

Differences in Ventilatory Patterns between Overweight and Normal Weight Children during
Rest, Low, Moderate and High Speed Exercise

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ABSTRACT

MEGHAN O'BRIEN: Differences in Ventilatory Patterns between Overweight and Normal Weight Children during Rest, Low, Moderate and High Speed Exercise
(Under the direction of Robert McMurray, Ph.D)

This study examined if overweight youth have modified ventilatory patterns at rest and during low, moderate and high speed exercise, compared to normal weight youth. Eighty OW (>85th) were matched for age, sex and height with 80 NW (>5th and ≤85th) youth. Data was collected at rest and then during three exercise speeds (4 km/h, 5.6 km/h, and 8 km/h). Metabolic rates were higher for the OW in all conditions. Multiple regression analyses revealed that V_E , V_T , f_R and V_D were greater in the OW than NW ($p < 0.05$) during exercise, while no weight group difference was found in V_D/V_T , $P_{ET}CO_2$, V_E/VO_2 and V_E/VCO_2 ($p > 0.05$). Correlations between V_E and $P_{ET}CO_2$ were significant for all conditions for the OW, but only at rest for the NW. Findings suggest that overweight children must meet greater metabolic demands during exercise by increasing their V_E via V_T and f_R ; the possible stimulus may be CO_2 .

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LIST OF ABBREVIATIONS

Alveolar Ventilation = (V_A)

Arterial Pressure of CO_2 = ($PaCO_2$)

Breathing Frequency = (f_R)

Minute Ventilation = (V_E)

Partial Pressure of End Tidal CO_2 = ($P_{ET}CO_2$)

Physiological Dead Air Space = (V_D)

Tidal Volume = (V_T)

Ventilatory Equivalent for carbon dioxide = (V_E/VCO_2)

Ventilatory Equivalent for oxygen = (V_E/VO_2)

CHAPTER I

BASIS OF STUDY

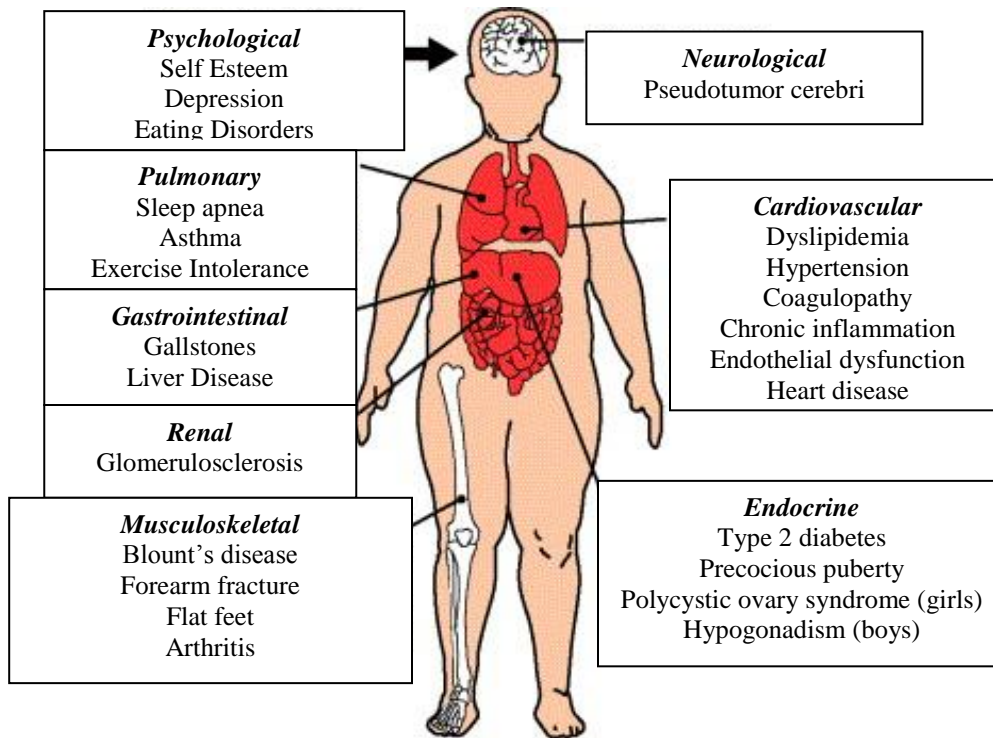
Introduction

The prevalence of overweight and obese children in the United States has become increasingly common, regardless of ethnicity and socioeconomic status (Ebbeling, Pawlak, & Ludwig, 2002). Definitions of overweight and obese within younger populations often differ between epidemiological studies due to the ongoing processes of growth and development (Ebbeling et al., 2002; Lazarus, Colditz, Berkey, & Speizer, 1997). Although the ideal characterization would be based on body fat percentage, more often percentiles based on body mass index (BMI) ($\text{weight (kg) / height (m}^2\text{)}$) for a child's age and sex are utilized, with a BMI above the 85th percentile being classified as overweight and those greater than the 95th percentile categorized as obese (Cole, Bellizzi, Flegal, & Dietz, 2000). Between 2003-2006 an estimated 11.3% of children and adolescents aged 2 through 19 years were at or above the 97th percentile, 16.3% were at or above the 95th percentile, and 31.9% were at or above the 85th percentile (Ogden, Carroll, & Flegal, 2008). Similar to adults, obesity in youth is a multi-system disease with many adverse consequences, as illustrated in Figure 1.

Excess adiposity can have several deleterious effects on an individual, especially within the pulmonary system. Previous studies have highlighted the negative influence fat can have on the oxygen cost of breathing and the symptomatic consequences (Gibson, 2000; Kress et al., 1999; Sahebji, 1998). Kress et al. (1999) conducted a study to show the effect fat can have on increasing respiratory muscle work in healthy obese adults at rest.

Researchers rationalized that this increase is likely to be augmented during exercise (Kress et al., 1999).

Figure 1. Complications of childhood obesity. (Ebbeling et al., 2002)



Lazarus, Gore, Booth, & Owen (1998) examined the effects of body composition and fat deposition on ventilatory function in adults and found that forced vital capacity (FVC) (adjusted for age, height, smoking and bronchial symptoms) was negatively associated with percentage body fat in both men and women. Additionally, Salvadori et al. (1999) investigated work tolerance, cardiac performance and ventilatory adaptation of obese vs. non-obese subjects during a graded cycle ergometer exercise test and found significantly higher VO_2 , heart rate and minute ventilation (V_E) values in obese participants during exercise, denoting a reduced cardio-respiratory efficiency. A decrease in chest wall and total respiratory system compliance of obese subjects, particularly in the supine position, has been previously established (Naimark & Cherniack, 1960). Naimark and Cherniack (1960) also

found that an estimated one-third of the increase in the mechanical work of breathing in obesity is due to the greater elastic work done on the chest wall. These significant differences found previously among healthy, obese adults may be reason to suspect related discrepancies in certain respiratory parameters of overweight youth.

