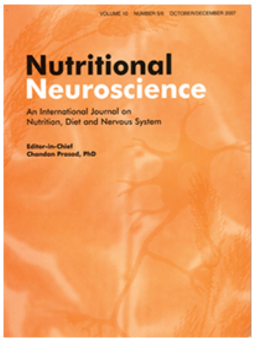

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Fruit and vegetable intake is inversely associated with severity of inattention in a pediatric population with ADHD symptoms: the MADDY Study

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ABSTRACT

Objectives:: Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder with a U.S. pediatric prevalence of 8–10%. It presents with inattention and hyperactivity/impulsivity; frequently associated with emotional dysregulation (ED) symptoms common in Oppositional Defiant Disorder and Disruptive Mood Dysregulation Disorder. The etiology of ADHD is multi-factorial; symptom severity is associated with diet. This study examines the association of diet quality with ADHD and ED symptoms within a pediatric research cohort.
Methods:: Baseline data were analyzed for 134 children aged 6–12 years with symptoms of ADHD and ED enrolled in an RCT of multinutrient supplementation. Diet quality was based on Healthy Eating Index-2015 (HEI-2015). ADHD and ED symptoms were assessed using Child and Adolescent Symptom Inventory-5 and Strengths and Difficulties Questionnaire. Linear regression models, adjusting for covariates when necessary, determined association.
Results:: The mean HEI Total Score of 63.4 (SD = 8.8) was not significantly associated with any outcome symptoms. However, after adjusting for covariates, HEI component scores for total fruit intake ($\beta = -0.158$, $p = .037$) and total vegetable intake ($\beta = -0.118$, $p = .004$) were negatively associated with inattention.
Conclusions:: The lack of association with total diet quality could be explained by the relatively good baseline diet quality and mild symptom severity in this sample, along with measurement error from dietary intake estimates and relatively small sample size. These findings suggest that dietary intake may impact inattention in children with ADHD and ED: those eating less fruits and vegetables were likely to have more severe symptoms of inattention. Causality is not established by this cross-sectional analysis.

KEYWORDS
Dietary quality; ADHD; inattention; children; mental health; Healthy Eating Index; emotional dysregulation; oppositional defiant disorder; disruptive mood dysregulation disorder

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder affecting about 7% of children worldwide [1] and up to 10% of children in the United States [2]. It is a significant public health concern, associated with poor social, academic, and economic outcomes as well as increased risk of hospital admissions and injuries [2]. ADHD is clinically diagnosed as a chronic pattern of inattention and/ or hyperactivity/impulsivity that interferes with functioning in two or more settings and is not due to another disorder [3]. Increasingly, ADHD is recognized as involving problems with self-regulation, which may include emotional dysregulation. Clinical features of emotional dysregulation include irritability, inappropriately positive or negative emotions, persistent anger, defiant behavior and/or vindictiveness, and impulsive aggression [4]. These symptoms occur in conditions like Oppositional Defiant Disorder (ODD) and Disruptive Mood Dysregulation Disorder (DMDD) [3].

The etiology of ADHD is multifactorial, involving genetic, environmental, social, and neurobiological factors [5]. Environmental factors associated with ADHD include pollution, exposure to toxins and contaminants (such as lead, pesticides, and cigarette smoke), and dietary intake [6]. Several aspects of dietary habits have been linked to

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ADHD including sensitivity to artificial food additives, fatty acid imbalances, and vitamin and mineral deficiencies [6]. The standard American diet/Western diet is characterized by low consumption of fatty fish and grass-fed meats, both of which are high in omega-3 fatty acids [7]. The ratio of omega-6 to omega-3 polyunsaturated fatty acids (PUFAs) has risen from 1:1 in traditional diets to 16:1 in western diets [8]. The imbalance in omega-6 to omega-3 fatty acid intake associated with the Western diet has been linked to neurodevelopmental disorders, including ADHD and autism spectrum disorder in observational studies [8,9]. The neurobiology of ADHD is theorized to be related to low levels of neurotransmitter catecholamines (epinephrine, norepinephrine, and dopamine), and abnormalities in the interactions between glutamatergic and dopaminergic systems in the brain [6]. Vitamins and minerals serve key roles (often as cofactors) in neurotransmitter synthesis and brain function and provide a potential link between vitamin/mineral insufficiencies or deficiencies and ADHD. There have been reports that supplementation with omega-3 fatty acids, zinc, iron, and magnesium may improve cognition and ADHD symptoms [5].

