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Depressive Symptoms and Cardiorespiratory Fitness in Obese Adolescents

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Abstract

Purpose—Adolescent depressive symptoms have been associated with reduced physical activity. However, existing studies have relied on questionnaire measures of physical activity, which may not necessarily reflect actual energy expenditures. We sought to evaluate the relationship between depressive symptoms and objectively-measured cardiorespiratory fitness among severely obese adolescents.

Methods—One hundred thirty-four obese (body mass index [BMI; kg/m²] ≥ 95th percentile) adolescent girls and boys (ages 12–17 years) reported their depressive symptoms on the Children's Depression Inventory. Adolescents also participated in a maximal cycle ergometry exercise test to measure cardiorespiratory fitness. Body composition was assessed with dual-energy x-ray absorptiometry (DXA) scanning.

Results—Among the 103 adolescents who reached maximal exertion, those with elevated depressive symptoms (16%) displayed poorer cardiorespiratory fitness than those without elevated depressive symptoms (VO_{2max} 1873.2 ± 63.6 vs. 2012.9 ± 28.6 mL/min, *p* < .05). Symptoms of anhedonia also were related to lower fitness (*p* < .05). These effects were observed after accounting for age, sex, race, and lean mass.

Conclusions—Among obese adolescents, elevated depressive symptoms are associated with poorer objectively-measured cardiorespiratory fitness. Future experimental tests should investigate whether cardiorespiratory fitness acts as a mediator of adolescent depressive symptoms' impact on obesity or obesity-related health co-morbidities.

Keywords

Adolescent; Depression; Physical fitness; Obesity; Body composition

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INTRODUCTION

Depression and obesity are two of our nation's most widespread public health concerns, particularly during adolescence [1, 2]. Elevated symptoms of depression affect over 25% of adolescents [1]. Even elevated symptoms at levels that do not reach the threshold for a major depressive disorder are related to significant psychosocial impairment [3]. Adolescent obesity is similarly widespread and has major health implications. Approximately 32% of youth are overweight (body mass index [BMI; kg/m²] $\geq$ 85th percentile), and 17% are obese ($\geq$ 95th percentile) [2, 4]. Overweight and obese adolescents are at heightened risk for a host of serious medical problems. These include type 2 diabetes, hypertension, dyslipidemia, impaired glucose homeostasis, steatohepatitis, sleep apnea, and intracranial hypertension [5, 6], as well as medical concerns unique to youth such as accelerated pubertal and skeletal development and orthopedic disorders [7, 8]. In spite of their common prevalence, it is only recently that the association between depression and obesity has been examined. Several meta-analyses support a relationship between symptoms of depression and obesity [9–11], and further indicate that depressive symptoms predict the development of obesity [9, 11]. In particular, among adolescent girls, elevated symptoms of depression are associated with an over 2.5 greater likelihood of becoming obese compared to girls without elevated symptoms [9]. Conversely, the experience of being obese may increase individuals' depressive symptoms [11].

The mechanisms that explain the relationship between symptoms of depression and obesity remain unclear. One possibility is that symptoms of depression promote excess weight gain during adolescence via reduced physical activity and consequently, lower energy expenditure. From a cognitive-behavioral theoretical framework, elevated symptoms of depression develop and are maintained as a result of a negative view of the self, one's experiences, and the future [12]. In particular, anhedonia—which refers to loss of pleasure in activities that one previously found enjoyable—ensues from these cognitions, and is theorized to prompt behavioral withdrawal from activities such as physical exercise, which further exacerbates depressed mood [13]. In support of this notion, a number of cross-sectional studies have found an inverse association between adolescents' symptoms of depression and self-reported physical activity, exercise, or sports participation [14–18]. In contrast, in a large sample of young adolescent girls, depressive symptoms were not significantly associated with physical activity assessed by accelerometer, an ambulatory device used to objectively monitor moderate-to-vigorous physical activity [19]. Longitudinal data indicate that increases in adolescents' depressive symptoms are associated with decreases in self-reported leisure-time, physical activity [20]. Results of another prospective study of adolescent girls found that depressive symptoms predicted reduced self-reported physical activity, and likewise, low self-reported physical activity predicted increased depressive symptoms [21]. However, some longitudinal studies have failed to find a significant relationship between depressive symptoms and physical activity in either direction [22, 23].

