Adiposity, Aerobic Fitness and Depressive Symptomology in Children at Risk for Obesity

By

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Abstract

Elevated levels of adiposity in children have been tied to various pathologies including increased depressive symptomology. Aerobic fitness has been associated with reductions in adiposity and depressive symptomology and may moderate the association between these variables. This study examined this association. Five hundred and two children completed questionnaires on depressive symptoms, were tested for VO$_2$ Peak, and underwent a DEXA scan to measure adiposity. Adiposity and aerobic fitness were tested as predictors of depressive symptomology while controlling for age, pubertal status and socioeconomic status. For boys, aerobic fitness but not adiposity was a significant correlate of depressive symptomology. The interaction between adiposity and aerobic fitness was significant. In girls, adiposity but not aerobic fitness was a significant correlate of depressive symptomology. The interaction between adiposity and aerobic fitness was not significant. These findings highlight sex-specific factors, which may inform targeted approaches to prevent and treat depressive symptoms in children.
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Chapter 1
Introduction

1 Introduction

Globally, the prevalence of overweight/obese status in children (youth under 18 years of age) has risen significantly in the past 30 years (Ng et al., 2014). Specifically, rates of overweight/obese status in children have risen by 47% from 1980 to 2013 (Ng et al., 2014). Canada is no exception to these global trends as the prevalence of overweight/obese Canadian children has also significantly increased in the past 25 years (Shields & Tremblay, 2010). For example, in 1979, approximately 23% of Canadian children were classified as overweight/obese, but in 2013 this prevalence had increased to over 30% (Rao, Kropac, Do, Roberts, & Jayaraman, 2016). Commonly cited reasons for this upward trend in childhood adiposity levels include factors such as increased caloric intake, increased sedentary behavior, and reduced levels of physical activity (Kumar & Kelly, 2017; Lobstein, Baur, & Uauy, 2004). Overall, this overweight/obese epidemic in children represents a significant public health concern given that elevated levels of adiposity (overweight/obese status) have been associated with various negative health outcomes of both a physiological and psychological nature (Kumar & Kelly, 2017).

The correlates of elevated adiposity in children are troublesome from both a physiological and psychological standpoint (Kumar & Kelly, 2017; Lobstein et al., 2004). Some of the physiological correlates of elevated adiposity in children include the following: type 2 diabetes, insulin resistance, dyslipidemia, hypertension, chronic inflammation and non-alcoholic fatty liver disease (Ebbeling, Pawlak, & Ludwig, 2002; Kumar & Kelly, 2017). There is further evidence to suggest that elevated adiposity is associated with increased levels of inflammation (Sacheck, 2008) which in turn may be linked to the early pathogenesis of cardiovascular disease (CVD) in
children (Sacheck, 2008; Thomas & Williams, 2008). Taken together, elevated adiposity in children appears to be a risk factor for various secondary pathologies (Ebbeling et al., 2002; Kumar & Kelly, 2017) as well as having implications for future health complications (Ebbeling et al., 2002; Sacheck, 2008).

There are various negative psychological correlates of elevated levels of adiposity in children (Nemiary, Shim, Mattox, & Holden, 2012; Sanders, Han, Baker, & Cobley, 2015). Depressive symptomology, in particular, is frequently elevated in children classified as overweight/obese (Csábi, Tényi, & Molnár, 2000; Dockray, Susman, & Dorn, 2009; Nemiary et al., 2012; Sanders et al., 2015). Various psychosocial factors have been proposed to play a role in the relationship between elevated levels of adiposity and depressive symptomology in children. Factors such as body image dissatisfaction, peer bullying, pressure to be thin, and body shape concern may explain the relationship between increased adiposity levels and depressive symptomology in this population (Allen, Byrne, Blair, & Davis, 2006; Chaiton et al., 2009; Nemiary et al., 2012). Specifically, body dissatisfaction has been shown to be a key factor in both boys and girls (Kostanski, Fisher, & Gullone, 2004) as it is has been tied to the emergence of depressive symptoms (Smolak, 2004). Girls may experience body dissatisfaction related to increased adiposity (Kostanski et al., 2004) which violates a sociocultural pressure to be thin (Smolak, 2004) while boys may experience body dissatisfaction owing to a failure to meet a sociocultural drive for muscularity (Kostanski et al., 2004). In both sexes, the ensuing body dissatisfaction has been linked to depressive symptomology (Chaiton et al., 2009; Smolak, 2004). Thus, there are various negative correlates of elevated adiposity in children, in both the physiological and psychological realms.

While a concern for children’s health, elevated adiposity also has implications for future body composition (Serdula et al., 1993; Srinivasan et al., 2005). For instance, childhood body
mass index (BMI) and triceps skinfold thickness have been associated with adult BMI and adiposity (Srinivasan et al., 2005). In addition, obese children are at a two-fold risk of obesity as adults when compared to their non-obese counterparts (Serdula et al., 1993). Therefore, childhood adiposity levels appear to be predictive of future body composition in adulthood, suggesting that children with elevated adiposity may be at risk for unhealthy body composition in the future (Serdula et al., 1993; Srinivasan et al., 2005). As such, childhood constitutes a critical time period for interventions, which may prevent the perpetuation of this condition.

Research on adiposity in children has commonly used BMI as the marker of adiposity (Flegal & Ogden, 2011) which is calculated from body weight divided by height squared (Nemiary et al., 2012). Though there are some discordant findings (Bazargan-Hejazi, Alvarez, Teklehaimanot, Nikakhtar, & Bazargan, 2010; Hillman, Dorn & Bin Huang., 2010), research using this measure has consistently demonstrated a positive association between elevated adiposity and depressive symptomology in both boys and girls (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2012). However, the use of BMI in children has been subject to some criticism as this measure may be accurate in assessing levels of adiposity in children who are overweight/obese, but may not be as accurate in leaner children where fat-free mass may account for differences in BMI values (Freedman et al., 2005). Consequently, some research has used more targeted measures of adiposity, specifically dual-energy X-ray absorptiometry (DEXA) scans (Hillman et al., 2010; Morrison, Shin, Tarnopolsky & Taylor, 2014) which may be used to measure various elements of body composition such as lean body mass, bone mass, and fat mass (adiposity) (Haarbo, Gotfredsen, Hassager, & Christiansen, 1991). Interestingly, some research has even demonstrated an association between adiposity and depressive symptomology when using adiposity measured via DEXA scans as opposed to BMI in children (Hillman et al., 2010; Morrison et al., 2014), suggesting the importance of using the most accurate measurements of
adiposity to examine this association. Overall, research has demonstrated a positive relationship between higher levels of adiposity, as measured by DEXA, and depressive symptomology in children (Hillman et al., 2010; Morrison et al., 2014). Exploration of the variables that may influence this association is warranted, and one factor that may play a role is aerobic fitness.

Levels of aerobic fitness in Canadian children have also demonstrated an unfavorable trend as its levels in this population have declined in recent years (Roberts, Shields, De Groh, Aziz, & Gilbert, 2012). Furthermore, within lifespan development, aerobic fitness levels also decline as children develop and approach adulthood (Roberts et al., 2012). This is unfortunate as aerobic fitness has demonstrated a beneficial association with various markers of both psychological and physiological health outcomes (Ortega, Ruiz, Castillo, & Sjöström, 2008). For example improved aerobic fitness has been associated with a healthier levels of blood triglycerides and lipoprotein levels as well as levels of depression, anxiety and self concept (Ortega et al., 2008). In conjunction with the rise of overweight/obese status in children (Shields & Tremblay, 2010), various aspects of children’s health may be at risk owing to such reductions in aerobic fitness levels.

There is a complex interaction between adiposity and aerobic fitness in children. Elevated adiposity has been shown to play a role in the reduction of aerobic fitness levels in children as it has been hypothesized that the added load of excess adipose tissue may be responsible for a concomitant reduction in aerobic fitness (Olds, Ridley & Tomkinson, 2007). Concurrently, improved aerobic fitness has been linked to reduced levels of overweight/obese status in children (Janssen & LeBlanc, 2010; Ortega et al., 2008). In addition, children who participate in higher levels of physical activity, which is associated with improved aerobic fitness (Ortega et al., 2008; Strong et al., 2005), demonstrate reduced levels of adiposity (Strong et al., 2005) and reduced risk factors for CVD (Ortega et al., 2008), thus highlighting inverse associations of aerobic
fitness with both elevated adiposity and its associated negative health outcomes. In conclusion, there appears to be a negative association between aerobic fitness and adiposity in children (Janssen & LeBlanc, 2010; Ortega et al., 2008) suggesting a protective role of aerobic fitness in its association with elevated adiposity in this cohort.

While research examining the association between aerobic fitness and mental health in children is limited (Ortega et al., 2008), there is evidence for a relationship between elevated levels of physical activity and improvements in measures of mental health such as reduced depressive symptomology, reduced anxiety symptomology and improved self-esteem (Ahn & Fedewa, 2011; Biddle & Asare, 2011; Ortega et al., 2008). Furthermore, increased aerobic fitness levels have been demonstrated to be inversely related to depressive symptomology in children (Esmaeilzadeh, 2015; Greenleaf, Petrie, & Martin, 2010; Ruggero, Petrie, Sheinbein, Greenleaf, & Martin, 2015). At the same time, lower levels of aerobic fitness have been shown to place children at an elevated risk of experiencing depressive symptoms (Rieck, Jacksen, Martin, Petrie, & Greenleaf, 2013) and children with elevated depressive symptomology demonstrate lower aerobic fitness compared to their non-depressed counterparts (Shomaker et al., 2012).

The importance of aerobic fitness during childhood years also has implications for future health status as aerobic fitness has been demonstrated to predict health status in early adulthood (Schmidt, Magnussen, Rees, Dwyer, & Venn, 2016). Furthermore, aerobic fitness interventions implemented during childhood and adolescence may exert a long-term beneficial effect as physical activity habits formed in this time period have been shown to track into young adulthood (Telama et al., 2005). Therefore, these years represent a time period where interventions to promote healthy living may be especially effective for long-term health status.

In summary, elevated levels of adiposity in children constitutes a major health concern as this condition is linked to various negative health outcomes which impact both physiological and
psychological well being (Ebbeling et al., 2002; Nemiary et al., 2012). Depressive symptomology, in particular, is strongly linked to elevated adiposity in children (Morrison et al., 2014). Fortunately, aerobic fitness has demonstrated an inverse association with both depressive symptomology (Ruggero et al., 2015) and elevated adiposity in children (Ortega et al., 2008). As such, aerobic fitness warrants examination as a variable capable of influencing the association between adiposity and depressive symptomology in children.