With growing evidence linking essential nutrients to ADHD, it is important to study dietary patterns because diet is the primary source of essential nutrient intake. Globally, studies have shown that ADHD is associated with a Western dietary pattern [10,11] and diets that are high in added sugars [12,13] and refined carbohydrates [14]. Additionally, ADHD and emotional symptoms are inversely associated with better diet quality reflecting adherence to dietary patterns such as the Mediterranean [12] and Dutch [15] dietary patterns. Since high pediatric ADHD prevalence is coupled with the predominance of a Western dietary pattern in the U.S. and Canada, it is imperative to investigate how dietary patterns relate to ADHD symptom severity in the U.S. and Canadian population. To the best of our knowledge, only one study has examined the relationship between ADHD symptom occurrence and diet quality among children in the U.S. [16]. Furthermore, there is a gap in the literature about the relationship between diet quality and co-occurring emotional dysregulation. This study aims to fill these gaps by examining the association of dietary quality with severity of ADHD and emotional dysregulation symptoms in a pediatric sample in the U.S. and Canada.

Methods

Sample

The data for this analysis was obtained from the Micronutrients for ADHD in Youth (MADDY) Study, an 8-week randomized double-blind placebo-controlled trial that examined the efficacy of a 36-ingredient vitamin/mineral supplement to treat symptoms of ADHD and emotional dysregulation in a select pediatric population conducted from 2018 to 2020 [17]. Additional details on study design, recruitment, and enrollment are described elsewhere [18]. Participants included in the study were between 6 and 12 years old and met the DSM-5 criteria for ADHD as assessed by a clinical cut-off of six or more inattention and/or hyperactivity/impulsivity symptoms on the parent-reported Child and Adolescent Symptom Inventory-5 (CASI-5). Additionally, participants demonstrated at least one symptom of irritability or anger from the CASI-5 ODD or DMDD subscales. Participants were psychotropic-medication-free, medication-naïve, or had discontinued medications for at least 2 weeks prior to starting the study. They were recruited using flyers, referrals from pediatricians and mental health providers, and through social media from three sites: two in the U.S. (Columbus, OH and Portland, OR) and one in Canada (Lethbridge, AB). Written informed consent from parents and assent from children were completed at the baseline visit prior to any study procedures.

The current analysis used cross-sectional data from the MADDY Study baseline visits. All participants who attended a baseline visit and completed a food frequency questionnaire were included in this analysis, resulting in a sample size of 134. For the primary MADDY Study, a sample size of 123 was needed to adequately detect differences between groups; 135 participants were recruited to allow for attrition. For this study, it was determined that a sample size of 134 would detect a medium effect size (f^2 of 0.15) at 0.8 power and an alpha of 0.05 [19].

Measures

Sociodemographic measures

Demographic information was collected at the baseline visit using a demographics and history questionnaire. Questions included gender, ethnicity, race, parent/guardians' occupation, parent/guardians' level of education, and family income.

Dietary intake and diet quality measures

Dietary intake was collected using VioScreen™, a digital food frequency questionnaire (FFQ). VioScreen (https://www.viocare.com/vioscreen.html; Viocare Inc, Kingston, NJ) is a validated graphics based dietary analysis software that provides the equivalent of 90 days of nutrition tracking in about 20 minutes utilizing 1500 food images (including portion sizes) from approximately 400 food items [20]. Parent/caregiver completed the VioScreen questionnaire to report their child's dietary intake within 3 days of the baseline visit. VioScreen's dietary analysis uses food and nutrient information from the Nutrition Coordinating Center (NCC) Food and Nutrient Database (University of Minnesota Division of Epidemiology and Community Health in Minneapolis). Calculation of diet quality used a predefined index, the Healthy Eating Index-2015 (HEI-2015), which has been validated for individuals ages 2 and up [21]. It is a density-based measure (e.g. amounts per 1000 kcal) and assesses adherence to the Dietary Guidelines for Americans, a set of dietary recommendations developed to help Americans consume nutritious diets that promote health and prevent disease. The HEI-2015 has 13 components, 9 of which represent food groups or dietary elements with recommendations for increased intake (Adequacy components), including: total fruit, whole fruit, vegetables, greens and beans, whole grains, dairy, protein foods, seafood and plant proteins, and fatty acids. The remaining four components represent food groups and dietary elements with recommendations for limited consumption (Moderation components): refined grains, sodium, saturated fat, and added sugars [22]. Each component has a minimum score of 0, and a maximum score between 5 and 10. The 'adequacy components' are scored such that higher intake corresponds with higher scores, while the 'moderation components' are scored with a lower intake corresponding to a higher score. Each component score is summed to create the HEI-2015 total score, ranging from 0 to 100 [22]. A higher total score is indicative of a better adherence to the Dietary Guidelines for Americans. HEI-2015 scores among general U.S. child population aged 6–11 based on 2009–2014 NHANES data [23] were used as a comparator for diet quality scores to better describe this sample.

