., 2014), such knowledge could be powerful in shaping and targeting EC interventions to promote more healthful eating in adolescence.

2. Method

2.1 Participants

The participants were 208 adolescents (52% female) ages 14 to 16 years (mean age = 14.5 years; SD = 0.75 years) participating in an ongoing longitudinal study focusing on cognitive development and health. The sample was originally recruited when the target participant was in preschool as a part of a study of normative early cognitive development. Initial recruitment methods included posting flyers in childcare centers, pediatrician offices, and other community locations serving young children and families in a small Midwestern city. Data for the current study are drawn from the adolescent phase of the larger longitudinal project, when adolescents and their caregivers visited the laboratory to complete measures of EC and key health behaviors. The sample is representative of the city and region from which it was recruited in terms of race and ethnicity (66.8% White, 13.0% Hispanic/Latino, 3.8% African American, 15.9% multiracial, <1% Asian) and oversampled for youth from families with lower socioeconomic status (40.4% considered at-risk based a combination of family factors; see Measures for details).

2.2 Procedures

Participating families in the broader longitudinal study were invited to participate in the adolescent phase of the study around the time of the adolescent's 14th, 15th or 16th birthday. Note that the broader study employs a lagged cohort sequential design, so the participating youth were at different ages at the start of the adolescent phase. Age 14 was the minimum age for participation in the adolescent phase, but some adolescents began participating at ages 15 or 16. Participation entailed a laboratory-based data collection session in which the adolescent completed a battery of cognitive tasks and questionnaires. Parents or legal guardians also completed questionnaires. Parents or legal guardians provided written consent for adolescent participation, and adolescents provided written assent prior to participating. All study procedures were approved by the Institutional Review Board at the University of Nebraska-Lincoln.

2.3 Measures

2.3.1 Performance-based EC Tasks.—Adolescent EC abilities in inhibitory control, working memory, and flexible shifting were assessed using a battery of well-established performance-based neuropsychological tasks. All tasks were individually administered to the participating adolescent by a trained research assistant during a laboratory visit. *Inhibitory control* was assessed using the widely-used *Go/No-Go task* (adapted from Bezdijian, Baker, Lozano, & Raine, 2009). In this computerized task, the adolescent is asked to press a button each time a letter appears on screen except when the letter is X, Y, or Z (in which case, they

must refrain from pressing the button). A total of 300 trials are presented, with 75% “go” trials and 25% “no go” trials. Errors of commission (incorrectly pressing the button upon presentation of X, Y, or Z) receive feedback in the form of a buzzer sound. The outcome variable is d-prime, which is calculated as the standardized difference between the adolescent’s hit rate and false alarm rate. **Working memory** was measured using the *Nebraska Barnyard* task, adapted from the Noisy Book task (Hughes, Dunn, & White, 1998). In this task, the adolescent is asked to remember a sequence of animal names that are transformed into a corresponding color sequence. The adolescent must then press the corresponding colored buttons on a screen in the correct order. The task begins with a training phase in which the adolescent is presented with a set of nine colored pictures of barnyard animals in a 3×3 grid of colored boxes. When the adolescent presses each animal box, a corresponding animal sound is produced. After training, the animal pictures are removed, and a set of nine trials is presented in which the examiner names each animal individually and then asks the adolescent to press the box corresponding to that animal. Then trials with sequences of animals are administered. The sequences begin with two animals and progressively increase until the adolescent meets discontinuation criteria. The maximum sequence length is nine animals. Correct responses for trials with only a single animal are given a point value of 0.33; all correct trials involving sequences of multiple animals are given a point value of 1. The outcome variable is the total number of points earned across all trials. **Flexible shifting** was assessed using the *Shape School-Switching Condition* (Espy, 1997; Espy, Bull, Martin, & Stroup, 2006). In this task, the adolescent is presented with stimuli on a screen of cartoon figures whose bodies come in two colors and two shapes, and are either wearing a hat or not. The adolescent must switch between naming the figure by color when hatless and by shape when hatted. One-third of the trials are shift trials, in which the relevant dimension of the stimulus differs from that in the preceding trial; two-thirds of the trials are no-shift trials, in which the relevant dimension is the same as the preceding trial. The outcome variable is percent correct on shift trials. On all EC tasks, higher scores indicate better EC abilities.

2.3.2 Behavioral Rating Inventory of Executive Function, Second Edition (BRIEF-2).—In addition to the performance-based EC tasks, and to assess daily symptoms of problems with executive control, adolescents completed the BRIEF-2 self-report form (Gioia et al., 2015). The BRIEF-2 is a widely-used norm-referenced questionnaire for youth ages 11 to 18 years old and consists of items that describe symptoms of executive dysfunction across various areas, which are rated on a Likert scale. A variety of clinical scales are available spanning a wide range of problems with executive control in daily life. For the current study, three subscales corresponding to the three main areas of executive control were used: *Inhibit* (e.g., problems related to impulsive behavior, acting without thinking of consequences; 8 items), *Working Memory* (e.g., problems remembering things, difficulty with multi-step tasks; 8 items), and *Shift* (e.g., difficulty adjusting to new situations or changes in routine; 8 items). These scales have all demonstrated good internal consistency (Inhibit: $\alpha = .87$; Working Memory: $\alpha = .86$; Shift: $\alpha = .82$; Gioia et al., 2015). Further, the BRIEF-2 has shown the ability to distinguish youth with and without Attentional-Deficit/Hyperactivity Disorder (ADHD), providing evidence for construct validity and clinical utility (Jacobson, Pritchard, Koriakin, Jones, & Mahone, 2016).

