University of Alberta

Determinants of Blood Pressure in Overweight Youth

by

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Dedication

I dedicate this work to my loving and supporting mother and father. They have provided me with the tools to succeed in whatever I put my mind towards. You are an amazing team teaching me to be a good person, a hard worker and showing me unconditional love when I have temporarily steered the wrong way. To my adoring grandmother who attacks everyday with an energy and spirit that I envy. My brother Robert can now stop asking me, are you still in school? His constant questioning and motivation only a brother can give has been both an irritant and also a wonderful stimulus. Rob has taught me how to listen and showed that it is a strength. My good friend Jon McGavock and his selflessness will always be admired. I will forever be thankful for your energy, hope, and faith towards this work. I am thankful to Dr Ron Plotnikoff and Dr Normand Boule for their time and never saying the word, "no" when I have asked for assistance. I appreciate and am very thankful of the diligence and attention to detail from Dr Geoff Ball I am grateful for the guidance. I am very appreciative to my supervisor Dr Richard Lewanczuk. Richard, thank you for your time over the last three years, you have treated me not as a student but as a colleague and have provided me with direction and inspiration. You have shown me mentorship, generosity, and most importantly friendship. A hearty appreciation to my running peers both retired and active, my life would not be sane if it were not for the many miles and many trials. Lastly, I am grateful for my girlfriend Krissy, who has provided patience and love.

Abstract

Background / Objectives: Obesity and low fitness levels are associated with cardiometabolic conditions in adults. The overall aim of this study was to gain insight into the mechanisms of high normal systolic blood pressure (SBP) often observed in overweight youth. A secondary aim was to determine if fitness was independently associated with SBP in youth.

Design / Methods: Annual surveys of anthropometry, fitness, SBP and its determinants were conducted in a school-based setting.

Results: Elevated SBP in overweight youth (n = 2089) was significantly ($p < 0.01$) associated with and expanded stroke volume and cardiac output (CO), with little difference in heart rate, arterial compliance and systemic vascular resistance. Fitness was not associated with SBP in a sample of youth (n = 1532) and within a subgroup overweight youth (n = 324).

Conclusions: Excess weight is associated with an elevated SBP secondary to a stroke volume-mediated expanded CO, while fitness was not associated with SBP.

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1.1 Introduction

Mean arterial blood pressure is the average pressure against the arterial walls throughout one cardiac cycle and is determined by two principle forces, cardiac output and systemic vascular resistance. Acutely, changes in either of these determinants are compensated by the other ensuring that mean arterial blood pressure is maintained. Chronically, changes in either of these determinants that results in a persistently elevated pressure are associated with an increased risk of myocardial infarction, renal disease and stroke in adulthood (Oparil et al., 2003). Interventions that reduce cardiac output and/or systemic vascular resistance in the setting of high blood pressure effectively prevent the development of these cardiovascular morbidities (Oparil, 2004). For example, diuretics reduce blood volume and cardiac output and are associated with cardiovascular protection in individuals diagnosed with hypertension (Kahn et al., 2007). Alternatively, lifestyle choices like physical activity can acutely and chronically lower systemic vascular resistance, reduce mean arterial blood pressure and subsequently attenuate cardiovascular risk (Bacon et al., 2004).

Hypertension affects 1 billion people world-wide and is the leading risk factor for heart disease and mortality in Canada (Joffres et al., 2007). Although several factors are associated with high blood pressure including genetic predisposition (Burke et al., 1998), ethnicity and sodium intake (diet), overweight[1] is the major

[1] Overweight in youth is defined as a body mass index (BMI) greater than or equal to the 85th percentile (CDC, 2000) for age and sex or above the international "overweight" cut-off for age and sex established by the International Obesity Task Force (IOTF) (Cole et al, 2000). Obesity is defined as a BMI greater than or equal to the 95th percentile (CDC, 2000) or above the obesity "cut offs" for age and sex established by the IOTF (Cole et al, 2000).

factor contributing to the rising population prevalence of hypertension in youth[2] (Chiolero et al., 2007; Paradis et al., 2004). This trend is not restricted to adults and the bourgeoning frequency of overweight and obese youth has led to a parallel rise in high normal blood pressure[3] in youth (Paradis et al., 2004; Sorof et al., 2004; Weiss et al., 2004; Pinhas-Hamiel et al., 1996).

Several population-based studies of youth have documented a prevalence of high normal blood pressure in excess of 25% within various regions worldwide (Paradis et al., 2004; Sorof et al., 2004; Ogden et al., 2002). In the Quebec Child and Adolescent Health and Social Survey, while 30% of adolescents aged 15-19 years demonstrated high normal systolic blood pressure, approximately 50% of overweight youth were considered to have high normal blood pressure (Sorof et al., 2004).

Cross sectional and population-based surveys in youth have consistently shown a positive, independent association between body weight and systolic blood pressure (Paradis et al., 2004; Sorof et al., 2004). Indeed, mean systolic blood pressure and the prevalence of high normal blood pressure are consistently higher in overweight children, relative to their normal weight peers (Paradis et al., 2004; Sorof et al., 2004; Weiss et al., 2004). The mechanisms underlying the relationship between overweight and high normal blood pressure in youth have traditionally been attributed to an increased resting heart rate (Sorof et al., 2004; Paradis et al., 2004). As the majority of these observations were made in the absence of simultaneous measurements of stroke volume, systemic vascular resistance or arterial compliance,

[2] Youth is the term we will use to encompass children and adolescents aged 5 and 19yrs old.

[3] The terms high normal and elevated blood pressure refers to a systolic or diastolic blood pressure above the 90^{th} and 95^{th} centile for age, sex and height, respectively. The thresholds of 90 and 95^{th} centile have also been classified as pre-hypertension and hypertension, respectively. The term high blood pressure is also commonly used throughout the text to describe blood pressure at or above the 90^{th} centile. Table 1.1 (p. 70).

the mechanisms contributing to an elevated blood pressure in overweight youth are relatively unknown.

In adults, vascular dysfunction resulting in an increased systemic vascular resistance (Davy, 2004; Oparil, 2003) is believed to be the underlying cause of obesity-related hypertension. Furthermore, increased physical activity and cardiorespiratory fitness[4] are associated with lower blood pressure in adults. In fact, the positive effects of high cardiorespiratory fitness have been shown to counter the increased risk for cardiovascular events in those already diagnosed with chronic diseases, including obesity (Myers et al., 2002).

In youth, reductions in cardiorespiratory fitness have been observed over the past few decades in parallel with the rising prevalence of risk factors for cardiovascular disease in childhood (Carnethon et al., 2005). Unfortunately, the association between cardiorespiratory fitness and blood pressure in youth remains poorly understood. Specifically, it is unclear if low cardiorespiratory fitness is associated with an increased risk of high normal blood pressure in youth. Furthermore, it is unclear if, similar to adults, high cardiorespiratory fitness protects overweight youth from developing high normal blood pressure. The analyses reported in this thesis were designed to address these issues and describe the associations between cardiorespiratory fitness, adiposity and blood pressure in a school-based sample[5] of youth.

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[4] Cardiorespiratory fitness is defined as maximal oxygen uptake measured either directly at the end of a graded exercise test or estimated from a submaximal test. It is a measure of work capacity that is independent of physical activity, which is defined later in this text.

[5] School-based studies refer to studies conducted in samples of youth recruited and tested within the school environment. Population-based studies refer to surveys of random samples of the community. Clinic-based studies refer to studies of clinical populations (i.e. youth with diagnosed clinical pathology).

1.2 **Statement of the Problem and Purpose of the Thesis**

Statement of the Problem: Population-based studies of adiposity and blood pressure in youth have frequently neglected to measure the determinants of blood pressure (i.e. arterial compliance, systemic vascular resistance and cardiac output) and cardiorespiratory fitness within the same sample of youth. Therefore, the mechanisms and determinants of obesity-related high normal blood pressure in youth are poorly understood.

Hypotheses: (1) Systolic blood pressure (SBP) in overweight youth is associated with higher systemic vascular resistance and reduced arterial compliance relative to their healthy weight peers. (2) Overweight and low cardiorespiratory fitness are independently associated with SBP in youth. (3) Overweight youth with high cardiorespiratory fitness have lower SBP than their overweight peers with low cardiorespiratory fitness.

To test these hypotheses, we developed the following aims which were applied to a cross sectional, school-based sample of 2089 children and adolescents aged 5-19yrs studied over a period of 3 years (2004-2006).

1.3 Study Aims

Aim 1 – Measure the determinants of systolic blood pressure (SBP) (arterial compliance, cardiac output, and systemic vascular resistance) in a school-based sample of youth 5-19 yrs with a wide range of body mass indexes.

Aim 2 – Determine the relationship between cardiorespiratory fitness and SBP in youth.

Aim 3 – Within a sub-sample of overweight and obese youth, describe the relationship of cardiorespiratory fitness and SBP.

1.4 Delimitations – External Validity

(1) Study sample was large (1101 boys and 988 girls) and representative of the target population.

(2) The sample was heteronegeous for body habitus (BMI range = 10-38 kg/m^2).

(3) Data were collected in a real-life school-based setting reducing "white coat" effects on blood pressure.

(4) Cardiorespiratory fitness was measured using a common field test (Leger 20M Shuttle Run Test) that is frequently included in physical education curriculum.

(5) The determinants of blood pressure were measured non-invasively.

1.5 Limitations

(1) All participants were recruited within the schools and were not randomly selected from the population at large.

(2) Body mass index (BMI) is used as definition of adiposity. A common criticism associated with BMI is that it measures body weight and cannot differentiate between fat and muscle.

(3) The degree to which fitness groupings represent functional fitness levels is not known.

(4) The study was cross sectional in nature.

(5) Physical activity was not assessed and fitness levels are only weakly associated with activity levels in children and adolescents.

1.6 Significance of Study

To our knowledge, this is the first time that determinants of blood pressure and cardiorespiratory fitness have been included in a school-based survey of youth. The study expands previous research that did not measure cardiac output and systemic vascular resistance in concert with measurements of blood pressure. Furthermore, the addition of an objective measurement of cardiorespiratory fitness provides novel insight into the association between a modifiable lifestyle factor and blood pressure in youth.

This thesis has extended previous work in the area in several ways. First, in contrast to previous studies, these data demonstrated that in a large population-based survey of children, the positive association between body weight and blood pressure may be mediated through a volume-dependant increase in resting stroke volume. These data may help broaden our understanding of the natural history of obesity-related high normal blood pressure in humans and stimulate further research questions. Second, this thesis revealed that any association between cardiorespiratory fitness and SBP is mediated through body mass index, highlighting the importance of weight control for the management of cardiovascular disease risk in youth. These data may also provide insight into the mechanisms underlying the blood pressure lowering effects of exercise in youth. Finally, the continuous nature of the association between body mass index and blood pressure suggested that current cut-offs for overweight and obesity may be neglecting a large segment of the pediatric population potentially at risk for developing high normal blood pressure.

The Healthy Hearts Survey is a unique project that presents the opportunity to evaluate health-related outcomes in a community setting by opening collaborative doors between the university and school districts. The participating communities have seen first-hand that research can uncover important health-related trends in youth that would not necessarily be observed in a clinical or laboratory setting. Healthy Hearts provides an opportunity to translate school-based research into meaningful evidence that can inform policy makers how to address child and adolescent obesity in the school environment.

1.7 Definition of Terms

Applanation Tonometry- The applanation method is a measurement of the force required to flatten a certain area. A tonometer is a sensor with a flat pressure transducer that converts the mechanical movement of the blood vessel into measurable electrical energy. When placed on the surface of an artery, recordings of pressure change within the vessel are possible.

Arterial Compliance – Compliance is defined as the change in volume per unit of pressure (V/P) and reflects the buffering function of the vessel. Arterial compliance is an important determinant of the afterload on the heart; a decrease in total arterial compliance contributes to a higher afterload (Lévy and Safar, 1992).

Atherosclerosis- Atherosclerosis is the loss of vessel elasticity, a slow progressive disease that hardens or narrows the artery. It encompasses the structural and functional vascular manifestations leading to a stroke or heart attack.

Cardiorespiratory Fitness: Maximal rate of oxygen consumption or maximal performance on an exercise test.

Diastolic Pulse Wave Analysis- Analysis of the diastolic decay portion of a pressure wave form. A transfer function is employed to estimate arterial compliance from this peripheral wave form. (Cohn et al., 1995)

Endothelial Dysfunction – Decreased vascular dilation in response to a given stress (i.e. vascular occlusion). It is the earliest detectable manifestation of atherosclerosis and a precursor to atherosclerotic disease (Verma et al., 2003).

Endothelium- The endothelium is the layer of thin specialized epithelial cells, comprising a simple squamous layer of cells that line the interior surface of blood vessels, forming an interface between circulating blood in the lumen and the rest of the vessel wall.

