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PEDIATRIC ORIGINAL ARTICLE

Co-occurring weight problems among children with attention deficit/hyperactivity disorder: the role of executive functioning

PA Graziano[1], DM Bagner[1], JG Waxmonsky[1], A Reid[2], JP McNamara[2] and GR Geffken[3]

OBJECTIVE: To explore the link between pediatric obesity and attention deficit/hyperactivity disorder (ADHD) by examining whether executive functioning (EF) and medication status are associated with body mass index (BMI) and weight status in children with ADHD.

METHOD: Participants for this study included 80 children (mean age = 10 years, 9 months) with a DSM-IV diagnosis of ADHD, confirmed by a comprehensive clinical diagnostic assessment. Children's EF was measured using three neuropsychological tests, and severity of ADHD symptoms and medication status were obtained from parent report. Children's height and weight were also measured during the visit using a wall-mounted stadiometer and a balance beam scale.

RESULTS: Children with ADHD who performed poorly on the neuropsychological battery had greater BMI *z*-scores, and were more likely to be classified as overweight/obese compared with children with ADHD who performed better on the neuropsychological battery. In addition, children with ADHD who were taking a stimulant medication had significantly lower BMI *z*-scores compared with children with ADHD who were not taking medication or who were taking a non-stimulant medication.

CONCLUSION: EF is more impaired among children with ADHD and co-occurring weight problems, highlighting the importance of self-regulation as a link between pediatric obesity and ADHD.

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INTRODUCTION

Pediatric obesity has increased dramatically in recent decades, with approximately 30% of children aged 2–5 years classified as overweight (body mass index (BMI) between 85th and 95th percentile for age and gender) or obese (BMI > 95th percentile).[1,2] The stability of pediatric obesity is staggering given that 75% of children who are obese will become obese adults.[3] The health risks and associated societal costs with pediatric obesity are well established, including an increased risk of hypertension, cardiovascular disease and type-2 diabetes.[4,5] Significant efforts have been made to identify groups of children who are at increased risk for being overweight, and recent research has identified children with attention deficit/hyperactivity disorder (ADHD) as an at-risk group.[6]

ADHD is one of the most common childhood psychiatric disorders with prevalence rates ranging from 3 to 7% worldwide and as high as 9% in the United States on the basis of the most recent epidemiological data.[7,8] The core symptoms of ADHD, which include inattention, hyperactivity and impulsivity, are associated with significant impairment across children's academic, social and familial functioning.[9] In terms of health-related outcomes, elevated rates of obesity have been observed in adults,[10] adolescents[11] and young children with ADHD in both epidemiological and clinical samples[6,12,13] that persist after controlling for gender, diet and activity patterns, socioeconomic status (SES) and psychiatric comorbidities. Similar associations with obesity have been found when inattention and impulsivity are measured dimensionally using neuropsychological tests.[14–16] Many children with ADHD are medicated with stimulants, which suppress appetite and potentially confound the relationship between ADHD and obesity in children. Unmedicated children with ADHD are, in fact, 1.5 times more likely to be overweight than age-matched controls.[6] Similarly, a retrospective chart review of 98 children with a clinical diagnosis of ADHD found that unmedicated children were over two times more likely to be overweight than children who were not on medication.[12] Elevated body fat percentages and abdominal circumferences have also been detected in unmedicated youth with ADHD.[17] Despite the association between ADHD and pediatric obesity, little research has examined the mechanisms linking obesity and ADHD.

A reward deficit syndrome stemming from abnormalities in the dopaminergic system has been proposed for both obesity and ADHD.[18,19] It is well documented that children with ADHD have impaired capacity to delay gratification and diminished responses to reinforcement schedules.[20,21] Similar reductions in dopamine-binding potential have been observed in adults with obesity.[22] For example, research has demonstrated diminished striatal dopamine release after eating desirable food,[23] and abnormalities in dopaminergic response to food cues and actual food consumption in adults with food addiction.[24] Diminished dopamine receptor-binding capacity in the hypothalamus, which controls satiety and hunger, has been observed in individuals with ADHD,[25] suggesting a direct causal link between ADHD and eating patterns, although research with children is limited. Hence, initial evidence suggests that dopaminergic dysfunction leads to impairment in reward processing that promote both obesity and ADHD.