In light of these mixed results, it is noteworthy that the existing literature on depression and physical activity primarily has relied upon self-report assessments of physical activity. Although convenient, such questionnaire measures are limited by poor validity [24]. Therefore, it is crucial to determine the relationship between symptoms of depression and objective measurements. Cardiorespiratory fitness, also called maximal aerobic power, reflects an individual's ability to carry out prolonged, strenuous physical exercise [25]. Cardiorespiratory fitness is the major component of physical fitness most relevant to an individual's risk of developing obesity health-related co-morbidities such as cardiovascular disease and type 2 diabetes [26]. Children and adolescents' cardiorespiratory fitness is highly influenced by regular engagement in moderate-to-high intensity physical exercise,

and, as such, may be a valid integrated marker of recent physical activity [27]. We, therefore, examined whether symptoms of depression were related to objective assessments of cardiorespiratory fitness among a population of adolescents at heightened risk for adult obesity: obese adolescents seeking weight-loss treatment [28].

Methods

Participants

Participants were a convenience sample of obese (BMI $\geq$ 95th percentile) adolescents studied prior to taking part in a weight loss treatment study (ClinicalTrials.gov ID: NCT00001723). Youth were recruited from the Washington, DC metropolitan area with a range of methods including newspaper advertisements, flyers posted in local commercial venues, and through physician referrals. Inclusion criteria were age 12–17 years, BMI $\geq$ 95th percentile, non-Hispanic White or Black race/ethnicity, and good general health other than $\geq$ 1 quantifiable obesity-related health co-morbidity such as systolic or diastolic hypertension, type 2 diabetes, impaired glucose tolerance, hyperinsulinemia, hyperlipidemia, hepatic steatosis, or sleep apnea. For purposes of the current study, adolescents were included if they completed a depression screening questionnaire, exercise test, and body composition measurement. Exclusion criteria were other hepatic, renal, gastrointestinal, most endocrinologic, or pulmonary disorders, current pregnancy or breastfeeding, regular use of prescription medications unrelated to obesity-related health complications (not including oral contraceptives), recent use of anorexiant medication for the purpose of weight loss, or the presence of a psychiatric diagnosis in the adolescent or parent that would have impaired study compliance.

Procedure

For the purposes of the current study, adolescents were studied at baseline, prior to the initiation of treatment. All assessments were conducted at the NIH Warren Grant Magnuson Clinical Research Center. Adolescents completed questionnaire measures assessing psychosocial adjustment, completed dual-energy x-ray absorptiometry (DXA) scanning, and took part in a maximal cycle ergometry test. Before exercise testing, participants were evaluated with a medical history, physical examination, and 12-lead electrocardiogram. All participants were free of a significant musculoskeletal injury, as determined by a physician. American Heart Association guidelines for exercise testing were observed [29]. Participants and their parents provided signed assent and consent, respectively. All procedures were approved by the Institutional Review Board of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development.

Measures

Body measurements—Height and weight were obtained after an overnight fast. Participants were clothed but with shoes removed. Height was measured three times to the nearest millimeter by a stadiometer (Holtain, Crymmych, Wales), calibrated before each adolescent's measurement. Weight was measured to the nearest 0.1 kg with a calibrated digital scale (Scale-Tronix, Wheaton, IL). Participant's height and weight were used to compute BMI. Body lean mass (kg) and percent body fat mass were assessed with DXA using a Hologic (Waltham, MA) QDR-4500A instrument.

Depressive symptoms—Participants completed the Children's Depression Inventory (CDI), a reliable and well-validated 27-item self-report questionnaire, to assess depressive symptoms [30]. Participants were deemed to have elevated depressive symptoms if their total raw score, derived from the sum of all items, exceeded twelve. This cut-off has been proposed for screening for youth at-risk for clinical depression [31, 32]. The CDI's total

score also was broken down into its five continuous sub-scales tapping different aspects of depressive symptoms: a) negative mood, b) interpersonal problems, c) ineffectiveness, d) anhedonia, and e) negative self-esteem. The CDI has demonstrated adequate internal consistency, test-re-test reliability, discriminative validity, and concurrent validity [33, 34].

