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Executive functioning difficulties in relation to food addiction, disordered eating attitudes, and metabolic syndrome markers among adolescents seeking obesity treatment: a cross-sectional analysis

Sarper İçen[1*], Yasemin Taş Torun[2], Esra Döğer[3] and Hesna Gül[4]

Abstract

Background Executive functioning (EF) difficulties may play a significant role in the vicious cycle of overeating and metabolic disturbances. We aimed to investigate the correlates of EF difficulties in terms of food addiction symptoms, eating attitudes, and metabolic syndrome markers among adolescents seeking obesity treatment.

Methods Thirty-five adolescents seeking obesity treatment were included. Executive functioning difficulties were assessed using both performance tasks (i.e. Stroop's task and Cancellation task) and parent reports on the Behavior Rating Inventory of Executive Function (BRIEF). Other measurements included adolescent self-reports of food addiction symptoms on the Yale Food Addiction Scale (YFAS) and eating attitudes on the Eating Attitudes Test-40 (EAT-40).

Results The mean total symptom score was 4.66 (± 1.45) on the YFAS. The most commonly endorsed symptoms were 'Repeated unsuccessful attempts to stop or decrease food consumption' in 94.3% (*N* = 32), 'Tolerance to the same amount of certain foods and consuming increasing amounts' in 80.0% (*N* = 28), and 'Continuing to eat despite knowing the negative consequences' in 77.1% (N = 27) of the sample. 48.6% of the adolescents with obesity (N = 17) met the criteria for diagnostic evaluation threshold according to YFAS, which was related to worse performance in Stroop Task and parent-reported difficulties in Emotional Control ($p < .05$ for both). Food addiction symptoms had differences in correlations with EF difficulties. "Eating for longer durations and higher amounts than intended" was related to difficulties in Emotional Control and Working Memory ($p < .05$ for both). "Continuing to eat despite knowing the negative consequences" was associated with difficulties in Shift, Emotional Control, Initiate, Plan/Organize, and Organization of Materials ($p < .05$ for all). Dieting was the only disordered eating attitude significantly correlated with EF difficulties. Specifically, less endorsement of dieting was correlated with difficulties in Inhibit and Working Memory ($p < .05$). Moreover, executive functioning difficulties were related to increased body mass index and

*Correspondence:
Sarper İçen
sarper.icen@gmail.com

Full list of author information is available at the end of the article

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waist circumference, in addition to worse metabolic parameters including fasting blood glucose, insulin, HOMA-IR, triglycerides, and blood pressure measurements.

Conclusion Our study points out that specific EF difficulties were related to food addiction symptoms, dieting, and metabolic syndrome markers among adolescents with obesity. Further studies are needed to with larger and more diverse samples.

Plain English Summary

This study explored how thinking skills, known as executive functions, are connected to eating habits, food addiction symptoms, and health markers in teenagers receiving treatment for obesity. Executive functions help people control their behavior, plan ahead, switch between tasks, and manage emotions. We worked with 35 adolescents who were seeking help for obesity.We tested their executive functions using both performance tasks and questionnaires completed by their parents. The teenagers also answered questions about food addiction and eating attitudes, and we measured their body weight, waist size, and various health indicators like blood sugar, insulin, and blood pressure. Almost half of the participants met the criteria for food addiction. Common signs included repeatedly failing to cut down on certain foods, needing more of the same food to feel satisfied, and continuing to eat despite knowing it could cause harm. Those with food addiction had more difficulties with emotional control, working memory, and other thinking skills. Lower interest in dieting was linked to poorer self-control and working memory. Importantly, teenagers with greater executive function difficulties tended to have higher body weight, larger waistlines, and less healthy metabolic measures. These findings suggest that challenges with thinking and self-control skills may play an important role in both unhealthy eating behaviors and physical health problems in adolescents with obesity. Understanding and addressing these thinking skills could help improve treatment for young people struggling with obesity and related health issues.

Keywords Obesity, Executive functions, Food addiction, Eating attitudes, Metabolic syndrome, Inhibition, Emotional control, Working memory

Introduction

Obesity among children and adolescents is a growing public health concern, associated with earlier onset of chronic conditions such as type 2 diabetes, hypertension, and atherosclerotic cardiovascular disease, largely due to metabolic disturbances [1–3]. In addition to physical health risks, obesity in youth is linked to adverse psychological and social outcomes, underscoring the need for a multidisciplinary approach to treatment that addresses both mental and metabolic health [1–2, 4–5]. A heterogeneity of psychological factors is related to adolescent obesity, including executive functioning (EF) difficulties, which are important cortical functions regulating behaviors such as inhibition, set-shifting, and working memory [6]. Increased adiposity and metabolic dysfunction have been linked to cognitive impairments across the lifespan, including children and adolescents [7, 8]. EF difficulties among children and adolescents with obesity are associated with dysregulated eating behaviors, reduced physical activity, sedentary behavior, and negative body image, all of which heighten their vulnerability to further weight gain, metabolic dysfunction, and psychological difficulties [9, 10].

While research on EF in adolescents with obesity has expanded, the specific eating behaviors associated with EF impairments remain underexplored. Among these, addictive-like eating patterns have garnered growing interest, particularly in relation to, but conceptually distinct from, binge eating and emotional eating [11, 12]. Although these behaviors share features such as overconsumption and loss of control, food addiction (FA) offers a distinct framework grounded in addiction theory. Operationalized by the Yale Food Addiction Scale (YFAS), FA emphasizes compulsive eating marked by tolerance, withdrawal, and persistent use despite negative consequences [13]. This perspective is particularly relevant for adolescents with obesity who may not meet criteria for binge eating disorder but exhibit similarly impairing behavioral patterns.

FA symptoms are thought to emerge from both the rewarding properties of highly palatable foods and the compulsive behavioral patterns involved in their consumption [13]. In addition to its behavioral features, FA symptoms have been increasingly linked to cognitive vulnerabilities, particularly deficits in EF. Studies suggest that EF impairments, especially in working memory and inhibitory control, may contribute to addiction-like eating behaviors [9, 14, 15]. Importantly, FA symptoms appear to be more prevalent among youth with obesity [11]. Yet, few studies have examined the specific EF profiles associated with FA symptoms in adolescents with obesity. Further research is needed to clarify how cognitive impairments may contribute to the development and maintenance of FA symptoms in this population [16]. The current study addresses this gap by focusing specifically

on FA symptoms in treatment-seeking adolescents with obesity.