Adjusted scores (which are raw scores corrected for any missing items) from the BRIEF-2 were used in the current study. On all BRIEF-2 scales, higher scores correspond to greater EC *problems*.

2.3.3 Three-factor Eating Questionnaire R-18 (TFEQ-R18).—To assess specific eating behaviors of interest, adolescents completed the Three-Factor Eating Questionnaire R-18 (TFEQ-R18; de Lauzon et al., 2004). The TFEQ-R18 is a revision of the original TFEQ (Stunkard & Messick, 1985) consisting of 18 Likert scale items about specific eating behaviors. The measure is comprised of three scales: *uncontrolled eating* (loss of control in eating, eating more than desired), *emotional eating* (eating in response to emotional cues), and *cognitive restraint* (consciously restricting food intake to prevent weight gain or promote weight loss). Example items include “*Sometimes when I start eating, I just can’t seem to stop*” (uncontrolled eating), “*When I feel anxious, I find myself eating*” (emotional eating), and “*I deliberately take small helpings as a means of controlling my weight*” (cognitive restraint). The TFEQ and TFEQ-R18 are widely used measures for assessing a set of eating constructs in adolescents and adults, with evidence supporting the three-factor structure, convergent validity, and reliability of the measure in both clinical and community samples (e.g., Anglé et al., 2009; de Lauzon et al., 2004). Particularly pertinent to the current study, the TFEQ-R18 has demonstrated good internal consistency with adolescents in a community sample (α s = .80, .78, and .80 for uncontrolled eating, emotional eating, and cognitive restraint scales, respectively; de Lauzon et al., 2004).

2.3.4 Adolescent Demographics.—Basic demographics for the adolescent were reported by the caregiver, including adolescent sex, age, and information related to family socioeconomic status (SES). For SES, the caregiver reported on family income, adolescent free/reduced lunch status, and family public health insurance status (e.g., Medicaid, CHIP, Champus). Families reporting low income-to-needs ratio (below the poverty line), qualifying for free/reduced lunch status, and/or using public health insurance were classified as “at risk.”

2.3.5 Adolescent Weight Status.—Adolescent height and weight were objectively measured by a trained research assistant using a high-quality digital scale and stadiometer. Height and weight data were converted to BMI and then to BMI-for-age percentiles using the Centers for Disease Control and Prevention (CDC) growth charts (CDC, 2019). The sample distribution by weight category was 59.6% healthy weight, 18.8% overweight, 19.7% obese, and 1.9% underweight. See Table 1 for descriptive statistics for all continuous variables.

2.4 Analysis Plan

Associations between specific aspects of EC (inhibitory control, working memory, flexible shifting) and eating behaviors (uncontrolled eating, emotional eating, cognitive restraint) were examined using path analysis. Separate models were run using performance-based EC tasks or BRIEF-2 subscales as predictors of eating behavior constructs. To account for measurement error, latent constructs were used to represent the three eating behavior constructs, with each item from the TFEQ scale loading on the corresponding construct (see

supplemental file for information regarding loadings). To explore unique associations, all EC measures were allowed to freely correlate and all eating behavior constructs were correlated, as well. EC tasks were standardized using the “STANDARDIZE” option in Mplus to put these scores on a common metric with a mean of 0 and a standard deviation of 1. Sex, age, family SES (dichotomous “at risk” status), and BMI-for-age percentile were included as covariates in both models. After conducting separate models with EC tasks or BRIEF-2 scores, a combined model was run with all six EC predictors (3 EC tasks, 3 BRIEF-2 scores) predicting eating behaviors to examine unique contributions. Missing data were minimal, resulting in final samples of 208 for each model. All analyses were conducted in Mplus version 8.4 (Muthén & Muthén, 1998–2017) using maximum likelihood - robust (MLR) estimation.

3. Results

3.1 Bivariate Correlations

Bivariate correlations between study variables are reported in Table 2. The working memory task was significantly negatively correlated with cognitive restraint, but no other tasks were significantly correlated with TFEQ scales. BRIEF-2 working memory problems and inhibitory control problems were both significantly correlated with uncontrolled eating and emotional eating on the TFEQ. BRIEF-2 shifting problems was significantly correlated with all three TFEQ scales. (Note: Because higher scores on EC tasks represent better performance and higher scores on the BRIEF-2 represent more *problems*, there is generally a negative correlation between EC tasks and BRIEF-2 scores.)

3.2 Performance-Based EC Tasks Predicting Eating Behaviors

In the model using EC tasks to predict factor scores on the TFEQ (N=208; see Figure 1), none of tasks significantly predicted uncontrolled eating or emotional eating. Performance on the *Nebraska Barnyard* task (working memory) was the only significant predictor of cognitive restraint, with better working memory scores predicting lower levels of cognitive restraint ($\beta = -.20$, $p = .016$), controlling for sex, age, at-risk status, and BMI. Model fit was acceptable (see Figure 1 for details).