Behavioral measures

At the baseline visit, parents completed the CASI-5 and Strengths and Difficulties Questionnaire (SDQ) to assess their child's current behavior. CASI-5 is a validated behavior rating scale with DSM-5-defined emotional and behavioral disorders in youths 5–18 years old [24]. The CASI-5 includes questions assessing symptoms of ADHD (2 subscales: inattention and hyperactivity/impulsivity), and subscales for the comorbid symptoms of DMDD and ODD, which include emotional dysregulation symptoms. There are 2–9 Likert-style questions for each subscale, with raw scores of 0 (never) to 3 (very often). An item-mean score was calculated for each subscale with a value from 0 to 3, with 3 being the most severe [24]. An item-mean score of 2 or greater was considered moderate to severe severity such that symptoms required intervention.

The Strengths and Difficulties Questionnaire (SDQ) is a validated 25-item behavioral screening questionnaire designed to measure positive and negative behaviors, with five scales consisting of five items each: emotional symptoms, conduct problems, hyperactivity, peer relationships, and prosocial behaviors [25]. The emotional problems and conduct problems scales were used as measures of emotional dysregulation. Each scale has a maximum score of 10, with higher scores denoting more severe problems. Cut-points are provided to differentiate between scores that are 'close to average,' defined such that 80% of the population would score in that range, and elevated scores. The 'close to average' ranges are 0–3 for emotional problems and 0–2 for conduct problems; anything above those ranges were considered elevated [26].

Statistical methods

Descriptive statistics were used to analyze demographic variables and diet quality scores for all participants. For the continuous variables, normally distributed data were reported as mean and standard deviation (SD) and non-normal data reported as median and interquartile range (IQR). Categorical variables were reported as count (or percent). ADHD and emotional dysregulation symptom scores and diet quality scores were analyzed as continuous variables. The scores for emotional dysregulation symptoms and ADHD symptoms for participants were compared across the categories for each categorical variable using Mann–Whitney test or Kruskal–Wallis test. One-sample t-test and Wilcoxon Signed-rank test were used to compare HEI total score and HEI component scores, respectively, to the national average. Pearson correlation coefficients were calculated to determine associations between age, BMI, and symptom severity scores. Ordinary least-squares linear regression models were used to examine the relationships between diet quality and the severity of ADHD and emotional symptoms. Each analysis was done separately to estimate the beta coefficients (β, 95% confidence interval-CI). Models were adjusted for sex, household income, and parental education based on univariate analysis results which identified potential confounders. Assumptions for linear regression were tested for each model using graphical and statistical methods including Shapiro-Wilks test for normality of residuals, Breusch–Pagan test for homoskedasticity of residuals, and variance inflation factors to assess independent variables for multicollinearity. All analyses were conducted using STATA version 16.1 software (College Station, TX: StataCorp LLC). Statistical significance was defined as a two-sided p-value <.05 for all analyses. For these exploratory analyses, significance level was not adjusted for multiple tests.

This study complies with the Strengthening the Reporting of Observational Studies in Epidemiology – nutrition epidemiology (STROBE-nut) guidelines (see STROBE-nut checklist, Supplementary Table 3) [27].

Results

Sample population characteristics

Sociodemographic characteristics and symptom scores of the study population is shown in Table 1. The study included 134 children aged 6–12 (median age = 9.9 years, IQR = 8.4–11.1), 71% of whom were male.

Table 1. Characteristics of the study population.

