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A Model for the Association Between Attention-deficit/ hyperactivity disorder and obesity: effects of physical activity, Sedentary Behavior, Gender, and Medication

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A MODEL FOR THE ASSOCIATION BETWEEN ATTENTION-DEFICIT/ HYPERACTIVITY DISORDER AND OBESITY: EFFECTS OF PHYSICAL ACTIVITY, SEDENTARY BEHAVIOR, GENDER, AND MEDICATION

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To: Dean Tomás R. Guilarte
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This dissertation, written by Danielle Quesada, and entitled A Model for the Association Between Attention-Deficit/Hyperactivity Disorder and Obesity: Effects of Physical Activity, Sedentary Behavior, Gender and Medication having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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DEDICATION

This dissertation is dedicated to my daughter Allegra, my reason. She filled me with the inspiration I needed to continue on my journey and persevere. May this serve as a reminder in her life that she is capable, strong and worthy.

To my parents, thank you for everything. My gratitude to you both is as endless as your love and support has been of me. Thank you for teaching me to never stop learning and always believe in myself. Mom, thank you for making it all possible. Your love gave me the confidence needed to accomplish my goals.

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ABSTRACT OF THE DISSERTATION

A MODEL FOR THE ASSOCIATION BETWEEN ATTENTION-DEFICIT/ HYPERACTIVITY DISORDER AND OBESITY: EFFECTS OF PHYSICAL ACTIVITY, SEDENTARY BEHAVIOR, GENDER, AND MEDICATION

by

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Attention-deficit hyperactivity disorder (ADHD) and obesity both present a significant burden to the health of children and adolescents. Research suggests a possible association between ADHD and obesity. This dissertation focused on examining the association between ADHD and obesity, and the roles physical activity, sedentary behavior, gender, and medication might play in this relationship.

The first manuscript is a review of the literature examining research on the association between ADHD and obesity in children and adolescents. The search included studies that reported on the prevalence of obesity among those with ADHD, the prevalence of ADHD among those who are obese, clinical studies comparing those with ADHD versus non-ADHD, and the association if any between ADHD, obesity, physical activity, eating behavior, medication, and gender. The search resulted in 657 studies, 233 after duplicates removed and 31 after screening. The studies suggested that there is a significant association between ADHD and obesity. Further, behavioral symptoms of ADHD, such as inattention and impulsivity might contribute to decreased physical activity, increased sedentary time, and dis-regulated eating. In addition, research indicated that medication possibly moderates the relationship between ADHD and body mass index BMI via a biophysical effect on the catecholamingeric system.

The second manuscript is an original study testing a model assessing the mediating effects of ADHD on physical activity, sedentary behavior, and BMI. The study sample consisted of 3,788 adolescents ages 11-17 from the 2011-2012 National Survey of Children's Health. Structural equation modeling was used to test the path associations. The model fit the data well, [RMSEA]=.043; [CFI]=.937; [TLI]= .889, and [SRMR]=.025. The total effect for ADHD was 0.073 and was significant. ADHD severity plays a role in increasing BMI status, working through physical activity and sedentary behavior.

The third manuscript is another original study assessing moderating effects of gender and medication on the relationship between ADHD and BMI. The model fit the data well for gender and medication [RMSEA]=0.052; [CFI]=0.850; [TLI]=0.775; [RMSEA]=0.053; [CFI]=0.825; [TLI]=0.715. Although the total effect for ADHD on BMI was significant, medication and gender did not moderate this relationship. Also, medication did not moderate the relationship between physical activity, sedentary behavior and ADHD severity.

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Introduction

Over the past three decades, attention-deficit/hyperactivity disorder (ADHD) and obesity have both become conditions of great concern for public health. Affecting the lives of children, adolescents and adults. ADHD affects an estimated 6.4 million children and adolescents in the United States (Visser et al., 2014); with an estimated economic burden ranging from $143-$266 billion dollars per year. Similarly, obesity affects approximately 12.7 million children and adolescents in the U.S. with an estimated economic burden ranging from $147- $330 billion dollars per year (Ogden et al., 2015).

ADHD and obesity are both growing epidemics, negatively affecting the health and well being of children and adolescents. ADHD is defined as having impairing, excessive levels of hyperactivity, impulsivity and inattention (American Psychiatric Association, 2013). These symptoms can affect a child's behavior, self- esteem and social development (American Psychiatric Association, 2013). Consequently, having deleterious effects on the quality of life of a child. A theoretical framework for ADHD posits that those with ADHD are afflicted by deficits in the catecholaminergic system which affects a person's executive functions. Executive functions in turn regulate impulsivity, inhibitory control and the ability to focus (Diamond, 2013)

Obesity is defined as having a body mass index (BMI) at or above the 95th percentile for children and adolescents of the same age and sex (Barlow, 2007). Obesity is associated with the development of chronic diseases, such as type-2 diabetes and certain types of cancer (Gallagher et al. 2015; Fagot-Campagna et al., 2000). In addition, children and adolescents who are overweight or obese are more likely to suffer from depression, problems at school, lower- self esteem and compromised peer relationships (Schwimmer, 2003).

As the prevalence of those with ADHD and/or obesity increases so has the interest in studying the association between ADHD and BMI. Studies found that obese children and adolescents have a significantly higher prevalence of ADHD than children who are not obese (Agranat-Meged et al., 2005; Erermis et al., 2004). The same was true when examing the weight status of those who have ADHD compared to those without ADHD. The prevalence of overweight and obese was much higher among those with ADHD (Biederman et al., 2003). Furthermore, a study found that the risk for developing obesity was higher among patients with ADHD not taking medication (Curtin, Bandini, and Perrin, 2005). Indicating that medication maybe playing a role in moderating the relationship between ADHD and weight outcome. Furthermore, research into pharmacotherapies for treating ADHD has shown that these medications have appetite suppressing side affects. So is it the appetite suppressing effect that leads those diagnosed with ADHD and taking medication to have lower weight or is it the cognitive improvements that the drugs are intended for that lead to better weight outcomes? In addition, despite the positive effects of physical activity on ADHD symptoms, children and adults with ADHD are less likely to engage in physical activity and more likely to engage in sedentary behavior (Waring and Lapane, 2008; Kim et. al., 2011; Khalife et al., 2014).

Although previous studies do provide evidence for the association between ADHD and obesity; there is a lack of research exploring the indirect effects of factors that might mediate or moderate the relationship. The first manuscript is a systematic review aimed at gathering and understanding the research that has already been done. The information provided by the review and the theoretical framework discussed guided the selection of factors and their roles in the proposed model for the second and third manuscripts. In the second manuscript, the mediating effects, if any, of both physical activity and sedentary behavior on BMI status and the severity level of ADHD were examined. The third manuscript, sought to test the possible moderating effects of medication and gender on the association between ADHD severity and BMI.

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A Review: Associations Between Attention-deficit/hyperactivity Disorder, Physical Activity, Medication Use, Eating Behaviors and Obesity in Children and Adolescents

Abstract

In the past few years we have become increasingly aware of strong associations between obesity and ADHD. Both conditions are major public health issues, affecting children, adolescents and adults alike. This review seeks to (1) examine prior research on the association between ADHD and obesity in children and adolescents; (2) discuss mechanisms and consequent behavioral attributes to gain understanding of the path association between ADHD and obesity, (3) review studies examining the role of physical activity, medication, eating behavior and gender on the relationship between ADHD and obesity in children and adolescents.

PubMed, CINAHL and PsycINFO databases were used to search for studies whose subjects were children and adolescents, ages 0-–17 years and whose publication years were from 2000 to 2016. After screening 31 studies were included in the review.

The literature suggests that there is a significant association between ADHD and obesity. Further, the inattentive and impulsive behaviors that characterize ADHD could contribute to dis-regulated eating behaviors and a lack of motivation to engage in physical activity. In addition, it is proposed that medication, gender and physical activity play a role in mediating and moderating the relationship between ADHD and obesity.

KEYWORDS: ADHD; OVERWEIGHT; IMPULSIVITY; INATTENTION; EXERCISE; BINGE EATING

Background

Attention deficit/hyperactivity disorder (ADHD) and obesity are significant public health problems (Ogden, Carroll, & Kit, 2014; Cortese & Morcillo Peñalver, 2010; Faraone, Sergeant, Gillberg, & Biederman, 2003). ADHD is considered to be one of the most common neurodevelopmental disorders among children (Biederman, 2005; Visser et al., 2014). The condition is characterized as having impairing and developmentally excessive levels of hyperactivity, impulsivity, and inattention (American Psychiatric Association, 2013). Consequently, affecting an individual''s behavior and making it challenging to focus on daily tasks, plans, routines and organization (Lara et al., 2009; Schei, Jozefiak, Novik, Lydersen, & Indredavik, 2016; Thomas, Sanders, Doust, Beller, & Glasziou, 2015). ADHD can be a significant detriment to the quality of life of those afflicted (Agranat-Meged et al., 2005; Birnbaum et al., 2005; Klassen, Miller, & Fine, 2004). ADHD affects an estimated 7%-–11% of children worldwide and an estimated 6.4 million children 4-–17 years of age in the United States; (Faraone et al., 2003; Visser et al., 2014).

Similarly, obesity affects a significant portion of the population and presents a growing threat to the health and development of children. Obesity is defined as a BMI at or above the 95th percentile for children and adolescents of the same age and sex (Barlow, 2007). Obesity is present in about 17% of children and 35% of adults in the United States (Ogden et al., 2014). Preventing this condition is paramount because it is associated with the development of chronic diseases, such as heart disease, type-2 diabetes, gall bladder disorders, osteoarthritis and certain types of cancers (Freedman, Dietz, Srinivasan, & Berenson, 1999; Fagot-Campagna, Pettitt, & Engelgau, 2000; Gallagher & LeRoith, 2015; Reyes et al., 2016). Also, children and adolescents who are overweight or obese are at increased risk for lower-self esteem, problems at school, and compromised peer relationships (Schwimmer, Burwinkle, & Varni, 2003; Strauss, 2000).

Recent research suggests strong links between the two conditions. Considering the high prevalence of childhood obesity it is helpful to elucidate groups that are at increased risk. As previous studies have shown, children with ADHD may be one such risk group. Studies show that children with ADHD lack motor skills, have decreased levels of physical fitness and are at increased risk for obesity in comparison to children without ADHD (Waring & Lapane, 2008; Harvey & Reid, 2005; Holtkamp et al., 2004). Furthermore, these characteristics can persist into adulthood and cause numerous impairments in social, academic and occupational functioning, leading to further risk for negative health behaviors and health outcomes. Consequently, there is a large economic burden that falls on the families, the school system, and medical professionals of children with ADHD (Birnbaum et al., 2005; Kim, Mutyala, Agiovlasitis, & Fernhall, 2011). In addition, the economic burden that falls on the individuals and families of those affected by both ADHD and obesity is great, and even greater if considering the accompanying chronic diseases (Biederman, 2005; Dietz & Robinson, 2005; Doshi et al., 2012). The annual economic strain to the United States is estimated at $143 billion–$266 billion and it is projected to increase $48 billion–$66 billion per year by 2030 (Doshi et al., 2012; Wang et al., 2011). Both obesity and ADHD present a great burden to public health; understanding the factors and associations that contribute to each is increasingly important in order to create and implement efficacious evidence-based prevention and intervention strategies.

Studies on both children and adults have found a significant association between obesity and ADHD (de Zwaan, Gruss, & Müller, 2011; Güngör, Celiloğlu, Raif, Özcan, & Selimoğlu, 2013; Spencer, Faraone, & Tarko, 2014; Waring & Lapane, 2008). It might seem counter intuitive that an individual with ADHD would be overweight or obese because one associates ADHD with being "hyperactive" (Khalife et al., 2014). However, ADHD is characterized as impulsivity and inattention leading to dis-regulation of health behaviors such as eating, physical activity and sedentary time, possibly resulting in weight gain (Cortese et al., 2007; Gapin, Labban, & Etnier, 2011; Graziano et al., 2012; Kim et al., 2011). Recent research suggests strong links between ADHD and obesity even though findings may not always be consistent (Caci, Morin, & Tran, 2014; Cortese, Ramos Olazagasti, & Klein, 2013; Dubnov-Raz, Perry, & Berger, 2011; Sanchez-Lopez et al., 2015). Understanding this association is relevant because it may contribute knowledge about possible behavioral and physiological mechanisms that manage both ADHD and obesity. Congruently, it might lead to important implications for the treatment and prevention of these conditions (Cortese & Vincenzi, 2012).