Difficulties with EF have to be addressed in obesity treatment due to potential problems following through with diet, exercise, and medication regimens. Specific aspects of EF difficulties related to dieting behaviors among adults were defined, such as inhibitory control and working memory problems [17, 18]. However, more investigation is needed to clarify these relationships among adolescents in clinical samples. This cross-sectional study examines the correlates of EF difficulties regarding obesity-related measurements (e.g., body mass index, waist circumference), addictive-like eating behaviors (e.g., FA symptoms), eating attitudes (e.g., dieting), and metabolic syndrome markers (e.g., fasting glucose, fasting insulin, HOMA-IR, fasting triglycerides, fasting HDL, systolic and diastolic blood pressure) in adolescents seeking obesity treatment. Given the limited research on EF in this population, particularly in relation to FA symptoms, this study was designed as an exploratory investigation. We used both performance-based and parent-reported EF assessments to capture complementary aspects of executive functioning. Performance-based tasks offer standardized, objective measures of cognitive processes, while parent reports provide insights into how EF difficulties manifest in daily life. Together, these approaches offer a more comprehensive understanding of EF difficulties in adolescents with obesity. Our goal is to generate insights that can inform more integrated and effective multidisciplinary interventions.

Methods

Study design and procedure

This was a cross-sectional, exploratory study conducted among adolescents seeking treatment for obesity. The study procedure included clinical evaluation of obesity and metabolic syndrome markers by the pediatric endocrinology department, in which body measurements, including body weight, height, and waist circumference, were obtained in addition to arterial blood pressure. Fasting blood samples were collected to assess plasma glucose, insulin, triglycerides, and HDL cholesterol levels. Insulin resistance was assessed by calculating HOMA-IR. Moreover, adolescents were evaluated by the child and adolescent psychiatrists in the outpatient clinics, in which participants completed performance-based tests to evaluate different aspects of EF. Parents completed the Behavior Rating Inventory of Executive Function (BRIEF) – Parent Form. The Yale Food Addiction Scale (YFAS) and the Eating Attitudes Test-40 (EAT-40) were used to evaluate the FA symptoms and disordered eating attitudes based on adolescents' self-reports, respectively.

Ethical considerations

Before inclusion, written informed consent was obtained from all participants and accompanying parents regarding participation in the study and publication of study findings anonymously. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2013. All procedures involving human subjects/patients were approved and monitored by the Clinical Research Ethical Board of Gazi University with approval number 11.01.2021/33.

Participants

Although the study was exploratory and not driven by formal hypotheses, an a priori power analysis was conducted using G*Power to guide sample planning [19]. A minimum of 29 participants was required to detect a correlation of $r = .50$ with 80% power at $\alpha = 0.05$. This value was chosen based on Cohen's (1988) guidelines and informed by prior research linking psychosocial and behavioral measures [20]. Given the exploratory nature of the study and the range of constructs assessed, we recognize that not all associations were expected to reach this magnitude.

We included 35 adolescents (ages 11–18) seeking obesity treatment in pediatric endocrinology department outpatient clinics of the university hospital by consecutive sampling between January 2021 and June 2021. The inclusion criteria required a diagnosis of obesity based on age-adjusted BMI percentiles for sex being over 95 according to national standardization [21]. Participants with a known or suspected psychiatric disorder, neurological condition, developmental or intellectual disability, according to patient history and clinical evaluation, were excluded from the study.

Measurements

Executive functioning difficulties

Performance-based assessments of executive functioning difficulties

a. Stroop Task: The Stroop TBAG Form was administered in a standardized paper-and-pencil format. This version is based on the original Stroop (1935) paradigm and the Victoria Form [22–24]. Its reliability has been established in both adult and child samples. In a study with a sample of young adults (mean age = 20), test–retest correlations over a 12-month interval were $r = .56$ (speed) and $r = .44$ (interference effect), both statistically significant [22]. In a separate validation with children aged 6 to 11, completion time scores showed test–retest reliability coefficients ranging from 0.63 to 0.81, supporting its applicability in pediatric settings [25].

The Stroop Task TBAG form comprises five sections targeting inhibitory control, selective attention, and cognitive flexibility:

- Section I: Reading color words printed in black ink (baseline reading speed).
- Section II: Reading color words printed in incongruent ink colors (resistance to interference in reading).
- Section III: Naming the colors of colored circles (baseline color naming).
- Section IV: Naming the ink colors of neutral, non-color words.
- Section V: Naming the ink colors of color words printed in incongruent colors (interference condition).

Each section includes 24 items arranged in a 4 × 6 grid on an A5-sized card. The order of administration was fixed across all participants. Standardized instructions were provided by trained research staff prior to each section. They were instructed to proceed from left to right, top to bottom, completing each section as quickly and accurately as possible. Errors were marked with slashes, and corrected responses were circled in the administration form, following the standardized scoring protocol. For each section, the following metrics were recorded:

- Completion time (from start to last item).
- Number of errors.
- Number of self-corrected responses.

Because this task was administered in a paper-based format, individual item reaction times were not recorded. Instead, three section-level interference indices were calculated to assess cognitive inhibition:

- Time-based interference score: Difference in completion time between the incongruent condition and a congruent baseline.
- Accuracy-based interference score: Difference in error count between the incongruent condition and a congruent baseline.
- Percent interference score: Proportional increase in completion time from the congruent to the incongruent condition.

Higher scores on these indices reflected greater difficulty with inhibitory control under conflicting stimulus conditions.

b. Cancellation Task: The cancellation task was adapted to Turkish and validated for use in children, with test–retest reliability coefficients ranging from 0.45 to 0.83 ($p < .01$ for all indices) [26]. This task assesses selective attention, visual scanning, and processing speed by requiring participants to identify and cancel target stimuli while ignoring distractors. Participants completed four separate sheets, each containing a structured matrix of visual items:

- One sheet with regular letters.
- One sheet with irregular letters.
- One sheet with regular symbols.
- One sheet with irregular symbols.