The purpose of this thesis was to (i) examine the association between adiposity and depressive symptomology in children at risk for obesity and (ii) test aerobic fitness as a moderator of this association.

The following research questions were proposed:
RQ1. Is adiposity associated with depressive symptomology in children at risk for obesity?
RQ2. Is aerobic fitness associated with depressive symptomology in children at risk for obesity?
RQ3. Does aerobic fitness moderate the association between adiposity and depressive symptomology in children at risk for obesity?

It was hypothesized that adiposity would be positively associated with depressive symptomology. It was further hypothesized that aerobic fitness would be inversely associated with depressive symptomology. Finally, it was hypothesized that aerobic fitness would moderate the association between adiposity and depressive symptomology, with higher levels of aerobic fitness weakening the association between adiposity and depressive symptomology.

1.1 Literature Review

1.1.1 Adiposity

In Canada, elevated levels of adiposity constitute a major public health concern as rates of overweight (Body Mass Index [BMI] = 25.0 - 29.9) and obese (BMI ≥ 30) (Shields & Tjepkema, 2006) statuses have risen significantly (Twells, Gregory, Reddigan & Midozi, 2014).
For instance, from 1985 to 2011 the prevalence of overweight Canadian adults (≥ 18 years of age) increased from 27.8 percent to 33.6 percent and the prevalence of obese Canadian adults rose from 6.1 percent to 18.3 percent (Twells et al., 2014). Equally troublesome are the findings in Canadian children, as there has also been an increase in rates of overweight/obese status in this cohort in the past 30 years (Shields & Tremblay, 2010). Presently, approximately 30 percent of Canadian children (6 – 17 years of age) are considered overweight/obese (Rao et al., 2016). Given the recent trends, there is now an especially high prevalence of overweight/obese Canadian adults and children, which has multiple implications for the health of these populations (Kumar & Kelly, 2007).

Elevated levels of adiposity have been tied to various negative pathologies in both adults (Djalalinia, Qorbani, Peykari, & Kelishadi, 2015) and children (Kumar & Kelly, 2007). Adults with increased adiposity are at an augmented risk of various pathologies such as type 2 diabetes, hypertension, cardiovascular disease, arthritis and cancer (Djalalinia et al., 2015). Furthermore, there is evidence for various negative mental health correlates for this condition such as low self-esteem, body image dissatisfaction, eating disorders and depression (Djalalinia et al., 2015). As such, being overweight/obese represents a major health risk that extends into various realms, threatening the wellbeing of men and women. However, the correlates of heightened adiposity in children are less clear as the associated health related problems do not typically present until later in life during adulthood (Shields & Tremblay, 2010) though comorbidities previously considered exclusive to the adult population are now becoming apparent in childhood (Kumar & Kelly, 2017). Similarly to adults, the comorbidities linked to increased adiposity in children also span various realms of health and wellbeing (Kumar & Kelly, 2017). From a cardio metabolic standpoint, excess adiposity in children has been linked to insulin resistance, the development of type 2 diabetes, high blood pressure, and elevated blood levels of triglycerides (Kumar & Kelly,
As well, elevated levels of inflammatory markers, often observed in children with elevated levels of adiposity (Sacheck, 2008), have been linked to the development of cardiovascular disease (CVD) in this cohort (Thomas & Williams, 2008). Still, obese/overweight children are at an increased risk of asthma, obstructive sleep apnea, non-alcoholic fatty liver disease and various musculoskeletal problems (Kumar & Kelly, 2017). Taken together, there is ample evidence to suggest negative health effects of being overweight/obese, which are already present in children, have implications for both present and future health status as well.

Childhood appears to be an important time in predicting future health status in adulthood as increased adiposity during this time period tracks strongly into adulthood (Kumar & Kelly, 2017; Lobstein et al., 2004; Serdula et al., 1993; Srinivasan et al., 2005) and children with elevated levels of adiposity will likely continue to carry it as adults (Kumar & Kelly, 2017). At the same time, higher levels of adiposity in childhood have been shown to predict future risk of CVD in adulthood (Daniels, 2006) demonstrating the importance of this time period for future health status. Thus, the prognosis for overweight/obese children is not favorable given the persistence of this condition into adulthood (Kumar & Kelly, 2017) as well as its associated comorbidities (Daniels, 2006). Therefore, interventions, which can both prevent and treat increased adiposity in this cohort, are vital to prevent present and later pathologies related to this condition.

While increased levels of adiposity in children have already been strongly linked to various negative physiological pathologies (Kumar & Kelly, 2017; Lobstein et al., 2004), there is also evidence which has demonstrated an association between high levels of adiposity and poor mental health in this same cohort (Lobstein et al., 2004; Morrison et al., 2014). Children with elevated levels of adiposity have frequently presented with poor mental health exemplified by body image dissatisfaction, low self-esteem, and depressive symptomology (Chaiton et al., 2009;
Morrison et al., 2014). In particular, depressive symptomology has been linked to elevated adiposity in this cohort (Anderson, Cohen, Naumova, Jacques & Must, 2007; Morrison et al., 2014; Mühlig, Antel, Föcker, & Hebebrand, 2016). There have been various mechanisms proposed for the link between adiposity and depressive symptomology from both a psychosocial as well as physiological perspective (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2012; Shelton & Miller, 2010).

From a psychosocial standpoint, multiple variables have been proposed to play a role in the relationship between high levels of adiposity and depressive symptomology in children. Concern about body weight/shape, body dissatisfaction, pressure to be thin, and negative social evaluation have been shown to play a part in the association between overweight/obesity and depressive symptomology in children (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2012). It has been proposed that overweight/obese children experience these factors owing to their weight status and this in turn may contribute to their experience of depressive symptoms (Chaiton et al., 2009). Thus, there is a complex interplay between adiposity, various psychosocial factors and depressive symptomology in children with multiple different psychosocial variables proposed to influence this relationship.

From a physiological perspective, there also are factors, which may be involved in the association between elevated adiposity and depressive symptoms in children. For example, in children, there is evidence for an association between inflammation and depressive symptoms, through there is evidence for bi-directionality in this association and longitudinal examination of this relationship is required (Byrne, O’Brien-Simpson, Mitchell, & Allen, 2015; Kim, Szigethy, Melhem, Saghafi, & Brent, 2014). Still, heightened levels of inflammatory markers are commonly found in children who are overweight/obese (Sacheck, 2008; Shelton & Miller, 2010) suggesting that adiposity and depression may be linked via inflammatory factors (Shelton &
Miller, 2010). However, improvements in children’s aerobic fitness have an inverse association with levels of adiposity (Ortega et al., 2010), its associated inflammatory levels (Ruiz, Ortega, Warnberg, & Sjöström, 2007) and depressive symptoms (Ortega et al., 2008). Given these associations it may be important to examine whether aerobic fitness moderates the association between adiposity and depressive symptoms in children.

While much evidence supports the association between adiposity and depressive symptoms in children (Anderson et al., 2007; Morrison et al., 2014; Mühlig, Antel, Föcker, & Hebebrand, 2016) some studies have shown no association between adiposity, as measured via BMI, and depressive symptoms (Bazargan-Hejazi et al., 2010; Hillman et al., 2010). To properly assess these discordant findings, it is important to acknowledge limitations of these studies, which may influence results. Studies on this association have examined children at different points of development (Anderson et al., 2007; Chaiton et al., 2009) which may introduce confounding factors. For instance, pubertal changes (e.g. hormonal alterations) and morphological changes may influence levels of depressive symptomology in children (Angold, Costello, & Worthman, 1998). Therefore, studies, which examine boys and girls at different points of pubertal development, may yield diverse results owing to these developmental influences. Thus, caution must be taken in comparing results across studies, which may examine children at different stages of development where pubertal changes may influence findings.

Some research has demonstrated this relationship may be sex-specific (Anderson et al., 2007; Chaiton et al., 2009). Specifically, some studies have demonstrated that girls, in particular, may be more likely to demonstrate a positive association between elevated levels of adiposity and depressive symptomology which may not occur to the same extent in boys (Anderson et al., 2007; Chaiton et al., 2009). For example, in a sample of 13 and 16 year old boys and girls, adiposity, as measured by BMI and skinfold thickness, predicted depressive symptomology in
girls but not boys (Chaiton et al., 2009). Interestingly, adiposity did not predict depressive symptomology directly in girls but rather indirectly through its association with pressure to be thin and body dissatisfaction (Chaiton et al., 2009) thus suggesting that perceptions of weight status play an important role in this relationship for girls. Explaining this sex difference, the authors postulated that the “thin ideal”, the cultural standard of female beauty in Western society (Flynn, 1997), is a social pressure which girls especially are vulnerable to and which makes them more likely to experience depressive symptomology as a result of increased adiposity which violates this cultural norm (Chaiton et al., 2009). Similar findings emerged in a study of 701 male and female youth with an average age of 14.7 years (Anderson et al., 2007). In males, increased weight status, as measured using BMI Z – Score, was not associated with an increased risk of future major depressive disorder (MDD) (Anderson et al., 2007). However, in females, obesity (BMI Z – score above age and gender specific 95th percentile) was associated with a 3 fold increased risk of being identified with subsequent MDD compared to their non–overweight counterparts (Anderson et al., 2007). Similarly, to Chaiton and colleagues (2009), Anderson et al. (2007) theorized that the increased social pressure for thinness in girls in Western society might be responsible for this apparent sex difference in mental health outcomes.

Stice, Hayward, Cameron, Killen, and Taylor (2000) have proposed a gender-additive model, which holds that females experience added risk factors for depressive symptomology beyond those experienced by males. Specifically, pubertal changes in body composition typically result in females moving away from the thin ideal of Western society, with increases in adipose mass (Alberga, Sigal, Goldfield, Prud Homme, & Kenny, 2012) while boys move towards the ideal body type, therefore leading to greater body dissatisfaction in females and a concomitant augmentation of depressive symptomology in this sex (Stice et al., 2000). Furthermore, in girls, alterations in hormonal levels during pubertal development may also be linked to increased
depressive symptomology (Conley & Rudolph, 2009). Such factors may account for the sex-discrepant findings in certain studies.

In sum, overweight/obese status during childhood deserves attention as an important marker of both present and future health status (Daniels, 2006; Kumar & Kelly, 2017). The association of heightened levels of adiposity with negative physiological outcomes in children has been well established and continues to receive support (Kumar & Kelly, 2017). However, the link between increased adiposity and mental health in children is especially pronounced at an early age (Anderson et al., 2007; Morrison et al., 2014; Mühlig et al., 2016). Multiple mental health markers have demonstrated this association (Chaiton et al., 2009; Morrison et al., 2014) and depressive symptoms, in particular, appear strongly linked to elevated levels of adiposity in children (Morrison et al., 2014).