During the past decade there has been a strong response to exploring the link between ADHD and obesity in adults (Cortese et al., 2016). This review is focused on studying this association in children and adolescents. There is a growing interest in studying this relationship as it manifests earlier in life. Since ADHD is diagnosed at an early age it would be essential from a prevention standpoint to understand the strength and mechanism of this association in childhood and adolescence (Cortese et al., 2016; Erhart et al., 2012; Goldman, Genel, Bezman, & Slanetz, 1998).

Methods

We searched for studies that reported on the prevalence of obesity among those diagnosed with ADHD, the prevalence of ADHD among those who are obese, clinical studies comparing those with ADHD versus non-ADHD, and the association if any between ADHD, obesity, physical activity, eating behavior, medication and gender. Empirical studies were included and case-reports and non-published works were excluded. Selection criteria included having ever been diagnosed with ADHD by a healthcare provider, having been diagnosed based on DSM criteria, or other standardized, validated criteria. Weight and height were either self reported or acquired via medical records. Both cross-sectional and longitudinal studies were included. Study subjects were children and adolescents ages 0-–17 years of age. The aims of this study are to (1) examine prior research on the association between ADHD and obesity; (2) discuss mechanisms and consequent behavioral attributes to gain understanding of the path association between ADHD and obesity, (3) review studies examining the role of physical activity, medication, eating behavior and gender on the relationship between ADHD and obesity (Fig. 1).

The databases searched included PubMed, CINAHL, and PsycINFO. The majority of the research in this field has happened within the last two decades and so the search included studies from 2000 to 2016. The following

keywords were used in the search: Attention-deficit/hyperactivity disorder, ADHD, children, adolescents, inattention, obese, overweight, physical activity, sedentary time, inactive, medication, and eating behavior. The search resulted in
657 studies, 233 after duplicates removed and 31 after screening (Table 1).

Results

ADHD and Obesity

Three clinical studies (Agranat-Meged et al., 2005; Braet, Claus, Verbeken, & Van, 2007; Erermis et al., 2004) were found describing the prevalence of ADHD among obese children and adolescents. Based on these data, the evidence points to higher than expected prevalence of ADHD in clinical samples of obese patients seeking for treatment.

Two of the studies showed a higher prevalence of ADHD among study subjects who were obese. Agranat-Meged et al. (2005), studied a clinical sample of 26 children ages 8-–17, hospitalized for the treatment of their obesity. The research found that 57.7% of participant children had ADHD, a 47.7% increase compared to the 10% of the general population in the same age group. Similarly, in a study by Erermis et al. (2004), a sample of 30 obese adolescents taken from a pediatric endocrinology outpatient clinic (clinical), 30 obese adolescents (non-clinical) and 30 normal weight (control) adolescents were compared and showed that the prevalence of ADHD was significantly higher in the clinical obese group compared to the non-clinical and control groups. Also, Braet et al. (2007), identified 56 overweight children in a clinical setting and 53 normal weight children ages 10–18 years. The study''s findings showed that overweight boys demonstrated significantly more impulsivity, hyperactivity, and attention-deficit symptoms than the boys in the control group however no higher prevalence of ADHD.

Although the sample sizes were small and taken from clinical settings the results serve as evidence that children who are obese are at increased risk for co-morbidly having ADHD. As such clinicians and healthcare providers should be aware of the high comorbidity of the two conditions and screen for ADHD when presented with an obese patient. Also, a patient who has ADHD but is not obese might benefit from early intervention/prevention treatments for the development of obesity.

Further evidence for the association between ADHD and obesity was provided by an epidemiologic study by Erhart et al. (2012), consisting of a cross sectional nationally representative survey of 2,863 children ages 11–-17 years, they found higher prevalence of ADHD among over weight/obese children and adolescents when compared to normal and underweight children and adolescents. Further analysis revealed obese children and adolescents were twice as likely to receive an ADHD diagnosis.

In addition to finding the prevalence of ADHD among obese subjects, the following studies examined the weight status of children and adolescents with ADHD. The studies indicate that the same trend follows when looking at the prevalence of obesity in children and adolescents with ADHD. Biederman et al. (2003), compared the weight and height of a sample of 140 ADHD girls and 122 female controls between the ages of 6–-17 years. The study resulted in the age- and height-corrected weight index of ADHD subjects being greater than average, indicative of a risk for obesity. However, no significant differences were found between ADHD girls and the control group, as well as between treated and untreated subjects.

Holtkamp et al. (2004), studied a clinical sample of 97 inpatient and outpatient boys, 5-–14 years old diagnosed with ADHD, from a unit of the Department of Child and Adolescent Psychiatry of the University of Aachen in Germany. The study’'s results showed the mean BMI-SDS (standard deviation score) of the 97 boys was higher than average reference values of the population. Also, the proportion of obese and overweight participants was significantly higher than the prevalence of obesity and overweight in the population.

Curtin, Bandini, and Perrin (2005) included in their study 98 children, ages 2-–19, with ADHD from a child psychopathology unit. The study resulted in 29% of subjects being at risk for overweight and 17.3% were overweight. Furthermore, in the 2-–5 year old group, prevalence of at risk for overweight was 42.9%. However, the prevalence of at risk for overweight and obesity in children not treated with ADHD medication was significantly higher than that found in the medicated study subjects.

In another study, Hubel, Jass, and Marcus (2006) examined 39 boys with ADHD and 30 controls ages 8-–14 years old. The main results were BMI-SDS scores higher in boys with ADHD than in controls indicating a possible increased risk for obesity.

Furthermore, Anderson, Cohen, Naumova, and Must (2006), in a larger sample, included 655 subjects 17 years and younger in a prospective cohort study on the determinants and correlates of psychiatric disorders. This study reported that subjects with ADHD had higher mean BMI scores at all ages compared to those who did not have a disruptive disorder.

Similarly, Güngör et al. (2013), compared 362 children with ADHD and 390 children without ADHD. They found that the frequency of overweight/obese patients was higher in ADHD cases compared with the control group.

In summary, data from the above mentioned studies serves as evidence that those with ADHD have a greater prevalence of elevated BMIs. Proposing that having ADHD is a risk factor for the development of dis-regulated health behaviors and thereby obesity. Finally, a more recent meta-analysis provides further evidence that there is a significant association between obesity and ADHD, taking into account possible confounders (Cortese et al., 2016). In the meta-analysis produced by Cortese et al., 42 studies were used resulting in a total of 48,161 subjects with ADHD and 679,975 subjects for comparison. The study methods included a search of multiple databases through 2014 and for study quality rating the Newcastle-Ottawa Scale was used. The results of the analysis yielded a significant association between obesity and ADHD (odds ratio = 1.20, 95% CI = 1.05–1.37) and adults (odds ratio = 1.55, 95% CI = 1.32–1.81). The pooled prevalence of obesity was increased by about 40% in children with ADHD (10.3%, 95% CI = 7.9–13.3) compared with those without ADHD (7.4%, 95% CI = 5.4–10.1) (Cortese et al., 2016).

ADHD and Physical Activity

As mentioned earlier, studies have found that physical activity can have positive effects on the dopaminergic and noradrenergic systems thereby improving symptoms brought on by ADHD. These symptoms include moodiness, lack of attention retention, and impulsivity. However, despite these established positive effects studies have found that children and adults with ADHD are less likely to engage in physical activity and more likely to engage in sedentary time activities. This study by Kim et al. (2011) provided evidence that children with ADHD, regardless of medication status and gender, are less likely to participate in vigorous physical activity and organized sports compared to those without ADHD. A possible hypothesis for this behavioral mechanism is that those with ADHD are inhibited by the biological manifestation (adrenergic/noradrenergic dysfunction) and subsequently the behavioral symptoms of ADHD (lack motivation, attention, and motor control). For example children with ADHD exhibit low gross motor performance, physical fitness, and delayed motor development (Gapin et al., 2011; Graziano et al., 2012).

A recent study by Khalife et al. (2014), examined whether obesogenic behaviors, namely, physical inactivity and binge eating, underlie the potential ADHD symptom–obesity association. They found that childhood ADHD symptoms were significantly associated with adolescent obesity. In addition, they found that children exhibiting reduced physically active play was a predictor of adolescent inattention. Childhood ADHD and conduct disorder symptoms were linked with physical inactivity in adolescence. Consequently, physical inactivity mediated the associations. Hence physical activity may be beneficial in treating both behavior problems and obesity.

Although limited, these studies are evidence that an association exists and that physical activity has a positive effect on children''s behavior and cognitive performance. The findings of the studies mentioned suggest that physical activity is possibly an effective supplement to medication by reducing the behavioral and cognitive impairments that are characteristic of ADHD. In addition, physical activity will have a positive effect on treating obesity and ADHD together.

ADHD, Medication and Gender

Medication has a biophysical effect on those with ADHD. The psychostimulants used to treat ADHD act on the dopaminergic and noradrenergic system, leading to improved frontal cortex function and thus improved symptoms of ADHD. It has been hypothesized that medication moderates the relationship between ADHD and obesity by acting on the systems mentioned and/or via the anorexigenic side effects of medications used to treat ADHD. A few studies have looked at the effects of medication and gender on ADHD and weight outcome. The research mostly demonstrates that those with ADHD and taking medication are less likely to be obese than those with ADHD and not medicated.

Schwartz et al. (2014) used longitudinal electronic health record data from the Geisinger Health System on 16,820 children and adolescents ages 3-–18 years in Pennsylvania. They aimed to determine to what degree ADHD diagnosis, stimulant use, age of first use, and duration of use were associated with BMI trajectories. They found that those with ADHD and un-medicated had higher BMIs during childhood compared with those without ADHD or medication. In addition, first stimulant use and longer duration of use were associated with slower BMI increase in early childhood, however the opposite was true for late adolescence.

In the previously mentioned study by Kim et al. (2011) on a sample of 6-–17 year old children and adolescents from a nationally representative survey, found that when compared to children without ADHD, children with ADHD had increased risk of obesity for both boys and girls if not medicated. Also, girls with ADHD and not on medication were more likely to have higher media time than those without ADHD and this was associated with higher odds of obesity. As for studying the differences by gender, they found that boys were diagnosed with ADHD significantly more often than girls (boys = 12.3%; girls = 5%). However the use of medication among those with ADHD was similar for both boys and girls (boys = 59.7%; girls = 57.2%). There seemed to be a large disparity by gender when looking at the odds for obesity among those with ADHD and not medicated. Boys with ADHD who were not on medication for ADHD had 42% higher odds of being obese compared to boys without ADHD, after controlling for socio-demographic variables. Girls with ADHD, who were not on medication for ADHD, had 85% higher odds of being obese compared to those without ADHD. The study also found that regardless of medication status and gender, children and adolescents with ADHD are less likely to participate in physical activity and sports compared to those without ADHD.

Furthermore, Swanson, Kinsboume, and Nigg (2007) found that, among children diagnosed with ADHD and not medicated, they had BMIs larger at baseline than the norm (BMI z-score > 0; $p < .05$). Indicating that children with ADHD are larger. As explained by the authors, it was hypothesized that if medication was reintroduced then there would be a rebound in growth. However, after initiating treatment with medication there was a decrease in growth rate both in height and weight, indicating that medication could have an anorexigenic effect and that those with ADHD are on average heavier.

Using a nationally representative sample of 8–-15 year old children and adolescents from the National Health and Nutrition Examination Survey, Byrd, Curtin, and Anderson (2013) showed that medicated males with ADHD had lower odds of obesity compared to males with out ADHD. However the odds of being obese were the same for both unmedicated males with ADHD and males with out ADHD. Females on the other hand had an odds of obesity 1.54 times greater than those of females without ADHD. Although it should be noted that these results were not statistically significant.

In a longitudinal population-based study, 336 children with ADHD and 665 age and sex-matched children were taken from a birth cohort. The study resulted in patients with ADHD being 1.23 times more likely to be obese during the follow-up period than were non-ADHD controls. Patients with ADHD who were not obese as of the date ADHD research criteria were met were 1.56 times more likely to be obese during subsequent follow-up than were controls (Aguirre Castaneda et al., 2016).

ADHD and Eating Behaviors

The cognitive impairments that are characteristic of ADHD and are thought to lead to behaviors of impulsivity, inattentiveness and hyperactivity, might mediate the relationship between ADHD and obesity. Evidence for this was found in a study by Cortese et al. including 99 severely obese adolescents (12–17 years) in which there was a significant correlation between inattentive and impulsive ADHD symptoms and binge eating behaviors, even after controlling for comorbid depression and anxiety (Cortese et al., 2007). Furthermore, evidence that a deficit in executive functions is related to abnormal eating behaviors was provided by Pieper and Laugero (2013). Their findings showed a significant correlation between executive function deficits and eating in the absence of hunger in children 3–-6 years old. On the other hand research by Duckworth, Tsukayama, and Geier (2010) found that low impulsivity predicted decreases in BMI in children. Those with self-control and who were non-impulsive appeared to be protected from weight gain.