3.3 Self-Reported Daily Executive Dysfunction Symptoms Predicting Eating Behaviors

In the model using scores from the BRIEF to predict factor scores on the TFEQ (N=208; see Figure 2), the *Inhibit* subscale significantly and uniquely predicted uncontrolled eating ($\beta = .25$, $p = .007$), with more problems with inhibitory control associated with more uncontrolled eating. *Inhibit* scores were not significantly associated with either cognitive restraint or emotional eating. The *Shift* subscale was significantly and uniquely associated with emotional eating ($\beta = .25$, $p = .034$), with more problems with shifting associated with more emotional eating. *Shift* scores were not significantly associated with cognitive restraint or uncontrolled eating. *Working Memory* scores were not significantly associated with any of the eating factors, controlling for sex, age, at-risk status, or BMI. Model fit was acceptable (see Figure 2 for details).

3.4 Combined Model

To supplement the models separately examining the predictive value of objective and subjective EC measures, respectively, we also conducted a path model with all six EC scores (three performance-based tasks and three BRIEF subscale scores) predicting the three latent eating factors (N=208; see Figure 3). The findings largely replicated the results of the separate models with *Nebraska Barnyard* (working memory task) significantly and uniquely predicting cognitive restraint ($\beta = -.20, p = .014$), BRIEF *Inhibit* predicting uncontrolled eating ($\beta = .28, p = .004$), and BRIEF *Shift* predicting emotional eating ($\beta = .26, p = .034$). Taken together, the EC scores accounted for statistically significant amounts of variance in each of the three eating scores ($R^2 = .115, p = .026$ for cognitive restraint; $R^2 = .203, p = .001$ for uncontrolled eating; and $R^2 = .176$ for emotional eating, $p = .004$). Model fit was acceptable (see Figure 3 for details).

4. Discussion

The current study examined associations between specific components of EC and eating behaviors in the pivotal period of adolescence. The study extended previous literature in several key ways. The use of *both* subjective norm-referenced questionnaires of daily EC problems *and* objective performance-based laboratory tasks is more comprehensive compared to most previous studies, providing assessment of both cognitive abilities in a controlled setting and more contextualized symptoms of EC problems in daily life. Relatedly, the current study employed a more comprehensive conceptualization and measurement approach to EC than previous research, including measures that covered the three main aspects of EC – inhibitory control, working memory, and flexible shifting. This broad coverage allowed for an exploration of which aspects of EC might be most related to specific eating behaviors, with potential implications for targeted interventions. In addition to measuring core components of EC, the current study assessed key eating behaviors associated with health risk, most notably uncontrolled eating and emotional eating. These eating behaviors, perhaps more so than the intake of specific types of foods (e.g., snacks, fruits and vegetables) that has been the focus of much of the previous research, may be particularly relevant to deficits in EC. As outlined by Nelson and colleagues (2019) in their conceptual framework for EC and adolescent health, deficits in specific EC components might lead to a loss of “top-down” control of food-related attention and behavior, thus leading to eating behaviors that are driven more by emotion and loss of control than planful execution of an adolescent’s health goals. Further, the current study explored associations between EC and eating behaviors while controlling for potential confounding variables such as weight status and socioeconomic status. These extensions of previous literature all help the current study to make unique contributions to the literature on EC and eating behaviors in adolescence.

The a priori hypotheses that deficits in specific aspects of EC would be associated with uncontrolled eating and emotional eating were partially supported in the current study. While significant associations were found between certain aspects of EC problems measured by self-report questionnaire and both uncontrolled eating and emotional eating, performance-based tasks did not show significant associations with these problematic eating

behaviors. When using the BRIEF, problems with inhibitory control significantly and uniquely predicted uncontrolled eating, while problems with shifting predicted emotional eating. These links are consistent with theory: difficulties with inhibiting behaviors in everyday life would be expected to put an individual at risk for lack of control over a wide range of behaviors that may be immediately reinforcing but ultimately less healthful, such as excessive consumption of energy-dense, nutrient-poor foods and beverages. An adolescent who struggles with inhibitory control may feel overwhelmed by cues for less healthful eating – including both internal cues, such as cravings, and external cues, such as advertisements – increasing the risk of episodes in which the adolescent “loses control” and eats in a way that is contrary to dietary goals. Further, consistent with the “disengagement hypothesis,” (Koster, De Lissnyder, Derakshan, & De Raedt, 2011) individuals with poor inhibitory control may find it especially difficult to disengage from both internal and external cues for consumption, further undermining control of attention and ultimately behavior. Adolescents who have difficulty with cognitive flexibility and shifting may be especially vulnerable to emotional eating due to difficulties in problem-solving and in implementing healthy strategies for dealing with stress and negative emotions. Inflexibility in dealing with the challenges of daily life may lead to maladaptive responses to negative emotion, such as consuming high fat/high sugar foods and drinks, as well as difficulty breaking patterns of emotional eating once established.