1.1.2 Depression

Depression has various definitions, which include “episodes of unhappiness which affect most people from time to time, to persistent low mood and inability to find enjoyment,” (Biddle & Mutrie, 2001, p.207). There are multiple symptoms of depression such as feelings of sadness, feelings of guilt, appetite disturbances and lack of energy (Lox, Ginis & Petruzzello, 2011). Depression has been shown to first appear during the childhood years (Seeley, Rohde, Lewinsohn, & Clarke, 2002; Thapar, Collishaw, Pine & Thapar, 2012) with its prevalence increasing significantly during adolescence (Merry & Spence, 2007; Seeley et al., 2002; Thapar et al., 2012). Some research has demonstrated that the prevalence of depression rises from 4.1-7.8% at the age of 15 to 16.7-18.2% at the age of 18 years (Merry & Spence, 2007). In particular, girls, show increased depressive symptomology throughout adolescence (Byrne et al., 2015). Body composition alterations (e.g. elevated adiposity) (Alberga et al., 2012) as well hormonal alterations (Conley & Rudolph, 2009) related to puberty are both thought to contribute to this
increased prevalence in girls. Some estimates suggest by the age of 19 years as many as 20-24% of young people have suffered from a clinically significant depressive episode (Merry & Spence, 2007). Thus, depression represents one of the most common psychiatric disorders during the adolescent years (Seeley et al., 2002).

Depressive symptomology during development has been associated with various comorbidities (Cicchetti & Toth, 1998). Children who experience depressive symptoms are at an elevated risk for other disorders such as anxiety disorder, substance abuse and alcohol abuse (Birmaher et al., 1996; Cicchetti & Toth, 1998). As well, children experiencing these symptoms are at a higher risk for suicidal ideation and also experience academic and social impairments (Birmaher et al., 1996). Some evidence even suggests that the unhealthy behaviors associated with depressive symptomology may place these children at an increased risk of obesity (Roberts & Duong, 2013). As well, depression during adolescence may promote the development of various inflammatory diseases (e.g. heart disease, diabetes) in adulthood (Duivis et al., 2015). Overall, depression during childhood and adolescence is associated with morbidity and mortality (Brown, Pearson, Braithwaite, Brown & Biddle, 2013) owing to its association with various maladaptive behaviors and co-morbidities both physiological and psychological.

Various factors have been proposed to be place children at an elevated risk for depressive symptomology. As was previously mentioned, children with increased levels of adiposity frequently present with elevated depressive symptomology (Chaiton et al., 2009; Morrison et al., 2014). There is evidence to suggest that various psychosocial factors play a role in this relationship (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2005). Typically, children with excessive adiposity display greater degrees of body dissatisfaction feel a greater pressure to be thin and may even experience social shaming because of their body composition (Allen, Byrne, Blair, & Davis, 2006; Chaiton et al., 2009; Nemiary et al., 2012). Factors such as body
dissatisfaction have in turn been shown to place the children at higher risk of depressive symptomology (Smolak, 2004). Furthermore, the relationship between adiposity and depressive symptomology may have physiological mechanisms underpinning it. Adipose tissue has been shown to be associated with a pro-inflammatory state (Sacheck, 2008), which may be associated with the pathogenesis of depression (Shelton & Miller, 2010). Though the precise mechanisms are unclear, there appear to be links between adiposity and depressive symptomology through both psychosocial and physiological pathways.

Fortunately, preliminary investigations into the association between aerobic fitness and depressive symptomology in children have shown promise. Children with elevated aerobic fitness have frequently demonstrated reduced depressive symptomology (Esmaeilzadeh, 2014, 2015; Greenleaf et al., 2010; Ruggero et al., 2015) thus highlighting the negative association between these variables. Aerobic fitness, in particular, appears to play a unique role in its relation to depressive symptomology. For instance, Norris, Carroll and Cochrane (1992) demonstrated that only a high intensity physical activity group experienced a significant change in depression scores compared to control and moderate intensity physical activity group. The authors suggested that the beneficial association between physical activity and depressive symptomology might be contingent upon improvements in aerobic fitness (Norris et al., 1992) though it should be acknowledged that physical activity at moderate levels have also been linked to improvements in depressive symptoms (Janssen & Leblanc, 2010). Overall, changes in aerobic fitness may lead to improvements in depressive symptomology highlighting the potential of this factor in promoting optimal mental health in children.

1.1.3 Aerobic Fitness

Paralleling the rise in pediatric adiposity has been a concomitant decline in fitness levels of children in Canada (Roberts et al., 2012). For instance, musculoskeletal strength and
flexibility have declined significantly in Canadian children since 1981 (Roberts et al., 2012). At the same time, aerobic fitness levels has been shown to decline throughout development for Canadian children (Roberts et al., 2012) thus highlighting a worsening fitness profile for this cohort as they approach early adulthood. One of the commonly cited reasons for this decline in fitness levels is because of reductions in physical activity levels in Canadian children (Roberts et al., 2012). Levels of physical activity have declined in recent years such that, at present, only 7 percent of Canadian children are attaining the recommended levels of physical activity (Colley et al., 2011). At the same time sedentary behavior and adiposity is on the rise in this cohort (Colley et al., 2011; Roberts et al., 2012) with both of these factors also independently contributing to reductions in fitness levels (Olds et al., 2007; Roberts et al., 2012). As such, fitness status in Canadian children is not promising. This is unfortunate given the beneficial effects of physical fitness on various aspects of health and well-being in children (Ortega et al., 2008).

Aerobic fitness is associated with a wide range of health benefits in children (Ortega et al., 2008). For instance, various CVD risk factors (blood triglyceride and lipoprotein levels) have been demonstrated to be inversely associated with aerobic fitness in children (Ortega et al., 2008) and adiposity has also shown a negative association with aerobic fitness (Olds et al., 2007; Ortega et al., 2008). At the same time, increases in adiposity have been associated with reductions in aerobic fitness in children (Olds et al., 2007). Mechanistic links for this association have suggested that extra adipose tissue leads to a reduced running economy, added load and increased metabolic demand; all of which lead to a reduction in aerobic fitness (Olds et al., 2007). In a study of 113 Italian boys and girls aged 11 to 13 years old, Martone and colleagues (2014) found that physical activity levels along with body mass index (BMI) and waist circumference were related to reduced aerobic fitness levels in the boys. Again, it was theorized by the authors that the added load of excess adiposity may be responsible for the concomittant
reduction in aerobic fitness levels (Martone et al., 2014). Furthermore, in a sample of 2474 Spanish adolescents aged 13 to 18.5 years, Artero and colleagues (2010) examined how various measures of aerobic fitness differed based upon weight status as measured by BMI (Artero et al., 2010). It was demonstrated that children who were overweight/obese had worse performances in various weight bearing activities such as 20 meter shuttle run with this relationship no longer significant after adjustment for adiposity (Artero et al., 2010). These findings suggest an inverse relationship between adiposity and aerobic fitness in children.

A distinction should be drawn between the terms physical activity and aerobic fitness as these terms, while correlated though not synonymous (Strong et al., 2005). While levels of physical activity may fluctuate on a weekly basis, aerobic fitness is a product of regular and prolonged physical activity (Welk, Meredith, Ihmels, & Seeger, 2013) and may thus represent a more stable measure of children’s health status. Currently, there is strong evidence in favor of the positive role physical activity may play in promoting optimal mental health in children (Ortega et al., 2008). Much of the research in this cohort has demonstrated a beneficial association between engagement in physical activity and multiple markers of mental health such as depressive symptomology, anxiety symptoms, self-esteem and cognitive functioning (Ahn & Fedewa, 2011; Biddle & Asare, 2011). With regards to depressive symptomology, the inverse association between physical activity and depressive symptoms has been demonstrated in children at both vigorous and moderate intensities (Janssen & Leblanc, 2010). While research into physical activity’s association with mental health shows promise, there is a dearth of literature into the relationship between aerobic fitness and mental health in this cohort (Ortega et al., 2008). However, given the positive association between physical activity and aerobic fitness (Strong et al., 2005), there is reason to believe a beneficial association should also exist between aerobic fitness and mental health (Greenleaf et al., 2010). In fact, previous investigations into
this topic have suggested a beneficial relationship between aerobic fitness and mental health, specifically depressive symptomology. For example, Esmaeilzadeh (2014) examined the association between aerobic fitness and depressive symptomology in 568 Iranian schoolboys aged 8 to 11 years old. Aerobic fitness was assessed based on time of completion for 1 mile and depressive symptomology was assessed using the Children’s Depression Inventory (Kovacs, 1992). Results found that increasing 1-mile run/walk time (signifying lower aerobic fitness) was associated with an increase in measures of depressive symptomology ($p < 0.001$; partial $\eta^2 = 0.128$). Thus, aerobic fitness appears to be protective against depressive symptomology in boys.

In a similarly designed study, using 7 to 11 year old Iranian schoolboys, Esmaeilzadeh (2015) again, using regression analysis, demonstrated that aerobic fitness was significantly associated with depressive symptomology in this cohort ($\beta = 0.37; p < 0.001$). Therefore, it appears that aerobic fitness may confer protection against depressive symptoms in boys.

Importantly, there have been some semi-discordant findings in this developing area of literature. In 933 boys and girls from Arizona with ages ranging from 8 to 12 years the relationship between aerobic fitness and depressive symptomology was also examined (Tomson, Pangrazi, Friedman, & Hutchison, 2003). This study used the Dimensions of Depression Profile for Children and Adolescents (DDP) (Harter & Nowakowski, 1987) to assess depressive symptomology and 1-mile run/walk test was used to assess aerobic fitness. Based on performance on the 1-mile run/walk test the subjects were classified into dichotomous groups based on whether they met minimum time standards for the mile test based on population standards (Tomson et al., 2003). The relative risk of depressive symptomology was 2.8 times higher for girls not meeting the aerobic fitness standards compared to those who did while boys did not demonstrate a significant difference (Tomson et al., 2003). Furthermore, in a longitudinal study design, Ruggero and colleagues (2015) examined how aerobic fitness in the sixth grade
was associated with depressive symptomology in the seventh grade in a sample of boys and girls (Mean age = 11.55 years SD = 0.59). Aerobic fitness was measured using a combination of objective measures as well as self-report statements, and depressive symptomology was assessed using the 20-item Centre for Epidemiological Studies Scale for Children (CES-DC) (Radloff, 1977). Aerobic fitness in grade 6 was shown to significantly predict lower depressive symptomology in grade 7 for girls ($\beta = -16; p < 0.05$) even when controlling for body composition and current depressive status (Ruggero et al., 2015). In boys, the effect was in the same direction but not significant ($p > 0.05$) however, it was interesting to note that sixth grade depression did predict poorer seventh grade aerobic fitness in this sex ($\beta = -13; p < 0.05$) still suggesting an interaction between these factors (Ruggero et al., 2015). Notwithstanding, aerobic fitness in grade 6 was still negatively associated with depressive symptomology in the same year in both sexes (Ruggero et al., 2015) thus demonstrating an inverse relationship between aerobic fitness and depressive symptomology that is present in both sexes. Thus, there is preliminary evidence for at least beneficial cross-sectional associations of aerobic fitness and depressive symptomology in both boys and girls though this area of research is still in its early stages (Tomson et al., 2003).