Although growth and development can complicate studies examining the ventilatory function of children (Ondrak & McMurray, 2006), Lazarus et al. (1997) established a negative association between height-adjusted FVC and forced expiratory volume in one second (FEV_1) with total percent body fat in school children aged 9, 12 and 15 years. Marinov, Kostianex, & Turnovska (2002) also found that obese children had increased relative ventilation (V_E/kg), tidal volume (V_T/kg) and ratings of perceived exertion (RPE), in addition to significantly ($p < 0.001$) lower anaerobic thresholds, as compared to non-obese children. These findings indicate that obese youth display greater ventilation during exercise, as well as a faster onset of fatigue (Marinov et al., 2002). However, despite these few studies published on selected samples of obese children (Lazarus et al., 1997; Marcus et al., 1996; Reybrouck, Mertens, Schepers, Vinckx, & Gewillig, 1997; Marinov et al., 2002), no randomized population samples have measured differences in respiratory function between overweight and normal weight youth at rest, low, moderate and high speed exercise. Fat deposits could have negative mechanical effects on ventilatory function by impeding the chest wall and diaphragm; therefore, overweight children may potentially have altered respiratory function at varying exercise speeds (Lazarus et al., 1998).

Purpose:

The purpose of this study is to determine if overweight youth have modified ventilation patterns at rest and during exercise compared to normal weight youth.

Null Hypotheses:

- 1) V_E , f_R and V_T will be similar between overweight and normal weight youth during rest and low, moderate and high exercise speeds.
- 2) No significant differences exist in V_E/VO_2 and V_E/VCO_2 between normal weight and overweight youth during rest, low, moderate or high speed exercise.
- 3) No significant differences exist in $P_{ET}CO_2$, V_D and V_D/V_T ratio between overweight and normal weight youth at rest or during low, moderate and high speed exercise.

Delimitations:

1. The data was obtained from youth, aged 6 to 18 years of age, who participated in a previous study: Energy Expenditure of Physical Activity in Youth (PI: JS Harrell and RG McMurray)
2. Groups were assigned based on BMI with the overweight group having a BMI $>85^{th}$ percentile and the normal weight group having a BMI of $\leq 85^{th}$ percentile, but $>5^{th}$ percentile.
3. Pairs were matched for sex, age (± 1 year) and height (± 4 cm).
4. Not all subjects were able to perform all three exercise intensities and were therefore matched based on number of activities completed. If this was not possible, they were still matched to a member of the opposite group based on sex, age and height.

Limitations:

1. Not all subjects were able to perform at all exercise intensities.
2. Results may only be applicable to specified population.
3. Three overweight subjects had to be paired with normal weight subjects that had a height difference greater than 4 cm.

Definitions of Terms:

1. Alveolar Dead Air Space (V_A): volume of air that contacts alveoli (McArdle, Katch, & Katch, 2001)
2. Breathing Frequency (f_R): number of breaths per minute
3. Minute Ventilation (V_E): product of V_T and f_R ; volume of air respired each minute (McArdle et al., 2001)
4. Partial Pressure of End Tidal CO₂ ($P_{ET}CO_2$): measure of the amount of carbon dioxide present in the exhaled air; reflective of arterial CO₂ (McArdle et al., 2001)
5. Physiological Dead Air Space (V_D): volume of air that is respired but does not partake in gas exchange; has a ventilation-perfusion ratio that approaches zero (McArdle et al., 2001)
6. Tidal Volume (V_T): air volume moved during either inspiratory or expiratory phase of each breathing cycle (McArdle et al., 2001)
7. Ventilatory Equivalent for Carbon Dioxide (V_E/VCO_2): ratio of the volume of air ventilating the lungs to the volume of carbon dioxide produced; can define ventilatory efficiency because it reflects the matching of ventilation and perfusion in the lung (McArdle et al., 2001; Marinov et al., 2002)
8. Ventilatory Equivalent for Oxygen (V_E/VO_2): ratio of the volume of air ventilating the lungs to the volume of oxygen consumed, represents the amount of ventilation required for the consumption of each liter of oxygen (McArdle et al., 2001)

Significance of Study

Exercise intolerance is a common complaint among overweight and obese individuals. Due to increased body mass, changes in lung compliance and increased V_D ,

respiratory muscle function during exercise may be compromised in these individuals as a result of increased load on the muscles, along with a diminished capacity to do work (Gibson 2000; Marinov et al., 2002; Salvadori et al., 1999). This adverse load to capacity ratio results in more energy being required for ventilation and less available for the working muscle. Research in adults has shown that the accumulation of fat can result in reduced exercise capacity, primarily from mechanical obstruction of the rib cage, lungs and diaphragm, leading to an increase in the mechanical work of breathing during exercise (Babb, Wyrick, DeLorey, Chase, & Feng, 2008; Naimark & Cherniack, 1960; Wang & Cerny, 2004).

These complications typically reported in adults may also extend to younger populations and can potentially impact an overweight child's ability to exercise. This in turn may make it more difficult for overweight youth to use exercise as a modality for losing weight or increasing fitness. Consequently, negative self-esteem and related psychological issues may begin at a young age. Although an increased risk of asthma and sleep apnea among young overweight and obese populations has already been established (Xu, Jiaqing, Yuchuan, & Shen, 2008; Gilliland et al., 2003), the influence of high body fat on a child's pulmonary system during physical activity is not yet known. For this reason, the current study may provide evidence for the degree to which excess body mass may diminish overall exercise capacity and metabolic energy utilization through its negative impact on respiration.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Obesity has been acknowledged as a worldwide phenomenon that increases morbidity and reduces life expectancy (Parameswaran, Todd, & Soth, 2006). It can be defined as the excessive accumulation of body fat that causes a generalized increase in body mass (Luce, 1980). The prevalence of overweight and obese youth has increased exponentially in the last decade and has now become a common health crisis within the United States (Dehghan, Akhtar-Danesh, & Merchant, 2005). There are many adverse consequences of being overweight and obese including diabetes, dyslipidemia, hypertension and hyperinsulinemia (Ebbeling et al., 2002).