While the pattern of findings for the BRIEF-2 at least partially corresponded to theory and expectations, the lack of significant findings using EC tasks to predict uncontrolled eating and emotional eating was contrary to a priori hypotheses. Although these null findings were surprising, it is possible that some insight can be gleaned from the differential findings observed across the questionnaire versus task analyses. We posit the BRIEF-2 was potentially more predictive of uncontrolled and emotional eating behaviors than the performance-based tasks since the BRIEF-2 assesses more *contextualized* problems with EC in daily life, rather than cognitive abilities in a neutral laboratory context. This emphasis on behavioral breakdowns in control in real world contexts may be particularly relevant to eating behaviors, such as uncontrolled eating and emotional eating which represent breakdowns in directing eating behaviors in daily life. Here the distinction between “hot” and “cool” EC may be relevant (see Zelazo & Carlson, 2012); perhaps EC problems in the “hot” context of emotions and environmental pressures are more influential on eating behaviors than “cool” EC abilities that are assessed in a more neutral context. Alternatively, the pattern of significant findings for the BRIEF but not for the EC tasks may be the result of methodological issues (see discussion of limitations below). While there is clearly conceptual overlap between the BRIEF and performance-based EC tasks, these measures are intended to assess somewhat different constructs (and this difference in focus is supported by only modest correlations between the BRIEF and EC tasks in this study). EC tasks are designed to measure the adolescent’s underlying cognitive abilities, whereas the BRIEF explicitly focuses on *behavioral manifestations* of executive dysfunction in everyday life. This behavioral focus of the BRIEF might place it closer to the everyday behaviors of eating problems, thus resulting in higher correlations.

Although this study did not include a priori hypotheses regarding EC and cognitive restraint, it is noteworthy that working memory *task performance* did significantly and uniquely

predict cognitive restraint, with stronger working memory associated with less cognitive restraint. It is possible that individuals with stronger working memory do not need to constantly remind themselves of eating goals resulting in less cognitive restraint. Put another way, individuals with poor working memory may need to repeatedly and intentionally think about restraining their eating behavior because they tend to easily “lose track” of dietary goals when faced with distracting stimuli. Interestingly, some research has found that greater cognitive restraint is associated with higher BMI in adolescents (e.g., Anglé et al., 2009), so stronger working memory could be protective against obesity over time by freeing adolescents from the need to frequently engage in cognitive restraint. Consistent with this idea, the current study found a significant *positive* association between BMI and cognitive restraint, although the concurrent nature of these analyses precludes any inferences about causality.

In addition to findings regarding associations between *specific components of EC* and eating behaviors, the current study also found that *EC as a whole* accounted for a statistically significant amount of variance in each eating behavior on the TFEQ. In fact, for uncontrolled eating and emotional eating, the total variance accounted for by all of the EC measures (as represented by the R^2 values in the third model) was 20.3% and 17.6%, respectively. These findings add further support to the literature suggesting that EC broadly conceptualized is significantly associated with eating behavior in adolescence and a potential target area for intervention. The findings also map onto research with adults reporting links between constructs related to EC and uncontrolled eating (see Vainik, Garca-Garcia, & Dagher, 2019, for review).

Limitations and Future Directions

A number of limitations in the current study should be considered. First, the cross-sectional design of the study precludes any conclusions regarding the directionality of effects. While we cited theory supporting the idea of EC affecting eating problems, it is also plausible that eating problems may undermine ongoing EC development. Future studies should employ longitudinal designs with repeated measures of both EC and eating behaviors to explore the directionality of effects, including the possibility of bidirectional associations. Second, while the current study advanced research in this area by utilizing performance-based tasks that covered all three areas of EC, only a single task was used to represent each component. Given the challenges of task impurity and inherent limitations of single measures (Espy, 2016; Miyake et al., 2000), future research should consider even more robust batteries of EC measures with multiple tasks for each EC ability. Third, the TFEQ, while a well-established and widely-used measure, only covers a relatively narrow subset of disordered eating behaviors in a self-report questionnaire format. Given these limitations, more comprehensive approaches to measure adolescent eating, including rigorous assessments of dietary intake (e.g., multiple 24-hour dietary recalls) and behavioral measures of constructs such as eating in the absence of hunger, are needed. Fourth, the associations between the BRIEF-2 and TFEQ could be affected by common method variance because both measures rely on self-report (see Duckworth & Kern, 2011, for discussion of method effects for EC tasks versus questionnaires). Finally, adolescent eating behaviors are influenced by a wide range of factors, including both individual and environmental influences. While the current study

offers an in-depth examination of the individual-level factor of EC, important contextual factors such as family and peer influences are not included. It is likely the eating behaviors of adolescents in this age range are still significantly affected by these environmental systems. Therefore, future research on EC and eating in adolescence should consider inclusion of measures of the family food context and extend into late adolescence/early adulthood when eating independence is even more fully realized.