Hypertension - High normal blood pressure. In youth 6-18 yrs, high normal blood pressure is defined as SBP and/or DBP above the 90^{th} percentile for age, gender and height. This threshold is intended to be the equivalent to SBP > 130 mmHg and DBP > 85 mmHg in adults. Normative data for age and sex specific thresholds were based on tables published from the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents with normative data that was collected during the 1999-2000 National Health and Nutritional Survey (NHANES) (NBPED, 2004).

Insulin Resistance- An impairment in insulin-mediated glucose disposal. Insulin resistance is the earliest manifestation in the natural history of type 2 diabetes.

Leger Shuttle Run- A progressive, indirect field test to measure peak cardiorespiratory fitness. It involves running back and fourth over a 20m distance at progressively faster running velocities until exhaustion. The "end stage" is the final stage completed and is an estimate of one's VO_2 max, one's maximum capacity to transport and utilize oxygen during incremental exercise.

Physical Activity- Bodily movement produced by skeletal muscles that result in energy expenditure.

Physical Inactivity (Sedentary Behaviour) - A sedentary behaviour is defined as activity that costs less than 1.5 metabolic equivalents (MET). A physically inactive individual who expends less than 1.5 kcal/kg/day. Physical inactivity is believed to be a risk factor for cardiovascular disease.

1.8 Abbreviations

BMI – Body Mass Index

CO - Cardiac Output

DBP - Diastolic Blood Pressure

EYHS - European Youth Heart Study

HR - Heart Rate

LAC - Large Arterial Compliance

NHANES - National Health and Nutrition Examination Survey

SAC - Small Arterial Compliance

SBP - Systolic Blood Pressure

SVR - Systemic Vascular Resistance

VO_2max - Maximal rate of oxygen uptake

Chapter 2 - Review of Literature

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2.1 Overweight and obesity are emerging problems in children and adolescents.

The appearance of pediatric forms of chronic illness, in particular high normal blood pressure, underscores the enormous burden the childhood obesity epidemic is imposing on developed countries worldwide (Hannon et al., 2005; Sorof and Daniels, 2002). Currently, nearly 1/3 of all children in Canada and the United States are considered overweight, placing millions of children at risk for hypertension (Shields, 2006; Willms et al., 2003; Strauss and Pollack, 2001). In adults, the development of hypertension in obese individuals is chronic and progressive, taking years to develop (Mikhail et al., 1999). In youth, high normal blood pressure appears to develop more rapidly and persists into adulthood suggesting that the mechanisms for the disease may be unique (Sorof and Daniels, 2005). Regardless of the pathology, the appearance of overweight-related high normal blood pressure in youth forecasts a major health care burden and a need for early intervention strategies.

A suspected cause for the growing prevalence of overweight and its associated diseases is a reduction in habitual physical activity in youth over the past two decades (Tremblay and Willms, 2003). It is possible that disproportionately low physical activity patterns also predispose overweight youth to a premature progression to high normal or elevated blood pressure. Studies in adults provide overwhelming evidence that low physical activity patterns or fitness are associated with an exaggerated risk for chronic diseases, including hypertension (Carnethon et al., 2003). Conversely, increased daily physical activity and high cardiorespiratory fitness reduce the risk for a large number of chronic diseases including hypertension (Hu et al., 2004; Hayashi et al., 1999; Paffenbarger et al., 1983). Increased physical activity patterns and/or high cardiorespiratory fitness can confer protection from chronic illness in individuals with underlying risk factors, including overweight (Tanasescu et al., 2003; Myers et al., 2002). Unfortunately, there is little evidence describing the potential for increased physical activity to attenuate cardiovascular risk in youth. More importantly, it is unclear if increased physical activity can protect overweight youth from developing high normal blood pressure, the most prevalent chronic illness associated with overweight related disease in childhood (Jago et al., 2006). The purpose of this review is to provide a summary of the current literature describing the influence of overweight on blood pressure and its determinants in youth. Furthermore, we would like to explore the potential role of physical activity as a countermeasure against the development of high normal blood pressure in the overweight and obese pediatric population.

2.2 The relationship between overweight and elevated systolic blood pressure in children.

A number of population-based studies have demonstrated that there is a strong positive relationship between body mass index (BMI) and blood pressure in children and adolescents (Falkner et al., 2006; Muntner et al., 2004; Jiang et al., 1995; Clarke et al., 1986; Aristimuno et al., 1984; Voors et al., 1977). The original and most compelling evidence emerged from the Bogalusa Heart Study, a school-based longitudinal tracking study of cardiovascular disease risk factors in multiple samples of school-aged children that began in 1973 (Jiang et al., 1995; Aristimuno et al., 1984; Voors et al., 1977). In a series of studies, they have conclusively demonstrated that systolic blood pressure is significantly elevated in children within the upper percentiles of BMI or ponderosity relative to their leaner peers. Furthermore, longitudinal tracking of children included in the original cohort revealed that those who remained within the upper percentiles of BMI displayed a disproportionate rise in systolic blood pressure over time, relative to children who remained within the lower percentiles for body habitus (Aristimuno et al., 1984).

Cross-sectional comparisons between overweight children admitted to pediatric weight loss clinics and their lean peers have also demonstrated that overweight children display significantly higher blood pressure than their lean peers, in a dose-response manner (Muntner et al., 2004; Weiss et al., 2004). The positive relationship between BMI and systolic blood pressure has been reproduced in several other large population-based studies including, the Third National Health and Nutrition Examination Survey (NHANES III) (Muntner et al., 2004). Interestingly, national survey data indicate a trend towards an overall rise in the average blood pressure values in children in the U.S., which the authors attribute to the increasing prevalence of overweight in youth (Muntner et al., 2004).

Despite the large number of population-based studies reporting a positive relationship between body habitus and systolic blood pressure, few reports have attempted to describe the prevalence of high normal blood pressure within these populations. This is for good reason, as the criteria for high normal blood pressure in children is not as clear-cut as in adults, and is dependant on many variables including age, relative height and gender (www.nhlbi.nih.gov/guidelines/hypertension/child_tbl.htm) (Appendix 1, Table 1.2).

Two recent community-based surveys have attempted to address this limitation (Paradis et al., 2004; Sorof et al., 2004). In a study of 5100 children and adolescents, aged 10 to 19yrs, Sorof and colleagues (2004) reported that the prevalence of high normal blood pressure was higher in children within the upper quintiles of BMI and that 38% of obese children (BMI > 95^{th} percentile) displayed high normal blood pressure for their height when initially screened. More recently, the Quebec Family Study revealed a similar 30% prevalence of high normal systolic blood pressure in a cohort of overweight Canadian adolescents (Paradis et al., 2004). Multiple linear regression analysis revealed that within the cohort of children aged 9, 13 and 16yrs, BMI was a primary determinant of systolic blood pressure ($\beta = 0.9\text{-}1.1$, $p < 0.001$), after controlling for age, sex, smoking status, insulin and a family history of hypertension. Taken together, these data strongly suggest that overweight and obesity are key determinants of elevated systolic blood pressure in children and adolescents and is a major contributing factor to the rising prevalence of high normal blood pressure in children and adolescents.

2.3 Mechanisms underlying the development of elevated systolic blood pressure in children. The mechanism(s) that contribute to elevated systolic blood pressure in obese individuals is a controversial topic. Conventional wisdom suggests that the root cause of high normal blood pressure in obese individuals is due primarily to a combination of factors that raise systemic vascular resistance (Rahmouni et al., 2005; Hall and Davy, 2004). Several factors are believed to contribute to the increased vascular tone in obese individuals, including but not limited to: (1) activation of the sympathetic nervous system; (2) insulin resistance and (3) vascular dysfunction (Figure 1, p.14).

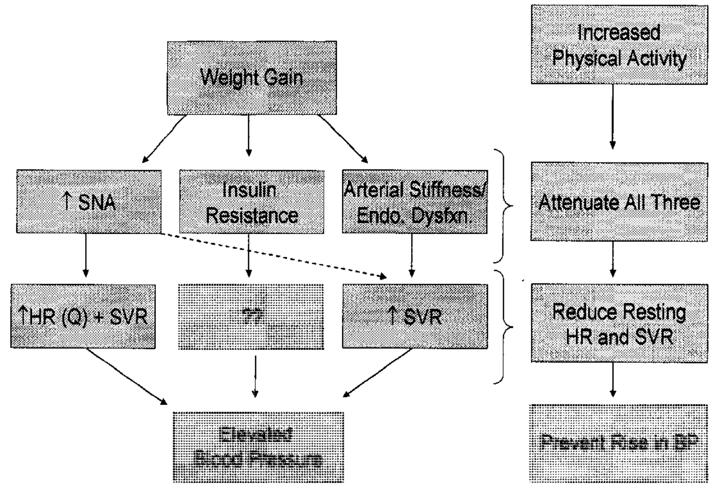

Figure 1. Determinants of Blood Pressure (Torrance et al., 2007)

Data accumulated over the past decade strongly suggest that activation of the sympathetic nervous system appears to be a leading candidate to explain the relationship between obesity and hypertension (Reaven et al., 1996; Scherrer et al., 1994; Landberg et al., 1991). Studies in animals placed on a high fat diet reveal a near dose-response increase in sympathetic outflow which is believed to be a centrally-mediated counter-response to restore the expanded adipose tissue mass to normal levels (Hall et al., 1993). Although overfeeding studies are unlikely to be performed in humans, measurements of muscle sympathetic nerve activity from the peroneal nerve reveal that overweight individuals are characterized by an increased burst frequency, indicating increased sympathetic activity relative to lean individuals (Alvarez et al., 2002; Abate et al., 2001; Grassi et al., 1995). The increased sympathetic activity is reduced substantially with weight loss, which coincides with a drop in blood pressure (Trombetta et al., 2003; Grassi et al., 1998). Furthermore, overweight individuals with normal blood pressure display low muscle sympathetic nerve activity relative to overweight peers with hypertension (Spraul et al., 1993). Finally, treatment of obese individuals with sympatholytic agents effectively reduce systolic blood pressure and muscle sympathetic nerve activity (Wofford et al., 2001) providing evidence that the sympathetic nervous system is a key determinant of overweight-related hypertension.

Insulin resistance is a common well characterized corollary of overweight (Reaven et al., 1996; Rabinowitz et al., 1962). The coordinated appearance of insulin resistance and high blood pressure in overweight individuals and the observation that lean hypertensive individuals exhibit some degree of insulin resistance, led several authors to hypothesize that insulin resistance or hyperinsulinemia is a major determinant of increased systemic vascular resistance in obese individuals (Landsberg, 1992; Rochinni, 1991; Tuck, 1991; Modan et al., 1985). In support of this theory, several large epidemiological studies have noted a relationship between fasting insulin (a measure of insulin resistance) and systolic blood pressure within a broad sample of adults including those with hypertension (Saad et al., 2004; Saad et al., 2004; Ferannini et al., 1991; Saad et al., 1991). Furthermore, high insulin sensitivity (measured using a frequently sampled intravenous glucose tolerance test) is associated with a lower 5-yr incidence of hypertension in individuals without type 2 diabetes (Goff et al., 2003). Observational studies also reveal that obese individuals with hypertension are more insulin resistant than BMI-matched peers with normal blood pressure (Manicardi et al., 1986). Conversely, Ferannani and colleagues (1987) revealed that insulin-mediated glucose disposal is reduced 30-40% in lean hypertensive individuals relative to normotensive peers.

Although these relationships appear to be robust, they are not universal, as Hispanic Americans and the Pima Indian population have a disproportionately high level of insulin in lean healthy controls to levels seen in overweight individuals, do not cause a rise in blood pressure (Scherrer et al., 1997; Vollenweider et al., 1994; Laakso et al., 1990;). In fact, short (hours) or long (days)-term hyperinsulinemia causes a peripheral vasodilatation and a slight reduction in systemic vascular resistance, with little change in blood pressure (Scherrer et al., 1997; Brands et al., 1991; Hall et al., 1990). These studies have been performed in both lean and overweight animals and humans, revealing that hyperinsulinemia alone has little effect on blood pressure acutely (Davy and Hall, 2004). Finally, transgenic manipulation of systems involved in both the regulation of blood pressure and insulin-mediated glucose disposal (i.e. central control centers for leptin signaling) reveal that it is possible to uncouple these two consequences of overweight, suggesting that hyperinsulinemia is not a primary cause of hypertension associated with obesity (Tallam et al., 2005; Mark et al., 2004). It is entirely possible that the two conditions share a similar cellular defect/pathway that is exacerbated with weight gain, which would explain why the two conditions frequently appear simultaneously (Sowers, 2004).