Characteristics	
Child's Age, (in years), median (IQR)	9.9 (8.4–11.1)
BMI, median (IQR)	16.6 (15.3–18.6)
Child'sSex, n (%)	
Male	95 (70.9)
Female	39 (29.1)
Family Income, n (%)	
< $30,000/yr	12 (9.0)
$30,001–60,000/yr	28 (20.9)
$60,001–80,000/yr	18 (13.4)
> $80,001/yr	76 (56.7)
Parent Marital Status, n (%)	
Married	101 (75.4)
Divorced	25 (18.7)
Single	8 (6.0)
Parent Educational Level, n(%)	
High school	21 (15.7)
Technical college/ trade school	32 (23.9)
University or higher	81 (60.4)
Ethnicity[1], *n (%)*	
Not Hispanic or Latino	92 (68.7)
Hispanic or Latino	8 (6.0)
Other	7 (5.2)
Race[1], n (%)	
Asian	5 (3.7)
Black	8 (6.0)
White	106 (79.1)
Other	7 (5.2)
Diet Quality, mean (SD)	
Total HEI-2015 Score	63.4 (i.8)
Symptom Severity, median (IQR)	
CASI-5 Item Mean Scores	
Inattention	2.2 (1.9–2.7)
Hyperactivity	1.9 (1.3–2.3)
ODD	1.8 (1.1–2.3)
DMDD	1.0 (0.5–2.0)
SDQ Scores	
Emotional Problems	3.0 (2.0–5.0)
Conduct Problems	3.0 (2.0–5.0)

Values are presented as medians (IQR) or means (SD) where noted for continuous variables or as frequencies (percentages) for categorical variables.
IQR, interquartile range; BMI, Body Mass Index; HEI, Healthy Eating Index; SD, standard deviation; CASI-5, Child and Adolescent Symptom Inventory-5; ODD, Oppositional Defiant Disorder; DMDD, Disruptive Mood Dysregulation Disorder; SDQ, Strengths and Difficulties Questionnaire.
[1]27 participants did not report ethnicity and 8 participants did not report race.

Approximately 79% of the sample identified as White. Over half of the sample (57%) had family income greater than $80,000/year. The characteristics of the study participants as related to symptoms of ADHD and emotional dysregulation are included in supplemental materials. There was an inverse relationship between family income and symptom severity scores for all outcomes [Hyperactivity ($\chi^2 = 8.32$, $p = .04$), Emotional Problems ($\chi^2 = 11.00$, $p = .01$), Conduct Problems ($\chi^2 = 14.27$, $p = .003$), ODD symptoms ($\chi^2 = 13.18$, $p = .004$), and DMDD symptoms ($\chi^2 = 12.37$, $p = .006$)], except inattention ($\chi^2 = 0.547$, $p = .91$) [Supplemental Tables 1 and 2]. There was a significant association between age and the CASI-5 Inattention score (r = 0.19, $p = .02$) and between BMI and SDQ Emotional Problems score (r = 0.18, $p = .04$); the rest of the relationships between age, BMI, and symptom severity scores were not significant. Also, no significant associations were found between the demographic variables and HEI scores.

The average total HEI-2015 score for the study sample was 63.4 [(SD = 8.8); range (40.8–81.2)]. In comparison, this average is significantly higher (t = 12.42, $p < .0001$) than the mean of 53.9 (95% CI: 52.5–55.1) reported among the general U.S. child population aged 6–11, based on 2009–2014 NHANES data [23]. A radar plot comparing the dietary component scores for the study sample compared to the NHANES sample is shown in Figure 1. This sample also had significantly better scores than the national average for the following HEI component scores reported as study median (IQR) vs. NHANES population mean: Total Fruit [5.0 (4.1–5.0) vs. 3.7, $p < .0001$], Total Vegetables [3.8 (2.9–5.0) vs. 2.1, $p < .001$], Greens and Beans [3.2 (1.7–5.0) vs. 1.6, $p < .0001$], Whole Grains [5.1 (2.5–7.8) vs. 2.6, $p < .0001$], Total Protein Foods [5.0 (4.1–5.0) vs. 4.3, $p = .007$], Seafood and Plant Proteins [4.0 (2.4–5.0) vs. 2.9, $p < .0001$], Refined Grains [8.5 (6.3–10.0) vs. 4.2, $p < .0001$], and Added Sugars [9.4 (7.9–10.0) vs. 5.3, $p < .0001$]. The median score for Fatty Acids was not significantly different from the NHANES sample.

Relationship between ADHD symptom severity and diet quality in children

The median CASI-5 symptom score for the group at baseline for inattention was 2.2 (IQR: 1.9–2.7) and for hyperactivity/ impulsivity was 1.9 (IQR: 1.3–2.3) (Table 1).