In each condition, participants were instructed to cancel a specific target item (e.g., the letter "A" or a specific symbol) as quickly and accurately as possible. For each sheet, the number of correct hits, misses, and false alarms was recorded, along with the total completion time in seconds. A combined efficiency score was computed to reflect speed–accuracy trade-off:

(Correct hits − [misses + false alarms]) ÷ completion time (in seconds).

Higher combined efficiency scores indicated better attentional performance, reflecting both faster and more accurate target identification.

Because the task was administered in a paper-and-pencil format, reaction times for individual trials were not recorded, and performance was evaluated using aggregate (section-level) scores. Therefore, trial-level modeling approaches were not applicable for this task either.

Parent-reported evaluation of executive functioning difficulties

Behavior rating inventory of executive functions (BRIEF) - Parent form This tool was used to assess EF by obtaining information regarding adolescents' behaviors from the parents. The BRIEF is a standardized questionnaire that evaluates various domains of executive function across eight sub-scales [27]. It was adapted to our language and validated for use in both the clinical and normative populations of children [28, 29]. Cronbach's alpha for the subscale scores ranged from 0.60 to 0.94 for parent reports of the BRIEF in a sample of healthy children and adolescents [29]. Higher scores indicate that difficulties in that domain are experienced more often.

- *Inhibit*: the ability to control impulses and stop inappropriate behaviors.
- *Shift*: flexibility or the ability to transition smoothly between tasks or activities.
- *Emotional Control*: the ability to regulate emotional responses appropriately.
- *Initiate*: the ability to begin tasks independently and generate ideas or problem-solving strategies.
- *Working Memory (WM)*: the ability to hold and manipulate information during tasks.

- *Plan/Organize*: the ability to plan, manage tasks, and organize ideas efficiently.
- *Organization of Materials*: the skill of keeping belongings or workspaces orderly.
- *Monitor*: the ability to self-monitor and keep track of performance and behaviors.

Evaluation of addictive eating behaviors and eating attitudes

Yale food addiction scale (YFAS) FA symptoms were assessed using the original YFAS a self-report measure developed to reflect DSM-IV-TR criteria for substance dependence in the context of eating behavior [13]. Although the updated YFAS 2.0 aligns with DSM-5 criteria, a validated Turkish version of the revised tool was not yet available at the time of data collection. The original YFAS had been culturally adapted and, with a Cronbach's alpha of 0.93, validated for use in Turkish samples [30]. While the YFAS was originally developed for adults, it has been used in prior adolescent studies, including those conducted in Turkish samples [31–33]. In the present study, the questionnaire was administered in a clinical setting under supervision. Trained research staff were available to assist participants if any items were unclear, providing clarification without leading their responses.

The scale consists of 25 symptom-related items corresponding to seven diagnostic criteria, plus one impairment criterion as follows:

- Consuming "certain foods" in larger amounts or over longer periods than intended.
- Repeated unsuccessful attempts to cut down or stop eating these foods.
- Excessive time spent obtaining, eating, or recovering from the effects of such foods.
- Giving up important social, occupational, or recreational activities due to eating.
- Continued consumption despite awareness of adverse physical or psychological effects.
- Developing tolerance and needing increased amounts to achieve the same effect.
- Experiencing withdrawal-like symptoms that are relieved by consuming these foods.
- Clinically significant distress or impairment due to these symptoms (impairment criterion).

The presence or absence of each criterion was determined according to the validated scoring instructions provided by the developers. We emphasize that analyses regarding the individual FA symptoms were conducted at the diagnostic criterion level, consistent with the psychometric structure of the scale, and not at the individual item level.

Besides endorsement of the seven diagnostic criteria and impairment criterion, two main variables were derived from the YFAS:

1. A continuous score (range: 0–7): a continuous index of FA symptom severity resembling total symptom count (excluding the impairment criterion).
2. A dichotomous score (range: 0–1): a diagnosis-like threshold defined as meeting ≥ 3 criteria plus the impairment criterion.

In this study, we refer to these outcomes as "YFAS symptom score" and "diagnostic evaluation threshold based on YFAS", respectively. It is important to note that this classification is derived from self-report and does not represent a formal clinical diagnosis.

In addition, we examined responses to Item 26 of the YFAS, in which participants identified specific foods associated with FA symptoms they reported having. Reported foods were grouped into broader categories (e.g., sweet, fatty, starchy, salty, beverages) based on the original scoring instructions, and the frequency of endorsement for each category was calculated across the sample.

Eating disorder Test-40 (EAT-40) The EAT-40 was used to assess disordered eating attitudes. This self-report instrument was originally developed to identify symptoms associated with restrictive eating disorders [34]. However, it has also been widely applied in adolescent populations with overweight or obesity to capture maladaptive eating-related cognitions, including dieting behaviors, food-related guilt, and body image concerns. In this study, the EAT-40 was used as a dimensional measure of disordered eating attitudes, rather than as a diagnostic tool. The Turkish adaptation of the EAT-40, with a Cronbach's alpha of 0.70, demonstrated acceptable reliability [35]. The scale consists of 40 items, and the adaptation study identified four subscales.

- Anxiety about gaining weight.
- Dieting.
- Social pressure.
- Thin body preoccupation.

Higher scores on each subscale indicate a greater degree of disordered eating behaviors in that area. Additionally, an individual scoring equal to or greater than 30 on the total EAT-40 score is considered at increased risk of developing an eating disorder.