Several studies have also demonstrated that overweight individuals appear with unfavourable reductions in subclinical measures of vascular health (Freedman et al., 2005; Zebekakis et al., 2005; Caballero, 2003; Gordano et al., 2003; Wildman et al., 2003; Steinberg et al., 1996; Laakso et al., 1990). For example, non-invasive measurements of central and peripheral arterial stiffness are elevated ~15 and 25 % in young and middle aged obese men and women (Zebekakis et al., 2005; Widlman et al., 2003). Similarly, obese individuals are characterized by reduced endothelial-dependant dilatation (Steinberg et al., 1996; Laakso et al., 1990) and carotid artery wall thickening (Freedman et al., 2004). These adverse changes in vascular function are believed to contribute to the propensity towards hypertension in overweight and obese adults.

Unfortunately, a similar body of knowledge is not currently available describing the mechanisms responsible for high normal blood pressure in youth. A limited number of studies have measured the determinants of blood pressure in lean and overweight children using non-invasive measures, such as acetylene re-breathing and echocardiography (Daniels et al., 1996; Rochinni et al., 1989; Voors et al., 1982). In contrast to commonly-held beliefs, these studies revealed that overweight children are shown to have an increased resting cardiac output mediated in large part by an expanded stroke volume and not an elevated systemic vascular resistance (Daniels et al., 1996; Rochinni et al., 1989). Seminal work in this area was performed by Rocchinni and colleagues (1989) in which cardiac output and plasma volume were determined in obese adolescents in response to a salt-loading diet before and after weight loss. In 60 obese adolescents, aged 10-16yrs, elevated blood pressure was directly associated with a volume-dependant increased stroke volume, which could be reduced with a low sodium diet. Weight loss not only normalized blood pressure, but desensitized adolescents to the sodium-dependant high blood pressure. It was concluded that increased sodium sensitivity mediated a plasma volume-dependant increase of stroke volume and cardiac output, thereby increasing blood pressure (Rochinni et al., 1989). Interestingly, weight loss also reduced serum norepinephrine concentrations, suggesting that the changes in sympathetic tone may also have contributed to the blood pressure lowering effects of weight loss.

Although reports of muscle sympathetic nerve activity in children and adolescents have yet to be published, evidence from several large population based studies suggest that autonomic activation is a common feature of high blood pressure and in particular overweight-related high normal blood pressure in youth (Sorof et al., 2002; Gutin et al., 2000; Rochinni et al., 1987). Using serum measurements of norepinephrine, resting heart rate and heart rate variability as surrogates of autonomic tone, several population-based studies in children have revealed that overweight in children is associated with an activation of the sympathetic nervous system (Nagai and Moratini, 2004; Berenson et al., 1979). In support of these observations, smaller randomized intervention studies have shown that heart rate and norepinephrine levels decline significantly with weight loss in children, implicating autonomic tone in the development of high normal blood pressure in overweight youth (Rabbia et al., 2003; Daniels et al., 1996).

Large studies in youth have also demonstrated a relationship between serum insulin concentration and blood pressure (Lambert et al., 2004; Pankow et al., 2004; Tounian et al., 2001; Kanai et al., 1990). For this reason, several authors have hypothesized that insulin resistance may play a role in the development of high normal blood pressure in children and adolescents (Sorof and Daniels, 2002; Rochinni, 1991). A modified oral glucose tolerance test was performed on a subset of participants studied in the early cohorts in the Bogalusa Heart Study. Stratification of youth into categories according to the glucose and insulin response to this challenge revealed that those with a hyperinsulinemic or hyperglycemic response displayed significantly elevated systolic blood pressure, relative to the more insulin sensitive controls (Kanai et al., 1990). Similar to adults however, the relationship between insulin sensitivity and blood pressure seems to be dependant upon race, being less robust in African American and Hispanic children (Kanai et al., 1990; Berenson et al., 1979). It is likely, that, similar to adults, the relationship between these two conditions is coordinated, but may not be causal.

Overweight children also appear to be characterized by adverse changes in vascular health, which may also contribute to the propensity for high normal blood pressure seen in this population (Ribeiro et al., 2005; Whincup et al., 2005; Watts et al., 2004; Woo et al., 2004a, 2004b). For example, ultrasound imaging of the carotid artery revealed that severely obese (BMI ~34 kg/m^2) children display arterial stiffness and increased diastolic wall stress, compared to age and gender matched lean (BMI ~16 kg/m^2) peers (Woo et al., 2004). These same children also displayed significantly attenuated endothelial dilatation in response to forearm ischemia demonstrating that the endothelium is sensitive to the negative effects of weight gain, even in children. More recent studies in a larger sample of children who exhibited a broader range of BMI values support this concept; endothelial-dependant dilatation in response to forearm ischemia was negatively associated with BMI ($r = -0.47$; $p < 0.01$) in children aged 9-12 yrs (Whincup et al., 2005). Furthermore, carotid artery stiffness and carotid intima media thickness are both significantly elevated in overweight children and negatively correlated with several measures of adiposity (Tounian et al., 2001). The pattern of vascular dysfunction in overweight children is strikingly similar to that observed in overweight adults, suggesting that children are not immune to the cardiovascular consequences of being overweight. Unfortunately, few population-based studies of children and adolescents have incorporated measurements of these determinants of blood pressure in their research design. Therefore, at the population-level it is unclear if the pattern of elevated blood pressure associated with overweight is similar in children and adults.

2.4 Physical activity as a countermeasure for high normal blood pressure in youth.

The benefits of physical activity in the prevention and treatment of hypertension in adults have been very well described (Whelton et al., 2002; Hagberg et al., 2000). Individuals who perform regular physical activity have a lower risk for the development of hypertension (Blair et al., 1984), and acute and chronic physical activity lowers blood pressure in individuals with hypertension, including those who are obese (Hagberg et al., 2000). Conversely, low fitness (a surrogate of physical inactivity), is associated with a 2.6 and 1.3-fold increased risk for hypertension in lean and overweight young adults, respectively (Carnethon et al., 2003). Taken together, these data suggest that increased physical activity provides some degree of protection from hypertension in overweight adults.

Unfortunately, there is little evidence that increased physical activity can prevent the development of high normal blood pressure in overweight children. However, a large number of studies have emerged recently describing the influence of lifestyle interventions on various risk factors associated with high normal blood pressure in overweight and obese youth and have been reviewed elsewhere (Cruz et al., 2005; Watts et al., 2005; Bautista-Castano et al., 2004). The focus of this section includes the effects of activity-based interventions on blood pressure and its determinants in overweight youth. At the time of this review, there were few studies designed to specifically assess the influence of physical activity on elevated systolic blood pressure in overweight youth, however most suggested that physical activity can effectively reduce blood pressure (Appendix 1; Table 1.3). The majority of randomized controlled trials in overweight youth were designed to assess the influence of combined lifestyle changes including both diet and physical activity on multiple cardiovascular risk factors; however, it is difficult to interpret the influence of physical activity alone on blood pressure.

Longitudinal studies support the findings from cross sectional studies as they demonstrate that baseline fitness and improved fitness after one year follow-up are both associated with lower blood pressure in youth (Shea et al., 1994; Gutin et al., 1990). Specifically, relative to children who experienced no change in fitness, the age-related rise in systolic blood pressure was nearly 40% lower (2.94 vs 5.10 mmHg) in children who experienced the largest improvements in fitness after one-year of follow-up (Shea et al., 1994). More recent data from 1998-2002 NHANES, revealed a significant negative relationship between fitness and systolic blood pressure in adolescents (Carnethon et al., 2005) while low fitness was associated with a 35% increased odds of being diagnosed with high normal blood pressure. Unfortunately, these studies were performed in healthy children and so it is unclear if overweight children who are physically active display lower blood pressure than their overweight sedentary peers.

Intervention studies provide information regarding the causal relationship between activity and blood pressure in youth. Early studies by Hagberg and colleagues (1984; 1983) focused on the role of physical activity interventions on systolic blood pressure in adolescents with elevated blood pressure, some of whom would be considered overweight by current standards. Aerobic exercise training at an intensity of 70-80% of maximal fitness for 30-40 minutes per day, five days per week was associated with a significant 6-10mmHg reduction in systolic blood pressure in this cohort of high risk youth (Hagberg et al., 1984). Unfortunately, blood pressure returned to pre-training values within 9 months following cessation of exercise, suggesting that the exercise stimulus needs to be maintained for sustained blood pressure control. A similar response to aerobic training was observed in obese adolescents (13-16yrs), randomized to 8 months of "high-intensity" physical activity and lifestyle education (Gutin et al., 2000; Rochinni et al., 1988). In the study by Rochinni and colleagues (1988), activity was offered 5 days/week at an intensity of 75-80% of maximal fitness. This intervention significantly reduced systolic blood pressure by ~6 mmHg over the 8 month period, which was associated with a significant improvement in fitness. Unfortunately, the change in BMI was not reported in this investigation therefore, it is unclear if the blood pressure reducing effects of high intensity activity were related to weight loss or activity. Interestingly, the magnitude of blood pressure reduction was significantly less (~2 mmHg) in a third arm of the trial that performed low intensity (55-60%) aerobic exercise during the eight-month intervention (Rochinni et al., 1988).

Other studies have compared the influence of diet and exercise to diet alone on blood pressure or components of the insulin resistance syndrome in youth, including blood pressure (Ribeiro et al., 2005; Watts et al., 2004; Becque et al., 1988; Rochinni et al., 1988). Early studies by Becque and colleagues (1988) randomized 63 obese youth, 13 ± 3 yrs, to a dietary intervention or dietary intervention plus exercise for a period of 20 weeks. Systolic blood pressure dropped from 129 ± 9 to 113 ± 6 mmHg, in youth involved in the exercise and diet group, while those in the diet-only group observed a significant ~10 mmHg decline. Systolic blood pressure was unchanged in the control group. Youth in both intervention groups lost a similar amount of weight (~2 kg) suggesting that aerobic activity elicits blood pressure lowering effects over and above those observed with weight loss alone (Becque et al., 1988). Finally, in a more recent investigation, obese (BMI: 28 ± 1 kg/m^2) children (10 ± 0.2 yrs) were randomized to a dietary or dietary plus aerobic activity intervention for a period of four months (Ribeiro et al., 2005). The exercise component of the trial was administered for 60 minutes, three-times per week, at an intensity of 10% below ventilatory threshold. Both interventions effectively reduced mean arterial blood pressure by ~3-5 mmHg at rest, however children who undertook the exercise arm also observed a significant ~10% reduction mean arterial pressure coupled with a 25-30% increase in forearm blood flow during mechanical and mental stress, which was not noted in the diet-only group. Impressively, forearm vascular conductance was normalized (i.e., values were similar to age-matched lean children) in obese children within the exercise and diet intervention group, but remained lower in the diet-only intervention group (Ribeiro et al., 2005). Taken together, these data suggest that an aerobic exercise intervention lasting 4-8 months, at high-moderate intensities, effectively reduces blood pressure in overweight youth. Unfortunately, because weight loss was not uniformly reported in these investigations, it is unclear if the benefits of aerobic exercise on systolic blood pressure in youth are independent of weight loss. Furthermore, as these data clearly demonstrate that the benefits of exercise on blood pressure are transient; strategies are needed to ensure that physical activity patterns developed during an intervention can be sustained for prolonged periods after completion of the program.

The mechanisms through which physical activity reduces blood pressure in overweight youth are currently unclear. Hagberg and colleagues (1984) measured cardiac output and systemic vascular resistance in the study described above and revealed that the only change in resting hemodynamics associated with increased physical activity was a reduction in heart rate which paralleled the reduction in systolic blood pressure. More recent investigations have demonstrated that prolonged aerobic exercise alone or in combination with a hypocaloric diet is sufficient to improve vascular function in obese youth (Ribeiro et al., 2005; Watts et al., 2004; Woo et al., 2004;). However, the investigators have consistently selected youth with normal blood pressure and noted that blood pressure was not reduced any further with aerobic exercise, despite improved endothelial-dependant dilatation.

For example, Watts and colleagues (2004) measured brachial artery distensibility before and after an 8-week randomized-controlled, cross-over study in overweight children. They revealed that exercise training normalized endothelial dependant dilatation to levels seen in lean controls, however arterial reactivity returned to pre-training levels within eight weeks following cessation from exercises suggesting that the vascular adaptations to exercise training are transient and will remain sensitive to the negative effects of obesity if children return to sedentary habits. The beneficial effects of physical activity on endothelial dependant dilatation were replicated in two other studies of overweight youth with abnormal vascular function, implicating a role for physical activity in the prevention of vascular dysfunction in children (Ribeiro et al., 2005; Woo et al., 2004). Unfortunately, the mechanisms underlying the beneficial effects of physical activity on vascular health in overweight youth remain unresolved.