The results of the regression analysis between diet quality scores and ADHD symptom severity are shown in Table 2. The severity of inattention and hyperactivity-impulsivity symptoms were not associated with

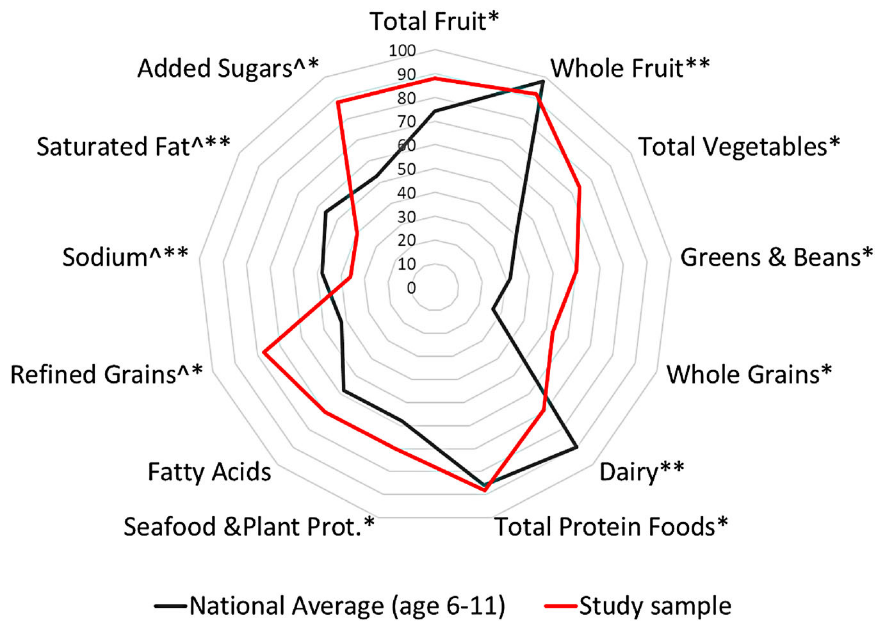

Figure 1. Mean HEI-2015 component scores as a percent of the recommendation for study sample versus the national average for children aged 6–11 [23]. ^HEI moderation component. Higher scores represent lower consumption of that component. *Mean score is significantly better than national average ($p \leq .05$). For moderation components, this sample consumed less of the component than national average. **Mean score is significantly worse than national average ($p \leq .05$). For moderation components, this sample consumed more of the component than national average.

the HEI-2015 Total Score (Table 2). In further analysis using the dietary component scores, vegetables ($\beta = -0.118$, $p = .004$) and total fruit ($\beta = -0.158$, $p = .037$) intakes were found to be negatively associated with -inattention, while refined grains component score was positively associated with inattention ($\beta = 0.056$, $p = .012$), even after adjusting for potential covariates of gender, household income, and parent education (Table 2).

Relationship between emotional dysregulation and diet quality in children

The median SDQ Emotional Problems subscale score for the study sample was 3.0 (IQR: 1.8–5.0) and the median Conduct Problems subscale score was 3.0 (IQR: 2.0–5.0). The median ODD symptom score for the sample population was 1.8 (IQR: 1.1–2.3) and the median DMDD symptom score was 1.0 (IQR: 0.5–2.0) (Table 1).

Table 3 includes the results of the regression analysis between diet quality scores and emotional dysregulation symptoms. In the unadjusted and adjusted models, HEI-2015 Total Score was not associated with conduct problems, emotional problems, ODD symptoms, or DMDD symptoms. Similarly, no significant associations were detected between dietary component scores and emotional dysregulation outcomes (Table 3).

Discussion

This study sought to determine the relationships between diet quality, ADHD and emotional dysregulation symptom severity among youth enrolled in a clinical trial for ADHD and emotional dysregulation. Findings showed that overall diet quality, as measured by HEI-2015 Total Score, was not associated with ADHD symptoms of inattention or hyperactivity/impulsivity. This finding is aligned with a prior study in the United States by Holton et al. (2019), which found no significant difference in HEI scores between those with and without ADHD among both children and college students [16]. However, this finding contrasts with results from several non-U.S. studies that used other *a priori* defined diet quality indices. Lower adherence to the Mediterranean diet was associated with ADHD diagnosis in children and adolescents in Spain [12]; hyperactivity/impulsivity scores were correlated with lower adherence to Healthy Nutrition Score for Kids and Youth guidelines in Germany [28]; and adherence to Dutch dietary guidelines at age 8 was found to be inversely associated with ADHD symptoms at 6 years of age [15].

Similarly, our study did not find a relationship between overall diet quality and symptoms of emotional dysregulation as measured by ODD symptoms, DMDD symptoms, emotional problems, and conduct problems. This finding also contrasts with several studies using

Table 2. Baseline associations between diet quality scores and ADHD symptom severities.