In a study by Ptacek et al. (2016)Ptacek et al. (2014) 100 boys 6–10 years of age with ADHD and 100 age matched healthy boys as controls were studied for patterns of eating behaviors and associated lifestyles. These were measured and scored by structured parental interviews using a nominal rating scale. The study results showed that there were statistically significant differences in patterned eating behaviors in subjects with ADHD in comparison to the healthy controls. The group with ADHD exhibited markedly diminished adherence to a traditional breakfast, lunch and dinner schedule, which was linked to a significantly higher frequency of irregular eating times. In addition, in the ADHD group, disruptive patterns of eating behaviors were associated with consumption of foods diminished in nutritional value.

Furthermore, in a clinical sample of 252 children in two pediatric mental health clinics, researchers found that there is a statistically significant association between binge eating and ADHD. The association persisted after adjusting for co-morbid diagnoses, medication, demographic variables and clinic. The association between ADHD and BMI was also statistically significant (Reinblatt et al., 2015).

The following study aimed to examine whether characteristics of ADHD as well as childhood eating disturbances predicted binge eating later in adolescence. The study sample consisted of 7,120 male and female children from the Avon Longitudinal Study of Parents and Children, a cohort study of children in the UK. Their findings indicate that early ADHD symptoms, in addition to an overeating phenotype, contribute to risk for adolescent binge eating. Hence, providing further evidence for the potential role of ADHD in the development of overeating and dis-regulated eating behavior. (Sonneville et al., 2015).

Discussion

Theoretical Linkage

The above mentioned studies point toward an association between obesity and ADHD. However, the studies reviewed here are mostly cross-sectional and therefore, do not allow for the inference of causality. In order to guide future research we believe the studies discussed here can be used to inform plausible theories for the mechanisms underlying the relationship between obesity and ADHD.

ADHD is a complex and heterogeneous disorder, in both clinical presentation and etiological bases. Despite its etiology not being fully understood, there is general agreement that a biological basis exists. Those diagnosed with ADHD often experience impairments in executive functions, which are neuropsychological processes that appear to be mediated by the prefrontal cortex and associated with facilitating self-regulation and goal-oriented activity (Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Evidence supporting this hypothesis is accumulating from genetic and neurobiological studies as well as from pharmacotherapy research demonstrating the positive effects of psychostimulants, which act as dopaminergic and noradrenergic agonists (Pliszka, Mattews, Braslow, & Watson, 2006; Swanson et al., 2006; Faraone, Biederman, Monuteaux, & Spencer, 2005; Graziano 2012; Albayrak et al., 2013). In addition, studies looking at the effect of physical activity on these same dopaminergic and noradrenergic systems have found that physical activity has the same positive influence as psychostimulants on the brain (Kim et al., 2011; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013) to improve attention, impulsivity, and mood, which are often problematic areas for children with ADHD. Although the benefits of exercise on both physical and psychological aspects of a person have been supported extensively in adult research, relationships between physical activity and behaviors and moods in children remain understudied, particularly in children diagnosed with ADHD (Gapin et al., 2011).

Conclusions

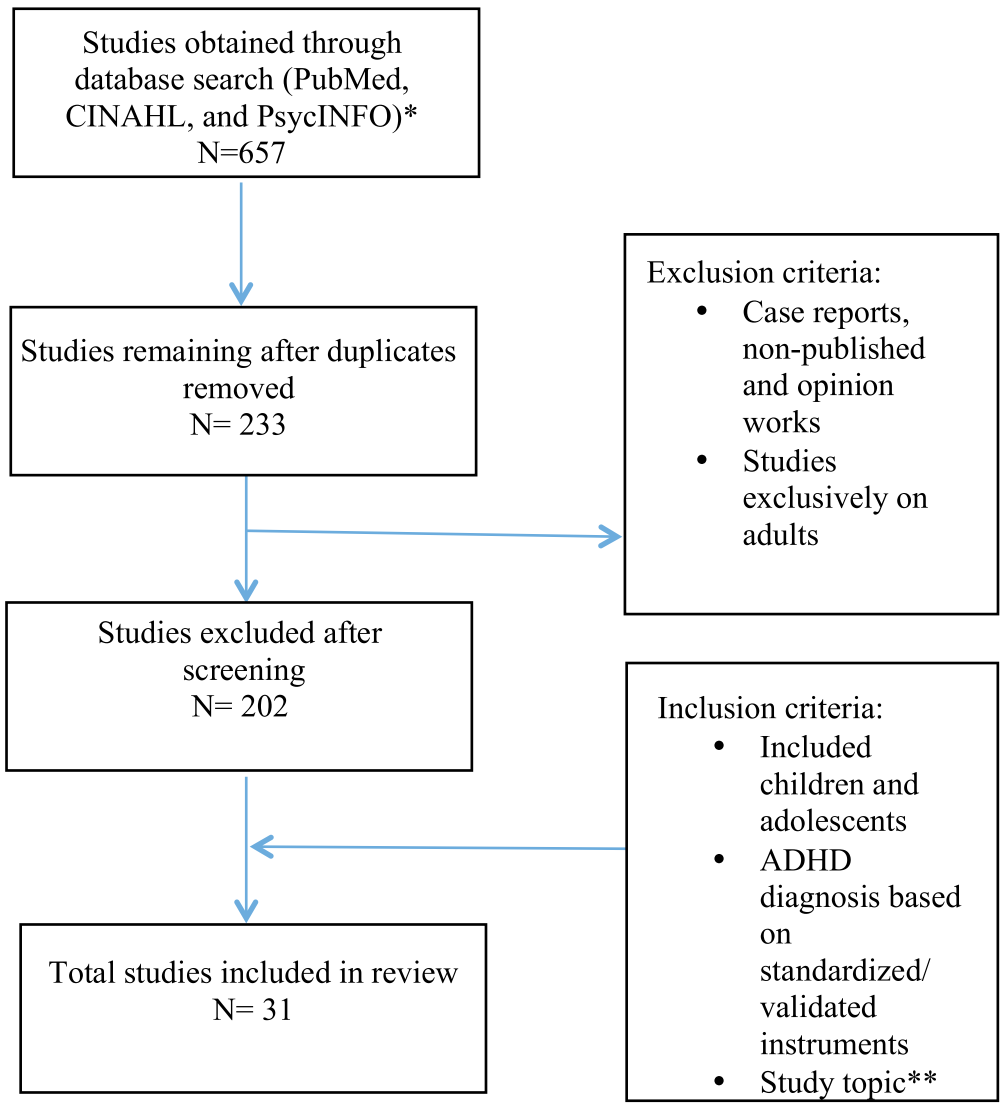
Gaining better insight into the relationship between ADHD and obesity is paramount because it may lead to a greater understanding of the causal path underlying obesity and ADHD. Also, greater insight on the mechanism of this relationship could be beneficial for the management of both conditions when found together. In addition, preventive measures could be applied to those with ADHD who might be at higher risk for the development of obesity. Finding efficacious and practical treatments for both ADHD and obesity would alleviate the great social and personal burdens that often accompany these conditions. Furthermore, understanding the moderating effects of medication on the relationship between ADHD and obesity in children and adolescents is necessary in order to gain an understanding as to why children with ADHD who are on medication have lower weight than their counterparts. Is it the appetite suppressing side effect of ADHD medication or is it an improvement in behavioral regulation and therefore healthier habits that leads to lower weight among those with ADHD who are treated with medication?

In conclusion, there is strong evidence showing an apparent link between ADHD and obesity. However, the studies thus far have mostly been clinical, more population based, methodologically rigorous studies are needed. This would include studies using standardized and formal diagnosis for ADHD, overweight and obesity. In addition to controlling for potential confounders such as psychiatric and physiological comorbid disorders. Also, more prospective and longitudinal studies to facilitate gaining knowledge about the causal pathway for this association are needed. Lastly, it would be most beneficial to produce more studies including data on medication use and physical activity because medication can have appetite suppressing effects and both can have positive effects on the adrenergic system. The more we learn about ADHD and obesity and how they coexist the better equipped we are to develop treatments and improve the lives of those afflicted by these conditions.

Psychiatric-mental health nurses are in a unique position to positively impact the monitoring of risk factors for obesity in patients with ADHD; because of their work environments, their access to patients and their knowledge of psychiatric and mental health conditions. Nurses can raise awareness of the higher propensity for obesity among patients with ADHD within their work communities. They can explain to family members, friends and caretakers the risk and the possible reasons for the development of obesity in those with ADHD. Thereby empowering caretakers to employ preventive strategies and monitor for the associated risk factors.

As mentioned, further research is needed in order to understand the relationship between obesity and ADHD. Nurses are in an advantageous position to observe and develop, pragmatic and efficacious strategies for the prevention and treatment of obesity among those with ADHD.

Figure 1. Flow diagram of study selection.



* Key words: Attention-deficit/hyperactivity disorder, ADHD, children, adolescents, inattention, obese, overweight, gender, physical activity, sedentary time, inactive, medication, and eating behavior.

** Study topics of relevance for inclusion in this review: the prevalence of obesity among those diagnosed with ADHD, the prevalence of ADHD among those who are obese, studies comparing those with ADHD versus non-ADHD, and the association if any between ADHD, obesity, physical activity, eating behavior, medication and gender.

Table 1. Studies examining the relationship between ADHD, health behaviors, medication, gender and obesity in children and adolescents.

First author (year)	Subjects	Objectives	Key results
Erermis et al. (2004)	30 obese (clinical) adolescents taken from endocrinology clinic, 30 obese adolescents (non-clinical), 30 normal weight adolescents (control) Age range: 12-16 years	Examined the prevalence of psychopathology (ADHD) in a clinical, non-clinical sample and in a normal weight control group	(13.3%) of clinical obese group had ADHD, (3.3%) of non clinical obese group had ADHD and (3.3%) of control group had ADHD
Agranat-Meged et al. (2005)	26 obese (clinical) hospitalized children Age range: 6-18 years	Investigated the prevalence of ADHD in a clinical sample vs. general population.	(57.7%) of sample had ADHD; (10%) ADHD in general population in the same age group ($p<.0001$)
Braet et al. (2007)	56 (clinical) overweight children, 53 normal weight children Age range: 10-18 years	Investigated whether or not obese children have a stronger tendency to act on impulse than normal weight children. Compare the prevalence of ADHD between overweight and normal weight groups.	Overweight children were significantly more impulsive than normal weight children ($P < .01$) Overweight boys demonstrated significantly more impulsivity ($P < .05$), hyperactivity ($P < .01$), and ADHD symptoms ($P < .001$) than the boys in the control group however no higher prevalence of ADHD.
Erhart et al. (2012)	2,863 children from a cross-sectional, nationally representative survey	Explored the association between overweight and ADHD in the general population.	(4.2%) of sample had ADHD; (7%) of overweight/obese children had ADHD; (3.5%) of normal weight children had ADHD; (4.9%) of underweight children had

	Age range: 11-17 years		ADHD. Overweight/obese children were twice as likely to have an ADHD diagnosis (OR = 2.0). Children with ADHD were 1.9 times (OR=1.9) more likely to be overweight/obese.
Biederman et al. (2003)	140 Females with ADHD 122 Females non-ADHD (controls) Age range: 6-17 yrs	Examine weight and height differences between ADHD and non-ADHD female children and adolescents.	The age and height corrected weight index of ADHD subjects was greater than average (1.1), hence at increased risk for obesity. No significant differences found between the ADHD group and control group.
Holtkamp et al. (2004)	97 males with ADHD (clinical) from a psychiatric department Age range: 5-14 yrs	Assessed if the prevalence of overweight/ obesity is lower in a population of boys with ADHD in comparison with the general population of the same age.	The proportion of obese/overweight was significantly higher than the prevalence of obesity and overweight in the general population. BMI-SDS of the 97 males with ADHD was higher than the age adapted reference values ($p=.038$).
Curtin et. al. (2005)	98 children with ADHD (clinical) from a child psychopathology unit Age range: 2-19 years	Determined the prevalence of overweight among a clinical population of children diagnosed with ADHD and autism spectrum disorders (ASD).	29% of subjects were at-risk-for-overweight; 17.3% were overweight; 42.9% of subjects ages 2-5 years were at risk for overweight. Although, prevalence estimates of boys and girls and across age groupings were not significantly different. Comparison to an age-matched reference population, children with ADHD have a prevalence of overweight that does not differ from children in the general population.