Currently, we are unaware of any studies designed specifically to evaluate the influence of physical activity on arterial stiffness in overweight youth. Using a cross-sectional design in 100 youth aged 10-12 yrs, we have recently demonstrated that high fitness is associated with lower arterial stiffness determined non-invasively with pulse wave analysis, relative to BMI-matched youth with lower fitness scores (Reed et al., 2005). These data suggest that positive adaptations in the peripheral vasculature may also contribute to the blood pressure reducing effects of physical activity in youth. Further, studies are required to determine the association between physical activity / fitness and systolic blood pressure in youth, in particular those who are overweight.

2.5 Review of Literature Conclusions

Weight gain is associated with high normal systolic blood pressure, regardless of age. The degree of elevation in blood pressure with weight gain in children is similar to that in adults; however, the mechanism underlying overweight-related high normal blood pressure seems to be a function of an increased heart rate and cardiac output rather than a rise in systemic vascular resistance. Physical activity is a potential countermeasure against high normal blood pressure in youth, in particular those who are overweight, however few studies have addressed this topic. A large population-based study of blood pressure and its determinants in youth would significantly enhance our understanding of the factors underlying the association between high normal blood pressure and adiposity in youth.

2.6 Methodological Considerations

As with any study, there are limitations to the methods used to measure blood pressure and arterial stiffening, a cause of increasing systolic blood pressure and pulse pressure. Although the automated tools currently used for the measurement of blood pressure are fairly comparable, the tools used for the measurement of arterial stiffness are significantly different from one another and each has their own strengths and weaknesses. All non-invasive methods for measuring arterial stiffness rely on the analysis of wave forms from surface residing tonometers placed on palpable arteries (O'Rourke et al., 2002). All methods provide similar information, an estimate of the stiffness of peripheral vessels, which is believed to increase left ventricular afterload and subsequently the premature development of left ventricular remodeling and wall thickening (Cohn et al., 1995). The traditional and gold standard method relies upon a measurement of pulse wave velocity across a given segment of the arterial tree, frequently an aortic segment (O'Rourke et al., 2002). This is considered the gold standard as it does not rely on a mathematical transformation of data to estimate central aortic stiffness. A second method, pulse wave analysis calculates an "augmentation index" which represents the degree of pressure elevation above pulse pressure attributed to reflected waves that are the result of stiff peripheral muscular arterioles (Nichols et al., 1998). Pulse wave analysis relies upon a transfer function that estimates aortic pressure augmentation from radial pressure wave forms. A third method developed in the mid 1990's analyses the diastolic portion of a peripheral wave (O'Rourke et al, 2002). It also relies on a transfer function to estimate stiffness in the large and small arteries simultaneously. Tonometrically-derived peripheral wave forms are collected from the radial artery, averaged and transformed to estimate central and peripheral stiffness. In brief, this method does not measure compliance directly; rather it uses a mathematical transfer function to estimate values from the shape of the wave. This transfer function was developed form invasive studies in adults and may not reflect wave form on youth. We chose to use this method, it as it is the only non-invasive method available that provides important information regarding stroke volume and systemic vascular resistance thereby permitting an analysis of the determinants of blood pressure in addition to arterial compliance (Pannier et al., 2002). The diastolic pulse wave analysis method has been found to be highly reliable and reproducible in healthy subjects (Zimlichman et al., 2005) and has been used previously in school age children (Bennett et al., 2003)

Cardiorespiratory fitness can be measured several ways. The gold standard method, which is almost always reserved for clinical or laboratory settings, is a direct measure of oxygen consumption at the end of a graded exercise test. There are also several indirect measures that estimate cardiorespiratory fitness from the final workload of a graded exercise test to exhaustion without the measurement of exhaled gases. Finally, there are submaximal field tests that estimate peak fitness from the heart rate response to a graded submaximal test. These tests rely on two assumptions: (1) a linear association between oxygen consumption and heart rate that is similar between two individuals and (2) that maximal heart rate can be estimated from a person's age and sex.

The Leger Shuttle Run Test requires little equipment, allows the participants to run in a comfortable setting (school gymnasium), and is capable of having large groups (10-12) participate simultaneously. The Shuttle Run Test has been found to be a model field test because error in pace is eliminated by using audio signals (Paliczka et al., 1987), the incremental test ensures a gradual rise in work rate and heart rate, and the test is highly reliable (r = 0.975; Léger and Lambert, 1982). Limitations to the Shuttle Run Test (Leger, 1980) are that there is no confirmation of a full maximal effort and participants may not put fourth a full effort for numerous motivational reasons.

The gold standard of cardiorespiratory fitness of measuring expired gases during maximal exercise directly with a metabolic cart. Benefits of the metabolic cart are that it verifies if a maximal effort is reached and an understanding of aerobic thresholds can be attained. Limitations to the metabolic cart are that only one participant can be tested at a time, the equipment is expensive and the cart requires a trained technician to operate. The cart would take a large amount of time and is impractical in a school-based study.

There are two common references used to classify boys and girls according to weight status. The Centers of Disease Control (CDC) includes data from five national surveys on youth 2-20yrs measured between 1963 and 1994. Based on this information, age and sex specific BMI percentiles were established. There are another set of definitions which were established by Cole and colleagues (2000) and adopted by the International Obesity Task Force, sometimes referred to as "International Cut Off Points" for the classification of overweight and obesity in children. These standards were derived from survey data collected in over 60,000 youth 6-18yrs from six countries and include the US national surveys between 1963 and 1980. The standards were derived by converting the Z-score of 25 and 30 kg/m^2 at age 18 for boys and girls into corresponding body mass index values for all ages from 6-17yrs. The CDC and international thresholds are very similar to each other, however, we used international thresholds as they are less arbitrary (i.e. statistically derived) and therefore are likely to be more appropriate for our survey.

2.7 Summary:

Studying the association between cardiorespiratory fitness and blood pressure in youth is an important extension of this research for several reasons. First, few studies have attempted to ascertain a threshold of cardiorespiratory fitness associated with healthy blood pressure in youth. Second, it is unclear if cardiorespiratory fitness is associated with blood pressure independent of weight status. Third, it is unclear if high cardiorespiratory fitness protects overweight youth from high normal blood pressure. Finally, the association between the determinants of blood pressure and both cardiorespiratory fitness and weight status has never been performed in youth.

The following study was designed to address these limitations. We have used state-of-the-art technology to measure blood pressure and a common validated field test to assess cardiorespiratory fitness in a large school-based sample of youth 5-19yrs.

Chapter 3 – Research Article

Portions of these data were published in McGavock J, Torrance B et al. American Journal of Hypertension. 2007;20:1038-44

3.1 Introduction

The prevalence of overweight and obesity in youth has tripled in Canada (Shields, 2006) and the United States (Ogden et al., 2002) in the last two decades and currently over 26% of youth in Canada are considered overweight (Shields, 2006; Willms et al., 2003). The epidemic of overweight youth has led to a parallel rise in the prevalence of pediatric forms of chronic illness, especially high normal and elevated blood pressure (Sorof et al., 2004; Weiss et al., 2004; Sinha et al., 2002; Pinhas-Hamiel et al., 1996).

The mechanisms underlying the relationship between overweight and high normal blood pressure in children have been largely attributed to an increased sympathetic tone and resting heart rate (Sinha et al., 2002; Pinhas-Hamiel et al., 1996). The majority of these observations were made however in the absence of simultaneous measurements of stroke volume, systemic vascular resistance and/or arterial stiffness. As a result, the mechanisms contributing the elevated blood pressure in overweight youth are unknown.

Physical activity and cardiorespiratory fitness are powerful positive determinants of cardiovascular risk in adults, in part due to acute and chronic reductions in blood pressure (Hagberg, 2000). Reductions in cardiorespiratory fitness have been observed in youth over the past decades in parallel with the rising prevalence of childhood overweight (Carnethon et al., 2003). Currently, there is a scarcity of data describing the association between cardiorespiratory fitness and the determinants of blood pressure in Canadian youth.

This study was designed to address these limitations and test the hypotheses that overweight and low cardiorespiratory fitness are independently associated with blood pressure in youth and that high cardiorespiratory fitness confers protection from high normal blood pressure in overweight youth.

3.2 Methods

Study Population

A convenience sample of 2089 (1101 males and 988 females) youth aged 5-19 years were recruited from 14 schools within the Black Gold School District in Central, Alberta, Canada. Cross sectional data were pooled across multiple years between 2004 – 2006. The Black Gold School District granted permission for the study to have access to any of its schools after a number of presentations of the value of the research to school administrators, the Superintendent, and the Board. This district encompasses five urban and rural communities within 100km of Edmonton, Alberta and includes >9000 students.

This study represents cross sectional analyses from a larger longitudinal investigation called Healthy Hearts. Collaboration between the Black Gold School District, the Alberta Initiative of School Improvement (AISI), and the University of Alberta, Faculty of Medicine began in 2002. Healthy Hearts is a prospective cohort study currently funded by the Canadian Diabetes Association through 2010.

Inclusion criteria were children, male or female, between the ages of 5 and 19, currently enrolled in the Black Gold School District, who are willing and able to participate in the study and who are able to provide assent and parental consent.

Exclusion criteria were self-reported presence of diabetes or hypertension and/or the use of medications to control blood pressure or glucose or lipid metabolism. Written informed consent was obtained from parents and verbal assent from participants prior to the investigation in each of the two years of the study. The Research Ethics Review Board at the Faculty of Medicine and Dentistry, University of Alberta, approved the study protocol. Participant recruitment was performed in schools and at community meetings held with the school district following support by school administration and Alberta Learning.

Procedures

Satellite laboratories were set up in each of the 14 schools and the data were collected over a period of three days in a span of a week, in the winter/spring semester (February – May of 2004 - 2006). All data were collected over the span of one school week. Lead teachers within each school were responsible for student removal from the classroom and to ensure laboratory space was available. All testing was completed during school hours. On Study Day 1, demographic, anthropometric data and resting hemodynamic data (systolic blood pressure, diastolic blood pressure, mean arterial pressure, arterial compliance, cardiac output, and systemic vascular resistance) were collected. On Day 2, cardiorespiratory fitness was measured in groups of eight to ten students. The schools provided access to the gymnasium for the Shuttle Run Test to measure cardiorespiratory fitness. On study Day 3, insulin sensitivity was measured non-invasively in the gymnasium in all students participating in the project for that particular school. Participants arrived in a fasted state and provided baseline breath sample prior to ingesting a 100mL 15% glucose solution with 25 mg ^{13}C-labelled dextrose. The participant verbally confirmed that they were in a fasted state before beginning the test. Participants returned to class with restrictions to continue to fast and to not take part in any strenuous physical activity. After 90 minutes, the participants returned at which time they provided a second breath sample for the determination of $^{13}CO_2$. Two research assistants and two participants were present at all times. A teacher accompanied students under the age of eight years. Determinants of blood pressure (cardiac output, systemic vascular resistance, and arterial compliance) were measured in duplicate and the average of the two values was used in the analysis.

Anthropometry

Weight was measured on two occasions on a calibrated digital scale to the nearest 0.1kg. Height was measured twice with a metre stick to the nearest 0.1cm. BMI values were then calculated. Participants were grouped into normal weight, overweight and obese categories according to definitions from the International Obesity Task Force (Cole et al., 2000). Waist and hip measurements followed the criteria from an existing set of reference data that have been developed for children and youth in the United Kingdom (McCarthy et al., 2001). Specifically, waist was assessed at the narrowest part of the waist or at the midpoint between the iliac crest and last rib if the narrowest point was not obvious. Hip circumference was measured at the widest part of the buttocks. Waist and hip measurements were taken to the nearest 0.1cm in duplicate by two researchers.

Cardiorespiratory Fitness

In order to estimate cardiorespiratory fitness in a large population, the Leger Shuttle Run Test was used to test cardiorespiratory fitness in children and adolescents (Leger, 1980). The test has been widely used to assess the aerobic fitness of individuals and predict maximal aerobic fitness. This field test consists of a number of one minute "stages" that increase in cadence until maximal volitional exhaustion. The final stage attained is used to estimate maximal oxygen uptake (VO_2 max). A research assistant participated with the participants for motivation, pacing assistance, and to ensure the participants put forth a maximal effort.