Statistical analyses

All statistical analyses were conducted using IBM SPSS Statistics 22. Descriptive statistics, means, medians,

Table 1 Descriptive analysis of the sample with participant characteristics and metabolic measurements

			Frequency	% (of 35)
Sex: female			19	54.3
Sex: male			16	45.7
	Mean	S.D.	Median	Range (min-max)
Age (years)	14.42	2.08	14.13	6.43 (11.57-18.00)
Body mass index (kg/m2)	32.06	3.55	31.65	13.49 (25.95–39.44)
Waist circumference (cm)	100.95	10.97	99.00	42.00 (79.00-121.00)
Fasting blood glucose (mg/dL)	89.57	8.11	89.00	37.00 (76.00-113.00)
Fasting insulin (mIU/L)	18.46	8.67	18.10	32.60 (6.40–39.00)
HOMA-IR	4.09	1.99	3.88	8.46 (1.41–9.87)
Fasting triglycerides (mg/dL)	116.54	48.29	105.00	204.00 (59.00-263.00)
Fasting HDL (mg/dL)	46.49	9.18	48.00	46.00 (24.00–70.00)
Systolic blood pressure (mmHg)	121.03	10.81	120.00	40.00 (100.00-140.00)
Diastolic blood pressure (mmHg)	77.93	9.40	80.00	35.00 (65.00-100.00)

Table 2 Assessments of executive functioning difficulties

	Mean	S.D.	Median	Range (min-max)
Performance-based tasks of executive functions				
Stroop's task				
- Time-based interference score	14604.29	6729.00	13270.00	23,770 (5820.00-29590.00)
- Accuracy-based interference score	0.20	0.63	0.00	3.00 (0.00–3.00)
- Percent interference	127.84	57.66	126.13	247.16 (46.59-293.75)
Cancellation task				
- Combined efficiency score	0.58	0.13	0.61	0.55 (0.31-0.86)
Parent-reported executive functioning difficulties				
BRIEF – Inhibit score	15.94	5.42	15.00	20.00 (10.00–30.00)
BRIEF – Shift score	16.60	2.92	17.00	12.00 (9.00–21.00)
BRIEF – Emotional control score	20.86	4.34	20.00	19.00 (11.00–30.00)
BRIEF – Initiate score	16.89	3.99	17.00	16.00 (8.00–24.00)
BRIEF – Working memory score	19.97	4.73	20.00	19.00 (10.00–29.00)
BRIEF – Plan/organize score	23.91	5.89	23.00	20.00 (13.00–33.00)
BRIEF – Organization of materials score	13.14	3.57	14.00	12.00 (6.00–18.00)
BRIEF – Monitor score	16.00	3.76	16.00	16.00 (8.00–24.00)

standard deviations, and minimum–maximum values, were calculated for all continuous variables. The distribution of each variable was assessed using both statistical tests (Shapiro-Wilk and Kolmogorov-Smirnov) and visual methods (histograms and Q-Q plots). Because most variables deviated from normality, non-parametric tests were used in all subsequent analyses. Specifically, Spearman's rank-order correlation was employed to examine associations between behavioral task performance (e.g., Stroop and Cancellation task scores) and psychological or behavioral measures (e.g., FA symptoms, eating attitudes, executive function ratings). This method was selected due to its robustness to non-normal distributions and its appropriateness for detecting monotonic relationships.

Results

Descriptive analyses of the measurements

The descriptive analysis of the sample with participant characteristics and metabolic measurements can be seen in Table 1. Our sample consisted of thirty-five adolescents with a mean age of 14.42 years (SD = 2.08), exhibiting a range from 11.57 to 18.00 years. Adolescents with female sex comprised 54% of the participants. The mean body mass index (BMI) was 32.06 kg/m² (SD = 3.55), and the mean waist circumference (WC) was 100.95 cm (SD = 10.97) in our sample. A detailed descriptive analysis of the EF difficulties in our sample, as assessed in both performance-based tasks (i.e., Stroop's task and Cancellation task) and parent-reported executive functioning difficulties in daily behaviors, is presented in Table 2.

Evaluation of food addiction symptoms, diagnosis, and the reportedly addicted food groups can be seen in Table 3. The mean total symptom score was 4.66 (± 1.45) on the YFAS. Participants exhibited notable food addiction symptoms in the YFAS evaluation. The most commonly endorsed symptoms were 'Repeated unsuccessful attempts to stop or decrease food consumption' in 94.3% (*N* = 32), 'Tolerance to the same amount of certain foods and consuming increasing amounts' in 80.0% (*N* = 28), and 'Continuing to eat despite knowing the negative

Table 3 Evaluation of food addiction symptoms and diagnosis on Yale food addiction scale

	Mean	S.D.	Median	Range (min-max)
YFAS total symptom score	4.66	1.45	5.00	5.00 (2.00–7.00)
				Frequency (% of 35)
Food addiction symptoms				
– Eating certain foods for longer duration and higher amounts than intended				23 (65.7)
– Repeated unsuccessful attempts to stop or decrease consuming certain foods				33 (94.3)
– Spending too much time to reach certain foods or eating-related activities				22 (62.9)
– Avoidance from important social, functional, and interpersonal activities due to consuming certain foods				11 (31.4)
– Continuing to eat certain foods despite knowing the negative consequences				27 (77.1)
– Tolerance to the same amount of certain foods and consuming increasing amounts				28 (80.0)
– Anxiety and other physical withdrawal symptoms when certain foods are not consumed				19 (54.3)
Distress or functional impairment due to food addiction symptoms				18 (51.4)
Diagnostic evaluation threshold based on YFAS				17 (48.6)
Food groups that cause addiction				
– Sweet foods such as ice cream, chocolate, and cakes				28 (80.0)
– Starch-rich foods such as bread, pasta, and rice				27 (77.1)
– Salty snacks such as crisps, pretzels, and crackers				24 (68.6)
– Fatty foods such as burgers, pizza, and fries				29 (82.9)
– Beverages such as cokes and sodas				19 (54.3)

Table 4 Evaluation of disordered eating attitudes on eating attitudes Test-40

	Mean	S.D.	Median	Range (min-max)
Anxiety about gaining weight	4.09	3.71	3.00	12.00 (0.0–12.00)
Dieting behaviors	1.89	2.75	1.00	12.00 (0.0–12.00)
Social pressure	1.20	1.55	0.00	6.00 (0.0–6.00)
Thin body preoccupation	0.63	1.11	0.00	4.00 (0.0–4.00)
Total score	21.29	8.32	22.00	30.00 (6.00–36.00)
				Frequency (% of 35)
Increased risk of eating disorders				7 (20.0)

consequences' in 77.1% (N = 27) of the sample. Distress or functional impairment due to FA symptoms was reported by 51.4% of the sample (N = 18). In diagnostic evaluation, 48.6% of the adolescents with obesity (N = 17) met the criteria for diagnostic evaluation threshold according to YFAS, based on three or more symptoms causing distress or impairment. Fatty foods such as burgers, pizza, and fries and sweet foods such as ice cream, chocolate, and cakes were the most commonly reported food groups that are related to their food addiction symptoms (see Table 3).