Cardiorespiratory fitness—Cardiorespiratory fitness was determined with cycle ergometry testing. Participants were familiarized with the cycle ergometer (Ergoline 800; SensorMedics, Yorba Linda, CA) prior to testing. Adolescents were instructed to pedal at a cadence of 60–65 revolutions per minute. Exercise began with a 4-minute warm-up period with no resistance applied to the pedals. After the warm-up, participants were encouraged to exercise to the limit of their tolerance. Predicted maximal power was used to adjust the rate of workload increase for each participant [35]; workload was increased until either the participant could no longer continue or could no longer maintain the prescribed pedaling cadence. Expired gas exchange was measured breath by breath throughout exercise using a metabolic cart (SensorMedics Vmax, Yorba Linda, CA). Maximal oxygen uptake during exercise ($\text{VO}_{2\text{max}}$) was calculated as the 20-second average of values achieved at the end of exercise, with higher values reflecting better cardiorespiratory fitness. Participants who met at least two of four criteria during cycle ergometry were considered to have achieved a maximal VO_2 test and reached their $\text{VO}_{2\text{max}}$: i) maximal heart rate of ≥ 185 beats per minute achieved during the last minute of exercise, measured with a 12-lead electrocardiogram; ii) respiratory exchange rate of 1.02, calculated as the 20-second average of values achieved at the end of exercise; iii) peak rating of perceived exertion during exercise of ≥ 18 , measured with the 20-point Borg Rating of Perceived Exertion Scale [36]; and iv) achievement of an oxygen plateau, defined as ≤ 2.0 mL/kg per minute change in oxygen uptake during the last minute of exercise [37].

Analytic Plan

Data were screened for problems of skew, kurtosis, and outliers. Descriptive statistics were generated on study variables. Validity criteria for measuring $\text{VO}_{2\text{max}}$ during cycle ergometry testing were examined. The primary independent variable was depressive symptoms status defined as no elevated symptoms ($\text{CDI} < 13$) vs. elevated symptoms ($\text{CDI} \geq 13$). We also considered depressive symptoms continuously as CDI total score and negative mood, interpersonal problems, ineffectiveness, anhedonia, and negative self-esteem. The dependent variable was $\text{VO}_{2\text{max}}$ (maximal oxygen uptake, mL/min). Independent samples t-tests, correlations, or chi-square analyses were used to describe the bivariate relationships among depressive symptoms status or $\text{VO}_{2\text{max}}$ with demographic characteristics (age in years, sex, and race as non-Hispanic White vs. non-Hispanic Black) and anthropometric characteristics (lean body mass in kg, percent body fat, height in cm, weight in kg, BMI z score, and number of obesity-related health co-morbidities). Analysis of covariance (ANCOVA) was conducted to test the relationship between depressive symptoms status (0 = no elevated symptoms vs. 1 = elevated symptoms) and $\text{VO}_{2\text{max}}$. A series of multiple hierarchical regressions was performed to test the relationships between continuous measures of total depressive symptoms, negative mood, interpersonal problems, ineffectiveness, anhedonia, or negative self-esteem and $\text{VO}_{2\text{max}}$. Covariates considered in all ANCOVA and regression models were age (years), sex (dummy-coded: 0 = male vs. 1 = female), race (dummy-coded: 0 = non-Hispanic White vs. 1 = non-Hispanic Black), lean mass (kg), percent fat mass, weight (kg), height (cm), and number of obesity-related health co-morbidities. Only age, sex, race, and lean mass were retained, as the other covariates were not significantly related to $\text{VO}_{2\text{max}}$ in any multivariate model. There were no apparent violations of homogeneity of variance (ANCOVA) or homoskedasticity (multiple regression) using Levine's test and plotted residuals/predicted values, respectively. Finally, the interaction between sex and depressive symptoms was tested to explore whether the relationship between depressive

symptoms and $\text{VO}_{2\text{max}}$ differed for boys and girls. In these analyses, the independent variables were depressive symptoms (mean-centered for continuous scales), sex, and their interaction. Age, sex, race, and lean mass were included as covariates.

Results

All variables approximated a normal distribution (skew < 3 , kurtosis $< |10|$). Outliers (approximately 1.5% of all data points) were recoded to fall within three standard deviations of the mean [38]. One hundred thirty-four adolescents participated. Descriptive information on demographic and anthropometric characteristics is provided in Table 1. Approximately 16% of adolescents ($n = 16$) endorsed elevated depressive symptoms (CDI total score ≥ 13). Those with elevated depressive symptoms did not differ from those without elevated depressive symptoms in age, sex, race, lean mass, percent fat mass, weight, height, BMI z score or number of obesity-related health co-morbidities.

One-hundred three adolescents met criteria for reaching $\text{VO}_{2\text{max}}$ on their cycle ergometry test. Of the 31 youth whose cycle tests did not meet validity criteria, approximately 96% did not achieve an oxygen plateau, 97% had a maximal heart rate < 185 beats per minutes, 90% did not endorse the criterion cut-off for perceived exertion, and 41% did not meet the respiratory exchange rate criterion. Compared to those who achieved a valid cycle test, adolescents who did not achieve a valid cycle test were more likely to be younger ($p < .01$), non-Hispanic Black (vs. non-Hispanic White; $p < .05$), and to have a greater BMI z score ($p < .05$). There were no significant differences between those with and without a valid cycle test on any other variable, including depressive symptoms, sex, lean mass, percent fat mass, weight, height, or number of obesity-related health co-morbidities.