Hubel et. al. (2006)	39 boys with ADHD 30 controls Age range: 8-14 years	Investigated a possible association between ADHD and overweight by comparing weight status (BMI-SDS) and energy expenditure (basal metabolic rate, BMR) for the ADHD group and controls.	BMI-SDS scores were higher in ADHD than in controls.
Anderson et. al. (2006)	655 children/ adolescents from a prospective cohort study on correlates of psychiatric disorders Age range: 1-17 years	Examined childhood to adulthood weight change associated with ADHD and disruptive behavior disorders.	Disruptive disorders were associated with elevated weight status that was maintained from childhood into adulthood. Female subjects with disruptive disorders were estimated to have mean BMI z scores 0.23 (95% confidence interval, 0.03–0.44) units higher than female subjects without disruptive disorders. Male subjects with disruptive disorders were estimated, to have mean BMI z scores 0.20 (95% confidence interval, 0.00–0.39) units higher than male subjects without disruptive disorders.
Gungor et. al. (2013)	362 with ADHD 390 non-ADHD (controls) Age Range: 5-15 years	Examine the frequency of overweight/ obesity in ADHD and non-ADHD children. As well as the frequency of malnutrition among ADHD versus controls.	The frequency of overweight/ obese patients was higher in ADHD cases compared with the control group. Subjects with weight standard deviation scores between <−2 and >2 were significantly higher in ADHD cases than the control group subjects.

Cortese et. al. (2016)	48,161 ADHD subjects 679,975 comparison subjects 42 studies included (meta-analysis) Children and adults	Conducted a meta-analysis to estimate the association between obesity/overweight and ADHD.	A significant association between obesity and ADHD was found for both children (odds ratio= 1.20, 95% CI=1.05–1.37) and adults (odds ratio=1.55, 95% CI=1.32–1.81). The pooled prevalence of obesity was increased by about 70% in adults with ADHD (28.2%, 95% CI=22.8–34.4) compared with those without ADHD (16.4%, 95% CI=13.4–19.9), and by about 40% in children with ADHD (10.3%, 95% CI=7.9–13.3) compared with those without ADHD (7.4%, 95% CI=5.4–10.1).
Wilcutt et. al. (2005)	3734 with ADHD 2969 non-ADHD 83 studies (meta-analysis) Age range: 1-17 years	Performed a meta-analysis to examine impairments on executive function of those with ADHD and those without ADHD.	Groups with ADHD exhibited significant impairment on all executive function tasks. Effect sizes for all measures fell in the medium range (.46-.69).
Pliszka et. al. (2006)	66 Patients treated with mixed salts amphetamine Age range: (9.0(mean); 2.3(SD)) 113 patients treated with methylphenidate Age range: (8.5(mean); 2.1(SD))	To determine whether methylphenidate and mixed salts amphetamine have different effects on growth in children with ADHD.	Mixed salts amphetamine and methylphenidate did not differ in their effects on height. Mixed salts amphetamine had more of an effect on weight than methylphenidate, although the effect was small in magnitude and maybe of limited clinical significance.
Swanson et. al.	140 children with ADHD	To investigate growth of children with	The average BMI was in the 86th percentile at the

(2006)	Age range: 3-6 years	ADHD in the Preschool ADHD Treatment Study (PATS) before and after initiation of treatment with methylphenidate at titrated doses (average, 14.2 mg/day) administered three times daily, 7 days/week for ≈1 year.	baseline assessment. During treatment, slopes were significantly ($p < .0001$) less than zero for z height (−0.304/yr) and z weight (−0.530/yr), indicating reduction of growth rates. For 95 children who remained on medication, annual growth rates were 20.3% less than expected for height (5.41 cm/yr − 6.79 cm/yr = −1.38 cm/yr) and 55.2% for weight (1.07 kg/yr − 2.39 kg/yr = −1.32 kg/yr).
Faraone et. al. (2005)	568 children with ADHD, enrolled study of the safety of MAS-XR for the treatment of ADHD symptoms.	Examined the long-term effects of extended-release mixed amphetamine salts (MAS-XR) with 10–30-mg doses on the growth of children being treated for attention-deficit/hyperactivity disorder (ADHD).	At baseline subjects were heavier than average (mean BMI z-score = 0.41). Children taking MAS-XR grew less than expected. The losses in expected weight and body mass index (BMI) were greatest for the heaviest children, and the losses in expected height were greatest for the tallest children.
Graziano et. al. (2012)	80 children with ADHD (mean age 10 years, 9 months)	Explored the link between pediatric obesity and ADHD by examining whether executive functioning (EF) and medication status are associated with body mass index (BMI) and weight status in children with ADHD.	Children with ADHD who performed poorly on the neuropsychological battery had greater BMI z-scores, and were more likely to be classified as overweight/ obese compared with children with ADHD who performed better on the neuropsychological battery. In addition, children with ADHD who were taking a stimulant medication had significantly lower BMI z-scores compared with children with ADHD who were not taking medication

			or who were taking a non-stimulant medication.
Albayrak et. al. (2013)	495 ADHD patients from six psychiatric in- and outpatient units 1,300 controls Age range: 6–18 years	Examined whether risk alleles for an increased body mass index (BMI) are associated with ADHD. and related quantitative traits (inattention and hyperactivity/impulsivity).	The NUDT3 gene (nudix; nucleoside diphosphate linked moiety X-type motif 3) was associated with ADHD risk (OR: 1.39; Pcorr = 0.01). (GNPDA2) were associated with inattention, whereas markers in the mitogen-activated protein kinase 5 gene (MAP2K5) and in the cell adhesion molecule 2 gene (CADM2) were associated with hyperactivity.
Pontifex et. al. (2013)	20 ADHD children 20 healthy matched controls Age range: 8-10 years	To explore the effect of a single bout of moderate-intensity aerobic exercise on preadolescent children with ADHD using objective measures of attention, brain neurophysiology, and academic performance.	Following a single 20-minute bout of exercise, both children with ADHD and healthy match control children exhibited greater response accuracy and stimulus-related processing, with the children with ADHD also exhibiting selective enhancements in regulatory processes, compared with after a similar duration of seated reading.
Kim et. al. (2011)	66,707 enrolled in the National Survey of Children's Health 2003 Age range: 6-17 years	Examined the levels of physical activity, sedentary behaviors, and obesity among children with ADHD by gender and medication use and estimated the associations between health behaviors and obesity.	ADHD prevalence was 8.6%. Children with ADHD engaged in less physical activity, organized sports, and reading than their counterparts. Children with ADHD had increased risk of obesity for boys [24.9% vs. 21.6%, OR(95% CI): 1.42(1.13–1.77)] and girls [21.9% vs. 16%, 1.85(1.26–

			2.73)], if not medicated. Only girls with ADHD and not on medication were more likely to have higher media time (52.7% vs. 42%) and this was associated with higher odds for obesity [27.7% vs. 19.5%, 2.51 (1.24–5.08)]. Children with ADHD on medication had higher prevalence of depression than those not taking medication [boys: 29.5% vs. 26.3%; girls: 30.9% vs. 23.6%].
Gapin et. al. (2011)	Literature review	Reviewed the literature regarding the potential of physical activity for ADH symptom management, particularly in regard to behavioral and cognitive symptoms.	Research supports the potential for acute and chronic physical activity to mitigate ADHD symptoms.
Khalife et. al. (2014)	8,106 children Age: 7-8 years 6,934 adolescents Age: 16 years	Investigated the association and directionality between ADHD symptoms and obesity from childhood to adolescence in the general population. Examined if physical inactivity and binge eating, underlie the potential ADHD symptom–obesity association. Explored whether childhood conduct disorder (CD) symptoms are related to adolescent obesity/physical	Childhood ADHD symptoms significantly predicted adolescent obesity. Inattention-hyperactivity symptoms at 8 years were associated with indices of obesity at 16 years (obese BMI: odds ratio [OR]=1.91, 95% confidence interval [CI]=1.10–3.33; 95th percentile WHR: OR=1.71, 95% CI=1.05–2.78). Child CD symptoms were associated with indices of adolescent obesity. Reduced physically active play in childhood predicted adolescent inattention (OR=1.61, 95% CI=1.16–2.24). Childhood ADHD and

		inactivity.	CD symptoms were linked with physical inactivity in adolescence (inattention-hyperactivity; OR=1.60, 95% CI= 1.20–2.13), but not binge eating. Physical inactivity mediated the associations.
Schwartz et. al. (2014)	16,820 children (information obtained from electronic health records) Age range: 3-18 years	Examine the association of ADHD diagnosis, stimulant use, age of first use, and duration of use with BMI trajectories.	Mean (SD) age at first BMI was 8.9 (5.0) years, and children provided a mean (SD) of 3.2 (2.4) annual BMI. Longitudinal evidence that ADHD during childhood not treated with stimulants was associated with higher childhood BMIs. In contrast, ADHD treated with stimulants was associated with slower early BMI growth but increase later in adolescence to levels above children without a history of ADHD or stimulant use.
Swanson et. al. (2007)	A literature review of brain imaging and molecular genetic studies including both children and adults.	Reviewed literature from brain imaging and molecular genetic studies to gain understanding of the role of dopamine in relation to ADHD. Reviewed evidence supporting the dopamine deficit theory.	The studies included in the review had the following objectives: (1)Provided evidence for the presence of dopamine deficits. (2) Proposed possible genetic etiologies of dopamine deficits. (3) Examined possible environmental etiologies of dopamine deficits.
Byrd et. al. (2013)	3,050 youth (nationally representative sample) Age range: 8–15	Investigated how associations between ADHD and obesity differ by gender and medication use in a which height and	Males with ADHD who were medicated had lower odds of obesity compared to males without ADHD (adjusted odds ratio [OR]= 0.42,

	years	weight were measured.	95% [CI]=0.23–0.78). Unmedicated males with ADHD were as likely as males without ADHD to be obese (adjusted OR=1.02, 95% CI=0.43–2.42). The odds of obesity for females taking medication for ADHD did not differ statistically from those of females without ADHD (adjusted OR=1.21, 95% CI=0.52–2.81). Females with ADHD not taking medication had odds of obesity 1.54 times those of females without ADHD; however, the 95% CI (0.79–2.98) was wide and not statistically significant at a=0.05.
Aguirre et. al. (2016)	336 patients with childhood ADHD 665 age- and sex-matched non-ADHD controls	Examined the association between obesity and ADHD. Examined obesity rates during childhood and young adulthood in patients with ADHD and age- and sex-matched controls derived from a population-based birth cohort.	Patients with ADHD were 1.23 (95% CI, 1.00-1.50; P<.05) times more likely to be obese during the follow-up period than were non-ADHD controls. Patients with ADHD who were not obese as of the date ADHD research diagnostic criteria were met were 1.56 (95% CI, 1.14-2.13; P<.01) times more likely to be obese at follow-up than were controls.
Cortese et. al. (2007)	99 obese adolescents Age range: 12-17 years	Preliminary evidence suggests a comorbidity Identified the clinical characteristics of obese adolescents with increased risk for ADHD. Examined the factors underlying the	Significant association between inattentive and impulsive ADHD symptoms and binge eating behaviors, even after controlling for depressive and anxiety symptoms. The degree of overweight, pubertal stage, age and

		association between obesity and ADHD.	gender were not significantly associated with ADHD symptoms.
Pieper and Laugero et. al. (2013)	37 child-parent pairs attending a research based pre-school Age range: 3-6 years	Examined the relationships between executive function, emotional arousal and eating in the absence of hunger (EAH) in 3–6 year-old children.	Children who had lower cognitive development scores as indicated by teacher reports had higher EAH ($F(1, 28) = 5.95$, $p = 0.02$).
Duckworth et. al. (2010)	105 fifth- graders (followed up at 8th grade) Age range: 10-11 years	Examined whether the personality trait of self-control protects against weight gain during the transition from childhood to adolescence.	Self-controlled fifth graders had lower BMI z-scores in eighth grade compared to their more impulsive peers. Self-control measured in fifth grade predicted decreases in BMI z-scores from fifth to eighth grade. These results suggest that more self-controlled children are protected from weight gain in the transition to adolescence.
Ptacek et. al. (2014)	Literature review (Studies included children and adults)	Review the literature studying the relationship between ADHD and eating disorders (EDs).	The studies examined the following postulates to explain the association between ADHD and EDs. (1) impulsive behavior leading to disordered eating behavior; (2)other psychologic comorbities affecting eating behaviors; (3) poor eating habits and leading to nutritional deficiencies contributing to ADHD symptoms; and 4) other risk factors common to both ADHD and EDs contribute to the coincidence of both diseases.
Reinblatt et. al. (2015)	79 children and adolescents	Examined inhibitory control in children with loss of control	Odds of LOCES were increased 12 times for children with ADHD

	Age range: 8–14 years	eating syndrome (LOCES) and its association with ADHD.	(adjusted odds ratio [aOR]=12.68, 95% CI=3.11, 51.64, p<0.001).
Sonneville et. al. (2015)	7,120 males and females Age range: 6-17	Examined whether characteristics of ADHD as well as childhood eating disturbances predicted binge eating later in adolescence.	ADHD symptoms, in addition to an overeating phenotype, contribute to risk for adolescent binge eating. Prevalence of binge eating during mid-adolescence was 11.6%. The final model of predictors of binge eating during mid-adolescence included direct effects of late-childhood overeating [standardized estimate 0.145, 95% confidence interval (CI) 0.038–0.259, p = 0.009] and early-adolescent strong desire for food (standardized estimate 0.088, 95% CI −0.002 to 0.169, p = 0.05). Hyperactivity/inattention during late childhood indirectly predicted binge eating during mid-adolescence (standardized estimate 0.085, 95% CI 0.007–0.128, p=0.03) via late-childhood overeating and early-adolescent strong desire for food.