[1]Center for Children and Families, Department of Psychology, Florida International University, Miami, FL, USA; [2]Department of Psychiatry, University of Florida, Gainesville, FL, USA and [3]Department of Psychiatry, Pediatrics, & Clinical & Health Psychology, University of Florida, Gainesville, FL, USA. Correspondence: Dr PA Graziano, Center for Children and Families & Department of Psychology, Florida International University, 11200 SW 8th Street, HLS 1 Rm. 235A, Miami, FL 33199, USA.
E-mail: pgrazian@fiu.edu
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Another potential mechanism linking obesity and ADHD that has received recent attention is an individual's self-regulation skills. Broadly speaking, self-regulation refers to an individual's conscious or unconscious efforts to alter his/her inner states or responses.[26] Self-regulation is a multilevel construct with control efforts that may include the use of physiological, emotional, behavioral and executive processes that become more sophisticated and integrated through development.[27] Self-regulation deficits across behavioral and emotional domains have been documented in both pediatric obesity and in children with ADHD. For example, individual differences in the self-regulation of energy intake, response inhibition and sustained attention have been linked to children's adiposity.[15,28-30] Additionally, children with impaired capacity to delay gratification at 4 years were more likely to be overweight at 11 years.[31] Similarly, toddlers with difficulties regulating emotion and delaying gratification during laboratory tasks were also more likely to be classified as overweight or obese at $5\frac{1}{2}$ years.[32] These self-regulation deficits across behavioral and emotional domains are also common in youth with ADHD.[33,34]

Even more prominent among current theoretical and neurobiological notions of the etiology of ADHD is neurocognitive or executive functioning (EF) deficits.[33] EF refers to a higher order cognitive skills that enable the child to self-regulate or maintain behavior on a goal and calibrate behavior to context.[35] Cognitive flexibility, which involves working memory processes and the ability to shift between response sets and process multiple sources of information, is among the most widely cited cognitive skill thought to represent EF.[35-37] Adult studies have also linked obesity to EF deficits,[38,39] and a few child studies yielded similar results.[40,41]

Initial evidence suggests that obesity and ADHD both present with prominent self-regulatory deficits,[31-35,39-41] which may act in synergy to promote excessive weight gain in patients with both disorders. However, it remains unclear whether a neurocognitive deficit can successfully differentiate which children with ADHD have comorbid weight problems. Validating such a mechanism is vital for intervention efforts to more accurately identify at-risk groups. Hence, the primary goal of the current study was to examine whether EF performance across a neuropsychological battery differentiates children with ADHD who are overweight from those who are normal weight. We expected the children with ADHD who are overweight to have poorer EF compared with children with ADHD who are normal weight. Given that a significant amount of children with ADHD take stimulant medication, we also explored any medication effects on weight status in order to more accurately examine self-regulation as the mechanism linking obesity and ADHD.

MATERIALS AND METHODS

Participants

Participants for this study included 80 children (18 girls) with a diagnosis of ADHD whose parents provided consent to participate in the study at a large university hospital in the Southeastern United States. These children were primarily referred from psychiatrists (79%) and pediatricians (11%). The mean age of the participating children was 10 years, 9 months (range: 4.5 years–18 years of age). Further, demographic characteristics of this sample are presented in Table 1. All participants had a previous DSM-IV diagnosis of ADHD ($n=51$ for combined type, $n=25$ for predominantly inattentive type, $n=1$ for predominantly hyperactive/impulsive type and $n=3$ for ADHD not otherwise specified) confirmed by a licensed psychologist through a comprehensive clinical diagnostic assessment including the use of a semistructured interview[42] and Conners Parenting Rating Scales.[43] In terms of treatment history, 64% of the children in our sample were currently taking medication to manage symptoms whereas 36% were medication naïve and had never been on any type of psychotropic medication. Exclusionary criteria included a diagnosis of mental retardation, autistic disorder or a psychotic disorder.