While, aerobic fitness has been demonstrated to have important health implications for the current health status of children (Ortega et al., 2008) it is important to acknowledge that aerobic fitness in this time period also has implications for future health status as well (Ortega et al., 2005; Ruiz et al., 2009). Aerobic fitness during childhood and adolescence, for both boys and girls, is a predictor of various cardiovascular disease risk factors such as abnormal levels of blood lipids, hypertension and overall and central adiposity during adulthood (Ruiz et al., 2009). At the same time, there is even evidence which has suggested that higher levels of aerobic fitness in childhood and adolescence reduce the risk of developing the metabolic syndrome and arterial
stiffness later in life (Ruiz et al., 2009). Taken together, aerobic fitness levels of children have implications for health status both at the present and in the future as well (Ortega et al., 2005; 2008; Ruiz et al., 2009). Interestingly, the period of childhood and adolescence constitutes an important time frame as health behaviors developed during this period have been demonstrated to track into adulthood (Ortega et al., 2008). Engagement in physical activity is one such behavior, as its occurrence in adolescence has been demonstrated to predict later engagement during adulthood (Hallal, Victora, Azevedo, & Wells, 2006). In support of this notion, Telama and colleagues (2005) performed a 21-year tracking study of Finnish youth and demonstrated that physical activity during the age range of 9-18 years old was a significant predictor of adult physical activity. Overall, health behaviors such as physical activity, when they are engaged in during childhood and adolescence, appear to be sustainable over time (Hallal et al., 2006; Telama et al., 2005). Given the importance of physical activity in promoting aerobic fitness in children (Strong et al., 2005), this time frame represents a critical period where aerobic fitness interventions, like physical activity, may be established and have long standing effects on both present and future health status.

1.2 Summary

Elevated adiposity is a factor that has been strongly associated with depressive symptoms in children (Morrison et al., 2014). There are multiple proposed mechanisms responsible for this association from both psychosocial (Nemiary et al., 2012) and physiological perspectives (Shelton & Miller, 2010); thus further elucidation of this relationship is required. Aerobic fitness has been shown to have an inverse association with adiposity (Ortega et al., 2008) and depressive symptoms (Rieck et al., 2013) in children. However, it is unknown how aerobic fitness may influence the relationship between adiposity and depressive symptoms in children.
Chapter 2
Manuscript

2 Manuscript

2.1 Abstract

The incidence of overweight/obesity in Canadian children has risen significantly in recent years. Such elevated levels of adiposity in children have been tied to various physiological pathologies and have been increasingly linked to poor mental health outcomes including increased depressive symptomology. Aerobic fitness has been associated with reductions in levels of adiposity as well as depressive symptomology in children and may moderate the association between adiposity and depressive symptoms. This proposition has not been tested, and is the purpose of the current study. The sample included 502 children (55% males; 67% tanner stage \( \geq 2 \); mean age 11.6 [0.94] years). Participants completed questionnaires on depressive symptoms, were tested for \( \text{VO}_{2}\text{Peak} \) to determine aerobic fitness and underwent a dual energy X-ray absorptiometry (DEXA) scan to measure adiposity. Using sex-stratified multiple regression models, adiposity and aerobic fitness were both tested as predictors of depressive symptomology while controlling for age, pubertal status and socioeconomic status. For males, aerobic fitness \((b = -2.95, \text{SE} = .76, p < .001)\), but not adiposity \((b = .01, \text{SE} = .02, p = .82)\), was a significant correlate of depressive symptomology \((R^2 = .11)\). The interaction term was also significant \((p = .02)\), demonstrating that aerobic fitness moderated the association between adiposity and depressive symptomology in males. In females, adiposity \((b = .08, \text{SE} = .03, p = .01)\), but not aerobic fitness \((b = -.7, \text{SE} = .89, p = .43)\), was a significant correlate of depressive symptomology \((R^2 = .10)\). The interaction term between adiposity and fitness was not significant \((p = .14)\). These findings highlight sex-specific factors that are related to depressive
symptomology in children. Knowledge of such factors may inform more targeted approaches to both prevent and treat depressive symptoms in children.

2.2 Introduction

Canadian children (youth under 18 years of age) have been experiencing a significant increase in their rates of overweight/obese status in recent years (Shields & Tremblay, 2010). Highlighting this trend, the prevalence of overweight/obese status in Canadian children was 11.5 percent higher in 2004 when compared to rates in 1978/1979 (Shields & Tremblay, 2010). As such, roughly 30% of Canadian children are currently considered either overweight or obese (Rao et al., 2016). This finding is particularly concerning as elevated levels of adiposity (denoting overweight/obese classification) in children have been frequently associated with various comorbidities such as insulin resistance, type 2 diabetes mellitus, dyslipidemia, hypertension, chronic inflammation, and non-alcoholic fatty liver disease (Ebbeling et al., 2002; Kumar & Kelly, 2017). In addition, one other comorbidity that has increasingly been linked to overweight/obese status during childhood is that of poor mental health (Nemiary et al., 2012; Sanders et al., 2015).

Children with elevated levels of adiposity are frequently stigmatized by their peers and are the subject of teasing, thus putting them at risk for poor mental health outcomes (Wardle & Cooke, 2005). Consequently, such children frequently present with poor mental health manifested in body image dissatisfaction, low self-esteem, and depressive symptoms (Chaiton et al., 2009; Morrison et al., 2014; Nemiary et al., 2012; Sanders et al., 2015). Depressive symptoms, in particular, have been demonstrated to be a major concern for children who are considered overweight/obese (Csábi et al., 2000; Dockray et al., 2009; Nemiary et al., 2012; Sanders et al., 2015; Swallen, Reither, Haas, & Meir, 2009). As symptoms of depression may first appear during childhood (Seeley et al., 2002) and increase throughout the adolescent years
(Merry & Spence, 2007) this condition represents an important mental health concern for all children. Moreover, children who are overweight/obese may be at an added risk for this condition (Nemiary et al., 2012) as symptoms of depression in this population are higher compared to their normal weight counterparts (Mühlig et al., 2016). Ultimately, depressive symptoms constitute an added health concern for children with elevated levels of adiposity (Csábi et al., 2000; Dockray et al., 2009; Nemiary et al., 2012; Sanders et al., 2015; Swallen et al., 2009) therefore examination into factors which may mitigate this mental health outcome are warranted.

Currently, much of the research on the associations between body composition and depressive symptoms has used body mass index (BMI) as the measure of adiposity, with this measure positively correlated with depressive symptomology in children (Csábi et al., 2000; Dockray et al., 2009; Goldfield et al., 2010; Jaser, Holl, Jefferson, & Margaret Grey, 2009; Swallen et al., 2009). However, some research has found no relationship between BMI and depressive symptomology in this population (Bazargan-Hejazi et al., 2010; Hillman et al., 2010). There are some potential factors, which may account for these discrepant findings. One limitation of comparison across studies is that multiple studies are performed on children at different points during development. As pubertal changes (e.g. hormonal alterations) may influence depressive symptoms (Angold et al., 1998) this may lead to differences in rates of depressive symptoms in children owing to such changes and making comparison across different age groups difficult. Alternatively, it may be that BMI provides inadequate information on adipose mass or distribution (Morrison et al., 2014; Olds et al., 2007). Furthermore, secretory products from adipose tissue called adipokines have been proposed to biologically link adiposity and depression (Taylor & Macqueen, 2010) thus highlighting a need for more specific measures of adiposity in order to better examine this physiological link. Collectively, these factors call for
research using more targeted measures of adiposity such as body fat percentage (Hillman et al., 2010; Morrison et al., 2014) in order to better assess the relationship between elevated adiposity and depressive symptomology in children.

Using more accurate measures of adiposity, such as body fat percentage, researchers have demonstrated that children who are overweight/obese experience elevated rates of depressive symptomology when compared to their counterparts with lower levels of adiposity (Hillman et al., 2010; Morrison et al., 2014). Psychosocial factors such as concern about body weight/shape, body dissatisfaction, pressure to be thin, and negative social evaluation have been suggested to influence the adiposity-depressive symptomology dyad in children (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2012). In particular, body dissatisfaction is a phenomenon which has been shown to be pervasive in both boys and girls (Kostanski et al., 2004) and has been linked to the development of depression (Smolak, 2004). There are various proposed sociocultural factors, which may contribute to body dissatisfaction in both sexes such as media influences, parental comments and peer influences (Smolak, 2004). In addition, it may be that perceptions of weight rather than actual weight may be more predictive of depressive symptoms (Daniels, 2005) suggesting that even normal/underweight children may be at risk owing to perceptions of their levels of adiposity. Therefore, adiposity levels appear to be significant for mental health status of overweight/obese children (Allen et al., 2006; Chaiton et al., 2009; Nemiary et al., 2012) and may also have implications for normal/underweight children as well (Daniels, 2005).

From a physiological perspective, there may be additional factors that help explain the association between adiposity and depressive symptoms. For example, in children, there is evidence for an association between inflammation and depressive symptoms, through the directionality of the association requires further elucidation (Byrne et al., 2015; Kim et al., 2014). Notwithstanding, heightened levels of inflammatory markers are commonly found in
children with elevated adiposity (Byrne et al., 2015; Shelton & Miller, 2010) suggesting that adiposity and depression may be linked via inflammatory mediators (Shelton & Miller, 2010). Fortunately, improvements in aerobic fitness in children have demonstrated a beneficial association with levels of adiposity (Ortega et al., 2010), its associated inflammatory levels (Ruiz et al., 2007) and finally levels of depression (Ortega et al., 2008). Given these associations it may be important to test aerobic fitness as a moderator of the relationship between adiposity and depressive symptoms in children.