	Inattention		Hyperactivity/ Impulsivity	
	Unadjusted	Adjusted	Unadjusted	Adjusted
Analysis 1: Total Diet Quality	***β* (95% CI)**			
HEI-2015 Total Score	0.00 (−0.01, 0.01)	0.00 (−0.01, 0.01)	0.01 (−0.01, 0.02)	0.01 (0.00, 0.02)
Analysis 2: Dietary components	***β* (95% CI)**			
Total Fruit	−0.14* (−0.28, 0.00)	−0.16* (−0.31, −0.01)	−0.12 (−0.32, 0.07)	−0.10 (−0.29, 0.09)
Whole Fruit	0.12 (−0.03, 0.26)	0.12 (−0.03, 0.27)	0.06 (−0.15, 0.26)	0.02 (−0.18, 0.21)
Total Vegetables	−0.16** (−0.28, −0.04)	−0.19** (−0.32, −0.06)	−0.02 (−0.19, 0.15)	−0.05 (−0.22, 0.11)
Greens and Beans	0.03 (−0.05, 0.11)	0.05 (−0.03, 0.14)	−0.08 (−0.19, 0.03)	−0.03 (−0.14, 0.08)
Whole Grains	−0.01 (−0.04, 0.02)	0.00 (−0.04, 0.03)	0.01 (−0.03, 0.05)	0.02 (−0.02, 0.06)
Dairy	−0.03 (−0.07, 0.02)	−0.02 (−0.06, 0.03)	0.02 (−0.04, 0.08)	0.00 (−0.05, 0.06)
Protein Foods	−0.01 (−0.12, 0.10)	−0.01 (−0.12, 0.10)	−0.03 (−0.18, 0.11)	−0.07 (−0.21, 0.07)
Seafoods and Plant Proteins	−0.01 (−0.07, 0.05)	−0.01 (−0.07, 0.05)	0.03 (−0.05, 0.12)	0.04 (−0.04, 0.11)
Fatty Acids	−0.01 (−0.06, 0.04)	0.00 (−0.06, 0.05)	0.03 (−0.04, 0.10)	0.03 (−0.04, 0.10)
Refined Grains	0.06* (0.01, 0.10)	0.06* (0.01, 0.10)	0.06 (0.00, 0.12)	0.04 (−0.02, 0.10)
Sodium	−0.02 (−0.07, 0.03)	−0.02 (−0.08, 0.03)	−0.04 (−0.11, 0.03)	−0.01 (−0.08, 0.06)
Saturated Fat	0.04 (−0.01, 0.09)	0.04 (−0.01, 0.09)	0.04 (−0.03, 0.11)	0.03 (−0.03, 0.09)
Added Sugars	0.05 (−0.02, 0.12)	0.04 (−0.04, 0.11)	−0.03 (−0.12, 0.07)	0.01 (−0.09, 0.11)

*$p < .05$, **$p < .01$.
Adjusted model: includes unadjusted model plus gender, household income level, and parental education level as covariates.
HEI, Healthy Eating Index.

other *a priori* defined diet quality scores. Adherence to the German Optimized Mixed Diet was associated with lower likelihood of emotional symptoms in 11-year-old children [29] and higher adherence to European healthy dietary guidelines at baseline was associated with fewer emotional and peer problems 2 years later among children aged 2–9 [30].

There are several plausible explanations for the difference in findings between the two studies using U.S./Canadian populations and the set of studies from Europe. First, the two U.S. studies had smaller sample sizes compared with most of the other studies, likely making it difficult to detect small effect sizes. Second, other diet quality indices (Dutch, German, Mediterranean diet, etc.) may measure dietary factors expected to affect ADHD more directly than the HEI-2015, such as distinct measures of consumption of foods such as seafoods, nuts, and seeds, since these foods are typically high in omega-3 fatty acids, iron, zinc, and magnesium. Finally, the participants of this study were recruited for a clinical trial for treatment of ADHD and emotional dysregulation while the previous studies did not offer an intervention or were studies of the general population; therefore, this study's sample reflects a treatment-seeking population that may have different characteristics than samples from the general population. For example, the sample was selected for being at one end of the range of possible behavioral scores, which would discard variance in behavioral scores that would have been available to show correlation in a general population sample. Further, if dietary scores do correlate with behavior scores, selecting for one end of the behavioral range would also select for one end of the diet range; in fact, this did happen: this sample's mean HEI score was above the national mean.