One way to reduce or prevent obesity is through exercise; however, physical activity is generally more difficult for an obese individual. Not only does fat mass increase the metabolic demands of exercise, but excess fat can also impede on other physiological systems. As body mass increases there can be a negative impact on an individual's ability to exercise due to mechanical obstruction and decreased respiratory efficiency (Luce, 1980; Parameswaran et al., 2006). The current study is looking at the implications that excess adiposity may have on ventilatory function in children during rest and various exercise speeds (low, moderate and high). This chapter begins with a background on ventilation and the differences between adult and youth respiration. The effects of obesity on the adult

pulmonary systems are then outlined in order to provide a useful foundation for the impact of excess fat on pediatric respiratory physiology.

Ventilation

The respiratory system serves as the link between the ambient air and the blood circulation of oxygen to the muscles. Minute ventilation is the air entering or leaving the lungs and airways every minute and is the product of tidal volume (V_T) and breathing frequency (f_R). Tidal volume is the amount of air per breath and can be divided into air that reaches the alveoli (alveolar ventilation (V_A)) and the air that simply fills air passages or does not partake in gas exchange (physiological dead space (V_D)). The concept of compliance reflects the amount of work required to move the extrapulmonary structures while breathing (Luce, 1980; Naimark & Cherniack, 1960). Any obstruction on the respiratory components in the body can negatively impact an individual's ability to breathe, in addition to negatively impacting V_T , V_D and V_A .

Respiration must be tightly controlled, particularly during exercise when increased metabolic demands and excess CO_2 production occurs within the body. The goal of ventilatory control is to maintain pH, O_2 and CO_2 partial pressure homeostasis (Keslacy, Carra, & Ramonaxo, 2008). Ventilation is controlled primarily by neural factors and secondly by CO_2 levels in the blood (Eldridge, Millhorn, Kiley, & Waldrop, 1985). Although the basic ventilatory components in adults and children are somewhat similar, their responses during exercise may differ depending on certain anatomical and functional aspects.

Differences between adult and youth pulmonary dynamics

The differences in ventilation between youth and adults, both at rest and during exercise have been previously established (Cooper et al., 1987; Gratas-Delmarche, Mercier,

Romanatxo, Dassonville, & Prefaut, 1993; Ondrak & McMurray 2006). Compared to adults, children have lower absolute V_E , absolute V_T and end-tidal CO_2 ($P_{ET}CO_2$) at rest and during submaximal and maximal exercise (Ondrak & McMurray 2006). Conversely, children display a greater f_R , relative V_E and ventilatory equivalent for oxygen (V_E/VO_2) compared to adults (Ondrak & McMurray 2006). Therefore, it is evident that the respiratory physiology of youth differs substantially from adults.

The shape, size and composition of the respiratory system changes dramatically from infancy to adulthood, thereby impacting the mechanical properties of ventilation (Lanteri & Sly, 1993). Alterations in rib cage configuration, chest wall maturation, respiratory muscle development and alveoli proliferation all occur within the first few years of life (Lanteri & Sly, 1993). Lung structure is not fully developed at birth, with the weight increasing three-fold and the surface area increasing 10-fold before adulthood is reached (Rowland, 1996). As a child increases in height, modifications in respiratory mechanics are associated with decreased airway resistance and increased respiratory compliance (Lanteri & Sly, 1993). As a result, height becomes an important factor for ventilatory work, duration of inspiration and expiration, and the relation of V_T to f_R (Rowland, 1996). Thus, the discrepancy in size and pulmonary development between adult and pediatric populations impacts ventilatory mechanics.

Evidence has shown that children hyperventilate more than adults during exercise, displaying lower alveolar PCO_2 and higher V_E/VO_2 (Cooper et al., 1987; Gratas-Delmarche et al., 1993; Robinson, 1938; Shephard & Bar-Or, 1970). V_E/VO_2 and V_E/VCO_2 define ventilatory efficiency and are reflective of the matching of ventilation and perfusion in the lung (Marinov et al., 2002; Wang & Cerny, 2004). The greater V_E/VO_2 values in youth, as

compared to adults, demonstrate that younger individuals ventilate more than adults to meet a similar metabolic demand during exercise (Rowland, 1996). Since V_E/VO_2 is inversely proportional with age, individuals increase their ventilatory efficiency into adulthood. Greater V_E values in children during exercise is due to increased sensitivity to CO_2 as compared to adults (Cooper et al., 1987; Gratas-Delmarche et al., 1993). Less CO_2 is required for children to elicit a response and modifications in ventilation must be made in order to maintain exercise and alter CO_2 concentration (Cooper et al., 1987).

In summary, development of the respiratory system continues until adulthood. Although pulmonary structures are sufficient to function outside the uterus at birth, the lungs continue to grow proportionally to height (Malina, Bouchard, & Bar-Or, 2004). The differences that exist between the respiratory systems of youth and adults are reflected in each individual's response and management of ventilation during exercise. In addition to dimensional disparities, excess fat can impose an impediment on the human body that requires an adjustment in ventilatory response, particularly during physical activity.

Effects of Obesity on Adult Respiration

In adults, obesity has been found to have a profound effect on the physiology of breathing (Parameswaran et al., 2006). Respiratory problems associated with excess adiposity include decreased compliance, altered breathing patterns and lung volumes, and elevated work of breathing (Parameswaran et al., 2006). These effects are amplified during exercise, when obese adults experience additional respiratory stress as a direct result of their increased body mass (Parameswaran et al., 2006).

Decreases in end-expiratory lung volume (EELV), forced vital capacity (FVC), expiratory reserve volume (ERV), maximal voluntary ventilation (MVV), functional residual

capacity (FRC), total lung capacity (TLC) and vital capacity (VC) lung volumes have been the most consistent findings among obese adults (Babb et al., 2008; Costa, Barbalho, Miguel, Forti, & Azevedo, 2008; Gibson, 2000; Lazarus et al., 1998; Luce, 1980; Parameswaran et al., 2006; Zerah et al., 1993). Decreased EELV is one of the earliest and most prominent changes in pulmonary function with obesity and can greatly impact gas exchange and work of breathing during exercise (Babb et al., 2008). Babb et al. (2008) observed approximately 11% lower EELV in obese men and women, in comparison to lean individuals. FVC volumes decreased by almost two liters in obese subjects when Lazarus et al. (1998) compared individuals based on body fat percentage. Additionally, the Costa et al. (2008) study found ERV to decrease by 5% per unit of increase in BMI, which is attributable to the reduction of diaphragm mobility and pulmonary compliance observed in obesity. MVV is a measurement of respiratory muscle endurance and is approximately 20% lower in obese, while TLC and VC are about 20-30% lower as body mass increases (Parameswaran et al., 2006; Zerah et al., 1993). These diminished lung volumes demonstrate the hazardous effects obesity can have on pulmonary function.