Canadian children have experienced a reduction in various measures of physical fitness (musculoskeletal strength and flexibility) since 1981 (Tremblay et al., 2010). Furthermore, aerobic fitness has been demonstrated to be higher in boys than girls with both sexes demonstrating a decline in this form of fitness throughout adolescence (Roberts et al., 2012). These findings are not surprising as only 7% of Canadian children are attaining the currently recommended level of physical activity (Colley et al., 2011) and the Active Healthy Kids Canada Report Card, in 2014, gave Canadian children and youth (3 to 17 years of age) a ‘D-’ rating based on the national physical activity levels of this cohort (Gray et al., 2014). These trends are concerning since lower levels of aerobic fitness have been shown to place children at an elevated risk of experiencing depressive symptoms (Rieck et al., 2013). Notwithstanding, multiple studies have still demonstrated a negative association between these factors in both boys and girls (Esmaeilzadeh, 2014, 2015; LaVigne, Hoza, Smith, Shoulberg, & Bukowski, 2016; Rieck et al., 2013). However, what is currently unknown is whether aerobic fitness levels may moderate the relationship between adiposity and depressive symptoms in children.

Based on previous literature, the purpose of the current study was to: (i) examine the association between adiposity and depressive symptomology in children at risk for obesity and (ii) test aerobic fitness levels as a moderator of this association. Age, pubertal status and
socioeconomic status were all covariates in these analyses. Age has been shown to be associated with rates of depression in children, with rates of depression increasing in children throughout development (Cicchetti & Toth, 1998). Also, pubertal status has been linked to changes in depressive symptomology in children throughout development (Angold et al., 1998). Finally, in children, socioeconomic status has been linked to both measures of adiposity (Shrewsbury & Wardle, 2008) as well as rates of depression (Quon & McGrath, 2015). It was hypothesized that adiposity levels would be positively associated with depressive symptoms in both boys and girls. It was also hypothesized that aerobic fitness would moderate the association between adiposity and depressive symptomology in boys and girls.

2.3 Methods

Participants

The original sample for this study consisted of 564 youth who took part in the second data collection of the Quebec Adipose and Lifestyle Investigation in Youth (QUALITY; Lambert et al., 2012) cohort. Of these participants, \( n = 41 \) (7.3%) of the youth were excluded for missing data, and \( n = 21 \) (3.7%) were excluded for having a major injury or illness within the last 2 months, as it was postulated that this could impact all variables under examination in the analysis (adiposity, aerobic fitness and depressive symptomology) leaving an analytical sample consisting of 502 (276 male; 226 female) children between the ages of 9 and 13 years (\( M = 11.65, \ SD = 0.94 \)).

The details of the QUALITY cohort are published elsewhere (Lambert et al., 2012). Briefly, the main aim of the QUALITY study is to describe the development of childhood obesity, and to identify associated predictors and cardio metabolic consequences. School based sampling was used at 1,040 primary schools all situated within 75 km of Montreal, Quebec City and Sherbrooke in Quebec, Canada (Lambert et al., 2012) to recruit potential participants. In
total, approximately 400,000 flyers were distributed to parents of children between grades 2 and 5 over a consecutive 3 year period (Lambert et al., 2012).

The inclusion criteria for the QUALITY study children were: Caucasian (to reduce genetic admixture) and of Western European ancestry, between the ages of 8 and 10 years of age at the time of recruitment, and have at least one obese biological parent (criteria for obesity: body mass index (BMI $\geq 30$ kg/m$^2$ or a waist circumference $> 102$ cm in men and $> 88$ cm in women). Children were excluded from the study for the following: (i) past diagnosis of type 1 or 2 diabetes mellitus, (ii) serious illness, psychological / cognitive disorder which would prevent complete participation in the study, (iii) undergoing treatment with anti-hypertensive medication or steroids (unless administered via inhalation or topical means) and (iv) adhering to a very restricted diet ($< 600$ kcal/day) (Lambert et al., 2012).

At baseline, participants in the QUALITY cohort included 630 (343 male; 287 female) children with a mean age of 9.6 years (SD = 0.9) and 41.9% being classified as overweight or obese (Lambert et al., 2012). Therefore, the current analytical sample represents 79.6% of the original sample and 89% of the sample who completed the follow-up testing approximately two to three years after the baseline assessment.

**Procedure**

The QUALITY study has completed two assessments, each separated by two to three years (Lambert et al., 2012). For each assessment, the parents and their children attended a full-day assessment at one of two hospitals: Unité de recherche clinique du Centre Hospitalier Universitaire (CHU) Sainte-Justine located in Montreal or Hôpital Laval located in Quebec City (Lambert et al., 2012). In the current study, cross sectional data from the second visit was used because measures of depressive symptoms and concurrent measurements of aerobic fitness and adiposity were completed.
Measures

Participant Characteristics

Age and sex were both reported by the children using self report questionnaires (Lambert et al., 2012). Annual household income was reported by parents using self reported questionnaires (Lambert et al., 2012) with this measure used as a measure of socioeconomic status. Pubertal status was scored by trained nurses according to stages of sexual maturation as outlined by Marshall and Tanner (Marshall & Tanner, 1969, 1970). Measurements of weight and height were taken with the participant dressed in light indoor clothing without wearing shoes. Weight is recorded using an electronic scale and height is recorded using a stadiometer (Lambert et al., 2012).

Depressive Symptoms

Depressive symptoms were assessed using the 12-item Center for Epidemiological Studies-Depression Scale from the National Longitudinal Study of Children and Youth (Poulin, Hand, & Boudreau, 2005). This scale has been deemed reliable and valid among adolescents (Poulin et al., 2005). The CES-D-12 is designed with the user reporting the frequency with which they experienced depressive symptoms within the past week. The responses are reported by the youth on a four-point scale, which spans the following: 0 (rarely or never), 1 (a little or sometimes), 2, (occasionally or every now and then), and 3 (most or all of the time). A total score is taken as the addition of all 12 items, with scores ranging from 0 to 36 and higher scale scores represent a higher frequency and magnitude of depressive symptoms. This scale is not intended to provide a clinical diagnosis of depression but rather to identify one’s risk of clinical depression (Poulin et al., 2005). Total scale score cutoffs have been previously used to denote varying degrees of depressive symptomology: 0-11 (minimal depressive symptoms), 12-20
(somewhat elevated depressive symptoms) and 21-36 (very elevated depressive symptoms) (Poulin et al., 2005).

**Adiposity**

Fat mass was measured using dual energy X-ray absorptiometry (DEXA Prodigy Bone Densitometer System, DF+14664, GE Lunar Corporation, Madison, WI, USA) (Goran, 1998). This measure has been previously demonstrated to provide an accurate and precise measurement of body composition (Haarbo et al., 1991). The measurement was taken with the participant lying in the supine position on the scanning table. The scan began at the top of the head and moved in a straight-line pattern inferiorly towards the feet. Results of the test produced a measure of fat mass in kilograms. From this Fat Mass Percentage (FM Percentage) was calculated using the formula: 100 x fat mass (kg) / (fat mass (kg) + fat free mass (kg) + bone mass (kg)). This value was used in subsequent analyses.

**Aerobic Fitness**

Peak oxygen consumption (VO$_2$ Peak), the measure of aerobic fitness, was measured using an incremental cycling test performed on an electromagnetic bicycle (Oxycon Pro, Jaeger) (Carter & Jeukendrup, 2002). The test was performed using a protocol adapted from the McMaster protocol (Bar-Or, 1983) with the children exercising until exhaustion (heart rate > 195 beats/min and/or respiratory exchange ratio (VCO$_2$/VO$_2$) > 1.0) (Docherty, 1996). Indirect calorimetry measurements were taken on a continuous basis throughout the test (Lambert et al., 2012). VO$_2$ Peak was reported as liters per minute, with higher values indicative of elevated aerobic fitness.

**Data Analysis**

Data were inspected for missing values and cases with missing data on any of the main variables in this study were removed from the analytical sample. Descriptive data from the
original sample were compared with the data from the analytical sample using independent samples t-tests. Data were examined for univariate normality by an assessment of skewness and kurtosis statistics (Tabachnick & Fidell, 2007), inspected for outliers which were defined as any value that fell more than 3 standard deviations outside of the mean (Tabachnick & Fidell, 2007), and tested on the basic regression assumptions of linearity of data, homogeneity of variance, and independence of variables (Osborne & Waters, 2002).

Descriptive statistics (means, standard deviations, skewness and kurtosis) and frequencies were calculated for all study variables. Reliability estimates of internal consistency for scale scores for depressive symptoms were calculated (Cronbach, 1951). Pearson bivariate correlations were calculated among all study variables. Fisher’s Z Test was performed to examine whether study variable associations differed based on sex. The sex-stratified main models examining VO$_2$ Peak as a moderator of the relationship between adiposity and depressive symptomology were analyzed using the PROCESS macro in SPSS (Hayes, 2013). Bootstrapping procedures (Hayes, 2013) were set at 5,000 resamples to assess whether VO$_2$ Peak moderated the adiposity-depressive symptomology relationship. If the moderation effect was significant ($p < 0.05$), Simple Slopes Analysis (Aiken, West & Reno, 1991) was used to model the interaction and the Johnson-Neyman Technique (Preacher, Curran, & Bauer, 2006) was used to examine the levels of VO$_2$ Peak which had a significant effect on the relationship between adiposity and depressive symptomology.

2.4 Results

For complete participant descriptive information, refer to Tables 1 and 2. The participants ranged in age from 9 to 13 (M = 11.7; SD = 0.94) years. Aerobic fitness, determined based on VO$_2$ Peak, ranged from 0.9 to 3.6 liters per minute (M = 1.9; SD = 0.41). Adiposity, determined based on fat mass percentages, ranged from 7.2 to 53.4 percent (M = 28.4; SD = 10.8).
Depressive symptoms, determined based on CES-D scale score totals, ranged from 0 to 21 (M = 5.8; SD = 4.09). Many (67%) participants had entered puberty (Tanner stage ≥ 2) and 45.5% of the participants came from a family with an annual household income greater than $100,000. Independent samples t-test revealed no significant differences between the original sample and analytical sample on any study variables.

Data for all variables were normally distributed based on skewness [maximum = 1.07 (SE = .11) and minimum = .01 (SE = .11)] and kurtosis [maximum = -1.96 (SE = .21) and minimum = -.32 (SE = .21)] values. The internal consistency reliability coefficient for the CES-D scale items was α = 0.69. The regression assumptions of linearity of data, homoscedasticity and homogeneity of variance were all met.