Table 4 presents the evaluation of disordered eating attitudes on EAT-40 in our sample. Subscale scores revealed that disordered eating attitudes exist in adolescents with obesity, especially anxiety about gaining weight and dieting behaviors. Moreover, an increased risk of eating disorders was observed in %20.0 of the sample ($N = 7$) according to the cut-off point of 30 on EAT-40.

Executive functioning difficulties associated with food addiction symptoms and disordered eating attitudes

Spearman's correlation analyses between EF difficulties and scale measurements of YFAS and EAT-40 revealed several significant associations, particularly concerning FA symptoms and dieting behaviors (see Table 5).

Firstly, we observed significant relationships between performance-based assessments of executive functions and YFAS (see Table 5). The Stroop Task Accuracy-Based Interference Score had moderate positive correlations with both "Distress or functional impairment due to FA symptoms" and "diagnostic evaluation threshold according to YFAS" ($r = .35$ and $r = .37$, $p < .05$ for both). In addition, we observed significant correlations between parent-reported EF difficulties and YFAS. Specifically, the BRIEF – *Emotional Control* score had moderate positive relationships with "Distress or functional impairment due to FA symptoms" and "diagnostic evaluation threshold according to YFAS" ($r = .38$ and $r = .42$, respectively; $p < .05$ for both). Moreover, the YFAS total symptom score positively correlated with the BRIEF – *Emotional Control* score ($r = .38$, $p < .05$), indicating that higher severity of FA symptoms is associated moderately with poorer emotional control. "Eating for longer durations and higher amounts than intended" showed positive correlations with the BRIEF – *Emotional Control* score ($r = .37$, $p < .05$) and the BRIEF – *WM* score ($r = .34$,

Table 5 Executive functioning difficulties associated with food addiction symptoms and disordered eating attitudes

	Parent-reported executive functioning difficulties in daily behaviors on BRIEF								Performance-based tasks of executive functions			
	Inhibit	Shift	Emotional control	Initiate	Working memory	Plan/organize	Organization of Materials	Monitor	Stroop task time-based interference	Stroop task accuracy-based interference	Stroop task percent interference	Cancellation task combined efficiency score
Yale Food Addiction Scale												
Eating for longer duration and higher amounts than intended	0.20	0.22	**0.37**[a]	0.26	**0.34**[a]	0.25	0.29	0.20	0.22	0.26	0.24	−0.19
Repeated unsuccessful attempts to stop or decrease consuming food	−0.26	−0.06	0.00	0.07	−0.17	−0.21	−0.08	−0.18	−0.16	−0.28	−0.23	0.10
Spending too much time to reach food or eating-related activities	−0.08	0.21	0.32	0.20	−0.04	0.09	0.19	−0.00	−0.26	0.10	−0.12	0.03
Avoidance from important social, functional, and interpersonal activities	−0.11	0.03	0.06	−0.08	0.06	0.04	0.09	0.10	−0.01	−0.06	−0.06	0.07
Continuing to eat despite knowing the negative consequences	0.26	**0.43**[a]	**0.38**[a]	**0.41**[a]	0.32	**0.38**[a]	**0.51**[b]	0.19	0.19	0.20	0.12	−0.16
Tolerance to the same amount of food and consuming increasing amounts	0.11	−0.13	−0.17	−0.09	−0.07	−0.05	−0.06	0.14	0.23	−0.05	0.30	−0.11
Anxiety and other physical withdrawal symptoms	−0.01	−0.06	0.24	−0.05	0.15	0.04	−0.06	−0.09	−0.28	−0.04	−0.24	0.24
Distress or functional impairment due to food addiction symptoms	0.04	0.17	**0.38**[a]	0.16	0.25	0.13	0.21	0.07	0.04	**0.35**[a]	0.12	0.16
Total symptom score	0.09	0.21	**0.38**[a]	0.19	0.21	0.18	0.30	0.13	−0.04	0.04	0.01	0.06
Diagnostic evaluation threshold based on YFAS	−0.05	0.15	**0.42**[a]	0.17	0.20	0.10	0.22	−0.02	0.02	**0.37**[a]	0.07	0.11
Eating attitudes test-40												
Anxiety about gaining weight	−0.24	−0.03	0.02	−0.09	0.03	−0.07	−0.07	−0.07	−0.06	0.23	−0.06	0.08
Dieting behaviors	**−0.39**[a]	−0.26	−0.15	−0.32	**−0.42**[a]	−0.33	−0.19	−0.24	−0.15	0.20	−0.04	0.27
Social pressure	−0.17	−0.01	0.20	−0.14	−0.13	−0.22	−0.07	−0.21	−0.09	−0.01	−0.18	0.01
Thin body preoccupation	−0.18	0.00	0.08	0.11	0.01	0.02	0.04	−0.02	0.01	0.14	0.08	0.10
Total score	**−0.34**[a]	−0.20	0.12	−0.17	−0.18	−0.19	−0.11	−0.31	−0.24	0.15	−0.19	0.18
Increased risk of eating disorder	−0.32	-29	−0.09	−0.17	−0.28	−0.18	−0.11	−0.32	−0.21	0.29	−0.18	0.17

[a] Spearman's rho is significant at $p < .05$; [b] Spearman's rho is significant at $p < .01$

$p < .05$), suggesting that these specific EF difficulties are moderately associated with increased eating duration and quantity. While "Continuing to eat despite knowing the negative consequences" was positively correlated with *Shift* ($r = .43$, $p < .05$), *Emotional Control* ($r = .38$, $p < .05$), *Initiate* ($r = .41$, $p < .05$), *Plan/Organize* ($r = .38$, $p < .05$), and *Organization of Materials* ($r = .51$, $p < .01$) scores on the BRIEF-parent form suggesting moderate to strong relationships.