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Manuscript 2:

(Positive review from Preventive Medicine Reports: Revision requested)

A Model Assessing Mediating Effects of Attention Deficit/Hyperactivity Disorder on Physical Activity, Sedentary Behavior, and Obesity

Abstract

The purpose of this study was to develop and test a conceptual model of the direct and indirect effects of attention-deficit/ hyperactivity disorder severity on obesity via physical activity and sedentary behavior.

A sample of 3, 788 children ages 11-17, diagnosed with ADHD, from the 2011-2012 National Survey of Children's Health (NSCH) was used to test whether ADHD severity predicts aspects of physical activity and sedentary behavior, which in turn impact BMI.

Structural equation modeling (SEM) identified direct and indirect effects and determined reliabilities for latent constructs. The model fit the data well, RMSEA (.043, 90% confidence interval .036-.050), CFI (.937), TLI (.889), and SRMR (.025). The total effect for ADHD was 0.073 and was significant. The direct effect for ADHD was 0.041 and was not statistically significant. The indirect effect of ADHD that passes through Physical Activity was 0.030 and was statistically significant. The indirect effect of ADHD that passes through Sedentary Behavior was 0.003 and was not statistically significant. The combined indirect effect of ADHD was 0.032 and was not statistically significant.

The model demonstrates that a mediating path association between ADHD severity, physical activity, sedentary behavior and obesity exists. ADHD severity plays a role in increasing BMI status, working through physical activity and sedentary behavior. Results suggest that interventions for obesity should target not only sedentary behavior and physical activity but also ADHD. Clinicians treating those with ADHD should be aware of these associations and apply obesity prevention strategies when appropriate.

KEY WORDS: ADHD; OVERWEIGHT; EXERCISE; PHYSICAL ACTIVITY; IMPULSIVITY; INATTENTION; OBESITY

Background

Obesity and attention deficit/hyperactivity disorder (ADHD) both present a significant burden to the health and development of adolescents. Approximately 7%-11% of children and adolescents worldwide suffer from ADHD (Faraone et al., 2003). In the United States an estimated 6.4 million 4-17 year old children and adolescents are afflicted with the condition (Visser et al. 2014, Thomas et al. 2015). Obesity presents a similar burden, with an estimated 17.2% of children and adolescents ages 2 to 19 considered to be obese and 6% to have extreme obesity in the United States (NHANES 2013/2014).

ADHD is one of the most common neurodevelopmental disorders found in children. ADHD manifests as impairing and developmentally excessive levels of hyperactivity, impulsivity, and inattention (American Psychiatric Association, 2013). ADHD affects an individual's behavior and makes focusing on daily tasks and routines a challenge. Those afflicted by ADHD may face challenges when trying to, get organized, make plans, stay focused on a task, and think before acting. Consequently, ADHD can be a significant detriment to the quality of life of a child and adolescent (American Psychiatric Association, 2013).

Similarly, obesity is a growing epidemic that negatively affects both the physical and mental development of children and adolescents. A child or adolescent is considered obese if he/she has a body mass index (BMI) at or above the 95th percentile for children and adolescents of the same age and sex (Barlow, 2007). It is important to prevent and find adequate interventions for those who are obese because it is associated with the development of chronic diseases, such as heart disease, type-2 diabetes, osteoarthritis, and certain types of cancers, to name a few (Freedman et. al., 1999; Fagot-Campagna et. al., 2000; Gallagher et. al., 2015; Reyes et. al., 2016). In addition, as a consequence of being overweight or obese children and adolescents are at an increased risk for lower-self esteem, depression, problems at school, and compromised peer relationships (Schwimmer, 2003). Considering the high prevalence of childhood obesity it is beneficial to elucidate groups that are at increased risk. Those with ADHD may be one such risk group. Several studies have shown that Children and adolescents with ADHD are at increased risk for obesity in comparison to those without ADHD. Furthermore, children and adolescents with ADHD lack motor skills and have low levels of physical fitness in comparison to those without ADHD (Waring et al., 2008; Harvey and Reid, 2005; Holtkamp et al. 2004). The characteristics of ADHD can continue into adulthood and cause numerous impairments in social, academic and occupational functioning, leading to further risk for negative health behaviors and health outcomes (Biederman 2005). In addition, one must consider the heavy economic burden that follows the individuals and families of those with ADHD and obesity. (Doshi et. al., 2012; Dietz and Robinson, 2005). In the United States, the annual economic strain is estimated at $143 billion- $266 billion and it is projected to increase $48 billion - $66 billion per year by 2030 (Doshi, 2012; Wang et al., 2011). Both obesity and ADHD present a substantial burden to public health; understanding the factors that contribute to this process is increasingly important in order to create and implement effective evidence-based prevention and intervention strategies.

In recent years there has been increased interest in studying the association between ADHD and obesity. Moreover, a growing number of clinical and epidemiological studies suggest a strong link (Thomas et al., 2015; Visser et al., 2014; Erhart et al., 2012). Agranat-Meged et al. found Children with ADHD have a significantly higher rate of obesity than children without ADHD (Agranat-Meged et al., 2005). Furthermore, despite the positive effects of physical activity on ADHD symptoms, children and adults with ADHD are less likely to engage in physical activity and more likely to engage in sedentary behavior (Waring and Lapane, 2008; Kim et. al., 2011; Khalife et al., 2014). In addition, studies found that children with ADHD had deficits in fine motor coordination and balance, when compared to children without ADHD (Harvey 2007; Fliers et al. 2010). Those with ADHD were also found to entertain negative feelings about physical activity and participation in group sports (Harvey 2009). Symptoms related to ADHD such as depression, lower self-esteem, lower inhibitory control and self-regulation all play a role in the motivation of a child to perform physical activity or disengage from sedentary time (Braet et.al., 2007; Pauli-Pott et. al., 2013).

Previous studies have explored the direct relationship between ADHD and obesity however there is a lack of research on the indirect effects of factors that might mediate this relationship. This study aimed to explore the mediating effects, if any, of both physical activity and sedentary behavior on BMI status and the severity level of ADHD.

Methods

This cross-sectional study employed data from NSCH 2011/2012 database. This is a public use dataset available through the Data Resource Center for Child and adolescent health Measurement Initiative (DRC). The study subjects included in our sample are 11-17 years of age and having ever been diagnosed with ADHD. Exclusion criteria for our sample included having cerebral palsy, bone joint or muscle problems, vision problems that cannot be corrected with lenses, or not owning TV or computer (Figure 1). Missing values were less than 10% of the data and pairwise deletion with weighted least squared mean was used.

The measures included obesity, ADHD severity, sports, exercise, clubs, television time, television in the bedroom, computer time, physical activity and sedentary behavior (Table 1). Obesity was measured using BMI class, with those who are obese measuring at or above the 95th percentile for children and adolescents of the same age and sex (Whitlock et al., 2010). BMI was calculated based on self reported weight and height. ADHD severity was described as either being "mild" or "moderate to severe." Our model included two latent variables, physical activity and sedentary behavior. The latent variable for physical activity was measured using "sports", "clubs" and "days of exercise". "Sports" was measured by the survey question "During the past 12 months, was selected child on a sports team or did [he/she] take sports lessons after school or on weekends?" "Clubs" was measured by asking "During the past 12 months, did [he/she] participate in any clubs or organizations after school or on weekends?" "Days of exercise" was measured by the survey question "During the past week, on how many days did selected child exercise, play a sport, or participate in physical activity for at least 20 minutes that made [him/her] sweat and breath hard?"

The second latent variable, "sedentary behavior," was measured using "computer time", "television in bedroom" and "television time." The variable "computer time" was measured by asking "On an average weekday, about how much time does selected child usually spend with computers, cell phones, handheld video games, and other electronic devices?" "Television in bedroom" was measured by the question "Is there a television in your child's bedroom?" Lastly, "television time" was measured with survey question asking "On an average weekday, about how much time does selected child usually spend in front of a TV watching TV programs, videos, or playing video games?" (Table 1).

Data were analyzed using Structural Equation Modeling. The goodness of fit indices used to asses the model included Root Mean Square Standard Error of Approximation (RMSEA), the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI) and standardized root mean square residual (SRMR) (Figure 2). A value less than 0.06 indicates a good fit for RMSEA. For CFI and TLI values close to 0.95 correspond to a good model fit (Keith 2006; Kline 2011).

In addition, the standardized loadings for measured indicators on latent constructs and composite reliabilities for each of the latent variables were reported. Loadings greater than 0.3 with statistical significance indicate that the measured indicators are good measures of the constructs (Figure2).

Data were analyzed using Mplus (Muthen & Muthen, Los Angeles, CA).

Results

Based on the goodness of fit measures of the SEM analysis the model fitted the data from adolescents with ADHD well. The results for the RMSEA (0.043, 90% confidence interval 0.036-0.050), CFI (0.937), TLI (0.889), and SRMR (0.025) suggest a good model fit (Figure 2).

The reliability estimates showed that the latent constructs accounted for 2.4% of the variance in BMI ($p<.0001$). Furthermore, the latent constructs influencing physical activity and sedentary behavior accounted for a modest but statistically significant percentage of the variance ($p= 0.0001$ for all estimates) (Table 2). On BMI, the direct effect of ADHD severity was 0.036 and was not statistically significant. However, the total effect was statistically significant. The indirect effect of ADHD severity that passes through physical activity is 0.035 and was statistically significant. The indirect effect of ADHD severity that passes through sedentary behavior was 0.003 and not statistically significant. However, the total indirect effect for ADHD was 0.037 and was statistically significant. Last, the total effect for ADHD severity was 0.073 and was statistically significant (Table 3).

As for the measurement component, the indicator variables included in the model were found to be good indicators of the constructs they were intended to measure with statistically significant standardized loadings >0.30 (Figure 1).

Discussion

Based on the literature and the knowledge about the biological pathways involved in the etiology of ADHD and obesity, we developed and tested a model depicting this association. The model was completed with data representative of the US population. The model was a good fit and although the direct effect of ADHD on BMI was not significant, it was smaller than the total effect and the total effect was statistically significant. As expected, ADHD severity had an influence on BMI through physical activity and sedentary behavior.

In addition to reinforcing what previous research had shown to be a strong link between ADHD and obesity; This study adds to the literature by exploring possible indirect path associations and thereby developing a model explaining a portion of the relationship between ADHD and BMI.

The common pathophysiology of ADHD and obesity remains to be elucidated, although increased evidence shows that hypoactivity in dopaminergic neurocircuits relevant for executive function impulsivity, deficits in inhibitory control and reward deficiency link ADHD and obesity [Cortese et al., 2007; Pauli-Pott et al., 2010;Cortese and Vincenzi, 2012; Volkow et al., 2013].