Some of the respiratory changes in obese individuals are related to a reduction in respiratory compliance by as much as two-thirds the normal value (Naimark & Cherniack, 1960). Lung volume abnormalities are related to changes in compliance since the end-expiratory position of the lungs, chest wall and diaphragm is determined by the balance of the elastic recoil forces of these structures (Zerah et al., 1993). This decreased compliance is primarily due to the central accumulation of fat, which increases the elastic resistance of the chest wall, decreasing the ability for chest expansion, and ultimately decreasing lung volumes (Naimark & Cherniack, 1960; Zerah et al., 1993). Additionally, increased

pulmonary blood volume contributes to decreased lung compliance, which may also play a role in the reduced distensibility of extrapulmonary structures (Naimark & Cherniack, 1960). These findings support the idea that obesity requires extra respiratory work to expand the chest and ventilate the lungs adequately, particularly during exercise. Consequently, obese individuals must overcome these obstacles by modifying pulmonary function.

Obese adults tend to display a rapid, shallow breathing pattern that may increase their overall respiratory muscle work (Luce, 1980; Parameswaran et al., 2006; Wang & Cerny, 2004). A combination of smaller V_T and higher f_R attempts to reduce the oxygen cost of each breath, but is ultimately uneconomical because each breath contains a larger V_D in proportion to V_E (Luce, 1980). The respiratory muscles of an obese individual do not generate as much inspiratory and expiratory pressures as a normal weight individual, despite having to work against a less compliant chest wall (Parameswaran et al., 2006). Increased central adipose limits diaphragm function and prohibits the muscle from adequately contracting during ventilation (Babb et al., 2008; Parameswaran et al., 2006). Many of these respiratory consequences in adults may be translated to children, despite the morphological differences between the two populations.

Effects of Obesity on Youth Respiration

The effects of obesity on respiration have been well established in adults (Babb et al., 2008; Costa et al., 2008; Gibson, 2000; Lazarus et al., 1998; Luce 1980; Naimark & Cherniack, 1960; Parameswaran et al., 2006; Wang & Cerny, 2004; Zerah et al., 1993). However, the rapid development and growth of children, particularly of the lungs, makes obtaining pulmonary measurements a challenge. Yet, several studies have found decreased lung volumes, in addition to diminished chest compliance in overweight youth (Gonzalez-

Barcala et al., 2007; Lazarus et al., 1997; Marinov et al., 2002; Reybrouck et al., 1997; Zanconato et al., 1989).

Similar to adults, lung volumes in children are decreased relative to increasing body mass (Lazarus et al., 1997). Compared to normal weight children, overweight children in one study (Gonzalez-Barcala et al., 2007) were found to have 11% lower FVC and 10% lower forced expiratory volume in one second (FEV_1), which is in accordance with similar values detected by Lazarus et al. (1997). Additionally, Inselman, Milanese, & Deurloo (1993) found decreased ERV and MVV in obese youth that were only 35 and 61% of predicted values, respectively. Investigators ascribe these reductions to the large extrinsic load on the chest wall that diminishes normal exhalation of the chest wall and lungs (Inselman et al., 1993). These findings indicate a decrease in ventilatory function with increasing proportions of body fat.

Increased metabolic cost during exercise has also been previously established in overweight youth (Inselman et al., 1993; Marinov et al., 2002; Reybrouck 1997; Zanconato et al., 1989). Marinov et al. (2002) found approximately 25% greater absolute peak VO_2 values (L/min) in the obese group signifying a greater metabolic demand; however, once body weight was taken into account, obese subjects' values became about 10% lower than the controls (29.2 vs. 33.6 mL/kg/min, respectively). Consequently, this suggests that obese youth require more oxygen and may be limited in their physical capacity, thereby making it more difficult for them to lose weight (Marinov et al., 2002).

Although no differences in ventilatory efficiency between obese and normal weight children have been found, greater V_E via increased f_R and absolute V_T have been observed in obese youth (Inselman et al., 1993; Marinov et al., 2002). Greater V_T in obese children is in

contrast to lower V_T values found in obese adults, although the reason explaining this finding is currently unknown (Luce, 1980; Parameswaran et al., 2002). However, research suggests that the same decreased chest wall compliance found in adults can account for increased f_R in youth during exercise (Reybrouck et al., 1997). These findings suggest increased ventilatory requirements by overweight youth.

Summary

Excess adiposity can have detrimental effects on the human body and can greatly diminish exercise capacity. Lower ventilatory function and decreased physical activity, previously found within the pediatric population, are just two major components in the vicious cycle of obesity, leading to greater fat accumulation and increased risk of cardiovascular disease (Lazarus et al., 1997). This chapter reviewed the effects of obesity on the respiratory system in adults and youth and examined the differences in pulmonary dynamics between the two populations. Few studies have examined the differences in ventilatory patterns between overweight and normal weight youth and no study has looked at these differences during different speeds of physical activity. Therefore, current research would provide more insight into whether being overweight has an impact on the respiration of youth during rest, low, moderate and high speed exercise.

CHAPTER III

METHODOLOGY

Subjects

This study is a secondary analysis of data obtained previously from the Energy Expenditure of Physical Activity in Youth (EEPAY) study, a sample of 356 volunteer youth, 6 to 18 years of age, whose methodological procedures are described in detail elsewhere (Harrell et al., 2005; Ondrak & McMurray, 2006). The participants in this sample were separated into overweight and normal weight groups based on their BMI, with those above the 85th percentile for their age and sex defined as the overweight group (OW) and those at or below the 85th percentile, but above the 5th percentile, belonging to the normal weight (NW) group. The Center for Disease Control (CDC) Growth Charts (National Center for Health Statistics, 2000) on body mass index (BMI)-for-age percentiles for boys and girls, ages 2 to 20 years, were used to determine each child's BMI percentile. Each of the overweight youth (n=80) were match paired to a normal weight youth (n=80) based on sex, age (± 1 year), height (± 4 cm) and number of activities (running, low walking, high walking) completed (1, 2 or 3 out of 3). Age, sex and height parameters took precedence, so if an overweight subject was closer in age and height to a normal subject with a different number of activities then they were match paired with that participant, regardless of his/her activity number. Three overweight subjects had to be paired with normal weight subjects that had a height difference greater than 4 cm. Subjects were matched to each other via identification numbers assigned previously in the EEPAY study.