Measurement of Blood Pressure and its Determinants

Blood pressure and its determinants were measured in a quiet room provided by each school with 3-4 youth in the room at one time. Participants sat quietly for 5 minutes prior to the assessment of arterial compliance. Within the testing room, the researchers had no control over temperature, lighting, and sound. Large (conduit) and small (resistance) artery compliance were estimated from arterial waveforms obtained from a surface residing tonometer placed on the radial artery (Romney et al., 2001; McVeigh et al., 1999). Specific arterial compliance values were estimated by applying a computerized transfer function to peripheral arterial waveforms collected and averaged over a period of 30 seconds (Hypertension Diagnostics, Eagan MN). The non-invasive system used to measure arterial compliance and blood pressure has been previously used in individuals aged 9-83 years of age (Reed et al., 2005; Bennett et al., 2003; Abbott et al., 2002) and has been shown to predict the development of hypertension in young adulthood (Arnett et al., 2001). Blood pressure was measured oscillometrically on the left arm while the tonometer was strapped to the right hand with the transducer lying flat on the radial artery. Participants were measured for appropriate cuff size by a research assistant and measured three times in a supine position. The diastolic decay of a visually acceptable waveform was analyzed mathematically, and the two components of arterial compliance were calculated based on a modified Windkessel model of circulation: capacitive (conduit) and oscillatory (resistance) compliance. This technique has been validated previously with invasive measures of arterial waveforms (Cohn et al., 1995).

Insulin Sensitivity

Insulin sensitivity was assessed using [^{13}C] glucose breath test method (Diatest, Isodiagnostika, Edmonton AB, Canada) as previously described (Lewanczuk et al, 2004). The [^{13}C] glucose breath test is a noninvasive estimate of insulin sensitivity that determines the rate of absorption and metabolism of [^{13}C]-labeled glucose by measuring exhaled $^{13}CO_2$ in a fasted state and 90 minutes after ingestion of 25 mg of [^{13}C] glucose mixed with 15 g dextrose. Differences in baseline and 90-min breath samples reflect insulin-mediated glucose disposal and incorporation into CO_2. The $^{13}CO_2$ was measured in breath samples using an AP2003 isotope ratio mass spectrometer (Analytical Precision Limited, Cheshire, England) by a technician from Isotechnika™ blinded to the status of the study subject. The analyses of expired breath were measured within one month of data collection and stored in a controlled laboratory environment. This method has been validated in our laboratory and correlates well with glucose disposal rate during a hyperinsulinemic-euglycemic clamp in adults (20-60yrs) ($r = 0.69$, $P < .001$) (Lewanczuk et al., 2004).

3.3 Statistical Analyses

As most data points represent replicate measurements, data are presented as mean ± SE unless otherwise stated.

Aim 1 - *Measure the determinants of systolic blood pressure (SBP) in a school-based sample of youth 5-19 yrs with a wide range of body mass indexes. We hypothesize that systemic vascular resistance will be higher in overweight youth that is associated with a compensatory reduction in arterial compliance.*

The primary outcome measure for this aim was SBP. **The primary exposure variable** was weight classification. Secondary outcomes included systemic vascular resistance, cardiac output and arterial compliance. High normal blood pressure was defined as a SBP at or above the 90^{th} percentile for age, sex and height, based on standard charts established by the National High Blood Pressure Education Program working group from the 1999 and 2000 National Health and Nutritional Examination Survey data. Group-wise comparisons were made between youth classified as healthy weight, overweight or obese according to age and sex-specific BMI thresholds established by the International Obesity Task Force (Cole et al., 2000). Preliminary differences in demographic data were tested for using an analysis of variance (ANOVA), while a one- way analysis of co-variance (ANCOVA) was used to test for differences in SBP and its determinants while controlling for group-wise differences in age, sex and height. Following categorical analyses, BMI and SBP were treated as continuous variables and a multiple linear regression analyses were used to determine the association between these two variables was independent of other establish determinants of SBP (ie. age, sex, and height).

Aim 2 - *Determine the association between cardiorespiratory fitness and SBP in youth. We hypothesized that cardiorespiratory fitness is inversely associated with SBP in children, independent of BMI, sex and age.*

The primary outcome measure for this aim was SBP. **The primary exposure variable** was fitness classification. Bi-variate correlation analyses were used to test for an association between cardiorespiratory fitness and SBP while a multiple linear regression analysis was used to test for the independent nature of the relationship between cardiorespiratory fitness and SBP, independent of BMI, sex and age. Youth were then categorized into quintiles of fitness based on age and sex-specific standards established by Leger (Leger and Boucher, 1980): (1) Very high fitness; (2) High fitness; (3) Average fitness; (4) Below average fitness; (5) Low fitness. The categories reflect the age and sex-specific quintiles of shuttle run test scores obtained from a sample of >6000 children surveyed in Quebec between 1977 and 1980 (Leger et al., 1984). Secondary outcomes included systemic vascular resistance, cardiac output and arterial compliance. Analyses were performed on stratified data to aid in the interpretation and application of results into a practical setting. Preliminary differences in demographic data between the groups were tested for using an analysis of variance (ANOVA), while a one-way analysis of co-variance (ANCOVA) was used to test for differences in SBP and its determinants while controlling for group-wise differences in BMI, sex and age.

Aim 3 – *The relationship of cardiorespiratory fitness and SBP in overweight youth. We hypothesized that SBP is lower in overweight youth with high cardiorespiratory fitness relative to their peers with low cardiorespiratory fitness.*

The primary outcome measure for this aim was SBP. **The primary exposure variable** was cardiorespiratory fitness and was treated as a categorical variable within the subgroup of 324 overweight youth aged 9-19 yrs that had measurements of cardiorespiratory fitness and arterial compliance. Preliminary differences in demographic data between fitness tertiles were tested for using an analysis of variance (ANOVA), while a one- way analysis of co-variance (ANCOVA) was used to test for differences in SBP and its determinants while controlling for group-wise differences in age, sex and height. Bi-variate correlation analyses were used to test for an association between fitness and SBP and a stepwise multiple linear regression analysis was used assess the independence of this association after controlling for differences in age, sex and BMI. All data were analyzed using SPSS for Windows, version 14.0 (SPSS Inc, Chicago, IL.).

3.4 Results

Aim 1 - Participant characteristics are provided in Table 2.1 of Appendix 2. When individual data from all three survey years were pooled (n=2089) the prevalence of overweight and obesity was 17.2 and 5.7% respectively. Mean SBP and the prevalence of high normal blood pressure were significantly greater in overweight and obese youth, relative to healthy weight peers (Appendix 2, Table 2.1). Cardiac output was ~50% higher ($p < 0.001$) and systemic vascular resistance was slightly lower ($p < 0.01$) in overweight and obese youth relative their healthy weight peers (Appendix 2, Table 2.1). No differences in arterial compliance were noted across the groups. Insulin sensitivity was 27 and 21% lower in obese and overweight youth ($p < 0.05$), respectively, relative to their healthy weight peers (Appendix 2, Table 2.1).

Overweight and obese youth were also characterized by significantly lower cardiorespiratory fitness compared to their healthy weight peers, independent of differences in age (Appendix 2, Table 2.1; $p < 0.01$). Multiple linear regression analysis revealed that age, gender, BMI, (Appendix 2, Table 2.2a) as well as heart rate, stroke volume, large and small arterial compliance and systemic vascular resistance (Appendix 2, Table 2,2b) were all significantly ($p < 0.01$) associated with SBP in this sample of youth.

Aim 2 – From the original sample of 2089 youth, 1532 aged 9-19 yrs had both cardiorespiratory fitness and SBP data collected in one year of the survey. Subject characteristics are presented in (Appendix 2, Table 2.3). Before adjusting for co-variates, SBP was significantly higher in youth from the lowest quintile of fitness relative to the higher quintile ($p < 0.05$), however, these differences were no longer significant after adjusting for baseline differences in age, BMI, and sex (Appendix 2, Table 2.3). When the fitness scores were converted to a predicted VO_2max and treated as a continuous variable, we observed a negative correlation between SBP and cardiorespiratory fitness ($r = -0.12$, $p < 0.01$). This relationship was no longer significant after adjusting for BMI, sex and age. Multiple linear regression analyses revealed that cardiorespiratory fitness was not associated with SBP within this sample of youth (Appendix 2, Table 2.4).

Aim 3 – From the original sample, 324 overweight youth were studied for Aim #3 and stratified into tertiles on fitness (predicted VO_2max) (Appendix 2, Table 2.5). Before adjusting for co-variates, SBP was higher in youth within the tertile with the lowest fitness (123 ± 11 vs 119 ± 10 mmHg, $p < 0.05$) relative to youth in the tertile with the highest fitness. After controlling for differences in BMI, age and sex, the group-wise differences were no longer significant (120 ± 0.9 vs 119 ± 1.0 mmHg, $p < 0.05$). The preliminary exploratory bi-variate correlation matrix revealed a significant negative relationship between VO_2max and SBP ($r = -0.13$, $p < 0.05$). This relationship was no longer significant after adjusting for group wise differences in stepwise multiple linear regression analysis (Appendix 2, Table 2.6).

3.5 Discussion

Overweight is associated with a volume-dependant high normal and elevated blood pressure.

Data from these annual school-based surveys of youth 5-19yrs old revealed that overweight and obese youth are characterized by an elevated SBP, relative to their lean peers. Additionally, resting cardiac output was ~ 20% higher in overweight youth without any difference in resting heart rate and/or arterial compliance. Therefore, an elevated stroke volume appears to be mediating the increased cardiac output in overweight youth. The data presented here support previous population-based studies demonstrating that overweight is a determinant of blood pressure in youth (Paradis et al., 2004; Sorof et al., 2002; Freedman et al., 1999) and extends them by suggesting that increased stroke volume mediates this association.

The mechanism(s) underlying the development of obesity-related high normal and elevated blood pressure is a controversial area of research (Engeli et al., 2000; Rocchini et al., 2000; Reaven et al., 1996) with many proposed root-causes. Using non-invasive measures of resting hemodynamics, we demonstrated that an elevated

BMI was accompanied by an increased stroke volume-dependant expanded cardiac output. In contrast to previous cross sectional studies (Iannuzzi et al., 2006; Sorof et al., 2004; Tounian et al., 2001; Freedman et al., 1999), heart rate and arterial compliance were not different between healthy weight and overweight youth. The disparate results could be explained by differences in the sample of the youth studied (school-based sample vs clinical sample) and/or differences in methodology for measuring arterial compliance (pulse wave analysis vs echocardiographic determination of carotid artery distensibility). It is also possible that changes in heart rate and arterial stiffness are more closely related to the duration of overweight or the degree of excess fat mass in children. Unfortunately, that information was not available for the analyses presented here.

In adults, hypertension is commonly categorized into two forms, essential and isolated systolic hypertension (McEniery et al., 2005), that are distinguishable by the presence of elevated diastolic blood pressure. Isolated systolic hypertension is the most common form of hypertension in older aged populations and is associated with arterial stiffening. The arterial stiffening in isolated systolic hypertension is thought to be caused by a fatigue of the elastic fibers and is described as an exaggeration of "normal age related stiffening" (McEniery et al., 2005). Similar to McEniery (2005), we observed isolated high normal SBP was common in overweight youth and accompanied by an elevated stroke volume with little difference in arterial compliance. Longitudinal research in youth would help clarify the independent role of cardiac output and vascular stiffening in the development of high normal blood pressure associated with overweight.

The progression to hypertension in overweight adults is typically attributed to

The progression to hypertension in overweight adults is typically attributed to an increase in systemic vascular resistance possibly due to increased sympathetic tone (Davy et al., 2004; Grassi et al., 1995). Studies in overweight adolescents suggest that the mechanisms for elevated blood pressure may be different than adults and more closely associated with changes in blood volume and cardiac output (McEniery et al., 2005; Rocchini et al., 1989;). Using a large school-based survey of youth, we confirm the findings of Rocchini and McEniery by demonstrating that overweight youth are characterized by high normal SBP secondary to an increased stroke volume. Rocchini (1989) proposed that the increased stroke volume (cardiac output) in overweight youth was caused by increased sodium sensitivity and subsequent expanded blood volume. Our data support the concept that the pathophysiology of elevated blood pressure in youth is different compared to adults.

The relationship between cardiorespiratory fitness and SBP in youth.

The data from this cross sectional school-based study revealed that the association between cardiorespiratory fitness (determined by the Leger Shuttle Run Test) and SBP was weak, and mediated by BMI. In fact, SBP differed by only 2-3 mmHg between children in the highest and lowest fitness strata. The European Youth Heart Study (EYHS) found an association between cardiorespiratory fitness measured on an ergometer bike and SBP (Klasson-Heggebo et al., 2006). Klasson-Heggebo (2006) found a difference of 6mm Hg between the low and high fit groups. We observed a similar absolute difference however, after controlling for differences in BMI, the differences were no longer significant. The lack of an association between cardiorespiratory fitness and SBP was surprising, considering the wealth of data suggesting an association in adults (Blair et al., 2003; Hagberg et al., 2000). Similarly, there was not an association between fitness and arterial compliance within this cohort. These data are in contrast to a number of cross sectional studies suggesting that individuals with low fitness are characterized by arterial stiffening, relative to low fit peers (McGavock et al., 2007; Seals et al., 2000). Differences between our study and others can likely be explained by the indirect measures used to assess fitness and the strong effect of adiposity on SBP in youth.