Lastly, adolescent-reported eating attitudes showed significant correlations with parent-reported EF problems (see Table 5). The dieting subscale on the EAT-40 evaluation had moderate negative correlations with the BRIEF – *Inhibit* score ($r = -.39$, $p < .05$) and the BRIEF – *WM* score ($r = -.42$, $p < .05$), suggesting that difficulties in these areas may lead to ineffective dieting strategies. Similarly, the Total Score of EAT-40 had a significant negative correlation with the BRIEF – *Inhibit* score ($r = -.34$, $p < .05$).

Executive functioning difficulties associated with obesity measurements and metabolic parameters

Spearman's correlation analyses between EF difficulties and obesity measurements revealed several significant associations, indicating a relationship between increased adiposity and executive dysfunction (see Table 6). BMI showed moderate positive correlations with the BRIEF – *WM* score ($r = .34$, $p < .05$) and the BRIEF – *Plan/Organize* score ($r = .33$, $p < .05$). On the other hand, WC showed moderate to strong positive correlations with *Shift* ($r = .42$, $p < .05$), *Initiate* ($r = .59$, $p < .01$), *WM* ($r = .40$, $p < .05$), *Plan/Organize* ($r = .53$, $p < .01$), *Organization of Materials* ($r = .38$, $p < .05$), and *Monitor* ($r = .42$, $p < .05$) scores on the BRIEF-parent form.

Moreover, there were significant relationships between metabolic syndrome markers and EF difficulties (see Table 6). First, fasting blood glucose had positive correlations with the Stroop Task Accuracy-Based Interference Score ($r = .36$, $p < .05$) and Stroop Task Percent Interference ($r = .34$, $p < .05$), suggesting moderate associations with difficulties in inhibition and cognitive control. Second, fasting insulin exhibited positive correlations with multiple scales of the BRIEF-parent form: *Inhibit* ($r = .41$, $p < .05$), *Shift* ($r = .53$, $p < .01$), *Initiate* ($r = .58$, $p < .01$), *WM* ($r = .57$, $p < .01$), *Plan/Organize* ($r = .70$, $p < .01$), *Organization of Materials* ($r = .50$, $p < .01$), and *Monitor* ($r = .56$, $p < .01$) scores, indicating moderate to strong relationships with EF difficulties in various domains. In addition, fasting insulin also exhibited significant moderate correlations with performance-based EF assessments, such as the Stroop Task Time-Based Interference Score ($r = .35$, $p < .05$), indicating problems with inhibition and cognitive control and a negative correlation with the Cancellation Task Combined Efficiency Score ($r = -.46$, $p < .01$), indicating impairments in visual scanning, selective attention, and processing speed. Correlations between EF difficulties and HOMA-IR were similar to fasting insulin (see Table 3). Similar to fasting insulin, fasting triglycerides correlated positively with *WM* ($r = .35$, $p < .05$), *Plan/Organize* ($r = .34$, $p < .05$), and *Organization of Materials* ($r = .39$, $p < .05$) scores on the BRIEF-parent form, suggesting moderate level relationships with specific EF difficulties. At the same time, fasting triglycerides exhibited a moderate positive correlation with the Stroop Task Time-Based Interference Score ($r = .41$, $p < .01$) and a strong negative correlation with the Cancellation Task Combined Efficiency Score ($r = -.52$, $p < .01$). Lastly, systolic blood pressure exhibited positive correlations with the BRIEF – *Initiate* score ($r = .45$, $p < .05$) and the BRIEF – *Plan/Organize* score ($r = .41$, $p < .05$). In contrast, diastolic blood pressure had positive correlations with the BRIEF – *Initiate* score ($r = .44$, $p < .05$) and the BRIEF – *Organization of Materials* score ($r = .38$, $p < .05$), suggesting moderate-level associations with EF difficulties.

Discussion

In this cross-sectional study, we investigated the correlates of EF difficulties regarding FA symptoms, eating attitudes, and metabolic syndrome markers in adolescents seeking obesity treatment. First, our results demonstrated that EF difficulties have important behavioral correlates in adolescents with obesity. Poorer EF in various domains was associated with FA symptoms, such as 'eating certain foods for longer durations and larger amounts than intended' and 'continuing to eat certain foods despite knowing the negative consequences.' In addition, EF difficulties in inhibition and WM were associated with less endorsement of dieting, which is critical for obesity treatment. Moreover, we observed noteworthy associations between metabolic syndrome markers and EF difficulties. First, a weaker performance on task-based evaluations of EF was linked to metabolic syndrome markers such as heightened fasting blood glucose, fasting insulin, and fasting triglycerides. Second, EF difficulties reported by the parents' observations were associated with higher body-mass index and waist circumference, reflecting increased total body fat and abdominal adiposity, respectively. Moreover, we observed that EF difficulties had significant relationships with fasting insulin levels, HOMA-IR, triglyceride levels, and systolic and diastolic blood pressure. Our findings align with previous studies linking executive functioning deficits to maladaptive eating behaviors and metabolic risk markers in obesity.[7,14,17–18,36–42] These results suggest that obesity interventions for adolescents may benefit from a multidisciplinary approach, one that includes not only nutritional and medical management but also psychological

Table 6 Executive Functioning Difficulties Associated with Obesity Measurements and Metabolic Parameters