Table 1. Demographics for sample

Characteristic	*Percentage in sample*
Race/ethnicity (%)	
Non-Hispanic white	71
African-American	14
Hispanic	11
Other	4
Family status (%)	
Intact two-parent household	48
Single-parent household	30
Remarried household	11
Adoptive/foster family placement	11
Participating legal guardian (% mothers)	87
Total family income (%)	
<$20 000	3
$20 001–35 000	11
$35 001–50 000	14
$50 001–65 000	22
$65 001–80 000	9
$80 001–95 000	14
$95 001–110 000	8
>$110 000	19

Measures

ADHD symptoms. The Conners' Parent Rating Scale, 3rd edition, a widely used questionnaire, was administered[43] to assess children's current ADHD symptoms. The parent version used for children aged 6–18 years contains 108 items, and each item is rated on a four-point scale with respect to the frequency of occurrence (that is, never, occasionally, often and very often). The measure yields *t*-scores on internalizing, hyperactivity/impulsivity, learning problems, EF, defiance/aggression and peer relations, as well as DSM-IV-TR symptom scales. The Conners-3 has well-established internal consistency, reliability and validity.[43] For the purpose of the present study, the inattention ($\alpha=0.92$) and hyperactivity/impulsivity *t*-scores ($\alpha=0.94$) were used to measure severity of ADHD symptoms.

Anthropometrics. Trained research assistants measured children's height and weight (removing shoes and heavy outer clothing such as jackets or sweaters) during their visit using a wall-mounted stadiometer (Seca, Columbia, MD, USA) and a balance beam scale (Healthometer, Bridgeview, IL, USA). BMI *z*-scores were calculated based on age/gender norms from the Centers for Disease Control.[44]

Self-regulation measure: EF. Children were administered the Trail Making Test, Verbal Fluency and Color-Word Interference Test from the Delis–Kaplan Executive Function System,[45] which are three widely used neuropsychological tests that measure EF. The Trail Making Test consists of five conditions: visual scanning, number sequencing, letter sequencing, number-letter switching and motor speed. Of particular interest to the current study is the number-letter switching condition, which requires cognitive flexibility to successfully switch back and forth between connecting numbers and letters in sequence. The Verbal Fluency Test is a fluency task that involves three conditions: letter (F, A and S), category (animals' and boys' names) and switch (switching between naming fruits and furniture). In the switch condition, which is the primary EF condition in this test, children are asked to switch back and forth between naming fruits and furniture (for example, apple, bed, orange, desk) as quickly as possible. Finally, the Color-Word Interference Test is a stroop task that involves four conditions: color naming, word reading, inhibition and inhibition/switching. The inhibition/switching condition, which is the primary EF condition in this test, involves children being instructed to name the ink color of several words that are written on a stimulus page in an incongruent ink color (for example, the word 'red' written in blue ink) as quickly as possible. However, half of the words appear in a box, and

Table 2. Descriptive statistics

	M	*s.d.*	*Minimum*	*Maximum*
ADHD severity measures (P)				
Inattention T-score	78.05	12.66	18	100
Hyperactivity/impulsivity T-score	76.96	16.98	43	113
Obesity related measures (L)				
Height in inches	56.77	8.21	41	73.5
Weight in pounds	94.10	43.83	35	265
Body mass index	19.58	5.04	13.5	37.5
Body mass index *z*-score	0.40	1.17	−2.05	2.81
Executive functioning measures (L)				
Verbal fluency Condition 3: category switching-SS	8.81	3.75	1	19
Trail making Condition 4: number-letter switching-SS	6.84	3.42	1	14
Color-word Condition 4: inhibition-switching-SS	8.02	3.13	1	14

Abbreviations: P, parent report; L, laboratory measure; SS, standard score.

children are required to switch the application of the rules and read the word instead of the ink color for these words. Performances on the Trail Making and Color-Word Interference tasks were assessed by the total time in seconds required to complete the task, with faster scores being indicative of better EF skills. Performance on the verbal fluency switch task was assessed by the number of correct items generated in this condition. Standard scores were then derived for children aged >8 years (no norms are available for younger children).

Medication status. Children's medication status was assessed during the clinical interview as part of the diagnostic assessment. Parents also completed a demographic questionnaire, in which they listed their child's current medications. A medical records review was conducted when parents were not sure what medications their children were taking.