Cardiorespiratory fitness and systolic blood pressure in overweight youth

Randomized controlled trials demonstrate that exercise-mediated improvements in fitness reduce BMI (Allen et al., 2007; Carrell et al., 2005) and improve vascular function (Ribeiro et al., 2004; Watts et al., 2004) in youth. As these studies were limited to youth with extreme obesity, we employed a school-based survey approach to determine if high levels of cardiorespiratory fitness protected overweight youth from high normal blood pressure and its associated complications. To our knowledge, this was the first study to include an estimate of cardiorespiratory fitness, (a modifiable determinant of health) in a school-based survey of hemodynamics in youth. In contrast to intervention studies, we did not observe any association between cardiorespiratory fitness and SBP in overweight youth.

Ribeiro and colleagues (2005) showed that habitual structured physical activity significantly reduced mean arterial blood pressure and improved vascular function in overweight 10-12 yr old children. Furthermore, two studies in adults training at 70-85% of maximal heart rate were found to be associated with an improved blood pressure (Braith et al., 1994; Tashiro et al., 1993). Using an indirect field test, we did not observe an association between cardiorespiratory fitness and SBP in youth. However, in the absence of an objective measure, it remains unclear if increased physical activity is associated with lower SBP in overweight youth.

3.6 Conclusion:

In conclusion, overweight and obese children are characterized by low cardiorespiratory fitness and high normal SBP. The mechanisms underlying the relationship between BMI and SBP in youth with healthy body weights appears to be related more to an elevated cardiac output and less an abnormality in systemic vascular resistance and reduced arterial compliance. Furthermore, the value of school-based measures of fitness may not be indicative of the risk of elevated blood pressure in youth, suggesting that objective measures of activity may be preferred. The relationship between cardiorespiratory fitness and SBP was not as robust as we predicted. The most powerful determinant of an increased CO and SBP was BMI. Collectively, these data could prove useful for the development of targets for weight management to prevent high normal and elevated blood pressure in youth.

Chapter 4

4.1 General Discussion

Overweight is the number one lifestyle-related disorder in youth in Canada and represents an uncontrolled and increasing worldwide epidemic (Shields, 2006). The consequences of this epidemic are relatively unknown, but conventional wisdom forecasts a major burden of obesity related chronic illness. Accordingly, overweight has become the dominant risk factor for high normal and elevated blood pressure in youth (Paradis et al., 2004; Sorof et al., 2004). Public health strategies are needed to curb these trends and physical activity is an attractive lifestyle intervention to achieve these goals at the population level. Indeed several studies have showed that physical activity may prevent the progression to hypertension in adults (Whelton et al., 2002; Hagberg et al., 2000). Although substantial evidence exists demonstrating the benefit of physical activity for chronic disease prevention, research is needed to unravel the association between adiposity, physical activity and high normal blood pressure in youth.

In the current study, we replicated the finding that there was a positive association between BMI and SBP in a school-based sample of youth (Klassen-Haggebo et al., 2006; O'Laughlin et al., 2006; Paradis et al., 2004; Sorof et al., 2004). Our data extend these previous studies by demonstrating that the high normal SBP in overweight youth was associated with a volume-dependant increased stroke volume, independent of differences in vascular stiffness. These data challenge the current paradigm suggesting that vascular dysfunction is a major determinant of high normal SBP associated with obesity. The finding that SBP was not related to vascular stiffness or resting heart rate (i.e. sympathetic tone) implies that the mechanisms leading to high normal SBP in the setting of obesity may be age-dependant.

Although this is one of the first studies to assess the association between cardiorespiratory fitness and SBP in a large sample of school aged youth, data for physical activity was not assessed in the first few waves of the study. As a result, it is not possible to distinguish between the independent role of physical activity and cardiorespiratory fitness on SBP in youth. Physical activity and cardiorespiratory fitness have recently been found to be associated with metabolic health in adults and youth (Brage et al., 2004; Blair et al., 2001). In adults, prospective cohort studies demonstrate that both high levels of physical activity and high cardiorespiratory fitness are protective against cardiovascular mortality and morbidity (Blair et al., 2001; Manson et al., 1999) even among those who are obese. While physical activity is readily modifiable, cardiorespiratory fitness is a measure of work capacity and is influenced by several components including genetics, musculo-skeletal development and adiposity (Pfeiffer et al., 2007). Therefore, it is less simple to elicit changes in fitness than physical activity in an effort to reduce cardiovascular morbidity in youth (Blair et al., 2001).

Previous population and school-based studies in youth have demonstrated that high fitness confers some degree of protection from metabolic risk in youth matched for physical activity levels (Brage et al.,2004). These findings are consistent with reports in adults showing that high fitness reduces mortality-risk independent of underlying chronic illness (i.e. presence of obesity, type 2 diabetes, or hypertension). The independent effects of physical activity and cardiorespiratory fitness are difficult to differentiate due to weak measurement tools used to assess physical activity in epidemiological studies (Kohl et al., 2000). In children, cardiorespiratory fitness is more strongly correlated to metabolic risk than physical activity (Rizzo et al., 2007; Brage et al., 2004) however, the two are very closely associated. Using a field test for assessing cardiorespiratory fitness, we found that cardiorespiratory fitness did not predict SBP in youth but future studies using objective measures are needed to determine if physical activity is associated with SBP in youth. Research is required in which physical activity is measured objectively in a longitudinal design before we can determine the dose (i.e. intensity and duration) needed to lower the risk of developing high normal blood pressure in youth, in particular those who are overweight.

4.2 Future Directions

From the standpoint of disease prevention, a better understanding of the amount of physical activity for protection from high blood pressure is important. Andersen and colleagues (2006) working with the European Youth Heart Study (EYHS) found that the dose of physical activity associated with optimal child health is higher than the current international guidelines of one hour per day. They found that a minimum of 116 minutes for 9 year-olds and 88 min for 15 year-olds was associated with a reduced prevalence of cardiovascular risk factor clustering (Andersen et al., 2006). Longitudinal population-based studies of physical activity are needed to confirm this finding and provide evidence for a specific dose of physical activity needed for optimal health and body weight in youth.

Prospective cohort designs have traditionally provided important objective evidence for the dose response association of physical activity and health outcomes.

This type of design would be ideal for identifying the threshold of activity to prevent high blood pressure in youth. A second direction would be to understand the independent role of diet and physical activity on blood pressure in overweight youth. A randomized control trial comparing diet and/or weight loss on blood pressure in overweight youth would prove useful to clinicians and policy makers for the development of guidelines for the prevention of cardiovascular complications of overweight and obesity in youth.

The long-term continuation of this study will provide important insight into the changes in the current rates of overweight and obesity and its health consequences in children in the school district. Furthermore, Healthy Hearts is in the unique position to directly translate any findings from our research into practice (i.e. within the school curriculum). Working closely with schools and communities, we can take any information gathered in this study and apply it to interventions targeted at reducing the prevalence of overweight and sustaining healthy body weights in youth.

4.3 Public Policy Considerations

Overweight and obesity in youth is a major public health concern and both policies and initiatives are being developed to reduce this burden on the health care system (Katzmarzyk et al., 2000). The information gathered in this investigation provides yet another example of the deleterious effects of overweight on health in youth. Furthermore, it provides policy makers and practitioners with evidence that SBP is elevated in youth, irrespective of their overweight classification. More importantly, short of a randomized trial, this study provides unique contextual 'real-world' evidence regarding the targets for weight and potentially weight gain in youth, most closely associated with optimal health and chronic disease risk. The school-based nature of these experiments are generalizable to the public and reinforce a growing body of evidence demonstrating the negative effects of overweight on cardiovascular risk in youth. Future studies are required to develop lifestyle targets aimed at preventing high normal, elevated blood pressure and other overweight related diseases in high risk youth.

Current criteria for "elevated" or "high normal" blood pressure in youth are statistically derived, representing percentiles from the population at large. In contrast to cut-offs for adults, the current overweight standards for youth are not directly associated with any major cardiovascular outcomes (i.e. stroke, myocardial infarction, renal disease). These standards allow for early detection, appropriate intervention, and prevention against overweight related disease. Studies such as Healthy Hearts provide important information describing the continuous association between body weight and blood pressure in youth suggesting that current standards need to be revisited as they may be missing a large number youth at risk for cardiovascular disease.

Although cardiorespiratory fitness was not independently associated with SBP in healthy weight or overweight youth, trends did emerge suggesting an association. That controlling for BMI negated any observable association implies that blood pressure lowering effects of high cardiorespiratory fitness may be mediated through weight reduction. An increase in physical activity and/or improvement in cardiorespiratory fitness are perhaps insufficient to observe a reduction in SBP unless they are accompanied by weight loss. From a public health perspective, future studies need to be conducted to better understand the lifestyle factors (diet and activity) that are most effective for attaining healthy blood pressure in lean and overweight youth.

4.4 Conclusion of Thesis

This thesis has brought greater understanding to the association between overweight, SBP and cardiorespiratory fitness in a large school-based population of youth. The knowledge gained throughout this thesis may contribute to healthier populations and prevent the adverse health consequences of overweight and obesity in youth.

The purpose of this thesis was to determine modifiable risk factors and mechanisms for high normal blood pressure in youth. We observed that, in contrast to adult hypertension, the mechanisms underlying high normal and elevated blood pressure in overweight youth may be more related to central hemodynamics than peripheral vascular dysfunction. Furthermore, we observed that cardiorespiratory fitness is only marginally associated with blood pressure in youth and likely mediated through adiposity. Future more detailed longitudinal studies are needed to confirm these cross sectional observational findings.

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Appendices

Appendix 1: Tables from Review of Article

Table 1.1 Definitions of overweight, obesity, and high normal blood pressure in youth.

Term	Definition	Source	Adult Equivalent
Classification of Weight Status			
At risk for overweight	≥ 85th -94th percentile for age and gender	CDC	25-29.9 kg/m^2
Overweight	≥ 95th percentile for age and gender	CDC	≥ 30 kg/m^2
Overweight (international standard)	Age and gender specific values	International Obesity Task Force	25-29.9 kg/m^2
Obese (international standard)	Age and gender specific values	International Obesity Task Force	≥ 30 kg/m^2
Classification of High Blood Pressure			
High normal blood pressure (pre-hypertension)	SBP or DBP >90th and <95th centile for age, height and sex	NHLBI	≥ 130 and/or ≥ 85 mmHg
Elevated blood pressure (hypertension)	SBP or DBP >95th centile for age, height and sex	NHLBI	≥ 140 and/or ≥ 90 mmHg

Table 1.2 Thresholds for high-normal blood pressure (mmHg) in boys (NHANES).

Age (yrs)	Percentile of Height			
	25th	50th	75th	90th
4	109	111	112	114
6	112	114	115	117
8	114	116	118	119
10	117	119	121	122
12	122	123	125	127
14	127	128	130	132
16	132	134	135	137

Table 1.3. Review of Literature Chart

Study (sample size)	Age (yrs)	BMI (kg/m^2)	Intervention				Change in Outcome	Weight change	Conclusions
			Duration	Intensity	Frequency	Type			
Hagberg (1983) n = 25	16 ±1	NR –	6 ± 1 mos 30-40 min	70-80% of VO_2max	5x/week	Aerobic: Walking/ jogging	SBP: ↓ 8 mmHg	None	Returned to baseline following cessation
Becque et al (1988) n = 36	~13	~29	20 wks 50 min	60-80% of age pred. max	3x/wk	Aerobic, walk, jog, activities	SBP: ↓ 1.4 Z-score	None	Combined with diet was effective in reducing BP and CHD risk factors
Rocchini et al. 1988 n = 25	10-17 ~12	>75th %	20 wks 40 min	70-75% max HR	3x/wk	Aerobic walk, jog activities	SBP: ↓ 16 mmHg	↓ 2kg	Combined with Diet exercise lowered BP and improved forearm reactivity
Ewart et al. (1998) n = 88	NR	NR	18-wks 50 min	NR	5x/wk	Aerobic during PE class	SBP: ↓ 6 mmHg	None	Aerobic activity in PE class reduces BP in adolescent girls
Gutin et al. (2002) n = 20 LI / 21 HI	13-16		8 mos 29 min/ 43min	LI=55-60% HI=75-80%	5x/wk	Activities	SBP: LI: ↓ 2.1 HI: ↓ 6.1 mmHg	↓ VAT	High-intensity activity was associated with favorable changes in markers of insulin resistance syndrome

McMurray et al. (2002) n = 1140	11-14	21-22	8 weeks 30 min	NR	3x/wk	Activities	SBP: ↓ ~3 mmHg	None	Exercise reduced systolic blood pressure to a greater degree than education alone
Watts et al (2004) n = 19	14 ± 2	34 ± 1	8 wks cross over 60 min	65-85% of HR max	3x/wk	Circuit Weight Training	↔ SBP	None	Aerobic activity restored endothelial reactivity to levels seen in lean controls
Woo et al. (2004) n = 82	9-12	25 ± 3	6 wks – 1 yr 75 min	60-70% of pred. HRmax	2x/wk – 1x-wk	Aerobic + resistance + activities	NR	None	Compared to diet, exercise improved endothelial reactivity which returned to baseline following cessation
Ribiero et al (2005) n = 21	10 ± 1	28 ± 1	16 weeks 60 min	10% below VT	3x/wk	Walking/ Jogging + Activity	MAP: ↓ 6 mmHg	↓ 5kg	Compared to diet alone; improved BP response to mental and physical stress

Appendix 2: Tables for Research Article

Table 2.1: Subject Characteristics (Aim 1). Unadjusted for covariates.