	Parent-reported executive functioning difficulties in daily behaviors on BRIEF								Performance-based tasks of executive functions			
	Inhibit	Shift	Emotional control	Initiate	Working memory	Plan/organize	Organization of Materials	Monitor	Stroop task time-based interference	Stroop task accuracy-based interference	Stroop task percent interference	Cancellation task combined efficiency score
Metabolic parameters												
Body-mass index (kg/m^2)	0.04	0.30	0.25	0.29	**0.34**[a]	**0.33**[a]	0.18	0.17	−0.04	−0.27	−0.05	0.17
Waist circumference (cm)	0.27	**0.42**[a]	0.27	**0.59**[b]	**0.40**[a]	**0.53**[b]	**0.38**[a]	**0.42**[a]	−0.09	−0.14	0.08	0.16
Fasting blood glucose (mg/dL)	0.09	0.14	0.14	0.12	0.02	0.04	−0.02	0.24	0.23	**0.36**[a]	**0.34**[a]	−0.07
Fasting insulin (mIU/L)	**0.41**[a]	**0.53**[b]	0.14	**0.58**[b]	**0.57**[b]	**0.70**[b]	**0.50**[b]	**0.56**[b]	**0.35**[a]	0.11	0.27	**−0.46**[b]
HOMA-IR	**0.38**[a]	**0.52**[b]	0.14	**0.56**[b]	**0.54**[b]	**0.67**[b]	**0.48**[b]	**0.54**[b]	**0.36**[a]	0.19	0.30	**−0.43**[a]
Fasting triglyceride (mg/dL)	0.20	0.28	−0.07	0.28	**0.35**[a]	**0.34**[a]	**0.39**[a]	0.31	**0.41**[a]	0.01	0.30	**−0.52**[b]
Fasting HDL (mg/dL)	−0.03	0.01	0.08	−0.09	0.01	−0.16	−0.05	−0.03	0.11	−0.15	0.06	−0.17
Systolic blood pressure (mmHg)	0.23	0.27	0.35	**0.45**[a]	0.34	**0.41**[a]	0.33	0.35	0.15	−0.17	0.22	0.14
Diastolic blood pressure (mmHg)	0.24	0.35	0.32	**0.44**[a]	0.26	0.34	**0.38**[a]	0.35	0.00	−0.06	0.15	0.11

[a] Spearman's rho is significant at $p < .05$; [b] Spearman's rho is significant at $p < .01$

support targeting executive functioning, emotional regulation, and addictive eating tendencies.

In previous studies, inhibitory control deficits among adolescents with FA symptoms were shown with food-related neuropsychological tasks and neuroimaging studies [14, 36]. Moreover, previous literature suggests that EF difficulties associated with FA symptoms can be better captured with food-related tasks and not commonly with classical neuropsychological tasks [43]. In this respect, we remarkably found that meeting the diagnostic evaluation threshold according to YFAS was associated with inhibitory control deficits measured with the classical Stroop task. However, we did not observe the same relationship with parent-reported EF difficulties in inhibition in our study. Instead, meeting the diagnostic evaluation threshold according to YFAS was related to parent-reported EF difficulties in emotion control, besides the problems with inhibitory control evidenced in Stroop task performances. Although we did not investigate the affective state at the time of task assessments, this discrepancy may be attributed to emotion-driven impulsivity. Specifically, adolescents with obesity may experience more problems with inhibitory control in negative affective states, which may be associated with emotional overeating [44]. Indeed, negative urgency increased poor weight-related quality of life through FA symptoms and emotional eating among adolescents with severe obesity [45]. Together with the results of previous studies, our results imply that adolescents who reported more severe FA symptoms as high as diagnostic levels experience more problems with emotional control and may benefit from emotion regulation training to reduce emotional eating.

Regarding individual FA symptoms, only two out of seven had significant correlations with EF difficulties: 'eating certain foods for longer durations and higher amounts than intended' and 'continuing to eat certain foods despite knowing the negative consequences.' Both symptoms were related to EF difficulties in emotion control, aligning with the significant role of emotional overeating in adolescent obesity further. Moreover, we observed a significant relationship between 'eating certain foods for longer durations and higher amounts than intended' and EF difficulties in WM in addition to difficulties in emotion control, supporting a previous report of worse WM performance related to loss of control eating among children with obesity [37]. Besides difficulties in emotion control, the FA symptom of 'continuing to eat certain foods despite knowing the negative consequences.' was associated with EF difficulties in shifting, initiating, planning/organizing, and most strongly with organization of materials. We interpret these relationships as multiple aspects of EF impairments contributing to higher-level dysfunctions, including delaying

gratification, decision-making, and problem-solving, through which maintaining the problematic eating behaviors despite knowing the negative consequences [7].

Our results revealed that EF difficulties in inhibition were inversely related to dieting attitudes in EAT-40 among adolescents seeking obesity treatment, in line with previous results suggesting inhibition and WM difficulties impact dieting behaviors [17, 18]. Dieters with better inhibitory control have been more successful in weight loss as they were more likely to resist and inhibit their food desires [17]. Indeed, higher uncontrolled eating and snacking frequency associated with inhibitory control problems, as well as increases in both BMI and WC, have been reported for adolescents with obesity [38]. In addition to difficulties related to inhibitory control, we observed a negative relationship between EF difficulties in WM and dieting attitudes in EAT-40. Previous reports also suggested that successful and unsuccessful dieters differ regarding food cue-related WM and attention to food when holding food information [39, 40]. WM is essential for food-related decision-making in accordance with diet-related long-term goals [46]. Training WM skills among adolescents with obesity may strengthen self-regulation in dieting by reducing eating-associated thoughts and emotional eating [47].

Regarding the adverse impacts of obesity on executive functioning, evidence suggests that cognitive impairments can occur due to increased adiposity and/or metabolic dysfunction independently or concurrently [8]. Although we did not control for each other, our findings also support that both increased adiposity, indicated by BMI and WC measurements in our study, and metabolic dysfunction, indicated by fasting blood test results in our study, are related to EF difficulties among adolescents with obesity. In terms of increased adiposity, we observed significant EF difficulties in relation to both BMI and WC. Previous studies reported inverse associations between increased BMI and EF abilities, including inhibitory control [48], processing speed and WM [49], cognitive flexibility and WM [41], planning/organizing and problem-solving [42]. Inhibitory control deficits were most consistently associated with increased BMI among children and adolescents [7]. However, the previous results are primarily from studies conducted among non-clinical samples. We did not observe a significant relationship between BMI and inhibitory control in this clinical sample. However, increased BMI was related to parent-reported EF difficulties in WM and planning/organizing domains among adolescents seeking obesity treatment. In comparison, increased WC was related to a broader variety of EF difficulties in our sample, including problems with shifting (i.e., cognitive flexibility), initiating, WM, planning/organizing, organization of materials, and monitoring. Although increased BMI is a good measure of total body fat, increased waist circumference better reflects central obesity or visceral fat. Visceral fat was previously associated with EF problems more prominently than BMI among adolescents [49]. While we did not precisely measure the visceral fat in our study, our results regarding waist circumference correlates suggest that abdominal obesity may be more relevant for EF difficulties in clinical samples.