Our study also examined associations between the HEI-2015 dietary component scores and symptom severity. The HEI-2015 vegetable and fruit component scores were inversely associated with inattention even after adjusting for covariates, while refined grains score showed a positive association. The vegetable and fruit intake associations are consistent with previous findings that showed lower frequency of fruit and vegetable consumption was associated with higher prevalence of ADHD diagnosis [12,13]. Our study adds to this finding by linking lower fruit and vegetable intake specifically to increased severity of inattention.

Because refined grains are an HEI-2015 'moderation component,' a higher score for this component indicates less consumption of refined grains. The finding of a positive association between the refined grain component score and inattention was unexpected as it indicates that reduced consumption of refined grain is associated with higher levels of inattention. This finding is contrary to previous research where children with ADHD were reported to consume more refined grain compared to children without ADHD [14]. In addition, refined grains have been included as a component of the 'Western' dietary pattern that was found to be associated with ADHD, though it was not determined if there was a specific link between ADHD and the refined grains component alone [10]. One potential explanation for this finding is that many sources of refined grains in the U.S. and Canada are fortified with nutrients; for example, fortification of refined wheat flour with iron and other nutrients is mandatory in the U.S. and Canada [31].

Table 3. Associations between diet quality scores and emotional dysregulation symptoms.

	ODD		DMDD		Emotional Problems		Conduct Problems	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
Analysis 1: Total Diet Quality	***β* (95% CI)**							
HEI-2015 Total Score	0.00 (−0.01, 0.02)	0.01 (−0.01, 0.02)	0.01 (−0.01, 0.03)	0.01 (0.00, 0.03)	−0.04 (−0.09, 0.01)	−0.04 (−0.08, 0.01)	0.00 (−0.04, 0.04)	0.00 (−0.03, 0.04)
Analysis 2: Dietary components	***β* (95% CI)**							
Total Fruit	−0.04 (−0.25, 0.17)	−0.02 (−0.23, 0.18)	−0.04 (−0.29, 0.21)	−0.04 (−0.29, 0.21)	0.15 (−0.55, 0.85)	0.36 (−0.35, 1.08)	−0.50 (−1.06, 0.07)	−0.36 (−0.93, 0.20)
Whole Fruit	0.00 (−0.22, 0.22)	−0.04 (−0.26, 0.17)	−0.04 (−0.30, 0.22)	−0.10 (−0.35, 0.15)	−0.47 (−1.20, 0.26)	−0.72 (−1.44, 0.01)	0.16 (−0.43, 0.74)	−0.01 (−0.58, 0.57)
Total Vegetables	0.03 (−0.15, 0.21)	0.03 (−0.15, 0.21)	0.01 (−0.21, 0.23)	0.01 (−0.20, 0.22)	0.06 (−0.55, 0.68)	0.23 (−0.38, 0.85)	0.33 (−0.16, 0.82)	0.38 (−0.10, 0.86)
Greens and Beans	0.00 (−0.11, 0.12)	0.03 (−0.09, 0.15)	0.07 (−0.07, 0.21)	0.10 (−0.04, 0.24)	−0.03 (−0.42, 0.37)	−0.10 (−0.50, 0.31)	−0.13 (−0.45, 0.18)	−0.14 (−0.45, 0.18)
Whole Grains	0.02 (−0.02, 0.07)	0.04 (−0.01, 0.08)	0.03 (−0.03, 0.08)	0.04 (−0.01, 0.09)	0.02 (−0.13, 0.17)	0.05 (−0.10, 0.20)	0.06 (−0.06, 0.18)	0.10 (−0.02, 0.21)
Dairy	−0.02 (−0.09, 0.04)	−0.02 (−0.08, 0.04)	0.02 (−0.06, 0.09)	0.03 (−0.05, 0.10)	0.01 (−0.20, 0.22)	0.00 (−0.21, 0.21)	0.01 (−0.16, 0.18)	0.02 (−0.14, 0.19)
Protein Foods	−0.04 (−0.20, 0.12)	−0.06 (−0.21, 0.09)	−0.04 (−0.23, 0.15)	−0.06 (−0.24, 0.12)	0.16 (−0.37, 0.69)	0.14 (−0.38, 0.67)	0.21 (−0.22, 0.64)	0.19 (−0.23, 0.60)
Seafoods and Plant Proteins	0.00 (−0.09, 0.09)	−0.01 (−0.09, 0.08)	0.02 (−0.08, 0.13)	0.02 (−0.08, 0.12)	0.12 (−0.18, 0.42)	0.12 (−0.17, 0.41)	−0.10 (−0.34, 0.14)	−0.11 (−0.34, 0.12)
Fatty Acids	0.00 (−0.08, 0.08)	0.02 (−0.06, 0.09)	−0.01 (−0.10, 0.09)	0.02 (−0.07, 0.10)	−0.04 (−0.30, 0.21)	0.00 (−0.26, 0.25)	0.05 (−0.15, 0.26)	0.10 (−0.10, 0.30)
Refined Grains	0.04 (−0.02, 0.10)	0.02 (−0.04, 0.08)	0.03 (−0.05, 0.11)	0.00 (−0.07, 0.07)	−0.09 (−0.30, 0.12)	−0.15 (−0.36, 0.06)	0.10 (−0.07, 0.27)	0.05 (−0.11, 0.21)
Sodium	−0.01 (−0.09, 0.06)	0.01 (−0.07, 0.08)	−0.01 (−0.11, 0.08)	0.02 (−0.07, 0.11)	−0.14 (−0.41, 0.12)	−0.08 (−0.35, 0.18)	0.03 (−0.18, 0.24)	0.06 (−0.15, 0.26)
Saturated Fat	−0.02 (−0.09, 0.05)	−0.03 (−0.10, 0.04)	−0.01 (−0.09, 0.08)	−0.01 (−0.09, 0.07)	−0.13 (−0.37, 0.11)	−0.16 (−0.40, 0.08)	0.00 (−0.19, 0.19)	−0.03 (−0.22, 0.15)
Added Sugars	−0.07 (−0.17, 0.03)	−0.09 (−0.20, 0.01)	−0.03 (−0.15, 0.09)	−0.03 (−0.15, 0.10)	−0.15 (−0.50, 0.19)	−0.12 (−0.48, 0.25)	−0.13 (−0.40, 0.15)	−0.23 (−0.52, 0.06)