Instrumentation

Height was measured using a standard stadiometer (Perspective Enterprises, Portage, MI, USA) and body mass was obtained via a calibrated balance beam scale (Detecto Scales, Inc., Webb City, MO, USA). The children performed the submaximal walking and running exercises at low, moderate and high speeds on a calibrated Quinton, model Q65 treadmill (Quinton Instruments, Seattle, WA). Respiratory data was collected breath-by-breath from each child through a face mask (Hans Rudolph Inc., Kansas City, MO) that directed air into a 28 mm bidirectional digital turbine, which was part of the COSMED K4b² portable metabolic analyzer (Rome, Italy). This lightweight system was calibrated to ensure accuracy and then harnessed to the subject's torso in order to allow ample freedom of movement during the data collection periods.

Procedures

Data collection took place during two laboratory visits, with participants entering the lab three hours postprandial. Previously obtained height and weight measurements were used to calculate body mass index (kg/m^2). Following the procedure presented in Harrell et al. (2005), each child's ventilatory patterns were recorded for 15 minutes of reclined rest in a quiet room and then for 10 minutes at each of the following three exercise intensities at 0% incline: a slow walk (4 km/hr, 2.5 mph), a fast walk (5.6 km/hr, 3.5 mph) and a run (8.0 km/hr, 5 mph), in that order. The first three minutes and the last minute of each exercise were eliminated to ensure that steady state was reached and maintained. Thus, averages of minutes 4 through 9 were used for data collection. If the participant was unable to complete any exercise, a minimum of three minutes steady state was still required in order to be included in the analyses. Oxygen uptake (VO_2) and carbon dioxide output (VCO_2) were calculated by the

COSMED software in order to obtain metabolic rate. The tidal volume (V_T) and respiratory frequency (f_R) were measured directly from the turbine of the COSMED, while minute ventilation (V_E) and end-tidal CO_2 ($P_{ET}CO_2$) were calculated by the COSMED software. The partial pressure of arterial CO_2 ($PaCO_2$), which is needed for the calculation of V_D , was derived from $P_{ET}CO_2$ and V_T using the Jones, Robertson, & Kane (1979) equation ($PaCO_2 = 5.5 + 0.9 P_{ET}CO_2 - 0.0021 V_T$ ($r=0.915$)). Dead air to tidal volume ratio (V_D/V_T) and minute ventilation per unit CO_2 output and O_2 uptake ratios (V_E/VCO_2 , V_E/VO_2) were all derived from collected values (Ondrak & McMurray, 2006). Breaths less than 200 mL or greater than the 95th percentile were eliminated from the data set.

Data Analysis

All analyses were conducted using SAS software (Version 9.1, SAS, Cary, NC, USA) and presented in mean \pm standard deviation (SD) form. Variables were adjusted for sex, height and age and a multiple regression analysis was performed for each exercise speed to determine how weight status influenced the following variables: V_E , V_T , f_R , V_D , V_D/V_T , $P_{ET}CO_2$, V_E/VCO_2 , and V_E/VO_2 in the overweight and normal weight group. To further explore the relationship between ventilation and CO_2 in youth, a Pearson correlation was performed between the variables: $P_{ET}CO_2$, V_E , V_T and f_R . Breath-by-breath data values greater than two SD were removed from the final data set and mean and standard deviations were recomputed. For weight group designation, 0 represented normal weight subjects and 1 represented the overweight subjects. The subject's sex was indicated as 0 for female and 1 for male. Statistical significance was reported at the $p < 0.05$ level.

CHAPTER IV

RESULTS

Subject Characteristics

This study examined the potential differences in ventilatory patterns between overweight and normal weight children during both rest and various exercise speeds. A total of 160 children were included in this study. They were separated into two groups of 80 children with 40 males and 40 females in each one. The descriptive data for the overweight (OW) and normal weight (NW) groups is presented in Table 1. As expected, age and height was similar between the two populations, while body mass index (BMI) and weight was significantly higher in the OW group ($p < 0.0001$).

Table 1. Mean (\pm SD) of physical characteristics presented by Normal Weight (NW) and Overweight (OW) groups.

Characteristic	NW (n=80)	OW (n=80)
<i>Age (years)</i>	12.4 \pm 3.2	12.4 \pm 3.3
<i>BMI* (kg/m²)</i>	18.4 \pm 2.6	24.8 \pm 4.6
<i>Height (cm)</i>	155.1 \pm 16.9	154.8 \pm 17.0
<i>Weight* (kg)</i>	45.8 \pm 14.3	61.1 \pm 21.1

* OW vs. NW $p < 0.0001$

Metabolic Efficiency

Table 2 displays the metabolic responses of each group. The absolute VO_2 was significantly higher in the OW group at rest and all three exercise speeds ($p < 0.001$).

Heart rate was also significantly higher in the OW group at low and moderate speeds ($p < 0.0102$). However, no significant differences were found in either V_E/VO_2 or V_E/VCO_2 between the two groups ($p > 0.05$).

Table 2. Mean (\pm SD) of metabolic efficiency variables for the Normal Weight (NW) and Overweight (OW) groups during rest, low, moderate and high speed exercise.