Implications for Intervention

Although caution is warranted given the mixed findings and methodological limitations discussed above, the current study suggests a potentially important role for EC in developing eating behaviors during the critical period of adolescence. These findings suggest that multiple aspects of EC – not just inhibitory control – may contribute to specific eating behaviors. This raises the possibility of preventive interventions that focus on promoting specific EC abilities during particularly malleable developmental stages (such as preschool and adolescence) as a novel strategy for positively influencing developing eating behaviors. EC is modifiable (Diamond & Ling, 2016), so strengthening specific abilities such as inhibitory control and flexible shifting could be a promising strategy for reducing risk for uncontrolled and emotional eating. Importantly, our findings that problems with EC *in context* were most associated with these key eating behaviors hint at the possible importance of training in context. It is not clear at this time whether enhancing “cool” EC skills in neutral training contexts (such as computerized cognitive training programs) would help support daily behavioral applications of EC in “hot” contexts, or if training needs to specifically incorporate emotional and environmental context, but future research should explore this important question. Relatedly, it will be critical to explore if EC training is more effective when it is food-specific, or if general EC training alone translates to improved eating behaviors. Notably, the current study used measures of general EC abilities (both in the lab and in daily life), not food-specific EC measures, and found evidence of significant associations. However, the relative impact of general EC promotion versus food-specific EC promotion on actual eating behaviors remains an open and important question.

Conclusions

This study found evidence of associations between specific aspects of EC and eating behaviors in adolescence, even after controlling for potentially confounding variables such as weight status and socioeconomic status. Although the pattern of findings between objective and subjective measures of EC was mixed, EC measures taken broadly (including both performance-based tasks and ratings of everyday behavioral problems related to EC) accounted for a statistically significant amount of variance in uncontrolled eating, emotional eating, and cognitive restraint. The results suggest possible avenues for intervention targeting EC to promote more healthful eating behaviors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- Ames SL, Kisbu-Sakarya Y, Reynolds KD, Boyle S, Cappelli C, Cox MG, ... Stacy AW (2014). Inhibitory control effects in adolescent binge eating and consumption of sugar-sweetened beverages and snacks. *Appetite*, 81, 180–192. 10.1016/j.appet.2014.06.013 [PubMed: 24949566]
- Anglé S, Engblom J, Eriksson T, Kautiainen S, Saha MT, Lindfors P, ... Rimpelä A (2009). Three factor eating questionnaire-R18 as a measure of cognitive restraint, uncontrolled eating and emotional eating in a sample of young Finnish females. *International Journal of Behavioral Nutrition and Physical Activity*, 6, 41–47. 10.1186/1479-5868-6-41 [PubMed: 19615047]
- Banfield EC, Liu Y, Davis JS, Chang S, & Frazier-Wood A (2016). Poor adherence to U.S. dietary guidelines for children and adolescents in the NHANES population. *Journal of the Academy of Nutrition and Dietetics*, 428, 709–719. 10.1016/j.jand.2015.08.010.Poor
- Bassett R, Chapman GE, & Beagan BL (2008). Autonomy and control: The co-construction of adolescent food choice. *Appetite*, 50, 325–332. 10.1016/j.appet.2007.08.009 [PubMed: 17936413]
- Bazzano LA, Liu S, & Serdula M (2005). Prevention of type 2 diabetes by diet and lifestyle modification. *Journal of the American College of Nutrition*, 24, 310–319. 10.1080/07315724.2005.10719479 [PubMed: 16192254]
- Bezdijian S, Baker LA, Lozano DI, & Raine A (2009). Assessing inattention and impulsivity in children during the Go/NoGo task. *British Journal of Developmental Psychology*, 27, 365–383. 10.1348/026151008X314919 [PubMed: 19812711]
- Bleich SN, Jones-Smith J, Wolfson JA, Zhu X, & Story M (2015). The complex relationship between diet and health. *Health Affairs*, 34, 1813–1820. doi: 10.1377/hlthaff.2015.0606. [PubMed: 26526238]
- Centers for Disease Control and Prevention (CDC) (2019). BMI percentile calculator for child and teen. Retrieved from <https://www.cdc.gov/healthyweight/bmi/calculator.html>
- Clark CC, Sheffield TD, Wiebe SA, & Espy KA (2013). Longitudinal associations between executive control and developing mathematical competence in preschool boys and girls. *Child Development*, 84, 662–677. 10.1111/j.1467-8624.2012.01854.x [PubMed: 23006040]
- de Lauzon B, Romon M, Deschamps V, Lafay L, Borys JM, Karlsson J, et al. (2004). The Three-Factor Eating Questionnaire-R18 is able to distinguish among different eating patterns in a general population. *The Journal of Nutrition*, 134, 2372–2380. doi: 10.1093/jn/134.9.2372 [PubMed: 15333731]
- Diamond A (2013). Executive functions. *The Annual Review of Psychology*, 64, 135–168. 10.1146/annurev-psych-113011-143750
- Diamond A, & Lee K (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, 6045, 959–964. 10.1126/science.1204529
- Diamond A, & Ling DS (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, 18, 34–48. 10.1016/j.dcn.2015.11.005 [PubMed: 26749076]
- Ding D, Sallis JF, Norman GJ, Saelens BE, Harris SK, Kerr J, ... Glanz K (2012). Community Food Environment, Home Food Environment, and Fruit and Vegetable Intake of Children and Adolescents. *Journal of Nutrition Education and Behavior*, 44, 634–638. 10.1016/j.jneb.2010.07.003 [PubMed: 21531177]
- Duckworth AL, & Kern ML (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, 45, 259–268. [PubMed: 21643479]