As mentioned earlier, studies have found that physical activity can have positive effects on the dopaminergic and noradrenergic systems thereby improving symptoms brought on by ADHD. These symptoms include moodiness, lack of attention retention, and impulsivity. However, despite these established positive effects studies have found that children and adults with ADHD are less likely to engage in physical activity and more likely to engage in sedentary time activities. The study by Kim et. al. (2011) provided evidence that children with ADHD, regardless of medication status and gender, are less likely to participate in vigorous physical activity and organized sports compared to those without ADHD. A possible hypothesis for this behavioral mechanism is that those with ADHD are inhibited by the biological manifestation (adrenergic/ noradrenergic dysfunction) and subsequently the behavioral symptoms of ADHD (lack motivation, attention, and motor control). For example children with ADHD exhibit low gross motor performance, physical fitness, and delayed motor development (Graziano et. al., 2012, Gapin et. al., 2011).

A recent study by Khalife et al. (2014), examined whether obesogenic behaviors, namely, physical inactivity and binge eating, underlie the potential ADHD symptom–obesity association. They found that childhood ADHD symptoms were significantly associated with adolescent obesity. In addition, they found that children exhibiting reduced physically active play was a predictor of adolescent inattention. Childhood ADHD and conduct disorder symptoms were linked with physical inactivity in adolescence. Consequently, physical inactivity mediated the associations. Hence physical activity may be beneficial in treating both behavior problems and obesity.

Although limited, these studies are evidence that an association exists and that physical activity has a positive effect on children's behavior and cognitive performance.

The majority of these studies are done on clinical, small samples not representative of the national population of children and adolescents. Hence, this study addresses the dearth of studies that investigate this association using a large, US population representative sample for analysis. In addition, this research sought to develop and test a conceptual model of the path associations among physical activity, sedentary behavior, obesity and attention deficit/ hyperactivity disorder using structural equation modeling. The novelty of this study is that we exclusively use nationally representative

ADHD children to examine how the severity of ADHD plays a role in the process of obesity/ weight status.

Previous studies point toward an association between obesity and ADHD. However, the studies reviewed here are mostly cross-sectional and; therefore, do not allow for the inference of causality. In order to guide future research we believe the studies like ours could inform plausible theories for the mechanisms underlying the relationship between obesity and ADHD.

Conclusions

ADHD is a complex disorder and although its etiology is not fully understood, there is evidence for an underlying biological mechanism. One theory explains that those with ADHD suffer impairments in executive functions, such as those facilitating self-regulation and goal oriented activities. There is a deficit in the neuropsychological processes that appear to be mediated by the prefrontal cortex (Graziano 2005; Wilcutt et al., 2005). Genetic and neurobiological studies provide evidence supporting this hypothesis. There are also pharmacotherapy studies showing that psychostimulants have positive effects acting as dopaminergic and noradrenergic agonists (Pliszka et al., 2006; Faraone et. al., 2005; Graziano 2012; Albayrak et. al., 2013). Furthermore, studies found that physical activity has the same effect on these dopaminergic and noradrenergic systems as psychostimulants, improving attention impulsivity, and mood (Pontifex et. al., 2013; Kim et. al., 2011). Despite extensive research on adults and the benefits of physical activity on both their physical and psychological states; there is a lack of research into the relationship between physical activity, behaviors, and moods in children diagnosed with ADHD (Faraone et. al., 2008; Cortese et. al., 2008; Gapin et. al., 2011). Insight into the behavioral mechanism underlying the relationship between obesity and ADHD in children and adolescents provides clinicians, researchers and public health advocates with knowledge to best tailor obesity prevention and intervention programs for both obese and ADHD diagnosed patients.

Table 1. Measured and latent variables in the model

Variable name	Variable definition	Variable values
Obesity (measured)	BMI class	1, Underweight= Less than the 5th percentile 2, Healthy weight= 5th percentile to less than the 85th percentile 3, Overweight= 85th percentile to less than the 95th percentile 4, Obese= Equal to or greater than the 95th percentile
ADHD (measured)	ADHD severity	2, mild 3, moderate or severe
Sports (measured)	During the past 12 months, was selected child on a sports team or did [he/she] take sports lessons after school or on weekends?	0, No 1, Yes
Exercise (measured)	During the past week, on how many days did selected child exercise, play a sport, or participate in physical activity for at least 20 minutes that made [him/her] sweat and breath hard?	Number of days
Clubs (measured)	During the past 12 months, did [he/she] participate in any clubs or organizations after school or on weekends?	0, No 1, Yes
TV time (measured)	On an average weekday, about how much time does selected child usually spend in front of a TV watching	Number of hours

	TV programs, videos, or playing video games?	
TV in bedroom (measured)	Is there a television in your child's bedroom?	0, No 1, Yes
Computer time (measured)	On an average weekday, about how much time does selected child usually spend with computers, cell phones, handheld video games, and other electronic devices?	Number of hours
Physical activity (latent)	Levels of physical activity	Based on sports, clubs and days exercise
Sedentary behavior (latent)	Levels of sedentary behavior	Based on computer time, TV in bedroom and TV time

Source: 2011/12 National Survey of Children's Health. Maternal and Child Health Bureau in collaboration with the National Center for Health Statistics. 2011/12 NSCH Indicator Data Set prepared by the Data Resource Center for Child and Adolescent Health, Child and Adolescent Health Measurement Initiative. www.childhealthdata.org .

Figure 1. Inclusion/exclusion criteria

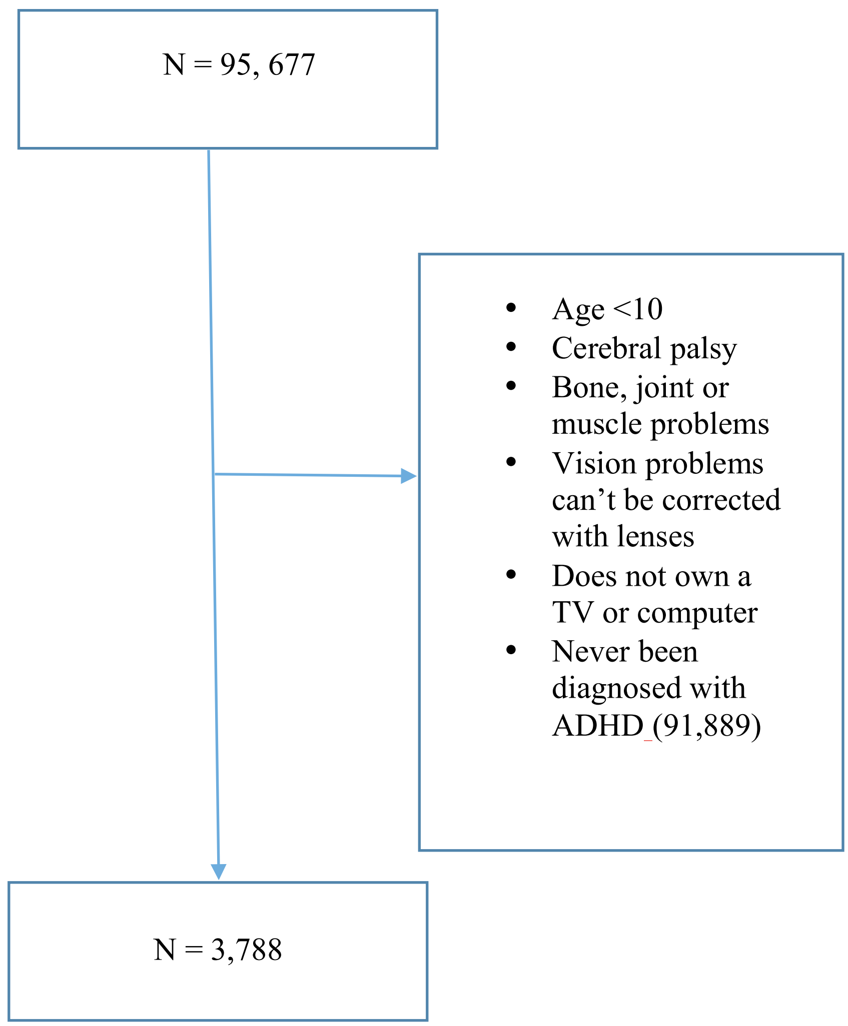

Table 2. Estimated reliabilty of measured and latent variables

R-square				
Observed Variables	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Participation in sports	0.357	0.032	11.151	0.000
Participation in clubs	0.187	0.019	9.599	0.000
Time spent exercising	0.132	0.016	8.103	0.000
Time spent in front of a television screen	0.435	0.032	13.505	0.000
Time spent with computers, cell phones, handheld video games, and other electronic devices	0.403	0.030	13.315	0.000
TV in the bedroom	0.069	0.011	6.515	0.000
Body mass index	0.024	0.007	3.679	0.000
Latent Variables	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Physical Activity	0.024	0.007	3.366	0.001
Sedentary Behavior	0.000	0.001	0.470	0.638

Participation in sports = SPORT; Participation in clubs = CLUBS; Time spent exercising = EXERCISE; Time spent in front of a television screen = TVTIME; Time spent with computers, cell phones, handheld video games, and other electronic devices = COMPUTER; TV in the bedroom = TVBED; Body mass index = BMI CLASS

Table 3. Estimated total, total indirect and direct effects

	Estimate	S.E.	Est./S.E.	P-Value
Effects from ADHD severity to BMI				
Total	0.073	0.033	2.236	0.025
Total indirect	0.037	0.011	3.527	0.000
Specific indirect effects				
BMI				
Physical activity				
ADHD severity	0.035	0.010	3.339	0.001
BMI				
Sedentary behavior				
ADHD severity	0.003	0.003	0.877	0.381
Direct				
BMI				
ADHD severity	0.036	0.034	1.061	0.289

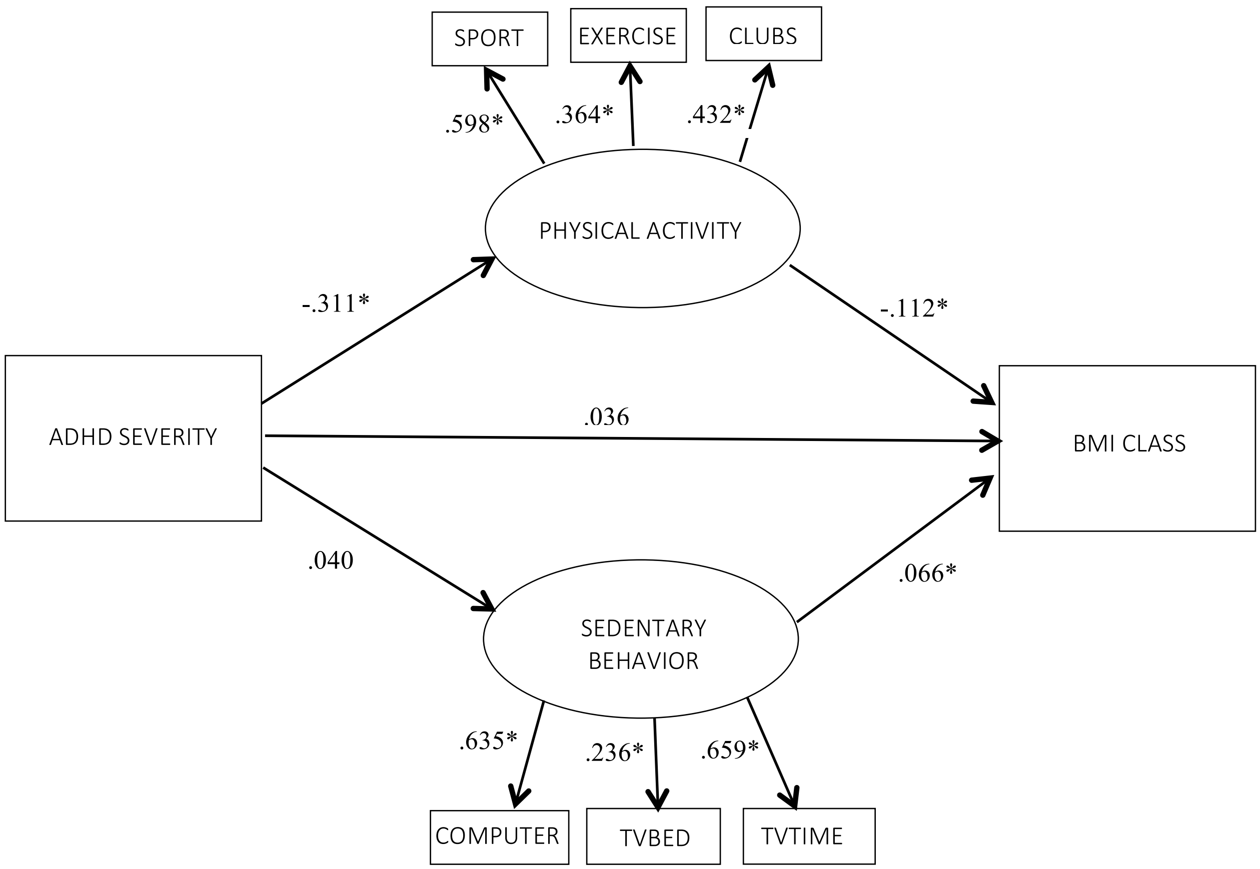

Figure 2. Model of associations between BMI, ADHD severity, sedentary behavior, and physical activity. Values with an asterisk represent statistically significant results. The model fits well according to the RMSEA (0.043, 90% confidence interval 0.036-0.050), CFI (0.937), TLI (.889), and SRMR (.025)

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Manuscript 3

Testing the Relationship between Attention-Deficit/ Hyperactivity Disorder and Obesity; Do Medication and Gender Moderate the Relationship?