Data analytical strategy

Descriptive statistics for the study variables, which were all normally distributed, are presented in Table 2. All analyses were conducted using Statistical Package for the Social Sciences Version 18.0 (SPSS Inc., Chicago, IL, USA). All available data were used for each analysis. First, preliminary analyses were conducted to determine any associations between demographic characteristics (that is, sex, race, maternal income, maternal education and child age) and any of the study's variables. Data reduction procedures were also conducted to determine the viability of having a single EF factor from the neuropsychological test battery. Then, the association between children's medication status and BMI *z*-scores was examined. Finally, a logistic regression was conducted to determine whether EF significantly differentiates children with ADHD who are overweight from those who are not overweight.

RESULTS

Preliminary analyses

Descriptive statistics for all of the study's variables are presented in Table 2. Preliminary analyses did not yield any significant associations between demographic variables (for example, socioeconomic status, sex, maternal education and racial status) and children's severity of ADHD symptoms or BMI *z*-scores. The broad age range of our sample did not influence any of our results, as our main variables controlled for age (that is, BMI-*z* scores and ADHD *t*-scores are based on age/sex norms and EF scaled scores are based on age norms).

Data reduction. A principal component factor analysis was conducted to determine the feasibility of having a single EF factor on the basis of the three neuropsychological subtests administered: verbal fluency-switch condition, trail making-number-letter switch condition and color-word interference-inhibition/switching condition. From this analysis, one factor emerged with an Eigen value >1 ($\lambda = 1.76$), explaining 58.77% of the total variance across measures for this sample. High loadings were observed across all three indicator variables: verbal fluency (0.71), trail making (0.75) and color-word (0.84). Hence, a single EF factor was retained with higher scores being indicative of better EF. This EF factor was significantly and positively associated with maternal education ($r = 0.32$, $P < 0.05$) and negatively associated with the severity of inattention symptoms ($r = -0.29$, $P < 0.05$). No other significant associations between demographic variables or medication status and this EF factor were found. On the basis of these preliminary analyses, all subsequent analyses controlled for maternal education and severity of inattention symptoms.

Medication status groups. Based on information gathered from parents, as well as a medical records review, we assigned children to three groups on the basis of their medication status. The first group, labelled medication naïve, included children who had never received any type of psychotropic medication ($n = 26$). The second group, labelled stimulant group, included children who were currently taking a stimulant medication, such as Concerta (Johnson & Johnson) ($n = 31$). The third group, labelled non-stimulant, consisted of children who were currently taking a psychotropic medication that was not a stimulant such as atomoxetine ($n = 18$). Preliminary analyses indicated that these medication status groups did not differ on any demographic variables or severity of ADHD symptoms.

An analysis of variance was subsequently conducted to determine whether these medication status groups differed on BMI-*z* scores. This analysis revealed a significant effect for medication status on BMI-*z* scores $F(2, 63) = 3.20$, $P < 0.05$, partial ε-squared = 0.09. Specifically, children in the stimulant group had significantly lower BMI-*z* scores ($M = 0.00$, s.e. = 0.21) than children in the non-stimulant group ($M = 0.79$, s.e. = 0.28; $P < 0.05$) and marginally lower than children in the medication naïve group ($M = 0.59$, s.e. = 0.23; $P < 0.06$). There were no significant differences in BMI-*z* scores between children in the medication naïve group and non-stimulant group.

EF, BMI and pediatric obesity

A regression was conducted to determine whether EF was associated with children's BMI *z*-scores. First, maternal education, severity of inattention symptoms and medication status were entered in the first step of the regression as control variables because of their significant relations with BMI and EF. The main effect of EF was entered in the second step of the analysis. As displayed in Table 3, after accounting for the control variables, this analysis revealed a marginal effect for EF on children's BMI *z*-scores ($\beta = -0.29$, $P < 0.06$) such that children with better performance on the neuropsychological tests had lower BMI

Table 3. Regression analysis examining predictors of BMI-*z* scores

	β	R^2	R^2 change	F change
Step 1				
Maternal education (P)	0.05	0.09	0.09	1.51
ADHD inattention t-score (P)	−0.01			
Medication status (P)	0.27+			
Step 2				
Executive functioning (L)	−0.29+	0.16	0.07	3.85+

Abbreviations: P, parent report; L, laboratory measure.