- Egbert AH, Bohnert AM, Bates CR, Loren DM, Creber C, Rosania KA,...Silton RL (2019). The heat is on: A mixed-method examination of eating behavior and executive functions among low-income minority girls during the summertime. *Journal of Early Adolescence*, 39, 625–641.
- Egbert AH, Creber C, Loren DM, & Bohnert AM (2019). Executive function and dietary intake in youth: A systematic review of the literature. *Appetite*, 139, 197–212. [PubMed: 31014952]
- Espy KA (1997). The shape school: Assessing executive function in preschool children. *Developmental Neuropsychology*, 13, 495–499. 10.1080/87565649709540690.
- Espy KA (2016). The changing nature of executive control in preschool. *Monographs of the Society for Research in Child Development*, 81, 1–179.
- Espy KA, Bull R, Martin J, & Stroup W (2006). Measuring the development of executive control with the shape school. *Psychological Assessment*, 18, 373–381. 10.1037/1040-3590.18.4.373 [PubMed: 17154758]
- Garon N, Bryson SE, & Smith IM (2008). Executive Function in Preschoolers: A Review Using an Integrative Framework. *Psychological Bulletin*, 134, 31–60. 10.1037/0033-2909.134.1.31 [PubMed: 18193994]
- Gioia GA, Isquith PK, Guy SC, & Kenworthy L (2015). BRIEF-2: Behavior rating inventory of executive function (Second ed.). Lutz, FL: Psychological Assessment Resources.
- Gowey MA, Lim CS, Dutton GR, Silverstein JH, Dumont-Driscoll MC, & Janicke DM (2018). Executive function and dysregulated eating behaviors in pediatric obesity. *Journal of Pediatric Psychology*, 43, 834–845. 10.1093/jpepsy/jsx091 [PubMed: 28595362]
- Hall PA, & Marteau TM (2014). Executive function in the context of chronic disease prevention: Theory, research, and practice. *Preventive Medicine*, 68, 44–50. 10.1016/j.ypmed.2014.07.008
- Hare TA, Tottenham N, Galvan A, Voss HU, Glover GH, & Casey BJ (2008). Biological Substrates of Emotional Reactivity and Regulation in Adolescence During an Emotional Go-NoGo Task. *Biological Psychiatry*, 63, 927–934. 10.1016/j.biopsych.2008.03.015 [PubMed: 18452757]
- Hillman C, Pontifex M, Castelli D, Khan N, Raine L, Scudder M, ... Kamijo K (2014). Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics*, 134, 1063–1071. doi:10.1542/peds.2013-3219.
- Hughes C, Dunn J, & White A (1998). Trick or treat? Uneven understanding of mind and emotion and executive dysfunction in 'hard-to-manage' preschoolers. *Journal of Child Psychology and Psychiatry*, 39, 981–994. 10.1111/1469-7610.00401. [PubMed: 9804031]
- Jacobson LA, Pritchard AE, Koriakin TA, Jones KE, & Mahone EM (2016). Initial examination of the BRIEF2 in clinically referred children with and without ADHD symptoms. *Journal of Attention Disorders*, 1–10. doi:10.1177/1087054716663632
- Jasinska AJ, Yasuda M, Burant CF, Gregor N, Khatri S, Sweet M, & Falk EB (2012). Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults. *Appetite*, 59, 738–747. 10.1016/j.appet.2012.08.001 [PubMed: 22885454]
- Kertz SJ, Belden AC, Tillman R, & Luby J (2016). Cognitive control deficits in shifting and inhibition in preschool age children are associated with increased depression and anxiety over 7.5 years of development. *Journal of Abnormal Child Psychology*, 55, 1185–1196. 10.1007/s10802-015-0101-0
- Koster EHW, Lissnyder ED, Derakhshan N, Raedt RD (2011). Understanding depressive rumination from a cognitive science perspective: The impaired disengagement hypothesis. *Clinical Psychology Review*, 31, 138–145. 10.1016/j.cpr.2010.08.005 [PubMed: 20817334]
- Larson NI, Neumark-Sztainer DR, Story MT, Wall MM, Harnack LJ, & Eisenberg ME (2008). Fast food intake: Longitudinal trends during transition to young adulthood and correlates of intake. *Journal of Adolescent Health*, 43, 79–86. 10.1016/j.jadohealth.2007.12.005 [PubMed: 18565441]
- Lake AA, Adamson AJ, Craigie AM, Rugg-Gunn AJ, & Mathers JC (2009). Tracking of dietary intake and factors associated with dietary change from early adolescence to adulthood: The ASH30 study. *Obesity Facts*, 2, 157–165. 10.1159/000219819 [PubMed: 20054220]
- Lake AA, Mathers JC, Rugg-Gunn AJ, & Adamson AJ (2006). Longitudinal change in food habits between adolescence (11–12 years) and adulthood (32–33 years): The ASH30 study. *Journal of Public Health*, 28, 10–16. 10.1093/pubmed/fdi082 [PubMed: 16473923]