Variable	Healthy Weight	Overweight	Obese
N (%)	1610 (77.1)	359 (17.2)	120 (5.7)
Sex (f/m)	841 / 769	201 / 158	59 / 61
Age (yrs)	11.0 ± 3.5	$11.5 \pm 3.2^{*}$	11.6 ± 3.6
Height (cm)	147.4 ± 19.9	$153.0 \pm 18.6^{*}$	$154.8 \pm 19.2^{*}$
Weight (kg)	40.3 ± 15.5	$54.8 \pm 18.1^{*}$	$69.0 \pm 25.0^{*}$
BMI (kg/m^2)	17.7 ± 2.5	$22.6 \pm 2.7^{*}$	$27.5 \pm 4.3^{*\dagger}$
Waist Circumference (cm)	63.3 ± 9.0	$75.4 \pm 9.9^{*}$	$88.4 \pm 14.1^{*}$
Hip Circumference (cm)	76.0 ± 12.2	$87.6 \pm 11.5^{*}$	97.0 ± 17.1
Expired $^{13}CO_2$ (‰)	15.5 ± 5.5	$13.5 \pm 4.3^{*}$	$12.1 \pm 3.5^{*}$
SBP (mmHg)	112 ± 16	$118 \pm 18^{*}$	$121 \pm 16^{*\dagger}$
DBP (mmHg)	58 ± 7	60 ± 8	60 ± 8
Prevalence High BP (%)	21%	$41\%^{*}$	$48\%^{*}$
HR (bpm)	75 ± 15	76 ± 15	76 ± 14
LAE (mL/mmHg*10)	13 ± 1	13 ± 1	13 ± 1
CO (L/min)	4.8 ± 1.0	$5.3 \pm 1.1^{*}$	$6.2 \pm 1.2^{*\dagger}$
SVR ($dynes/s/cm^5$)	1385 ± 438	$1295 \pm 452^{*}$	$1137 \pm 300^{*\dagger}$
VO_2peak (mL/kg/min)	46.2 ± 7.0	$44.0 \pm 6.7^{*}$	$40.0 \pm 5.1^{*\dagger}$

BMI = Body Mass Index CO = Cardiac Output
DBP = Diastolic Blood Pressure
HR = Heart Rate
LAE = Large Arterial Elastance
SBP = Systolic Blood Pressure
SV = Stoke Volume
SVR = Systemic Vascular Resistance
* $p < 0.05$ vs healthy weight
† $p < 0.05$ vs overweight.

Table 2.2: Anthropometric (A) and hemodynamic (B) determinants of systolic blood pressure in youth (Aim #1)

(A)

Variable	B	SE	P
Age	1.2	0.25	< 0.001
Sex	2.4	0.7	< 0.001
BMI	0.86	0.05	0.003
Insulin Sensitivity	-0.317	0.09	0.006
VO_2max	0.06	0.05	0.28

(B)

Variable	B	SE	P
HR	0.58	0.02	< 0.001
SV	0.64	0.03	< 0.001
LAE	-0.09	0.03	< 0.001
SAE	-0.92	0.13	< 0.001
SVR	0.008	0.01	< 0.001

BMI = Body Mass Index; HR = Heart Rate; LAE = Large Arterial Compliance; SAE = Small Arterial Elastance; SV = Stoke Volume; SVR = Systemic Vascular Resistance;

Table 2.3: Characteristics of youth 9-19yrs that performed a fitness test (Aim #2)

	Leger Fitness Category (n =1532)				
Variable	**I (high fit) n = 291**	**II n = 162**	**III n = 206**	**IV n = 250**	**V (low fit) n = 623**
Age (yrs)	12.0 ± 2.9	10.6 ± 3.2*	11.1 ± 3.1*	11.7 ± 2.6	14.2 ± 2.1*†‡
Sex (m/f)	140/151	70/92	100/106	122/128	290/333
Height (cm)	154.5 ± 17.7	146.8 ± 18.8	149.7 ± 18.0	152.2 ± 15.0	163.7 ± 11.4
Weight (kg)	45.8 ± 16.5	43.8 ± 16.7	41.5 ± 16.1	48.0 ± 14.8	61.4 ± 16.5*†‡
BMI (kg/m^2)	18.4 ± 3.0	18.5 ± 3.4	18.8 ± 3.1	19.8 ± 3.5*	22.4 ± 4.3*
Waist Circumference (cm)	65.7 ± 9.5	65.5 ± 1.4	66.0 ± 10.6	69.8 ± 10.7	76.4 ± 12.5*
Hip Circumference (cm)	77.4 ± 11.6	76.9 ± 12.7	78.4 ± 12.7	82.5 ± 11.5	92.1 ± 12.5 *
VO_2peak (mL/kg/min)	54 ± 4	48 ± 2	45 ± 1	42 ± 1	36 ± 3*†‡
Insulin Sensitivity (‰)^A	16.7 ± 0.2	17.6± 0.4	17.1 ± 0.3	17.4 ± 0.3	18.0 ± 0.1
SBP (mmHg)^A	113.6 ± 0.5	115.0 ± 0.6	113.3 ± 0.6	115.3 ± 0.6	114.5 ± 0.4
DBP (mmHg)^A	59.4 ± 0.4	59.2 ± 0.5	58.3 ± 0.4	59.6 ± 0.4	59.4 ± 0.3
HR (bpm)^A	72.1 ± 0.7	73.9 ± 0.7	74.9 ± 0.6	76.6 ± 0.6*	77.4 ± 0.7*†
LAE (mL/mmHg*10)^A	13.3 ± 0.5	12.5 ± 0.5	12.8 ± 0.5	11.8 ± 0.5	12.3 ± 0.5
CO (L/min)^A	4.9 ± 0.1	5.0 ± 0.1	5.0 ± 0.1	4.9 ± 0.1	4.9 ± 0.1
SVR ($dynes/s/cm^5$)^A	1366 ± 26	1324 ± 37	1335 ± 30	1318 ± 30	1368 ± 19

* = $p < 0.05$ vs Quintile I; † p 0.05 vs Leger Quintile II; ‡ = $p < 0.05$ vs Leger Quintile III

^{A} = Adjusted for group-wise differences in BMI, age and sex. Data presented as mean ± SE for adjusted means

BMI = Body Mass Index; CO = Cardiac Output; DBP = Diastolic Blood Pressure; HR = Heart Rate; LAE = Large Arterial Elastance; SBP = Systolic Blood Pressure; SV = Stoke Volume; SVR = Systemic Vascular Resistance.

Table 2.4: Determinants of systolic blood pressure in youth 9-19yrs who performed a fitness test (Aim #2)

Variable	B	SE	P
Sex	2.11	0.57	< 0.001
Age	1.07	0.14	< 0.001
BMI	0.93	0.09	< 0.001
Insulin Sensitivity	-0.08	0.07	0.264
VO_2max	0.02	0.50	0.660

Table 2.5: Characteristics of the sub-sample of overweight youth stratified according to fitness (Aim #3)

	Tertile of Fitness		
Variable	**I (n=108)**	**II (n=108)**	**III (n=108)**
Age (yrs)	12.5 ± 2.5	12.1 ± 2.3	13.6 ± 2.0*†
Sex (m/f)	60/38	50/58	49/59
Height (cm)	159.9 ± 16.7	156.0 ± 12.7	164.2 ± 11.6*†
Weight (kg)	61.3 ± 17.4	59.5 ± 14.6	73.7 ± 17.9*†
BMI (kg/m^2)	23.4 ± 2.9	24.1 ± 2.6	26.9 ± 3.9*†
Waist Circumference (cm)	77.6 ± 10.4	79.3 ± 9.2	87.3 ± 12.5*†
Hip Circumference (cm)	90.0 ± 11.4	90.6 ± 9.2	99.5 ± 14.7*
VO_2peak (mL/kg/min)	49 ± 6	42 ± 6	36 ± 7*
SBP (mmHg)[A]	120.3 ± 0.9	120.8 ± 0.9	119.9 ± 1.0
DBP (mmHg)[A]	60.3 ± 0.7	62.0 ± 0.7	61.5 ± 0.7
HR (bpm)[A]	73.4 ± 1.1	73.6 ± 1.1	77.0 ± 1.1
LAE (mL/mmHg*10)[A]	12.8 ± 0.6	12.3 ± 0.6	14.1 ± 0.6

* - $p < 0.05$ vs Tertile I, before adjusting for co-variates (BMI, age, and sex).
† - $p < 0.05$ vs Tertile II.

[A] = Adjusted for group-wise differences in BMI, age and sex. Data presented as mean ± SE for adjusted means

BMI = Body Mass Index; CO = Cardiac Output; DBP = Diastolic Blood Pressure; HR = Heart Rate; LAE = Large Arterial Elastance; SBP = Systolic Blood Pressure; SV = Stoke Volume; SVR = Systemic Vascular Resistance.

Table 2.6: Determinants of Systolic Blood Pressure in Overweight Youth (Aim #3)

Model	Unstandardized Coefficients B	Std Error	Sig.
(1)Constant	130.861	4.380	<0.001
VO2max	-.2480	.100	0.020
(2) Constant	128.250	4.470	<0.001
VO2max	-.2.940	0.100	0.005
Sex	3.140	1.300	0.014
(3) Constant	91.670	5.090	<0.001
VO2max	-0.110	0.090	0.210
Sex	1.280	1.100	0.240
Age	2.480	0.230	<0.001
(4) Constant	77.240	6.610	<0.001
VO2max	-.005	.0940	0.959
Sex	1.380	1.080	0.203
Age	2.000	0.270	<0.001
BMI	0.640	0.190	<0.001

BMI = Body Mass Index; CO = Cardiac Output; DBP = Diastolic Blood Pressure; HR = Heart Rate; LAE = Large Arterial Elastance; SBP = Systolic Blood Pressure; SV = Stoke Volume; SVR = Systemic Vascular Resistance; * $p < 0.05$ vs healthy weight; † $p < 0.05$ vs overweight

Appendix 3:

Consent Form

Data Collection Form 5-12yrs

Data Collection Form 13-19yrs

UNIVERSITY OF
ALBERTA

Healthy Hearts

INFORMED CONSENT / PERMISSION FORM

Name of School: ______________________

Part 1

Title of Project: **Impact of body mass on insulin sensitivity and arterial compliance in children and adolescents**

School Research Coordinator:	Mr Brian Torrance	Faculty of Medicine	cell	298 2341
Principal Investigator:	Dr. Richard Lewanczuk	Department of Medicine		407-6277
Co-Investigator(s):	Dr. Jon McGavock	University of Manitoba		204-480-1359
	Dr Paul Wozny	Principal Leduc Junior		986-2184

Part 2 (to be completed by the parent/guardian of research participant):

Do you understand that your child has been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw your child from the study at any time? You do not have to give a reason and it will not affect your child's care.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your child's records?	Yes	No
Do you want the investigator(s) to inform your family doctor that your child is participating in this research study? If so, please provide your doctor's name:	Yes	No

____

This study was explained to me by: ______________________

I agree that my child ______________________ may take part in this study.

______________________ ______________ ______________________

Signature of parent /guardian of Research Participant (If child is under 18 years of age) — Date — Witness

______________________ ______________________

Printed Name — Printed Name

Contact Phone Number: ______________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________ ______________

Signature of Investigator or Designee — Date

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE PARENT/GUARDIAN OF THE RESEARCH SUBJECT AND BLACK GOLD SCHOOLS.