*$p < .05$. Adjusted model: includes unadjusted model plus gender, household income level, and parental education level as covariates. ODD, Oppositional Defiant Disorder; DMDD, Disruptive Mood Dysregulation Disorder; HEI, Healthy Eating Index.

Strengths and limitations of the study

This study addresses several gaps in the existing literature on dietary quality, ADHD, and emotional dysregulation by being the first study to use the Healthy Eating Index to examine relationships with the severity of both ADHD and emotional dysregulation. To our knowledge, this is also the first study to investigate the HEI dietary component scores for potential associations with these symptoms. Use of a dietary index that has been evaluated for validity and reliability in children is a strength of this study. Additionally, the use of dietary pattern analyses as opposed to single nutrient analyses enables a broader picture of food and nutrient consumption, which is pertinent given the multi-factorial nature of ADHD and the potential effects of a variety of nutrients and nutrient interactions on symptoms.

A limitation of this study is the use of a FFQ to track dietary intake. While a validated tool for capturing habitual dietary intake, FFQs are vulnerable to random and systematic errors [32], making the detection of small effect sizes more difficult. Parent-reporting of the child's dietary intake may introduce additional errors if the child consumes meals and snacks away from the parent, such as at school. Additionally, the relatively small sample size of this study compared to larger population studies also makes detection of small effect sizes more difficult. Because this was an exploratory study, we did not correct for multiple testing, which increases the risk for type 1 error. The cross-sectional design of this study does not provide any indication of cause-and-effect relationships between overall diet pattern and symptoms. Finally, the generalizability of findings from this study may be limited by the relatively high mean HEI score of this study sample; caution is likely warranted in the generalization of study results to other cohorts of children with ADHD, who may have lower HEI scores.

Implications for future research

Although ADHD affects almost 10% of U.S. children and a substantial number of adults, there are few studies examining the relationship between ADHD and Western dietary patterns, especially as found in the U.S. and Canada. Future research should take advantage of larger sample populations in the U.S. and Canada to enable the detection of small effect sizes. Additionally, future research could use alternative dietary indices, such as measures of adherence to the Mediterranean diet, that may better capture nutrients of interest which are associated with ADHD and emotional symptoms as applied to the U.S. and Canadian population.

Conclusions

Increased intake of fruits and vegetables was inversely associated with severity of inattention. However, overall diet quality as measured by the HEI was not associated with ADHD symptoms nor emotional dysregulation severity in this cohort of children. These findings are important because they suggest that dietary intake is associated with symptoms of inattention in children with ADHD and emotional dysregulation: those eating less fruits and vegetables were likely to have more severe inattention.

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Data availability statement

The dataset for this manuscript is not currently available because it is a part of a clinical trial whose findings are still being analyzed. Data may be made available by contacting the corresponding author.

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