<i>Variable</i>	<i>Group</i>	Rest	4 km/hr (2.5 mph)	5.6 km/hr (3.5 mph)	8 km/hr (5 mph)
Absolute VO_2 (L/min)	NW	0.22 \pm 0.06	0.70 \pm 0.19	0.93 \pm 0.24	1.68 \pm 0.56
	OW*	0.26 \pm 0.07	0.84 \pm 0.24	1.13 \pm 0.31	1.89 \pm 0.60
Relative VO_2 (mL/kg/min)	NW	5.11 \pm 1.37	15.9 \pm 3.3	21.3 \pm 4.3	36.8 \pm 5.9
	OW	4.47 \pm 1.32	14.4 \pm 3.5	19.6 \pm 4.5	32.2 \pm 5.3
HR (bpm)	NW	76.7 \pm 13.9	101.4 \pm 26.3	118.6 \pm 26.6	171.4 \pm 15.2
	OW	76.5 \pm 14.1	110.7 \pm 15.0 \ddagger	130.5 \pm 17.3 \ddagger	176.3 \pm 16.1
V_E/VCO_2 (L/L)	NW	40.4 \pm 8.9	33.1 \pm 5.0	31.6 \pm 4.7	33.6 \pm 7.2
	OW	39.1 \pm 7.2	32.5 \pm 5.3	31.4 \pm 5.0	32.8 \pm 5.4
V_E/VO_2 (L/L)	NW	35.9 \pm 11.7	26.4 \pm 4.0	27.4 \pm 4.2	31.2 \pm 6.0
	OW	34.6 \pm 8.0	27.2 \pm 4.6	27.9 \pm 4.3	32.1 \pm 4.6

V_E/VCO_2 = Ventilatory Equivalent for CO_2 ; V_E/VO_2 = Ventilatory Equivalent for O_2 ; VO_2 = Oxygen Uptake; HR = Heart Rate

* OW vs. NW $p < 0.001$ for all four conditions

\ddagger OW vs. NW $p < 0.0102$ at low and moderate speeds

Pulmonary Variables

Table 3 displays the means \pm standard deviations (SD) for the pulmonary variables of each group during each condition (rest, low, moderate and high speed). Significant differences between the two groups were found, with the OW group having higher V_E and V_T at all four intensities ($p < 0.001$; $p < 0.035$, respectively). At low and moderate speed, the OW group had significantly higher f_R mean values in comparison to the NW group ($p < 0.001$). Additionally, the OW group had a greater V_D at low, moderate and high speeds ($p <$

0.004), but not at rest ($p > 0.05$). No significance was found in the $P_{ET}CO_2$ or V_D/V_T between groups ($p > 0.05$) at rest or during exercise.

Table 3. Mean (\pm SD) of respiratory variables for the Normal Weight (NW) and Overweight (OW) groups at rest, low, moderate and high speed exercise.

<i>Variable</i>	<i>Group</i>	Rest	4 km/hr (2.5 mph)	5.6 km/hr (3.5 mph)	8 km/hr (5 mph)
V_E (L/min)	NW	7.52 \pm 1.5	18.3 \pm 3.8	25.2 \pm 4.9	50.7 \pm 12.7
	OW*	8.77 \pm 1.8	22.3 \pm 4.4	31.1 \pm 6.0	59.6 \pm 15.2
f_R (breaths/min)	NW	19.9 \pm 5.5	29.2 \pm 7.7	34.7 \pm 10.3	51.1 \pm 12.8
	OW	20.6 \pm 4.3	32.6 \pm 7.4**	38.9 \pm 9.4**	53.9 \pm 11.7
V_T (L)	NW	0.42 \pm 0.13	0.69 \pm 0.27	0.82 \pm 0.34	1.11 \pm 0.45
	OW [#]	0.47 \pm 0.15	0.76 \pm 0.25	0.89 \pm 0.28	1.22 \pm 0.47
$P_{ET}CO_2$ (mmHg)	NW	38.9 \pm 4.3	39.8 \pm 4.0	40.3 \pm 4.3	38.6 \pm 5.1
	OW	38.4 \pm 5.1	40.5 \pm 4.2	41.0 \pm 4.1	38.8 \pm 4.6
V_D (mL)	NW	58.7 \pm 31.1	113.8 \pm 55.5	137.4 \pm 66.8	227.5 \pm 104.0
	OW	69.7 \pm 41.9	133.2 \pm 72.5‡	161.3 \pm 75.2‡	262.6 \pm 126.7‡
V_D/V_T (%)	NW	12.4 \pm 5.7	14.9 \pm 5.8	15.4 \pm 5.6	18.9 \pm 7.8
	OW	12.4 \pm 6.2	15.3 \pm 7.4	16.1 \pm 7.4	18.9 \pm 7.9

V_E = Minute Ventilation; f_R = Breathing Frequency; V_T = Tidal Volume; $P_{ET}CO_2$ = Partial Pressure of End-Tidal CO_2 ; V_D = Physiological Dead Space; V_D/V_T = Dead Space to Tidal Volume Ratio

* OW vs. NW $p < 0.0001$ for all four conditions

** OW vs. NW $p < 0.002$ at low and moderate speeds

OW vs. NW $p < 0.04$ for all four conditions

‡ OW vs. NW $p < 0.005$ at low, moderate and high speeds

Exploratory Analysis

Table 4 displays the results from the Pearson Product correlation between $P_{ET}CO_2$, V_E , V_T and f_R for both groups at rest and each exercise speed. Significant positive correlations were detected between $P_{ET}CO_2$ and V_E at rest in the NW group and at all four conditions in the OW group. Significant positive correlations were found between $P_{ET}CO_2$ and V_T at moderate and high speeds in the NW group and at low, moderate and high speeds in the OW group. Additionally, significant negative correlations were found at all four conditions between $P_{ET}CO_2$ and f_R in the NW and at low, moderate and high exercise speeds

in the OW. The strongest correlations in both groups were found to be between $P_{ET}CO_2$ and V_T and $P_{ET}CO_2$ and f_R during high exercise speed.

Table 4. Pearson product correlation values of $P_{ET}CO_2$ for Normal Weight (NW) and Overweight (OW) groups during rest, low, moderate and high speed exercise.

<i>Condition</i>	V_E		V_T		f_R	
	NW	OW	NW	OW	NW	OW
<i>Rest</i>	-0.38*	-0.35*	0.14	-0.22	-0.48*	-0.21
<i>4 km/hr (2.5 mph)</i>	-0.08	0.26*	0.22	0.4*	-0.38*	-0.42*
<i>5.6 km/hr (3.5 mph)</i>	0.01	0.28*	0.42*	0.48*	-0.54*	-0.49*
<i>8 km/hr (5 mph)</i>	0.22	0.31*	0.57*	0.66*	-0.63*	-0.68*

V_E = Ventilation; V_T = Tidal Volume; f_R = Breathing Frequency; $P_{ET}CO_2$ = Partial Pressure of End- Tidal CO_2

* indicates $p < 0.05$

CHAPTER V

DISCUSSION

Introduction

This is the first study to compare pulmonary and metabolic parameters in normal and overweight youth during rest and three speeds of exercise. The hypothesis was that there would be no differences in any of the measured pulmonary and metabolic variables between the overweight and normal weight groups at rest or during exercise. Walking and running exercises resulted in a higher metabolic cost for overweight youth than normal weight youth; however, V_E/VO_2 and V_E/VCO_2 were similar. Significantly higher V_E , V_T , f_R , and V_D were found in the OW group as compared to the NW. These results suggest that overweight children modify their pulmonary responses in order to compensate for their increased metabolic demands during exercise.