Pearson bivariate correlations with sex stratification (Table 3) revealed significant (p < .05) negative associations between depressive symptoms and both age (r = -0.15) and aerobic fitness (r = -0.26) for boys. For girls, depressive symptoms were significantly (p < .05) associated with age (r = -0.14), adiposity (r = 0.17) and socioeconomic status (r = -0.20). Fisher’s Z Test was performed to assess whether the relationships between adiposity and depressive symptoms, aerobic fitness and depressive symptoms and adiposity and aerobic fitness differed based on sex. 1 tailed tests for all associations revealed significant differences (p < 0.05) based on sex.

Moderation analysis was conducted to examine aerobic fitness as a moderator of the relationship between adiposity and depressive symptomology. In boys, aerobic fitness was significantly associated with depressive symptomology (b = -2.95, SE = .76, p < 0.01) and adiposity was not significantly associated with depressive symptomology (b = .01, SE = .02, p = .82). Pubertal status also was significantly associated with depressive symptomology in boys (b = .70, SE = .34 p = .04). Overall, the total model accounted for 11% of the variance in depressive
symptomology in boys ($R^2 = .11$). Furthermore, the interaction of aerobic fitness and adiposity was also significant ($b = .12$, $SE = .05$, $p = .02$) suggesting that the effect of adiposity on depressive symptomology in boys depends on the level of aerobic fitness. The remaining covariates, age and socioeconomic status, were not significantly associated with depressive symptomology in this cohort.

Johnson - Neyman technique (Preacher et al., 2006) was used to examine where the interaction between adiposity and aerobic fitness was significant. Analysis revealed a significant positive association between adiposity and depressive symptomology ($b = .0541$, $SE = .03$, $p = 0.03$) in boys with high aerobic fitness thus suggesting that adiposity is positively associated with depressive symptomology in high aerobically fit boys. Analysis of low aerobically fit boys did not reveal a significant association between adiposity and depressive symptomology ($b = -.04$, $SE = .04$, $p = 0.22$). Furthermore, it was demonstrated that boys with aerobic fitness levels above 2.3 liters per minute had a significantly positive association between adiposity and depressive symptomology with the relationship growing stronger as aerobic fitness levels increased. This finding suggests that greater adiposity is associated with increased depressive symptomology in high aerobically fit boys. Follow up simple slopes analysis (Aiken et al., 1991) was used to model the direct effect of adiposity on depressive symptomology at different levels of aerobic fitness (1 SD above mean and 1 SD below mean). As shown in Figure 1, the slope was significant ($p < .05$) for high, but not low, aerobically fit boys.

In girls, aerobic fitness was not significantly associated with depressive symptomology ($b = -.70$, $SE = .89$, $p = .43$) however adiposity was significantly associated with depressive symptoms ($b = .08$, $SE = .03$, $p = .01$). Socioeconomic status was also significantly associated with depressive symptoms in girls ($b = -.3$, $SE = .11$ $p = .01$). Overall, the total model accounted for 11% of the variance in depressive symptomology in girls ($R^2 = .10$). The interaction of
aerobic fitness and adiposity was not significant \( b = .11, \ SE = .07, \ p = .14 \) suggesting that the effect of adiposity on depressive symptomology in girls does not depend on their level of aerobic fitness.

2.5 Discussion

The purpose of this study was to examine how adiposity and aerobic fitness are related to depressive symptomology in children at risk for obesity. Overall, aerobic fitness was associated with depressive symptoms in boys and adiposity was associated with depressive symptoms in girls. Aerobic fitness was also a significant moderator of the association between adiposity and depressive symptoms in boys. These findings highlight potential sex differences in the fitness and adiposity factors associated with depressive symptomology in boys and girls.

The first research hypothesis was that adiposity would be positively associated with depressive symptomology in both boys and girls. The results of this study demonstrated that adiposity was significantly positively associated with depressive symptoms in girls, but not boys. Morrison and colleagues (2014) found similar results in that body fat percentage (measured using DEXA scan) was significantly related to an increased risk of depression in a cohort of youth who were obese. However, unlike the present study, Morrison et al. (2014) did not observe differences in prevalence of depression in females as opposed to males. Of note, Morrison and colleagues (2014) used a scale cut-off value of depressed versus non-depressed youth rather than a continuous outcome of depressive symptoms, which may account for the variation in their findings compared to the present study.

Previous literature examining the association between adiposity and depressive symptoms has mainly used BMI as the measure for adiposity, but has produced results similar to the present study. Anderson and colleagues (2007), in a prospective cohort study design, examined whether weight status (measured using BMI Z-Scores) predicted subsequent incidence
of Major Depressive Disorder (MDD) in a sample of 701 children with a mean age of 14.7 years. While weight status was not significantly associated with risk of MDD in males, there was a significant association observed with obese females having an almost 3 fold elevated risk of being identified with MDD in the future compared to normal weight females (Anderson et al., 2007). Moreover, Chaiton and colleagues (2009) produced similar results in a representative sample of Quebec children using both BMI and skinfold measures of adiposity. In girls, there was a significant indirect effect of adiposity on depressive symptoms which was mediated by pressure to be thin and body dissatisfaction (Chaiton et al., 2009). However, this effect was not shown to be statistically significant in boys (Chaiton et al., 2009). Therefore, in line with the present study, girls appear to be particularly at risk for depressive symptoms owing to levels of adiposity.

Reasons for this association may relate to various socio-cultural factors. Typically, there exists a drive for athleticism in boys (Ricciardelli, McCabe & Ridge, 2006) but a drive for thinness in girls (Smolak, 2004). As such, there is a strong social pressure for girls and women to be thin in Western society (Flynn, 1997). As body dissatisfaction has been linked to depressive symptoms (Chaiton et al., 2009; Smolak, 2004), this strong desire of girls to be thinner may explain why adiposity appears to be especially predictive of depressive symptomology within this sex.

In a test of the second hypothesis, aerobic fitness was associated with depressive symptomology in boys but not girls. The inverse association between aerobic fitness and depressive symptomology in boys has been previously demonstrated by Esmaeilzadeh (2014, 2015) who reported that longer one-mile walk/run times (measure of aerobic fitness) were significantly associated with depressive symptoms among Iranian pre-adolescent boys. The finding of a sex-specific association between aerobic fitness and depressive symptoms is a novel
finding of this study as previous research has demonstrated a protective association in both sexes (Rieck et al., 2013). Rieck and colleagues (2013) demonstrated that children not classified as having a healthy level of aerobic fitness were at a higher risk of depressive symptoms. This finding was evident across both sexes, however, when the authors split the population by sex, the sample sizes were reduced which decreased the statistical power of the study (Rieck et al., 2013).

Discordant findings from the present study have been reported which found that aerobic fitness is inversely associated with depressive symptoms in girls but not boys (Greenleaf et al., 2010; Ruggero et al., 2015). Classifying boys and girls as either highly aerobically fit or in need of improvement in aerobic fitness, Greenleaf and colleagues (2010) found that greater aerobic fitness was associated with reductions in self-reported depressive symptoms in girls but not in boys. The authors speculated that the girls in their study might have been more involved in sports participation outside of school, leading to both enhanced aerobic fitness but also improved self-esteem associated with sports participation (Greenleaf et al., 2010). As sports participation has been shown to improve social acceptance, which in turn is associated with reductions in depressive symptoms in children (Von Elm et al., 2007) this is a factor which may have played a part in the findings of Greenleaf et al. (2010). Ruggero et al (2015) also demonstrated a significant longitudinal protective effect of aerobic fitness on depressive symptoms in girls but not boys. However, cross-sectional data still demonstrated a negative association between aerobic fitness and depressive symptoms in both sexes (Ruggero et al., 2015) suggesting a discrepancy in these associations longitudinally rather than cross-sectionally and thus warranting further examination into these associations longitudinally.

Evidence for the sex-specificity of the association between aerobic fitness and depressive symptomology in boys may have much to do with body image ideals in the male cohort. Previous research has suggested that, for boys, fitness and endurance are viewed as important
components of functionality, which in turn is held to play a role in success at sport, a dominant value for boys (Ricciardelli et al., 2006). As such, given the link between body dissatisfaction and depressive symptoms (Smolak, 2004) elevated aerobic fitness may thus serve a protective effect on depressive symptomology for boys.

In this study, aerobic fitness was shown to moderate the association between adiposity and depressive symptomology in boys but not girls. Specifically, boys with higher aerobic fitness experienced a positive association with adiposity and depressive symptomology such that as adiposity increased depressive symptomology also increased significantly (Figure 1). However, boys with lower aerobic fitness experienced no association with depressive symptomology (Figure 1). While this is the first study to test these associations specifically, researchers have begun to test similar mechanisms. Though not examining the same direction as the present study, Gerber et al. (2017) examined whether aerobic fitness (assessed by 20-m shuttle run test) moderated the relationship between stress (caused by critical life events, family, peers, or school) and body composition assessed as BMI, skinfolds and waist circumference in Swiss children. Children with high stress levels experienced lower scores on measures of body composition if they were of high aerobic fitness status (Gerber et al., 2017). Thus, these findings demonstrate a protective effect of aerobic fitness on body composition however; they do not speak to whether this same effect is observed for mental health. One of the challenges of studying these effects is the possibility of reciprocal effects such that mental health and adiposity may possess a bi-directional association that needs to be tested in future research.

This study had a variety of limitations, which should be acknowledged. This study was performed in Caucasian children who are at risk for obesity. As this is a specific ethnicity these findings may not generalize to other ethnicities. As cultural perceptions of adiposity have not been examined to the same extent in other ethnicities there may be differences in perceptions
(Smolak, 2004), which may in turn produce different mental health outcomes in children. Furthermore, this study was cross sectional and did not follow these children in a longitudinal manner. As a result this study may only suggest an association between these variables but may not speak to which variable predicts another in a prospective fashion. As well, this study examined children who were between the ages of 9 and 12. As depressive symptoms have been shown to be influenced by both age and pubertal development (Angold et al., 1998), these findings may not be generalizable across the entire spectrum of childhood and adolescent development. Finally, owing to the measures of adiposity in this study, an absolute measure of aerobic fitness was used rather than a relative measure which assessed aerobic fitness based on weight. This measure makes conceptualization of the aerobic fitness of the children more challenging.