- Lee K, Bull R, & Ho RMH (2013). Developmental changes in executive functioning, *Child Development*, 84, 1933–1953. 10.1111/cdev.12096 [PubMed: 23550969]
- Liang J, Matheson BE, Kaye WH, & Boutelle KN (2014). Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *International Journal of Obesity*, 38, 494–506. 10.1038/ijo.2013.142 [PubMed: 23913029]
- Luna B, Padmanabhan A, & O’Hearn K (2010). What has fMRI told us about the development of cognitive control through adolescence? *Brain and Cognition*, 72, 101–113. 10.1016/j.bandc.2009.08.005 [PubMed: 19765880]
- Merikangas KR, He JP, Burstein M, Swanson SA, Avenevoli S, Cui L, ... Swendsen J (2010). Lifetime prevalence of mental disorders in U.S. adolescents: Results from the national comorbidity survey replication-adolescent supplement (NCS-A). *Journal of the American Academy of Child and Adolescent Psychiatry*, 49, 980–989. 10.1016/j.jaac.2010.05.017 [PubMed: 20855043]
- Mikkilä V, Räsänen L, Raitakari OT, Pietinen P, & Viikari J (2005). Consistent dietary patterns identified from childhood to adulthood: The Cardiovascular Risk in Young Finns Study. *British Journal of Nutrition*, 93, 923–931. 10.1079/bjn20051418 [PubMed: 16022763]
- Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, & Wager TD (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cognitive Psychology*, 41, 49–100. 10.1006/cogp.1999.0734 [PubMed: 10945922]
- Muthén LK & Muthén BO (1998–2017). *Mplus User’s Guide* (8th ed). Los Angeles, CA: Muthén & Muthén.
- Nederkooorn C, Houben K, Hofmann W, Roefs A, & Jansen A (2010). Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods. *Health Psychology*, 29, 389–393. 10.1037/a0019921 [PubMed: 20658826]
- Nelson TD, Kidwell KM, Nelson JM, Tomaso CC, Hankey M, & Espy KA (2018). Preschool executive control and internalizing symptoms in elementary school. *Journal of Abnormal Child Psychology*, 46, 1509–1520. 10.1007/s10802-017-0395-1 [PubMed: 29313184]
- Nelson TD, Nelson JM, Mason WA, Tomaso CC, Kozikowski CB, & Espy KA (2019). Executive Control and Adolescent Health: Toward A Conceptual Framework. *Adolescent Research Review*, 4, 31–43. 10.1007/s40894-018-0094-3 [PubMed: 30886888]
- Nelson TD, James TD, Nelson JM, Tomaso CC, & Espy KA (under review). Executive control in late elementary school: Factor structure and associations with early childhood executive control. Manuscript submitted for publication.
- Riggs NR, Spruijt-Metz D, Sakuma K, Chou C, & Pentz MA (2010a). Executive cognitive function and food intake in children. *Journal of Nutrition Education and Behavior*, 42, 398–403. doi:10.1016/j.jneb.2009.11.003. [PubMed: 20719568]
- Riggs N, Chou CP, Spruijt-Metz D, & Pentz MA (2010b). Executive cognitive function as a correlate and predictor of child food intake and physical activity. *Child Neuropsychology*, 16, 279–292. 10.1080/09297041003601488 [PubMed: 20234954]
- Riggs NR, Spruijt-Metz D, Chou CP, & Pentz MA (2012). Relationships between executive cognitive function and lifetime substance use and obesity-related behaviors in fourth grade youth. *Child Neuropsychology*, 18, 1–11. 10.1080/09297049.2011.555759 [PubMed: 21480013]
- Shearer C, Rainham D, Blanchard C, Dummer T, Lyons R, & Kirk S (2015). Measuring food availability and accessibility among adolescents: Moving beyond the neighbourhood boundary. *Social Science and Medicine*, 133, 322–330. 10.1016/j.socscimed.2014.11.019 [PubMed: 25619139]
- Stautz K, Pechey R, Couturier DL, Deary IJ, & Marteau TM (2016). Do executive function and impulsivity predict adolescent health behaviour after accounting for intelligence? Findings from the ALSPAC cohort. *PLoS ONE*, 11, 1–17. 10.1371/journal.pone.0160512
- Story M, Neumark-Sztainer D, & French S (2002). Individual and Environmental Influences on Adolescent Eating Behaviors. Supplement to the *Journal of the American Dietetic Association*, 102, S41–S51.

- Stunkard AJ, & Messinck S (1985) The three-factor eating questionnaire to measure dietary restraint, disinhibition, and hunger. *Journal of Psychosomatic Research*, 29, 71–83. 10.1016/0022-3999(85)90010-8 [PubMed: 3981480]
- Vainik U, Garcia-Garcia I, Dagher A (2019). Uncontrolled eating: A unifying heritable trait linked with obesity, overeating, personality and the brain. *European Journal of Neuroscience*, 50, 2430–2445. doi:10.1111/ejn.14352 [PubMed: 30667547]
- Wiebe SA, Espy KA, & Charak D (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, 44, 575–587. 10.1037/0012-1649.44.2.575 [PubMed: 18331145]
- Willoughby MT, Blair CB, Wirth RJ, & Greenberg M (2010). The measurement of executive function at age 3 years: Psychometric properties and criterion validity of a new battery of tasks. *Psychological Assessment*, 22, 306–317. 10.1037/a0018708 [PubMed: 20528058]
- Wouters EJ, Larsen JK, Kremers SP, Dagnelie PC, & Geenen R (2010). Peer influence on snacking behavior in adolescence. *Appetite*, 55, 11–17. 10.1016/j.appet.2010.03.002 [PubMed: 20211671]
- Zelazo PD, & Carlson SM (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, 6, 354–360. 10.1111/j.1750-8606.2012.00246.x

Figure 1.