Previous literature suggests that pediatric obesity and metabolic syndrome have impacts on brain structure and function [50]. Adolescents with metabolic syndrome may have more severe EF difficulties than adolescents without metabolic syndrome [51]. Supporting this difference, we have also observed worse task performance related to inhibitory control, selective attention, visual scanning, and processing speed associated with poorer metabolic health status indicated by increased fasting glucose, insulin, HOMA-IR, and triglycerides in our sample. Similarly, a previous study has demonstrated difficulties with reading, working memory, and attention among adolescents with metabolic syndrome [52]. Moreover, markers such as fasting glucose, insulin, and HOMA-IR were associated negatively with inhibitory control, even among healthy children as young as preschool ages [53]. In our study, fasting insulin and HOMA-IR also correlated significantly with EF difficulties in all domains but emotional control according to the BRIEF-parent form. While impaired glucose metabolism and insulin resistance are reflected in broader impairments of EF in our sample, other specific metabolic markers were associated differentially with specific EF difficulties. For instance, increased blood pressure was related to EF difficulties in initiating, planning/organizing, and organization of materials, while fasting triglycerides were associated with EF difficulties in WM, planning/organizing, and organization of materials. This suggests a need for further investigation to enlighten specific associations between metabolic impairments and EF difficulties.

The findings of our study should be interpreted with caution due to several limitations. First and foremost, the relatively small sample size is a key constraint, especially given the number of associations examined. While this raises the possibility of Type II errors, statistical power is primarily a design-phase concept; once data are collected, interpretation should emphasize the strength and direction of observed effects [54]. Accordingly, our findings should be considered preliminary and hypothesis-generating. Future studies with larger and more diverse samples are needed to replicate and extend these results. In our sample, the proportion of female adolescents was slightly higher (54.3%) than males (45.7%), yet we did not examine sex-based differences due to limited statistical power. However, this limitation should be interpreted

in the context of existing literature. Although sex differences are frequently reported in disordered eating, a recent meta-analysis of 22 studies found no significant sex effects on YFAS-C scores or food addiction prevalence in adolescents [11] suggesting that FA symptoms may reflect distinct underlying mechanisms and affect both sexes similarly. Second, we could not control for potential confounders, as numerous factors, including satiety, sleep, exercise, and stress, may impact performance-based evaluation of executive functioning. Another key limitation of the study lies beneath the measurements. Although we evaluated the EF difficulties based on both task performance and parent reports, other variables (i.e., food addiction symptoms and eating attitudes) were evaluated only by using self-report-based tools, which are inherently subjective, making these assessments susceptible to common biases such as social desirability, acquiescence, recall, and mood-dependent biases. The accuracy of responses to items of instruments used in our study may also vary due to variances in comprehension and awareness for both adolescent accounts and parental accounts. Future studies should consider incorporating more objective measures to complement report-based tools and enhance the robustness of the results. Lastly, the cross-sectional framework intrinsically constrains causal deductions, capturing merely a glimpse of the examined phenomena. These limitations emphasize the need for future inquiries with larger, more representative samples and longitudinal methodologies to substantiate and elaborate upon our findings.

Conclusions

In conclusion, with consideration of the mentioned limitations, this study has some important clinical implications for the treatment goals of adolescents with obesity. EF difficulties, especially those related to inhibition, WM, and emotional control, may constitute important treatment barriers. Interventions improving inhibitory control, especially in the context of palatable foods, may be needed to overcome addictive-like eating among adolescents seeking obesity treatment. Additionally, FA symptoms may be alleviated by therapeutic work on emotional control and reducing emotional eating in the treatment of adolescent obesity. In parallel with previous studies, we suggest developing interventions targeting emotion-driven impulsiveness to reduce unhealthy eating choices among adolescents with obesity [55]. Moreover, targeting problems associated with WM and planning/organizing may help adherence to dieting. Future inquiries may concentrate on the associations between negative emotionality and particular dimensions of EF difficulties among youths with obesity. Comprehending the associations between these variables may help clinicians in discerning therapeutic objectives for obesity, thereby facilitating the development of more tailored and efficacious interventions for adolescents experiencing obesity and EF difficulties.

Abbreviations

BMI	Body mass index
BRIEF	Behavior Rating Inventory of Executive Functions
EAT-40	Eating Attitude Test-40
EF	Executive functioning
FA	Food addiction
WC	Waist circumference
WM	Working memory
YFAS	Yale Food Addiction Scale

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Author contributions

Sİ contributed to data curation, analysed and interpreted the data, wrote the original draft; YTT conceptualized the study, contributed to data curation, revised the draft; ED contributed to data curation and design of the work, revised the draft; HG contributed to conceptualization and analysis, revised the draft. All authors have approved the submitted version. All authors have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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Data availability

The data supporting this study's findings are available on request from the corresponding author, Sİ. The data are not publicly available because they contain information that could compromise the privacy of research participants.

Declarations

Human ethics

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2013.

Ethics approval and consent to participate

The Clinical Research Ethical Board of Gazi University approved and monitored all procedures involving patients with approval number 11012021/33,

Consent to participate and publication

Before inclusion, written informed consent was obtained from all participants and accompanying parents regarding participation in the study and publication of study findings anonymously.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Child and Adolescent Psychiatry, Ahi Evran University Faculty of Medicine, Kırşehir, Turkey
[2]Department of Child and Adolescent Psychiatry, Gazi University Faculty of Medicine, Ankara, Turkey
[3]Department of Pediatric Endocrinology, Gazi University Faculty of Medicine, Ankara, Turkey
[4]Department of Child and Adolescent Psychiatry, Ufuk University Faculty of Medicine, Ankara, Turkey

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