The remaining sample was comprised of 103 obese adolescent girls (68%) and boys with an average age of 14.6 ± 1.4 years. Average $\text{VO}_{2\text{max}}$ was 1975.2 ± 349.6 mL/min and ranged from 1238 to 2894 mL/min. Maximal heart rate was similar among adolescents with and without elevated depressive symptoms (186.2 ± 13.6 beats/min vs. 188.8 ± 11.7 beats/min, $p = .43$), as was respiratory exchange rate ($1.17 \pm .07$ vs. $1.16 \pm .06$, $p = .51$). $\text{VO}_{2\text{max}}$ was positively correlated with age ($r = .24$, $p < .01$), lean mass ($r = .64$, $p < .001$), weight ($r = .54$, $p < .001$), and height ($r = .42$, $p < .001$). Also, boys displayed greater $\text{VO}_{2\text{max}}$ than girls ($M \pm SE$ 2154.9 ± 70.8 mL/min vs. 1890.5 ± 34.1 mL/min, $p < .01$).

Adjusting for age, sex, race, and lean mass, adolescents with elevated depressive symptoms displayed poorer $\text{VO}_{2\text{max}}$ than adolescents without elevated symptoms ($p = .04$; Figure 1). Depressive symptoms status accounted for 4% of the variance in $\text{VO}_{2\text{max}}$ ($\eta^2 = .04$). In analyses examining depressive symptoms continuously, the association between total depressive symptoms and $\text{VO}_{2\text{max}}$ did not reach significance ($\beta = -.11$, $p = .12$), accounting for age, sex, race, and lean mass. Adjusting for the same covariates, there was a significant, inverse association between anhedonia and $\text{VO}_{2\text{max}}$ ($p < .05$), such that higher reports of anhedonia were related to poorer exercise performance (Figure 2). Above and beyond the contribution of age, sex, race, and lean mass ($R^2 = .50$, $p < .001$), anhedonia explained a unique 3% of the variance in $\text{VO}_{2\text{max}}$ ($\Delta R^2 = .03$, $p = .016$). The relationships between other continuous dimensions of depressive symptoms and $\text{VO}_{2\text{max}}$ did not reach statistical significance ($ps = .06$ to $.81$).

Exploratory analyses tested sex as a potential moderator of the relationship between depressive symptoms and $\text{VO}_{2\text{max}}$. The only significant effect was an interaction of sex by negative mood ($p = .026$). Negative mood scale score was associated with poorer $\text{VO}_{2\text{max}}$ among boys only ($\beta = -.22$, $p = .024$), but not among girls ($\beta = .06$, $p = .56$). Sex did not act as a significant moderator in any other model.

Discussion

Among obese, weight loss treatment-seeking adolescents, those with elevated depressive symptoms displayed significantly poorer cardiorespiratory fitness, as assessed with cycle ergometry, than those without elevated depressive symptoms. Notably, the association between depressive symptoms status and cardiorespiratory fitness was observed after accounting for differences in lean mass, an important contributor to fitness levels, even among uniformly obese individuals [39]. Also, the relationship between depressive symptoms and fitness was not moderated by sex. In other words, obese girls, as well as boys, with elevated depressive symptoms were less fit relative to their counterparts without depressive symptoms.

Results from the present study are consistent with previous studies reporting a significant cross-sectional association between depressive symptoms and lower self-reported physical activity among non-treatment seeking samples of adolescents and young adults [14, 16–18]. The current findings' reliance on objectively-measured cardiorespiratory fitness, as opposed to self-report measures of physical activity that may be limited by poor validity [24], lend support to the notion that elevated depressive symptoms may exert an impact on voluntary energy expenditures such as engagement in leisure-time physical activities. Indeed, when types of depressive symptoms were examined, anhedonia was related to adolescent girls' and boys' poorer cardiorespiratory fitness, after accounting for lean mass and other relevant covariates. Negative mood also was related to poorer cardiorespiratory fitness, although only among boys. This sex by negative mood interaction is curious in light of data supporting a stronger relationship between depressive symptoms and obesity in girls compared to boys [9]. Yet, it should be considered with caution given the exploratory nature of these analyses and the null interaction effects observed for the other variables.