Future research may examine how the relationships between adiposity, aerobic fitness and depressive symptomology change across pubertal development. Given the vast physiological and psychosocial changes, which occur throughout pubertal development (Angold et al., 1998), awareness of how these associations may be influenced by pubertal status is relevant for guiding interventions, which are appropriate based on stages of development. In addition, given the uncertainty of the directionality of the association between adiposity and depressive symptoms (Byrne et al., 2015) future research may examine these associations longitudinally in order to determine the directionality of these relationships in children.

In conclusion, the findings of this study demonstrate sex-specific risk factors for depressive symptomology in children at risk for obesity. This study found that adiposity was positively associated with depressive symptomology in girls while aerobic fitness was negatively associated with depressive symptomology in boys. Finally, aerobic fitness was shown to moderate the association between adiposity and depressive symptomology in boys.
### 2.6 Tables

**Table 1: Participant descriptive statistics (n = 502)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall (n = 502) Mean (SD)</th>
<th>Boys (n = 276) Mean (SD)</th>
<th>Girls (n = 226) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>11.65 (.94)</td>
<td>11.68 (.92)</td>
<td>11.60 (.96)</td>
</tr>
<tr>
<td>VO$_2$ Peak (l/min)</td>
<td>1.88 (.42)</td>
<td>1.99 (.43)</td>
<td>1.75 (.36)</td>
</tr>
<tr>
<td>Fat Mass (%)</td>
<td>28.4 (10.83)</td>
<td>26.41 (11.21)</td>
<td>30.82 (9.84)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>48.96 (14.81)</td>
<td>48.98 (15.48)</td>
<td>48.93 (13.97)</td>
</tr>
<tr>
<td>Body Mass Index (kg/m$^2$)</td>
<td>21.03 (4.86)</td>
<td>20.96 (4.92)</td>
<td>21.11 (4.80)</td>
</tr>
<tr>
<td>Depression Scale Score</td>
<td>5.8 (4.1)</td>
<td>5.88 (3.80)</td>
<td>5.69 (4.44)</td>
</tr>
</tbody>
</table>

**Table 2: Complete participant frequencies (n = 502)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pubertal Stage</td>
<td>1</td>
<td>168 (33.5)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>162 (32.3)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>120 (23.9)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>42 (8.4)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>10 (2.0)</td>
</tr>
<tr>
<td>Sex</td>
<td>Male</td>
<td>276 (55.0)</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>226 (45.0)</td>
</tr>
<tr>
<td>Annual Household Income</td>
<td>&lt; $49,999</td>
<td>62 (12.4)</td>
</tr>
<tr>
<td></td>
<td>$50,000 – 79,999</td>
<td>121 (24.1)</td>
</tr>
<tr>
<td></td>
<td>≥ $80,000</td>
<td>319 (63.5)</td>
</tr>
</tbody>
</table>
Table 3: Sex-stratified participant frequencies (n = 502)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Boys (n = 276)</th>
<th>Girls (n = 226)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pubertal Stage</td>
<td>1</td>
<td>127 (46.0)</td>
<td>41 (18.1)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>86 (31.2)</td>
<td>76 (33.6)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>40 (14.5)</td>
<td>80 (35.4)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>21 (7.6)</td>
<td>21 (9.3)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2 (.7)</td>
<td>8 (3.5)</td>
</tr>
<tr>
<td>Annual Household Income</td>
<td>&lt; $49,999</td>
<td>36 (13.04)</td>
<td>26 (11.5)</td>
</tr>
<tr>
<td></td>
<td>$ 50,000 – 79,999</td>
<td>67 (24.28)</td>
<td>54 (23.90)</td>
</tr>
<tr>
<td></td>
<td>&gt; $80,000</td>
<td>173 (62.68)</td>
<td>146 (64.61)</td>
</tr>
</tbody>
</table>
Table 4: Sex–stratified bivariate correlations (Pearson’s r); (n = 502)

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Pubertal Stage</th>
<th>Annual Household Income</th>
<th>Fat Mass %</th>
<th>Body Mass Index</th>
<th>Weight</th>
<th>VO₂ Peak</th>
<th>Depression Scale Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubertal Stage</td>
<td>.582**</td>
<td></td>
<td>.003</td>
<td>.261**</td>
<td>.388**</td>
<td>.514**</td>
<td>.481**</td>
<td>-.028</td>
</tr>
<tr>
<td>Annual Household Income</td>
<td>.057</td>
<td>.025</td>
<td>- .045</td>
<td>-.066</td>
<td>-.094</td>
<td>.059</td>
<td>-.201**</td>
<td></td>
</tr>
<tr>
<td>Fat Mass %</td>
<td>.015</td>
<td>.005</td>
<td>-.172**</td>
<td>.874**</td>
<td>.795**</td>
<td>.399**</td>
<td>.167*</td>
<td></td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>.210**</td>
<td>.230**</td>
<td>-.196**</td>
<td>.864**</td>
<td>.936**</td>
<td>.585**</td>
<td>.158*</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>.419**</td>
<td>.465**</td>
<td>-.113</td>
<td>.726**</td>
<td>.923**</td>
<td>.724**</td>
<td>.108</td>
<td></td>
</tr>
<tr>
<td>VO₂ Peak</td>
<td>.581**</td>
<td>.601**</td>
<td>.033</td>
<td>.119*</td>
<td>.417**</td>
<td>.625**</td>
<td>-.031</td>
<td></td>
</tr>
<tr>
<td>Depression Scale Score</td>
<td>-.152*</td>
<td>-.078</td>
<td>-.076</td>
<td>.001</td>
<td>-.080</td>
<td>-.023</td>
<td>-.260**</td>
<td></td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Note: Bottom = Male (n = 276); Top = Female (n = 226)
2.7 Figures

Figure 1: Depression scale score vs. fat mass percentage as moderated by VO$_2$ Peak in boys;

* p < 0.05 for higher aerobically fit boys
Figure 2: Fat mass percentage vs. $VO_2$ Peak in boys

Figure 3: Fat mass percentage vs. $VO_2$ Peak in girls
Figure 4: Fat mass percentage vs. depression scale score in boys

Figure 5: Fat mass percentage vs. depression scale score in girls
3 Discussion

The purpose of this study was to examine the associations between adiposity, aerobic fitness and depressive symptomology in children at risk for obesity. Furthermore, this study aimed to examine whether aerobic fitness moderated the association between adiposity and depressive symptomology. Based on the findings, adiposity was associated with depressive symptoms in girls whereas aerobic fitness was associated with depressive symptoms in boys. Furthermore, aerobic fitness moderated the association between adiposity and depressive symptoms in boys. These findings offer considerations for factors which may differentially affect the mental health of boys and girls who are at risk for obesity.

Consistent with previous study findings, adiposity, was positively associated with depressive symptoms in girls (Boutelle, Hannan, Fulkerson & Crow, 2010; Chaiton et al., 2009; Morrison et al., 2014). This link between excess adiposity and depressive symptoms has been frequently demonstrated in girls. For example, while examining prospective associations between overweight/obese status and depressive symptoms in adolescent girls, Boutelle and colleagues (2010) found that obese status was prospectively associated with depressive symptoms during a follow up assessment one year later. There are various propositions for underlying mechanisms that may explain the association between adiposity and depressive symptoms in girls. Chaiton and colleagues (2009) demonstrated a cross-sectional association between adiposity and depressive symptoms in girls but not boys. Specifically, the relationship was explained through the children’s perceptions of pressure to be thin and body dissatisfaction (Chaiton et al., 2009). While not explicitly tested, Boutelle and colleagues (2010) also speculated that body dissatisfaction might be a factor in why adiposity is associated with depressive
symptoms in girls. Understanding female body image development may contribute to an understanding of this relationship. For instance, body image is typically centered around appearance in girls (Smolak, 2004) and athleticism in boys (Ricciardelli et al., 2006). As girls experience large sociocultural pressures to have an appearance that is thin they may be more concerned about adiposity than boys (Smolak, 2004). Prior to adolescence 40-50% of girls have reported they wish to be thinner however this increases to over 70% during adolescence while the numbers of girls who may be classified as overweight are significantly lower than this (Wertheim & Paxton, 2011). Thus, girls frequently have a desire to be thinner and consequently may consequently experience body dissatisfaction. The occurrence of body dissatisfaction has in turn been linked to various maladaptive outcomes, one of which is depressive symptoms (Smolak, 2004). Therefore, adiposity in girls may lead to body dissatisfaction, which in turn predicts depressive symptoms. This line of inquiry is important for future research.

There is also a potential explanation for this relationship using an immunological perspective as well. Adiposity has been shown to be associated with depressive symptoms (Morrison et al., 2014) but it also shares a relationship with inflammation (Sacheck, 2008). Adipose tissue is no longer viewed as dormant tissue containing extra energy but rather an endocrine organ, which may secrete various inflammatory agents (Taylor & MacQueen, 2010). Though the specific mechanisms through which adipose tissue is linked to inflammation are diverse and complex, it is well established that elevated adiposity is associated with elevated levels of various inflammatory agents in children (Sacheck, 2008). At the same time, there is evidence that inflammation may play a role in the pathogenesis of depression, though the directionality of this association remains to be elucidated, as there is evidence for both directions in this relationship (Kim et al., 2013). Notwithstanding, some research has hypothesized that adiposity may predict depressive symptomology through the mediating role of inflammation.
(Shelton & Miller, 2010). At the same time, girls may possess an elevated immune response to stressors compared to boys potentially owing to the presence of estrogen (Byrne et al., 2015). As immune cells possess estrogen receptors on their surfaces, this hormone may induce an augmented inflammatory response in girls (Byrne et al., 2015). Therefore, adiposity may contribute to an already heightened inflammatory state in girls, which may cause the presence of depressive symptoms. This relationship requires further elucidation (Byrne et al., 2015) but may be an explanation of the relationship between adiposity and depressive symptoms in girls observed in the present study.