Executive control (EC) tasks predicting eating behavior constructs

Note: WM = working memory task; INH = inhibitory control task; FS = flexible shifting task; TFEQ CR = cognitive restraint; TFEQ UE = uncontrolled eating; TFEQ EE = emotional eating Model fit: $\chi^2(237) = 363.28$, $p < .001$, RMSEA = .051, CFI = .89, SRMR = .063

Note: The variable labeled “BMI” refers to BMI-for-age percentile.

Figure 2.

BRIEF-2 scales predicting eating behavior constructs

Model fit: $\chi^2 (237) = 349.61$, $p < .001$, RMSEA = .048, CFI = .92, SRMR = .064

Note: The variable labeled “BMI” refers to BMI-for-age percentile.

Figure 3.

Combined model with both EC tasks and BRIEF-2 scores predicting eating behavior constructs

Model fit: $\chi^2 (222) = 316.33, p < .001, RMSEA = .045, CFI = .91, SRMR = .065$

Table 1.

Descriptive Statistics

	N	Mean	Std Dev	Minimum	Maximum
Age (years)	208	14.50	0.75	13.95	16.58
BMI percentile	208	69.52	25.97	1	99.99
BRIEF WM	208	13.49	3.40	8	24
BRIEF INH	208	13.48	3.27	8	23
BRIEF FS	208	13.46	3.29	8	21
WM	208	15.20	2.37	9	22
INH	206	3.15	0.71	1	5
FS	208	0.87	0.12	0	1
TFEQ CR	208	12.21	3.28	6	21
TFEQ UE	208	17.84	5.10	9	35
TFEQ EE	208	4.91	2.06	3	12

Note: WM = working memory; INH = inhibitory control; FS = flexible shifting; CR = cognitive restraint; UE = uncontrolled eating; EE = emotional eating

Table 2.

Bivariate correlations among study variables

	BMI	Sex	At Risk	Age	WM	INH	FS	EC-T	BRIEF WM	BRIEF INH	BRIEF FS	EC-B	TFEQ CR	TFEQ UE
Sex	0.06													
At	0.09	-0.03												
Risk														
Age	0.04	-0.03	-0.09											
WM	-0.01	0.03	-0.14 *	0.09										
INH	0.03	-0.06	-0.09	0.14 *	0.28 *									
FS	0.13	-0.12	-0.15 *	0.16 *	0.20 *	0.49 *								
EC-T	0.08	-0.07	-0.17 *	0.18 *	0.60 *	0.84 *	0.79 *							
BRIEF	0.05	-0.01	0.05	0.05	-0.14 *	-0.27 *	-0.14 *	-0.26 *						
WM														
BRIEF	0.04	0.12	0.09	-0.07	-0.14 *	-0.28 *	-0.21 *	-0.29 *	0.65 *					
INH														
BRIEF	0.08	-0.06	0.08	-0.04	-0.14 *	-0.16 *	-0.09	-0.17 *	0.64 *	0.52 *				
FS														
EC-B	0.07	0.01	0.09	-0.02	-0.16 *	-0.28 *	-0.17 *	-0.28 *	0.91 *	0.84 *	0.82 *			
TFEQ	0.25 *	-0.13	0.10	-0.01	-0.15 *	-0.01	-0.02	-0.06	0.10	0.13	0.16 *	0.15 *		
CR														
TFEQ	-0.14 *	0.13	-0.02	0.03	-0.05	-0.11	-0.03	-0.09	0.35 *	0.39 *	0.30 *	0.41 *	-0.02	
UE														
TFEQ	-0.02	-0.14 *	0.03	0.04	-0.03	-0.04	-0.01	-0.04	0.31 *	0.27 *	0.35 *	0.36 *	0.20 *	0.57 *
EE														

Note: WM = working memory; INH = inhibitory control; FS = flexible shifting; CR = cognitive restraint; UE = uncontrolled eating; EE = emotional eating; EC-T = composite score for all 3 EC tasks; EC-B = composite score for all 3 BRIEF scales

Note: "At Risk" status refers to families reporting income-to-needs ratio below the federal poverty line, qualifying for free/reduced lunch status, and/or using public health insurance.

Note: "BMI" refers to BMI-for-age percentile

Note: Total scores were used in bivariate correlations for TFEQ scales; however, latent constructs were used in path models.

Note: Composite scores combining all 3 EC tasks (EC-T) and all 3 BRIEF scales (EC-B) were used in the bivariate correlation table to allow comparisons to the literature using overall EC scores; however, individual task and BRIEF scale scores are included as independent predictor variables in the models to examine associations between specific components of EC and eating behaviors. Composite scores for tasks and BRIEF scales, respectively, were created by generating a latent factor with 3 tasks/scale scores as indicators and then outputting a factor score for use in the bivariate correlation table.