Table 4. Logistic regression analysis examining predictors of overweight/obese weight status

	OR (95% CI)	P-value
Maternal education (P)	1.24 (0.62 – 2.51)	0.55
ADHD inattention *t*-score (P)	0.99 (0.94 – 1.05)	0.75
Medication status[a] (P)	2.10 (0.47 – 9.49)	0.33
Medication status[b] (P)	1.07 (0.14 – 8.22)	0.95
Executive functioning (L)	2.31 (10.01 – 5.26)	0.04*

Abbreviations: CI, confidence interval; L, laboratory measure; OR, odds ratio; P, parent report. [a]Relative risk of medication naïve children compared with children in stimulant group. [b]Relative risk of children in non-stimulant group compared with children in stimulant group. *$P < 0.05$.

z-scores. It is important to note that EF explained only 7% of the variance in children's BMI-*z* scores. Medication status continued to be associated with children's BMI-*z* scores, as evident by a marginal effect. On the other hand, maternal education and severity of inattention symptoms were not associated with BMI *z*-scores. Of note, no significant interaction emerged between EF and medication status in predicting BMI *z*-scores.

It was also important to determine whether EF can differentiate which children with ADHD have significant weight problems. Based on CDC-age norms,[44] children whose BMI were in the ⩾85th percentile were classified as overweight/obese ($n = 21$) and children between the 6th and 84th percentile were classified as normal weight ($n = 51$). Three children had a BMI < 6th percentile and were excluded from the analyses, and BMI was not obtained in another five children, resulting in a total sample size of 72. There were no statistically significant differences in demographics between the children included and excluded from these analyses. As expected, the overweight/obese group had a significantly higher BMI *z*-score ($M = 1.84$, s.d. $= 0.55$) compared with the normal group ($M = -0.07$, s.d. $= 0.81$), $t = 10.98$, $P < 0.001$. Children in the overweight/obese group and children in the normal weight group did not significantly differ on any demographic variables.

A logistic regression was conducted to determine whether EF differentiated children with ADHD classified as overweight/obese compared with those classified as normal weight, holding constant maternal education, severity of attention problems and medication status. To facilitate interpretation, our EF factor was reverse scored with higher scores indicative of worse functioning. As seen in Table 4, this negative EF factor was significantly associated with weight status (binary outcome, 0 = normal weight and 1 = overweight/obese), odds ratio = 2.31 (1.01 – 5.26), $P < 0.05$, suggesting that for each unit increase (that is, s.d.) in poor EF, children's likelihood of being classified as overweight/obese more than doubled or increased by about 131%. Once again, maternal education, severity of inattention symptoms and medication status were not associated with weight status.

DISCUSSION

To our knowledge, this is the first study examining the extent to which EF can differentiate which children with ADHD have co-occurring pediatric obesity. First, it is important to note that medication naïve children with ADHD had BMI-*z* scores > 0 (0.59), which is consistent with both epidemiological and clinical samples showing elevated rates of BMI among children with ADHD compared with age reference norms.[10 - 13] Second, children with ADHD who were on a stimulant medication had significantly lower BMI *z*-scores compared with children with ADHD who were not on medication or who were on a non-stimulant medication. This finding is consistent with previous research demonstrating how stimulant medication may confound the association between ADHD and obesity.[6] In fact, recent research suggests that children with ADHD who are on stimulant medication for a significant amount of time suffer significant weight loss and decelerated growth velocities owing to appetite suppression, although the effects on final adult height remain unclear.[46 - 48] On the other hand and consistent with prior work,[49] no differences in BMI *z*-scores were found among children with ADHD who were not on any medication compared with those who were on a non-stimulant medication. Hence, although non-stimulant medication is considered a secondary line of treatment,[50,51] it may be a more appropriate choice for a subgroup of children with ADHD with lower BMI-*z* scores.