The second main finding of the current study was that aerobic fitness was inversely associated with depressive symptoms in boys. This finding is consistent with previous work. For example, Esmailzadeh (2014, 2015) demonstrated reduced aerobic fitness, as measured by longer one-mile walk/run times, was associated with depressive symptoms among a sample of schoolboys with an age range from 7 to 11 years old. In addition, Rieck and colleagues (2013) demonstrated that higher levels of aerobic fitness were associated with less reported symptoms of depression in both boys and girls. Improved aerobic fitness may lead to a reduction in depressive symptoms for various reasons. Ortega and colleagues (2008) postulated that physical fitness might improve psychological well being through its association with reductions in adiposity and increases in lean mass. These particular physiological changes may promote athleticism which is a dominant ideal for boys (Ricciardelli et al., 2006). This also may improve body image (Ortega et al., 2008) and mitigate any depressive symptoms commonly associated with body dissatisfaction (Smolak, 2004). Furthermore, physical fitness may affect levels of mood influencing neuro-chemicals such as serotonin and endorphins thus leading to positive changes in psychological well being (Ortega et al., 2008). These are some possible explanations for how aerobic fitness may be associated with reduced depressive symptomology in boys.
However, researchers have also suggested an inverse association between aerobic fitness and depressive symptoms in girls but not boys (Greenleaf et al., 2010; Ruggero et al., 2015; Tomson et al., 2003). Greenleaf and colleagues (2010) found that aerobic fitness was associated with more psychosocial variables in girls than in boys. Specifically, aerobic fitness was inversely associated with self-reported depressive symptoms in girls but not in boys. Greenleaf and colleagues (2010) hypothesized that the aerobic fitness may reduce depressive symptomology in girls through its association with reduced adiposity and effects on neurotransmitters. However, the authors did acknowledge that this sample of girls may have been more involved with sports participation and received psychosocial benefits, such as enhanced self-esteem (Dishman et al., 2006) from this participation. This effect may have influenced the associations observed in the study by Greenleaf et al. (2010). Furthermore, the sample of girls in the Greenleaf et al. (2010) study was of a slightly older age range (11 – 15 years old) compared to the current study. As both changes in age and pubertal status may impact depressive symptomology and its manifestations in children and youth (Angold et al., 1998) the results of Greenleaf and colleagues (2010) must be interpreted with caution in terms of their relation to the current study as these effects may have influenced the associations observed in their study. However, Tomson and colleagues (2003) found that there was a significant difference in the incidence of depressive symptomology for girls who attained health related fitness standards (for 1 mile walk/run test) compared to those who did not. While boys who did not meet the fitness standard experienced a larger incidence of depressive symptomology compared to those who did meet the standards, this relationship did not attain statistical significance (Tomson et al., 2003). These findings were unusual as, in the same study, boys who participated in sports outside of school had a lower relative risk for depressive symptoms while girls did not have a significant association (Tomson et al., 2003). These findings still suggest beneficial relationship between physical activity and
depressive symptoms in boys however aerobic fitness measures may not be as conclusive. Finally, Ruggero and colleagues (2015) demonstrated a longitudinal association between aerobic fitness and depressive symptoms one year later in girls but not boys, though the direction was the same in both sexes. However, there was an inverse cross-sectional association between aerobic fitness and depressive symptoms in both sexes suggesting beneficial associations in boys (Ruggero et al., 2015). Furthermore, the authors acknowledged that 1 year follow up may not be adequate time to truly observe the longitudinal effect of aerobic fitness on depressive symptoms (Ruggero et al., 2015) therefore a longer window of time may have presented an association in boys as well. Furthermore, the discrepant results may be because the measurement of fitness used in the aforementioned studies (Greenleaf et al., 2010; Ruggero et al., 2015; Tomson et al., 2003) was not as sensitive to boys as it was to girls and may have affected study outcomes. Notwithstanding, there is limited research into the relationship between aerobic fitness and depressive symptomology in boys and girls and future inquiry is needed to elucidate this relationship in both sexes.

The final finding of this study was that aerobic fitness moderated the association between adiposity and depressive symptomology in boys but not girls. Upon further analysis it was demonstrated that boys with higher aerobic fitness had a positive association between adiposity and depressive symptomology. However, in boys with lower aerobic fitness this association was not significant. Therefore, it appears that adiposity may be harmful to mental health for boys who have higher aerobic fitness as opposed to those with lower aerobic fitness. This finding may be comprehended in light of previous literature which has demonstrated that athleticism is a core concept in the identity of boys as they develop (Grogan & Richards, 2002; Ricciardelli et al., 2006). While female body image is based on appearance, the male body image is ultimately centered on functionality and athletic qualities (Smolak, 2004). Thus, in boys, superior aerobic
fitness will promote a more positive body image as fitness is held to be a contributing factor to athleticism and functionality (Ricciardelli et al., 2006). However, as the present study demonstrated, adiposity may still play a role in boys’ mental health. This may be because the desire for a lean, toned and muscular body is still a dominant cultural pressure for boys (Alberga et al., 2012). This type of body is valued is because boys with this physique are attributed the cultural values of athleticism and functionality (Smolak, 2004). Importantly, these values may be particularly relevant for boys who are involved in athletic endeavors as this cohort may experience added pressures for a lean and muscular body as it may promote athletic success in their respective sports (Ricciardelli et al., 2006). Boys involved in athletics who experience body dissatisfaction may have a desire to modify their bodies through multiple means such as increasing muscle mass and, importantly, reducing adiposity (Ricciardelli et al., 2006). Therefore, for boys engaged in any athletic pursuit, adiposity may be viewed as a hindrance to their performance and contribute to body dissatisfaction. This in turn may promote other negative mental health outcomes such as depressive symptomology (Smolak, 2004). At the same time, research into the body image development of boys has revealed that gaining adiposity is perceived as signifying a weak will and even a lack of self discipline (Grogan & Richards, 2002). Therefore, for boys who value achieving high fitness levels, adiposity may violate the virtues ascribed to a fit and athletic male body and consequently produce negative mental health outcomes.

For boys with lower aerobic fitness levels, there was no association between adiposity and depressive symptoms. This may be related to the fact that these boys live in an environment where at least one parent is obese and may not exemplify the cultural ideal of a thin or athletic body (Smolak, 2004). As parental behaviors and attitudes have been shown to influence body image development in children (McCabe & Ricciardelli, 2003) it is possible that these children
do not feel adiposity is a violation of the cultural ideal for male physique (Smolak, 2004). Furthermore, as these boys had lower aerobic fitness levels, it is possible that they did not engage in athletics to the same extent as the higher fitness group. Consequently, they may have placed less emphasis on the athletic and functional qualities commonly promoted in boys. Given this lack of concern with the cultural ideal of male qualities, and familiarity with adiposity in parents, these children may not have experienced deleterious effects on their body image as a result of any increases in adiposity. Therefore, increases in adiposity may not have been as detrimental for depressive symptomology in this cohort as it was for their higher aerobically fit counterparts. However, further examination into the familial influences on both fitness and adiposity attitudes is required to more accurately assess the relevance of these factors.

This research has implications for practical settings. As this research has demonstrated variables, which predict depressive symptoms differently based on sex, awareness of these intricacies may allow health care practitioners to employ a more tailored approach to preventing and treating depressive symptomology in children who may be at risk for obesity. This may lead to interventions, which employ different treatment methods, such as targeting adiposity reductions in girls while enhancing aerobic fitness levels in boys. Interventions, which may promote mitigation of sex-specific risk factors, may be used to ensure children are receiving the most effective measures to promote optimal mental health throughout their development.

This study also has implications for future research and inquiry. Future research may examine other forms of fitness as potential moderators of the relationship between adiposity and depressive symptomology. For instance, an examination of strength (e.g. 1 repetition maximum value) as a moderator of this relationship would be a valuable direction of research to determine whether specific forms of fitness play a more pronounced role in this interaction. Esmaeilzadeh (2014, 2015) was unable to demonstrate a protective effect of handgrip strength on depressive
symptomology in boys when compared to aerobic fitness. However, other measures of strength were not examined and may be worthy of examination. Finally, a comparison of the various measures of body composition (e.g. waist to hip ratio, waist circumference, and fat mass index) and their relation to depressive symptomology may assist researchers in determining which measure is most predictive of an elevated risk for depressive symptomology. As Morrison and colleagues (2014) found an association between body fat percentage, but not BMI, and depressive symptoms it may be that different measures of adiposity are more indicative of mental health status. Knowledge of the most predictive measures of body composition may assist healthcare practitioners in gauging the most potent risk factors for depressive symptomology in children.

Notwithstanding the novel findings from the current study, there are limitations that need to be acknowledged. First, this study sample consisted of Caucasian children of Western European Ancestry with a parental history of obesity who volunteered for the study. Thus such a sample limits the generalizability of the study findings to this specific segment of the population resulting in an inability to extrapolate these findings to more diverse populations. Secondly, given the cross-sectional nature of this study, the conclusions drawn may only infer correlation and do not necessarily infer a causal relationship between adiposity, aerobic fitness and depressive symptomology. Finally, this study used an absolute measure of aerobic fitness as a relative measure of aerobic fitness was too highly correlated to measures of adiposity. Therefore, results must be interpreted with care, as these results do not speak to relative fitness of children.

This study did include certain strengths. The use of DEXA scan allowed a targeted measure of adiposity which permitted a specific focus on adipose tissue without any discrepancies owing to fat free mass, which could potentially affect measures of weight or BMI (Freedman et al., 2005). Also, the use of aerobic fitness instead of physical activity is strength of
this study. As aerobic fitness is a stable feature of a participant, and does not fluctuate to the same degree as physical activity levels (Ruggero et al., 2015), it represents a more consistent measurement of participant health and well-being.

In conclusion, this study found that adiposity was associated with depressive symptoms in girls but not boys at risk for obesity. Furthermore, aerobic fitness was negatively associated with depressive symptoms in boys but not girls. Finally, aerobic fitness moderated the association between adiposity and depressive symptoms in boys but not girls; with higher aerobically fit boys experiencing a positive association between adiposity and depressive symptoms. These findings suggest risk factors for depressive symptomology may differ based on sex therefore mental health interventions should be planned with these considerations kept in mind.
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Appendices 1

Center for Epidemiological Studies Depression Scale (CES-D-12)

About You

99. **In the last week (7 days)**, how often have you felt or behaved in the following ways?

➢ *Please answer for each item.*

<table>
<thead>
<tr>
<th></th>
<th>Rarely or never (less than one day)</th>
<th>A little or sometimes (1-2 days)</th>
<th>Occasionally or every now and then (3-4 days)</th>
<th>Most of the time or all of the time (5-7 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. I did not feel like eating, I had no appetite.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>B. I felt down (had the blues) and didn’t feel better, even with the help of my family or friends.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>C. I had difficulty concentrating on what I was doing.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>D. I felt depressed.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>E. I felt too tired to do things.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>F. I felt optimistic about the future.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>G. I had trouble going to sleep or staying asleep.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>H. I felt happy.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>I. I felt lonely.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>J. I enjoyed life.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>K. I cried.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
<tr>
<td>L. I felt like people didn’t love/like me.</td>
<td>1 O</td>
<td>2 O</td>
<td>3 O</td>
<td>4 O</td>
</tr>
</tbody>
</table>