Abstract

We tested a model of the path associations among sedentary behavior, physical activity, attention-deficit/hyperactivity disorder (ADHD) and obesity for moderating effects of medication and gender.

A cross-sectional study, using a sample from the 2011-2012 National Survey of Children's Health. A total of 3,788 participants, ages 11-17 years were included in this study.

The model fit the data well for gender, root mean square error of approximation [RMSEA]=0.052, comparative fit index [CFI]=0.850; Tucker-Lewis index [TLI]=0.775. The model also fit the data well for medication [RMSEA]=0.053; [CFI]=0.825; [TLI]=0.715. The estimates for the interaction by gender for the direct relationship between body mass index (BMI) and ADHD severity were as follows (estimate: 0.032; 90% CI-0.064, 0.128). The estimates for the interaction by medication on the direct relationship between BMI and ADHD severity were the following (estimate: 0.035; 90% CI-0.025, 0.096). The estimates for the interaction by medication on the relationship between physical activity and ADHD severity (estimate: -0.052; 90% CI-0.041, 0.96) and that of sedentary behavior and ADHD severity were (estimate: -0.330; 90% CI-0.974, 0.315). On BMI, the direct effect of ADHD severity was 0.036 and did not achieve statistical significance. However, the total effect for ADHD severity was 0.073 and was statistically significant.

The relationship between ADHD severity and BMI was mediated by physical activity and sedentary behavior. Medication and gender did not moderate the relationship between BMI and ADHD severity. Furthermore, medication did not moderate the relationship between physical activity and ADHD severity; nor between sedentary behavior and ADHD severity.

Keywords: adolescent obesity, gender, ADHD, medication, physical activity, impulsivity

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Background

Obesity and attention-deficit/hyperactivity disorder (ADHD) are both major public health conditions. Obesity affects an estimated 12.7 million children and adolescents in the United States (Ogden, et al., 2015). In addition, approximately 6.4 million children in the U.S., ages 4-17 years, have been diagnosed with ADHD (Visser, et al., 2014). Consequently, the trend seems to be increasing with those with a history of ADHD diagnosis by a health care provider increasing by 42% between 2003 and 2011 (Visser et al. 2014).

Symptoms of ADHD include inattention, impulsivity and hyperactivity. Children and adults diagnosed with ADHD show consistent patterns of these symptoms for a minimum of six months. In addition, there must be evidence that symptoms interfere with, or reduce the quality of, social, academic or work functioning (APA, 2013).

Obesity in children is defined as having a body mass index (BMI) at or above the 95^{th} percentile for children and adolescents of the same age and gender. Overweight is defined as having a BMI at or above the 85^{th} percentile and below the 95^{th} percentile of the same age and gender (Barlow, 2007; CDC, 2000). Preventing and treating these weight conditions is important because they are associated with a myriad of chronic illnesses, some examples are diabetes, heart disease and even certain types of cancer.

Additionally, children and adolescents who are overweight or obese are at greater risk for developing social and emotional problems, such as difficulties interacting with others, issues with self-esteem, depression, and problems at school (Schwimmer, 2003).

Recent studies, point toward a possible comorbidity between obesity and ADHD (Waring et al., 2008; Thomas et al., 2015; Visser et al., 2014; Erhart et al., 2012). Agranat-Meged et al. found children with ADHD have a significantly higher rate of obesity than children without ADHD (Agranat-Meged et al., 2005). Furthermore, despite the positive effects of physical activity on ADHD symptoms, children and adults with ADHD are less likely to engage in physical activity and more likely to engage in sedentary behavior (Waring and Lapane, 2008; Kim et. al., 2011; Nigg et. al., 2013). In addition, low physical activity is a contributing factor for obesity among US youth with ADHD (Acevedo-Polakovich et al., 2006; Burdette and Whitaker, 2005).

Our interest in testing this association and the possible moderating effect of medication arose from previous studies showing the effects of ADHD medications on the catecholaminergic system and thereby improving executive function capabilities leading to healthier choices; for example increased physical activity and less sedentary behaviors (Cortese and Vincenzi, 2012; Schwart, et al., 2014; Kim, et al. 2011). A better understanding of the potential comorbid relation between obesity and ADHD is pertinent because it may lead to knowledge about the possible causal pathology underlying both ADHD and obesity. Also, for clinicians, comorbidity of these two conditions could have significance for the treatment of patients with both ADHD and obesity, leading to simultaneous interventions for both conditions when they coexist (Cortese et al., 2008).

Previous studies explored the direct relationship between ADHD and obesity however there is a lack of research on factors that may mediate or moderate this relationship. This study aimed to a) examine the direct and indirect associations of ADHD on BMI via sedentary behavior and physical activity; b) test the possible moderating effect of ADHD medication and gender on the direct path association between ADHD and BMI and c) examine the moderating effect, if any, of ADHD medication on the relationship between ADHD and physical activity and sedentary behavior.

Methods

This study employed data from National Survey of Children's Health (NSCH) 2011/2012 database. This is a public use dataset available through the Data Resource Center for Child and Adolescent Health Measurement Initiative (DRC). The participants in the NSCH 2011/2012 survey were obtained from telephone interviews conducted from February 2011 through June 2012 by the Centers for Disease Control and Prevention (CDC), National Center for Health Statistics. These interviews were completed by parents/caregivers, who knew the child or adolescent well (Table 1). The NSCH provides a broad range of information about the health of children and adolescents, ages <18 years in the U.S. The 2011/2012 NSCH resulted in a total of 95,677 interviews. Based on the inclusion and exclusion criteria, 3,788 participants remained in our study sample.

The inclusion criteria for our study were being 11-17 years of age and having ever been diagnosed with ADHD. We limited our study sample to adolescents to help control for developmental differences between very young children and those who are older.

Exclusion criteria were having cerebral palsy, bone joint or muscle problems, vision problems that cannot be corrected with lenses, or not owning a TV or computer.

We used Mplus 6.1 statistical software to analyze the data (Muthen & Muthen, Los Angeles, CA). The statistical method employed to test our hypotheses was structural equation modeling (SEM). Interactions for gender and medication were tested using the interaction command in Mplus. The goodness of fit indices used to assess the model included Root Mean Square Standard Error of Approximation (RMSEA), the Comparative Fit Index (CFI), and the Tucker-Lewis Index (TLI). A value less than 0.06 indicates a good fit for RMSEA. For CFI and TLI values close to 0.95 correspond to a good model fit (Kline, 2011).

In addition, the standardized loadings for measured indicators on latent constructs and composite reliabilities for each of the latent variables were reported. Loadings greater than 0.3, with statistical significance, demonstrate that the measured indicators are good measures of the constructs (Kline, 2011; Nesbit, 2015).

Results

The average age of participants in our sample was 13.9 ± 2.0, with ranges from 11-17 years; of 3,788 adolescents 70.80% were males and 29.20% were females. The distribution of the sample by ADHD severity groups was about equal, with 49.08% reporting mild ADHD symptoms and 50.92 reporting moderate to severe ADHD symptoms. As for BMI, 14.8% of participants were obese and 15.60% were considered overweight.

Based on the goodness of fit measures of the SEM analysis the model fitted the data from adolescents with ADHD well. The results for the RMSEA (0.043, 90% confidence interval 0.036-0.050), CFI (0.937), TLI (0.889), and SRMR (0.025) suggest a good model fit (Figure 1).

The reliability estimates showed that the latent constructs accounted for 2.4% of the variance in BMI ($p<.0001$). Furthermore, the latent constructs influencing physical activity and sedentary behavior accounted for a modest but statistically significant percentage of the variance ($p= 0.0001$ for all estimates) (Table 2). On BMI, the direct effect of ADHD severity was 0.036 and was not statistically significant. However, the total effect was statistically significant. The indirect effect of ADHD severity that passed through physical activity was 0.035 and was statistically significant. The indirect effect of ADHD severity that passed through sedentary behavior was 0.003 and was not statistically significant. However, the total indirect effect for ADHD was 0.037 and was statistically significant. Lastly, the total effect for ADHD severity was 0.073 and was statistically significant (Table 3).

The standardized loadings for the indicator variables were statistically significant with values >0.30 (Figure 1). Hence, the indicator variables used in the model were all good measures of the constructs defined in the model (Figure 1).

When testing for the interaction of gender, the model fitted the data well with RMSEA (0.052). CFI (0.850), TLI (0.775) suggesting a good model fit. Similarly, the model also fitted the data well for medication [RMSEA] 0.053; [CFI] 0.820; [TLI] 0.715. However, neither gender nor medications were found to moderate the relationship between BMI and ADHD severity. Gender did not moderate the relationship between

BMI and ADHD severity (estimate: 0.032; 90% CI -0.064, 0.128). Medication also did not moderate the relationship between BMI and ADHD severity (estimate: 0.035; 90% CI -0.025, 0.096). In addition, medication did not moderate the relationship between physical activity and ADHD severity (estimate: -0.052; 90% CI -0.041, 0.96) and that of sedentary behavior and ADHD severity (estimate: -0.330; 90% CI -0.974, 0.315) (Figure 1).

Discussion

In the process of conceptualizing a plausible model and testing interactions, one must understand the etiology of ADHD and obesity. Models of ADHD propound that a lack in frontal lobe function are responsible for the various cognitive and behavioral symptoms of ADHD (Gapin " The effects of physical activity on"). For example, when comparing brain scans of a group of ADHD individuals versus non-ADHD, the most notable differences were in the area of the prefrontal cortex (Durston, 2003, Bush et. al., 2005). As described by Diamond, executive functions are a set of neuropsychological processes mediated by the prefrontal cortex. Therefore deficiencies in the prefrontal cortex are thought to negatively affect executive functions (Diamond, 2013). Executive functions are necessary to carry out many of the skills that are important in our everyday lives. Executive functions aide us in achieving daily goals, tasks and challenges, allowing us to concentrate or focus, exercise discipline, and self control (Wilcutt et. al., 2005; Diamond, 2013). Furthermore, there is a growing number of research in the genetic, neurobiological and pharmacotherapy areas showing the positive effects psychostimulants have on executive functions by acting as dopaminergic and noradrenergic agonists (Pliszka et al., 2006; Swanson et.al., 2006; Faraone et. al., 2005; Graziano 2012; Albayrak et. al., 2013).

We were interested in testing the hypothesis that medication moderates the relationship between ADHD severity and BMI, physical activity and sedentary behavior. The reasoning being that if medication works by improving executive functions, then those on medication are more likely to engage in healthier habits, hence increase exercise and decrease sedentary time. Despite extensive research on the positive effects physical activity has on an adult's mind and body, the effects of physical activity on behaviors and the psychological state of children with ADHD remain understudied. (Faraone et. al., 2008; Cortese et. al., 2008; Gapin et. al., 2011). As for gender, well defined biological differences as well as differences in manifestations of symptoms prompted us to explore gender as a moderator in the direct path association between ADHD severity and BMI status. Insight into the behavioral mechanism underlying the relationship between obesity and ADHD should provide clinicians, researchers and public health advocates with knowledge to best tailor obesity prevention and intervention programs for both obese and ADHD diagnosed patients.

Findings from this research are consistent with previous literature linking ADHD and obesity. This study goes further by including the severity of ADHD and exploring mediating mechanisms (physical activity, sedentary behavior) and moderating factors (gender, medication); thereby developing a model explaining a portion of the relationship between ADHD and BMI. In addition, better understanding variables that might moderate this relationship have important implications for the treatment and prevention strategies used when considering these comorbid conditions.