Metabolic Efficiency

The absolute VO_2 (L/min) was higher in the OW group during all four conditions, as expected, considering their greater weight and the fact that metabolic rate is proportional to mass (Luce, 1980). Overweight individuals generally have increased muscle mass compared to a typical normal weight individual. This greater muscle mass causes a greater energy use. In addition, fat does not contribute to the production of energy for ambulation, but does contribute to the energy requirement (Luce, 1980). Thus, higher muscle mass combined with greater overall mass increases the metabolic rate and elicits a greater cardio-respiratory response to exercise (Bandini, Schoeller, & Dietz, 1990; Wasserman, Hansen, Sue, Casaburi,

& Whipp, 1999). Previous studies conducted in both adults (Salvadori et al., 1999; Wang & Cerny, 2004) and children (Gutin et al., 1994; Reybrouck et al., 1987; Rowland, 1991; Zanconato et al., 1989) found increasing absolute oxygen uptake values (VO_2 ; L/min) with increasing weight. However, once body composition was taken into account, both the present and aforesaid studies found that relative VO_2 (mL/kg/min) was inversely proportional to the subject's weight.

Heart rate was elevated in the OW group compared to the NW group during low and moderate exercise, which is consistent with a higher VO_2 requiring a greater cardiac output (Luce, 1980). The similarity in values between the two groups during high speed exercise was most likely due to the convergence towards maximum heart rate. Our findings are in agreement with previous studies that examined the heart rates of obese and normal weight adults (Dempsey, Reddan, Balke, & Rankin, 1966; Rowland, 1991; Salvadori et al., 1999) and youth (Marinov et al., 2002; Zanconato et al., 1989) during maximum work.

There were no significant differences in the ventilatory equivalents for O_2 or CO_2 between the two groups, suggesting that being overweight does not necessarily reduce ventilatory efficiency during exercise. The V_E/VO_2 values in this study are consistent with previous research in obese adults (Wang & Cerny, 2004; Wolfe, Hodgson, Barlett, Nicholas, & Buskirk, 1974) and adolescents (Rowland, 1991). Also consistent with the current findings, Marinov et al. (2002) found no difference in $V_E/V\text{CO}_2$ between obese and normal weight 6-17 yr old children during an incremental treadmill test. Previous research shows that obese subjects are able to compensate and receive adequate ventilation in order to sustain the metabolic demands of exercise (Wang & Cerny, 2004). Thus, the OW group in this study

was able to meet their increased oxygen needs by increasing their V_E in the same proportion as in the NW group.

Pulmonary Efficiency

The respiratory system must respond to the increase in metabolism during exercise by increasing V_E via rate (f_R) and volume (V_T) (Rowland, 1996). V_E is the product of V_T and f_R . Elevated f_R was found in the OW group during low and moderate exercise speeds, similar to previous findings among obese adults (Chlif, Keochkerian, Choquet, Vaidie, & Ahmaidi, 2009) and youth (Rowland, 1991). At all four conditions, the OW group was found to have a greater absolute V_T than the NW, which is consistent with similar studies in obese adults (Salvadori et al., 2008) and youth (Inselman et al., 1993; Marinov et al., 2002). Generally, normal weight individuals will adjust their respiratory patterns (V_T and f_R) in order to minimize their ventilatory work and muscle action during exercise (Dempsey et al., 1966). The increased values for V_T and f_R during exercise suggest that overweight individuals may increase their depth and rate of breathing in order to meet their metabolic demands, which could result in increased metabolic cost of breathing (Chlif et al., 2009; Dempsey et al., 1966; Luce, 1980; Wang & Cerny, 2004).

Increased V_T and f_R in the OW group may also be counteracting their decreased respiratory compliance. Diminished chest wall and lung compliance has been previously found in obese individuals, resulting in decreased lung volumes and an overload of inspiratory muscles (Costa et al., 2008; Naimark & Cherniack, 1960; Rowland, 1991; Salvadori et al., 1999; Wang & Cerny, 2004; Zerah et al., 1993). Reduction in lung volumes can contribute to greater energy requirements during exercise by increasing elastic and airway resistance (Luce, 1980; Naimark & Cherniack, 1960; Parameswaran et al., 2006;

Salvadori et al., 2008). Other factors that contribute to decreased respiratory compliance include excess fat and greater pulmonary blood volume (Naimark & Cherniack, 1960; Parameswaran et al., 2006). Central abdominal obesity in and around the ribs, diaphragm and abdomen, physically impedes these pulmonary structures (Parameswaran et al., 2006). Consequently, obese individuals are forced to take deeper breaths more frequently (via increased f_R and V_T) in order to deliver enough oxygen to working muscle. In addition, increased blood volume and cardiac output are related to increased fat (Luce, 1980). Obese individuals require more blood vessels and a larger blood supply to distribute oxygen over a greater body mass area (Luce, 1980). Increased pulmonary blood volume, in particular, has been suggested to decrease lung compliance due to the recruitment of previously under-perfused vessels (Parameswaran et al., 2006). This can result in impaired gas exchange, increased intravascular lung water and further reduction in lung compliance (Luce, 1980).

Table 5. Mean alveolar ventilation (V_A) and ratio of alveolar ventilation to oxygen uptake (V_A/VO_2) in normal weight (NW) and overweight (OW) groups during exercise.

Variable	<i>Group</i>	4 km/hr	5.6 km/hr	8 km/hr
V_A (mL/min)	<i>NW</i>	16.8	23.7	45.1
	<i>OW</i>	20.4	28.3	51.6
V_A/VO_2	<i>NW</i>	24	25.5	26.8
	<i>OW</i>	24.3	25	27.3

V_T is the sum of the physiological dead space (V_D) and alveolar ventilation (V_A). V_D is known to increase with age and is enlarged in some obstructive syndromes, such as obesity (Martin, Das, & Young, 1979). A larger V_D was found during exercise in the OW group, presenting the possibility of impaired ventilatory function and abnormal ventilation of non-perfused or under-perfused alveoli (Dempsey et al., 1966; Marinov et al., 2002). As V_D increases in obese individuals, typically their gas exchange rate decreases (Chlif et al., 2009).