In terms of the main research question and consistent with our hypothesis, we found that EF, as measured by three neuropsychological tests, was associated with BMI *z*-scores and significantly differentiated children's weight status. Specifically, children with ADHD who performed poorly on the EF tasks had greater BMI *z*-scores and were more likely to be classified as overweight/obese compared with children with ADHD who performed better on the EF tasks, even after controlling for maternal education, severity of inattention symptoms and medication status. These findings are consistent with the adult literature, in which overweight adults perform worse on EF tasks compared with normal weight adults, regardless of age and co-occurring medical complications, such as hypertension[38,39,52] as well as the emerging child obesity literature.[41,53] Most importantly, the detection of similar findings within an at-risk group of children with ADHD provide further evidence for examining self-regulation as a shared mechanism between obesity and ADHD.

Although the link between ADHD and pediatric obesity is often explained by dopaminergic dysfunction leading to impairments in reward processing,[18,19] isolating more proximal behavioral and/or neurocognitive skills involved in children's daily functioning is critical. The current study highlights EF as a more proximal self-regulation mechanism that appears to be particularly impaired among children with ADHD and co-occurring weight problems. It is important to acknowledge that the effect sizes found in this study between EF and BMI-*z* scores and weight problems were in the small-to-moderate range. We did not have information on children's eating patterns or physical activity, which are both inherently tied to weight problems.[54 - 56] It will be important for future research to examine the associations between eating behaviors, physical activity and observable self-regulation measures in order to clarify other mechanisms by which ADHD is linked to pediatric obesity.

Despite current theoretical notions, a significant portion of children with ADHD do not have EF deficits.[57,58] Hence, it may be the case that only the most severe children with ADHD are at a risk for having weight problems, especially after controlling for medication status. It is important for future research to longitudinally track children with early self-regulation deficits to determine which factors contribute to children developing both ADHD and weight problems. For example, environmental factors such as parenting feeding styles and families' physical activity levels likely have an important role in how a child with ADHD may also develop weight problems.

The cross-sectional aspect of the current study limits our ability to infer not only the temporal association between EF deficits and weight problems among children with ADHD but also its directionality. Although past longitudinal research has shown that other self-regulation deficits (for example, emotion regulation) during the toddlerhood period predict future weight problems in early childhood,[32] we must recognize the possibility that EF deficits may have emerged after children with ADHD gained weight, although we are not aware of any current findings showing such an effect. In addition, it is important to recognize that self-regulation skills entail control efforts across not only EF but also other domains (for example, emotion regulation and behavioral inhibition) that have a role in the development of both ADHD and pediatric obesity. Hence, it will be important for future studies to implement multiple time-point assessments to determine whether changes in children's self-regulation skills across various domains (for example, EF, emotion regulation and behavioral inhibition) represent risk factors for the development of weight problems, and/or if they are a consequence of weight gain. We must also acknowledge that although our EF factor was based on a well-established neuropsychological test battery (D-KEFS), it does not necessarily generalize to other neuropsychological indices (for example, visual-spatial and working memory), which may or may not be impaired among overweight children with ADHD. Lastly, our sample only included 18 girls, which may limit our ability to generalize our findings to both sexes.

Despite these limitations, the current study provides initial data suggesting that deficits in neurocognitive functioning can differentiate children with ADHD who exhibit co-occurring weight problems, even after accounting for children's medication status. These results may have significant implications for early intervention efforts. Specifically, for health providers who treat children with ADHD, it may be worth considering BMI when selecting initial treatment paradigms, with behavior therapy and non-stimulants being used preferentially in children who are underweight. Although further research is needed, based on these findings, treatment with stimulant medications may be more desirable in overweight children with ADHD and poor neurocognitive functioning, given their elevated risks for obesity. Alternatively, it will be important to investigate whether nonpharmacological interventions that target children's EF difficulties are successful in not only reducing behavioral and academic difficulties associated with ADHD but also improving weight status. Lastly, given the overlap between ADHD and pediatric obesity, and the significant costs and impairment associated with both disorders,[59,60] it may be cost-effective for future research to develop a joint treatment program simultaneously targeting obesity and ADHD. A joint intervention may yield synergistic effects, given the similarities in behavioral interventions commonly used for pediatric obesity and ADHD, such as home-based contingency reward systems, behavioral monitoring and parent-teacher-child contracting.[61,62] Research would then be able to examine whether the novel joint intervention is successful in improving children's weight management and attentional/behavioral functioning by improved self-regulation skills.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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