Taken together, these findings converge with cognitive-behavioral theories of depression that emphasize that depressed mood states prompt behavioral withdrawal from activities such as exercise, which in turn further exacerbates depressed mood [13]. Conversely, it is possible that engagement in physical activity affects depressive symptoms through a variety of potential mechanisms. Participation in physical activity or sports might decrease depressive symptoms through cognitive factors such as enhancing physical self-concept and self-esteem [15]. Similarly, exercise has been posited to increase positive affect through operating on neurotransmitters involved in emotion regulation such as serotonin, dopamine, acetylcholine, and norepinephrine [40]. Several longitudinal studies examining adolescent depression and self-reported physical activity support a cyclical interaction between depressive symptoms and physical activity over time [20, 21].

Nonetheless, the cross-sectional, observational nature of the current data limits the ability to make causal inferences about the depressive symptoms-cardiorespiratory fitness relationship. Also, while VO_{2max} is a criterion-measure of cardiorespiratory fitness, depressive symptoms were assessed with questionnaire, which although reliable and valid as a screening tool [33, 34], cannot distinguish between those with and without clinical depression. Further study of the relationship between depressive symptoms and cardiorespiratory fitness using interview-based measures of adolescent depression is warranted. Indeed, we only found an association of cardiorespiratory fitness with elevated depressive symptoms rather than total depressive symptoms considered continuously, calling for replication in adolescent samples enriched for clinical depression. The current sample studied was comprised of weight loss treatment-seeking obese adolescents with at least one obesity-related health co-morbidity. Individuals who required or who already were engaged in ongoing psychiatric treatment were excluded from participation. Consequently, a shortcoming of the current study is that the findings are limited in their generalizability to

other populations. Finally, it is important to recognize that the effects of elevated depressive symptoms or anhedonia on cardiorespiratory fitness were small relative to the effects of demographic/anthropometric variables.

The present findings are hypothesis-generating with regard to the potential mechanisms involved in the relationship between elevated depressive symptoms and obesity. Elevated depressive symptoms or major depression have been shown to predict the development of obesity [9, 11]; yet, there is much to be determined about how depressive symptoms lead to excess weight gain in adolescents who are still physically and affectively developing. The current results support the possibility that poor cardiorespiratory fitness, resulting from reduced physical activity, may be one such mechanism. Mechanistic research delving into the factors, such as cardiorespiratory fitness, that may help to explain how elevated depressive symptoms influence physical health outcomes is crucial to the design and implementation of effective obesity prevention and intervention efforts.

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Figure 1.

Adolescents with elevated depressive symptoms (CDI Total Score ≥ 13) displayed lower VO_{2max} (mL/min) during maximal cycle ergometry testing than adolescents with low depressive symptoms (CDI < 13), adjusting for age (years), sex, race, and lean mass (kg), $F(1, 103) = 4.23, p = .043$.

Figure 2.

Adolescents' self-reported anhedonia was inversely associated with VO₂max (mL/min) during maximal cycle ergometry testing, adjusting for age (years), sex, race, and lean mass (kg), β (standardized regression coefficient) = $-.17$, $p = .016$.

Table 1

Demographic Characteristics of Adolescent Study Participants by Depressive Symptoms Status

Variable	Low Depressive Symptoms (CDI Total Score < 13) n = 112	Elevated Depressive Symptoms (CDI Total Score ≥ 13) n = 22
Age (years) [†]	14.4 ± 1.4, 12–17	14.4 ± 1.4, 13–17
Sex (% Female)	67.0	77.3
Race (%)		
Non-Hispanic Black	54.5	50.0
Non-Hispanic White	45.5	50.0
Weight (kg) [†]	104.6 ± 18.0, 69.6–140.1	104.5 ± 17.4, 81.9–133.2
Height (cm) [†]	165.3 ± 6.8, 149.1–183.3	165.5 ± 8.3, 146.7–185.9
BMI (kg/m ²) [†]	38.2 ± 6.0, 27.1–53.0	38.1 ± 6.0, 27.6–49.9
BMI z [†]	2.4 ± 0.3, 1.7–3.1	2.4 ± 0.3, 1.6–2.9
Lean mass (kg) [†]	57.1 ± 9.5, 38.7–83.9	56.8 ± 9.2, 39.6–75.1
Fat mass (%) [†]	43.4 ± 4.4, 32.9–54.8	43.6 ± 5.6, 34.0–54.8
Valid cycle test (%)	78.4	72.7

[†] M ± SD, range