Studies thus far have been mostly clinical in setting; more methodologically rigorous population based studies are needed. Our study, used a large national dataset based on self-report information which may suffer from limitations. Future studies might consider using standardized and formal diagnosis for ADHD, overweight and obesity. In addition, prospective studies should control for potential confounders such as psychiatric and physiological comorbid disorders. Also, more longitudinal studies to facilitate gaining knowledge about the causal pathway for the association between ADHD and obesity are needed. Further more, it would be most beneficial to produce research collecting detailed data on medication use and physical activity since both can have positive effects on the adrenergic system leading to improvements in ADHD symptoms and consequently the weight outcome of a person. Medication usage should be formally obtained, so that dosage, length of time the medication is taken and type of medication are all taken into account in the analysis. Lastly, future studies should include younger study participants. As the average age of ADHD diagnosis is seven years old and studies show those with the most severe ADHD are diagnosed at early ages (Visser et al., 2014).

It is important to gain a better understanding of the causal workings of the relationship between ADHD and obesity in order to best guide preventive strategies for the development of obesity among those diagnosed with ADHD as well as implement efficacious interventions for those who are already obese and diagnosed with ADHD.F urther research is needed examining the relationship between ADHD and obesity and the effects of medication to treat ADHD, on appetite and executive functions. We believe it is necessary to study this relationship in order to answer the question "Why do children with ADHD who are not taking medication for treatment more at risk to be overweight as opposed to those diagnosed with ADHD and taking medication to treat the condition (Waring & Lapane, 2008; Ptacek et al. 2009)? "Is it the appetite suppressing side effect of ADHD medication or is it an improvement in behavioral regulation and therefore healthier eating habits that leads to lower weight among those with ADHD who are treated with medication" (Quesada et. al. 2018)?

Conclusion

Our model shows that there is a significant relationship between ADHD severity and BMI mediated by physical activity and sedentary behavior. However, medication and gender did not significantly moderate the relationship between BMI and ADHD severity in our study. Furthermore, medication did not moderate the indirect relationship between physical activity and ADHD severity. Nor did it moderate the indirect relationship between sedentary behavior and ADHD severity. However, because of the physiological and behavioral theory discussed we believe further research is needed to explore the effects of ADHD medication on this relationship. If there is a difference in risk for obesity among those who are medicated versus those who are not, then intervention strategies and clinicians implementing these strategies would be best guided by this knowledge.

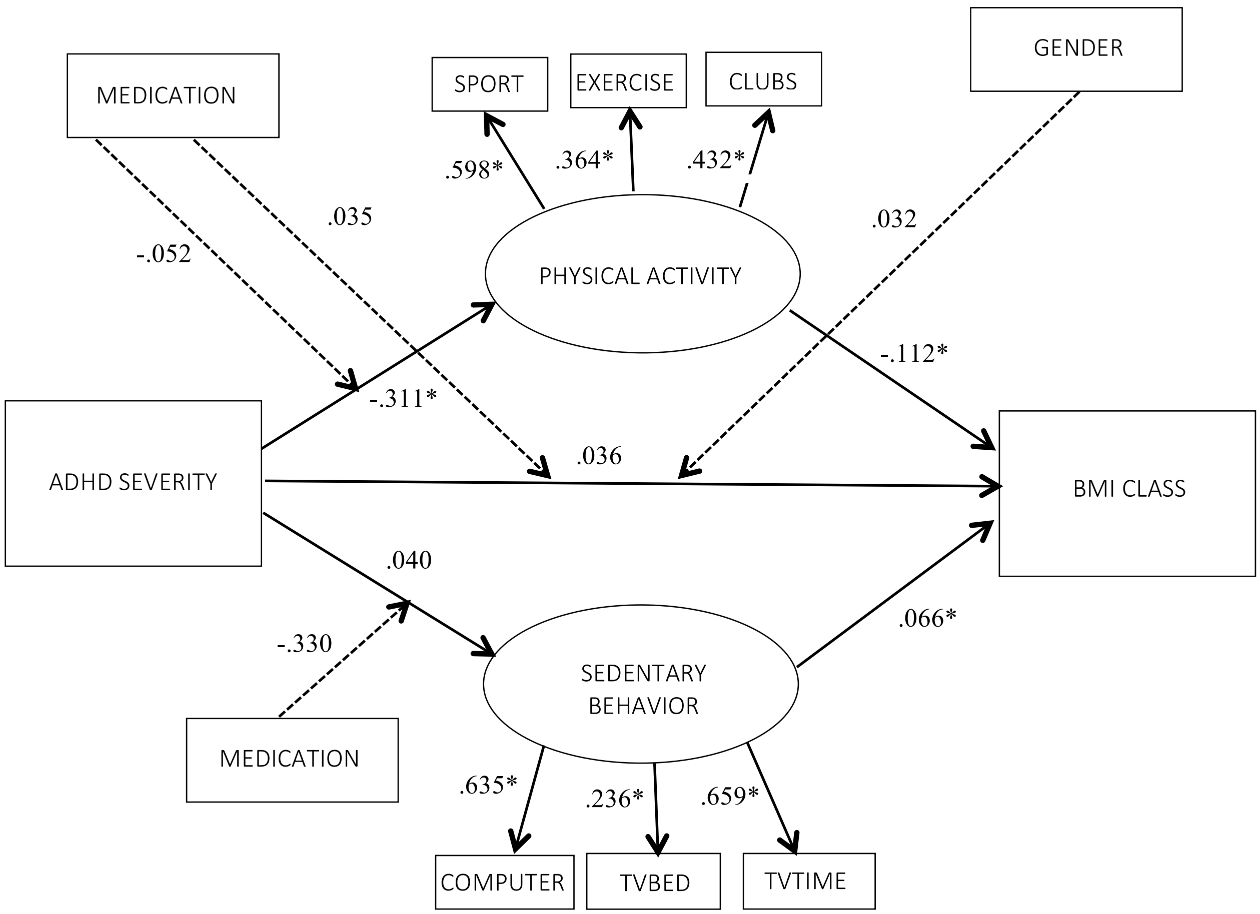
Table 1. Measured and latent variables in the model

Variable name	Variable definition	Variable values
Obesity (measured)	BMI class	1, Underweight= Less than the 5th percentile 2, Healthy weight= 5th percentile to less than the 85th percentile 3, Overweight= 85th percentile to less than the 95th percentile 4, Obese= Equal to or greater than the 95th percentile
ADHD (measured)	ADHD severity	2, mild 3, moderate or severe
Sports (measured)	During the past 12 months, was selected child on a sports team or did [he/she] take sports lessons after school or on weekends?	0, No 1, Yes
Exercise (measured)	During the past week, on how many days did selected child exercise, play a sport, or participate in physical activity for at least 20 minutes that made [him/her] sweat and breath hard?	Number of days
Clubs (measured)	During the past 12 months, did [he/she] participate in any clubs or organizations after school or on weekends?	0, No 1, Yes
TV time (measured)	On an average weekday, about how much time does selected child usually spend in front of a TV watching TV programs, videos, or playing video	Number of hours

	games?	
TV in bedroom (measured)	Is there a television in your child's bedroom?	0, No 1, Yes
Computer time (measured)	On an average weekday, about how much time does selected child usually spend with computers, cell phones, handheld video games, and other electronic devices?	Number of hours
Medication (measured)	Is selected child currently taking medication for ADD or ADHD?	0, No 1, Yes
Gender (measured)	Sex of selected child	0, male 1, female
Physical activity (latent)	Levels of physical activity	Based on sports, clubs and days exercise
Sedentary behavior (latent)	Levels of sedentary behavior	Based on computer time, TV in bedroom and TV time

Source: 2011/12 National Survey of Children's Health. Maternal and Child Health Bureau in collaboration with the National Center for Health Statistics. 2011/12 NSCH Indicator Data Set prepared by the Data Resource Center for Child and Adolescent Health, Child and Adolescent Health Measurement Initiative. www.childhealthdata.org .

Figure 2. Model of associations between BMI, ADHD severity, sedentary behavior, and physical activity with gender and medication as moderators.



Values with an asterisk represent statistically significant results. The model fits well according to the RMSEA (0.043, 90% confidence interval 0.036-0.050), CFI (0.937), TLI (.889), and SRMR (.025) The dotted lines represent statistically non-significant moderating pathways.

Table 2. Estimated reliabilty of measured and latent variables

R-square				
Observed Variables	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Participation in sports	0.357	0.032	11.151	0.000
Participation in clubs	0.187	0.019	9.599	0.000
Time spent exercising	0.132	0.016	8.103	0.000
Time spent in front of a television screen	0.435	0.032	13.505	0.000
Time spent with computers, cell phones, handheld video games, and other electronic devices	0.403	0.030	13.315	0.000
TV in the bedroom	0.069	0.011	6.515	0.000
Body mass index	0.024	0.007	3.679	0.000
Latent Variables	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Physical Activity	0.024	0.007	3.366	0.001
Sedentary Behavior	0.000	0.001	0.470	0.638

Participation in sports = SPORT; Participation in clubs = CLUBS; Time spent exercising = EXERCISE; Time spent in front of a television screen = TVTIME; Time spent with computers, cell phones, handheld video games, and other electronic devices = COMPUTER; TV in the bedroom = TVBED; Body mass index = BMI CLASS

Table 3. Estimated total, total indirect and direct effects

	Estimate	S.E.	Est./S.E.	P-Value
Effects from ADHD severity to BMI				
Total	0.073	0.033	2.236	0.025
Total indirect	0.037	0.011	3.527	0.000
Specific indirect effects				
BMI				
Physical activity				
ADHD severity	0.035	0.010	3.339	0.001
BMI				
Sedentary behavior				
ADHD severity	0.003	0.003	0.877	0.381
Direct				
BMI				
ADHD severity	0.036	0.034	1.061	0.289

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Conclusions

This dissertation provides further evidence that an association between ADHD and weight outcomes exits. Furthermore, this research adds to the literature in the field by presenting a model of behavioral mechanisms that drive the association between ADHD and BMI outcome. The model tested, demonstrates that physical activity and sedentary behavior mediate the relationship between ADHD severity and BMI in adolescents. Also, medication and gender were found to not moderate the relationship between ADHD and BMI. However, based on the evidence presented in the literature, for the effects of ADHD medication on executive function and therefore behavior, we believe more research is needed to determine the role of medication in the relationship between ADHD and weight outcome. Also, understanding the moderating effects of medication on the relationship between ADHD and obesity in children and adolescents is necessary in order to gain knowledge as to why children with ADHD, who are on medication, have lower weight than their counterparts. Is it the appetite suppressing side effect of ADHD medication or is it an improvement in behavioral regulation and therefore healthier habits that leads to lower weight among those with ADHD who are treated with medication?

This research was successful in gaining new insights and understanding of the behavioral paths that account for the strong link between ADHD and obesity, however more research is needed to better understand the workings between these two etiologically complex heath conditions. The knowledge gained through this research will aide clinicians, researchers and public health advocates to best tailor obesity prevention and intervention programs for those with ADHD and obesity.

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PUBLICATIONS AND PRESENTATIONS

Quesada, D., Ahmed, N. U., Fennie, K. P., Gollub, E., Ibrahimou, B. (2018). *A Review: Associations Between Attention-deficit/hyperactivity Disorder, Physical Activity, Medication Use, Eating Behaviors and Obesity in Children and Adolescents.* Archives of Psychiatric Nursing, Feb 2018 (In press) DOI: 10.1016/j.apnu.2018.01.006 .

Quesada, D., Ahmed, N. U., Fennie, K. P., Ibrahimou, B. (2018). *A Model Assessing Mediating Effects of Attention-Deficit/Hyperactivity Disorder on Physical Activity, Sedentary Behavior, and Obesity*. Preventive Medicine Reports (Positive review with revision).

Quesada, D., Ahmed, N. U., Fennie, K. P. (2018). *Testing the Relationship between Attention-Deficit/ Hyperactivity Disorder and Obesity; Do Medication and Gender Moderate the Relationship?* Preventive Medicine Reports (Submitted).

HARC
Presentation of research at 2011 HARC (Health Literacy Annual Research Conference) Chicago, Illinois, Oct. 17-18 2011. *Obesogenic Parent Behaviors in the Care of 2 Month Olds in the GreenLight Study: Role of Parent Health Literacy*
Shonna H. Yin MD (presenter), NYU School of Medicine; Eliana M. Perrin MD, MPH, UNC Chapel Hill; Lee M. Sanders MD, MPH, University of Miami School of Medicine; Russell Rothman MD, MPP, Vanderbilt University School of Medicine; Danielle Quesada MPH, University of Miami School of Medicine; Andrea Bachus, Vanderbilt University; Beth Throop, UNC Chapel Hill; Maria E. Cerra, NYU School of Medicine.