Oct, 2007
Version 3 - HREB # 5046

Parent/Guardian Information

Your current mailing address:

Name:______________________________ Date:____________________

Address:___________________________________

____ Postal Code:_______________________

Phone #: ____________________________

As we plan to follow and reassess the children for the next few years we ask that you provide a name and phone number of someone who we could contact in 3-5 years from now to obtain your new number and address should you move (i.e. Friend or family member):

Name: _______________________ Phone:______________________________

We are extremely grateful for your continued support and assistance in the collection of this valuable data. Thanks for being a part of Healthy Hearts!!

Oct, 2007
Version 3 - HREB # 5046

UNIVERSITY OF ALBERTA

Healthy Hearts

Physical Activity and Chronic Disease in Youth Data Collection Sheet **5-12 yrs old**

Name of Research Assistant / Administrator: ______________________

Date: ______________ **ID:** ____________________

Name: ______________________ **Date of Birth:** ____/____/____
Day Month Year

School: ______________________ **Home room:** __________

Height: 1. ________ **2.** ________ **Weight: 1.** ________ **2.** ________

Waist: 1. ________ **2.** ________ **Hip: 1.** ________ **2.** ________

Medications: ________________________________

Gender M ☐ F ☐ **BP:** _____

Race: Caucasian ☐ Black ☐ 1st Nations ☐ Asian ☐ Hispanic ☐ Middle Eastern ☐

Blood Pressure Data
Arm Circumference: ______________

Type of Cuff (circle): Child Adult Large

SITTING

	1	2	3	Signal
Manual				
SBP				
DBP				
Automated				
SBP				
DBP				
MAP				
HR				

SUPINE

Researcher Name: ______________

	1	2	3	Signal
SBP				
DBP				
MAP				
HR				
LAE				
SAE				
SVR				
TVI				
CO				
CI				

Fitness test:
Final Stage: ______________

Smoking history:
Parents Smoke: Yes ☐ No ☐

Have you been in HH before?

____
# of years

Version #2 March 6th 2007

UNIVERSITY OF ALBERTA

Healthy Hearts

SAPAC - Physical Activity Questionnaire Children under 12 yrs (Grade 6 and under)

The day before these tests **SHOULD NOT** be a fitness test day.

Please tell each child that purpose of this test is to tell us about the activity that you did yesterday. We have a checklist of activities to help you remember."

A. Defining Physical Activity:

A1: What day is it today?________/________________/________________
Day Month Year

A2: What day was yesterday?:

Mon. Tues. Wed. Thurs. Fri. Sun.

A3: School Starting Time: ______:______

A4: School Ending Time: ______:______

A5. Did you participate in Physical Education/Activity Yesterday?: Yes No

A6: If Yes, How many minutes: ____________ minutes. ____________Activity

A7: Did you participate in Recess Yesterday? Yes No

A8: **If Yes,** how many minutes of recess did you have?

First (morning) recess: ________________ minutes Activity: ________________

Lunch recess: ________________ minutes Activity: ________________

Second (afternoon) recess: ______________minutes Activity:________________

Instructions: Only write down which activities you did yesterday. But only write down the activities that you did for more than **5 minutes.**

N-S-M. During the activity that you performed we want to know if you had to breathe hard None (N), Some (S) or Most (M) of the time.

For example if you played soccer and ran the whole time, mark down that your breathing was hard M-Most of the time. If you didn't run very much mark S-Some. If you didn't breathe hard at all, mark N-None.

UNIVERSITY OF ALBERTA

Healthy Hearts

Checklist:

ACTIVITY	Before School	NSM	During School	NSM	After School/ Evening	NSM
Bicycling						
Hockey						
Floor Hockey						
Swimming Laps						
Gymnastics						
Exercises: Push-ups, sit-ups						
Basketball						
Baseball/softball						
Football						
Soccer						
Volleyball						
Racket sports						
Ball Playing – Dodge ball, 4-square						
Games: Tag, chase						
Outdoor play: Hide and seek						
Water play: playing at the lake / pool						
Jump rope						
Dance						
Outdoor chores:						
Indoor chores:						
Ringette						
Walking alone						
Running alone						
Four H club						
Indoor Play						
Outdoor Play (Snow)						
How did you get to school?						
Physical Education (Gym)						
Daily Physical Activity (DPA)						

Sedentary Time: Mark time in Hours and Minutes

Activity	**Before School**	**After School/ Evening**	**Weekend**
TV			
Computer			
Video Games			

UNIVERSITY OF ALBERTA

Healthy Hearts

Physical Activity and Chronic Disease in Youth Data Collection Sheet **13-18 yrs old**

Name of Research Assistant / Administrator: ____________________

Date:______________ **ID:** ____________________

Name: ____________________ **Date of Birth:** ____/____/____
Day Month Year

School:____________________ **Home room (Grade):**__________

Height: 1.________ **2.** ________ **Weight: 1.**________ **2.** ________

Waist: 1.________ **2.** ________ **Hip: 1.**________ **2.** ________

Medications:____

Gender M ☐ F ☐ **BP:**_____

Race: Caucasian ☐ Black ☐ 1st Nations ☐ Asian ☐ Hispanic ☐ Middle Eastern ☐

Blood Pressure Data
Arm Circumference:______________

Type of Cuff (circle): **Child** **Adult** **Large**

SITTING

	1	2	3	Signal
Manual				
SBP				
DBP				
Automated				
SBP				
DBP				
MAP				
HR				

SUPINE

Researcher Name:______________

	1	2	3	Signal
SBP				
DBP				
MAP				
HR				
LAE				
SAE				
SVR				
TVI				
CO				
CI				

Fitness test:
Final Stage:______________ Have you been in HH before? ______________
# of years

Smoking history:
Parents Smoke: Yes ☐ No ☐
Current tobacco smoker: Yes ☐ No ☐ Number of cigarettes/day: _____

APAQ – Adolescent Physical Activity Questionnaire
13-18yrs

Thank you very much for participating in this years Healthy Hearts Study. We would like you to work through this questionnaire and answer all the questions set out here as best you can. Many other students in the survey will complete the questionnaire as well; ***try to keep your work to yourself.*** *We also hope to repeat the questionnaire every year to get a feel for how your physical activity patterns change throughout your teen years.*

Please make sure you write your name on this form and that is has an ID number (sticker) attached. We will not use your name when we analyze the data and nobody will see these forms except for myself and a few other members of the research team. Your teachers, friends, parents and school staff will not have access to your answers on this questionnaire.

This is not a test, so there are no right or wrong answers. We do want your honest answers as the data is very important to us. It is important that you complete the form in private and please avoid talking to your friends while completing the form. We want you to concentrate on the answers and avoid being influenced by your friends.

To complete the questionnaire, please fill in the appropriate boxes. Please put up your hand if you have any questions especially if:

- *i) you do not understand the question,*
- *ii) you do not understand what a word means,*
- *iii) you make a mistake and want to change your answer. We have erasers and liquid paper (white out).*

So take your time in completing the questionnaire. If you need help, raise your hand or find a research assistant to help. Read over the questionnaire when you are finished to ensure that you did not leave out any questions. Make sure this form is returned to one of the research assistants before you leave.

Thank you again for helping us out this study. We look forward to seeing you again next year!

Best Regards,

The University of Alberta and the Healthy Hearts Team

NOW FOR SOME QUESTIONS ABOUT NON-ORGANIZED PHYSICAL ACTIVITY IN THE FALL

3. The following questions are about your participation **non-organized** physical activities before, after, and during school and on weekends during school terms. **This includes walking or cycling to and from school.**

The first questions are about organized sports, games and other activities you do during the **FALL MONTHS** (i.e. semester #1, before the Christmas holidays). Please think about a normal week and write in the table below the activity you usually do, how many times each week you normally do them and the amount of time you spend doing them.

There is a list of common activities at the bottom of the page to help guide you. If you do any other sports that do not appear on the list please list them as well.

If you do not do any physical activity please write a zero on the first line.

Physical Activity, Sports, and Games		Number of times each week you participate in the sport, including time spent practicing or training	Time EACH TIME you participate. (you can write fractions)
Eg. Walk to and from school		5 times to from school	20 min each time
1.			
2. Physical Education (Gym)			
3.			
4.			
5.			
6.			

Examples of activities:

Aerobics	Basketball	Bushwacking
Circuit Training (weights)	Cycling for fun	Cycling for transport
Dance (jazz, ballroom etc...)	Fishing	Golf
Martial Arts	Rollerblading	Sailing (canoeing)
Skateboarding	Soccer	Squash
Swimming	Tennis	Touch football
Ultimate Frisbee	Volleyball	Walking

Sedentary Time: Mark time in Hours and Minutes

Activity	**Before School**	**After School**	**Weekend**
TV			
Computer			
Video Games			

NOW FOR SOME QUESTIONS ABOUT NON-ORGANIZED PHYSICAL ACTIVITY IN THE SEMESTER AFTER CHRISTMAS

4. The following questions are about your participation non-organized physical activities before and after school and on weekends during school terms. **This include walking or cycling to and from school.**

   The first questions are about organized sports, games and other activities you do during the **Winter/Spring MONTHS** (i.e. semester #2, after the Christmas holidays). Please think about a normal week and write in the table below the activity you usually do, how many times each week you normally do them and the amount of time you spend doing them.

   There is a list of common activities at the bottom of the page to help guide you. If you do any other sports that do not appear on the list please list them as well.

   If you do not do any physical activity please write a zero on the first line.

Physical Activity, Sports, and Games		Number of times each week you participate in the sport, including time spent practicing or training	Time EACH TIME you participate. (you can write fractions)
Eg. Walk to and from school		5 times to from school	20 min each time
1.			
2. Physical Education (Gym)			
3.			
4.			
5.			
6.			

Examples of activities:

Aerobics	Basketball	Bushwacking
Circuit Training (weights)	Cycling for fun	Cycling for transport
Dance (jazz, ballroom etc...)	Fishing	Golf
Martial Arts	Rollerblading	Sailing (canoeing)
Skateboarding	Soccer	Squash
Swimming	Tennis	Touch football
Ultimate Frisbee	Volleyball	Walking (fun/transport)

Sedentary Time: Mark time in Hours and Minutes

Activity	**Before School**	**After School**	**Weekend**
TV			
Computer			
Video Games			

NOW SOME QUESTIONS ABOUT ORGANIZED SPORTS, GAMES AND OTHER PHYSICAL ACTIVITIES

1. The following questions are about your participation in **organized sports** and games before and after school and on weekends during school terms.

   The first questions are about organized sports, games and other activities you do during the **FALL MONTHS** (i.e. semester #1, before the Christmas holidays). Please think about a normal week and write in the table below the sports or games you usually do, how many times each week you normally do them and the amount of time you spend doing them. The time spent doing a sport includes the time you spend practicing or training as well.

   There is a list of common sports and activities at the bottom of the page to help guide you. If you do any other sports that do not appear on the list please list them as well.

   If you do not do any organized sports please write a zero on the first line.

Physical Activity, Sports, and Games	Length of Season	Number of times each week you participate in the sport, including time spent practicing or training	The usual amount of time you spend training EACH TIME you participate. (you can write fractions)
Eg. Football		2 practices + 2 games	90 min each time
1.			
2.			
3.			
4.			
5.			

Examples of activities:

Aerobics
Cycling
Golf
Indoor soccer
Polo (water)
Rugby
Softball
Tennis
Ringette
Baseball
Dance
Gymnastics
Lifesaving (guarding)
Rowing
Running
Squash
Triathlon
Basketball
Football
Hockey
Martial Arts
Rollerblading
Soccer
Swimming
Volleyball

QUESTIONS ABOUT ORGANIZED SPORTS AND GAMES IN THE SEMESTER AFTER CHRISTMAS

2. The following questions are about your participation in **organized** sports and games before and after school and on weekends during school terms.

   The first questions are about organized sports, games and other activities you do during the **WINTER/SPRING MONTHS** (i.e. semester #1, after the Christmas holidays). Please think about a normal week and write in the table below the sports or games you usually do, how many times each week you normally do them and the amount of time you spend doing them. The time spent doing a sport includes the time you spend practicing or training as well.

   There is a list of common sports and activities at the bottom of the page to help guide you. If you do any other sports that do not appear on the list please list them as well.

   If you do not do any organized sports please write a zero on the first line.

Physical Activity, Sports, and Games	Length of Season	Number of times each week you participate in the sport, including time spent practicing or training	Time EACH TIME you participate. (you can write fractions)
Eg. Hockey		2 practices + 2 games	90 min each time
1.			
2.			
3.			
4.			
5.			

Examples of activities:

Aerobics	Baseball	Basketball
Cycling	Dance	Football
Golf	Gymnastics	Hockey
Indoor soccer	Lifesaving (guarding)	Martial Arts
Polo (water)	Rowing	Ringette
Rollerblading	Rugby	Running
Soccer	Softball	Squash
Swimming	Tennis	Volleyball.