To examine this “post hoc”, mean V_A was estimated during exercise based on mean V_T and V_D values and normalized per unit of VO_2 (L/min); see Table 5. These post hoc findings suggest that increased V_T in the OW group is sufficient to compensate for their increased V_D ; thus, allowing for adequate gas exchange.

No significance was found in the partial pressure of end tidal CO_2 ($P_{ET}CO_2$) between groups. This is in agreement with the Salvadori et al. (2008) study that compared obese and normal weight adults. Wang & Cerny (2004) also found similar $P_{ET}CO_2$ values between control and obese-simulated subjects, suggesting that obese subjects were able to maintain adequate ventilation during exercise. From these results changes in CO_2 sensitivity cannot be determined; however, if CO_2 sensitivity had changed, this could provide the additional stimulus for increased V_T in the OW group (Cooper et al., 1987). The outcomes of the current and past studies indicate that ventilation of obese subjects is appropriate to remove the increased amount of CO_2 produced by metabolism (Salvadori et al., 2008).

Exploratory Analysis

Respiration during exercise is controlled primarily by neural input, and secondly by CO_2 levels in the blood (Eldridge et al., 1985). The relationship between $P_{ET}CO_2$ and V_E was analyzed to see if overweight children differed in their pulmonary response to CO_2 during exercise. In the OW group, a strong positive correlation was evident between $P_{ET}CO_2$ and V_E during exercise, while the NW group did not have any significant association. The strongest correlation between $P_{ET}CO_2$ and V_T was during high speed exercise, which may signify that as the OW group reached a higher speed, increased CO_2 levels may be the drive for increased ventilation. CO_2 may act as an additional stimulus to the OW group to increase their V_T by triggering them to take deeper breaths that expel more CO_2 . This mechanism may allow the

OW group to overcome their decreased respiratory compliance and increased V_D to maintain appropriate ventilation throughout exercise. Thus, for overweight youth, CO_2 is more closely related to ventilation, while neural input may be more dominant in the NW group.

In both the NW and OW groups, a strong negative correlation between $P_{ET}CO_2$ and f_R during exercise was found. This response indicates that neural input, rather than CO_2 concentration, may be more closely linked to breathing rate in both groups. This finding is supported by the Eldridge et al., (1985) study that found neural command signals from the hypothalamus were primarily responsible for fast respiratory changes, such as f_R , during exercise.

Strengths & Limitations

Strengths of the current study include a relatively large sample size and matched-pair research design, which allowed matches to be made based on subjects' height, sex and age. Matching subjects by height within 4 cm is a particularly important factor when studying children because of the rapid changes in lung volumes that occur with increasing height. A weakness in this study may include the inability to obtain data from every subject at every workload, since some subjects were unable to reach steady state at higher intensities. However, this can be justified by the matching of subjects based on number of activities completed, when possible. Another limitation may be the classification of overweight vs. normal weight children using BMI percentiles. BMI is a measurement that does not take body composition into account. However, this is the most common measurement used in clinical studies and is the most straightforward approach when organizing a large youth population (Cole et al., 2000; Dehghan et al., 2005). Also, there is currently no consensus on

a classification system based solely on body fat percentage in children (Cole et al., 2000; Dehghan et al., 2005).

Conclusions

The purpose of this study was to determine whether excess body fat modifies the ventilation of children at rest and during exercise. The increased V_E volumes in the OW group were attributed to increased V_T and f_R . The greater V_T and f_R were sufficient to compensate for the larger V_D volumes found in overweight youth. The exploratory analysis revealed that during exercise CO_2 may be responsible for the additional respiratory drive of overweight youth to increase V_T . In summary, the most important finding of this study is that overweight youth have higher metabolic demands during exercise that are met via increased ventilation. Although the ventilation of overweight children adequately compensates for their increased metabolic demands during physical activity, this may not be the case for adults (Costa et al., 2008; Naimark & Cherniack, 1960; Rowland, 1991; Salvadori et al., 1999; Wang & Cerny, 2004; Zerah et al., 1993). Therefore, early treatment and prevention of further weight gain is imperative for long-term health and decreased risk of chronic disease later in life.

Review of Hypotheses

The first hypothesis stated that V_E , V_T , f_R would be similar between the OW and NW groups at all conditions. Significant differences between the OW and NW children were found in all three variables requiring a failure to accept this hypothesis. The second hypothesis was that there would be no differences between V_E/VO_2 and V_E/VCO_2 between the two groups. Since no significance was found, the second hypothesis is accepted. The third hypothesis stated that no significant differences exist in $P_{ET}CO_2$, V_D and V_D/V_T among

the OW and NW groups. Failure to accept this hypothesis is attributable to significantly higher V_D values found in the OW group during exercise. Based on these findings, it can be concluded that excess adiposity causes alterations in ventilation during exercise in overweight children, but the alterations are sufficient to meet the metabolic demands of exercise.

Clinical Relevance

Exercise is a vital component of a healthy lifestyle. Promoting health and physical activity at a young age are important factors for disease prevention later in life. Exercise prescriptions can help treat and prevent chronic disease, but they must be prescribed appropriately and performed safely. In order for overweight children to become fit, they must exercise at a safe and comfortable level that does not exceed their physical capabilities. It was found that overweight children adequately increase their ventilation to meet increased demands during exercise. The increased ventilatory patterns utilized by overweight children should not be contraindications for exercise and clinicians should still encourage daily physical activity among pediatric populations for weight reduction and lifelong health benefits.

Recommendations

For future study, it would be important to determine if non-weight bearing (e.g. cycling) exercises have a similar impact on ventilation in overweight children as compared to weight bearing (e.g. walking, running) ones. Overweight subjects may have more difficulty on the cycle ergometer due to abdominal fat interference; however, they may be able to exercise for longer because of the reduced carry load. It would also be advantageous to

include more obese youth (>95th percentile) in future studies to see what further ventilatory modifications they have during exercise to compensate for an even greater mass.

To improve further study in this area, investigators should classify subjects based on body fat percentage rather than BMI. Even though this would involve body composition measurements, it would account for lean versus fat mass, thereby allowing for a more accurate categorization of each child. Future research may also include spirometric measurements to determine differences in static lung volumes between overweight and normal weight youth and any additionally problems these individuals may experience during exercise.

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