PATTERNS OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR AND CARDIOVASCULAR HEALTH IN CHILDREN

by

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Abstract

Introduction: Physical activity (PA) and sedentary behaviours are important modifiable risk factors for cardiovascular disease in adults; however, we know much less about their role for enhancing and sustaining children's cardiovascular health. The aim of this thesis is to evaluate the relation between PA, sedentary time, and cardiovascular health in children.

Methods: Participants were volunteers in a two-year randomized controlled dissemination trial of a whole school PA model (30 schools; 1,529 children). Activity intensity was measured via accelerometry (n=629), arterial compliance by applanation tonometry (n=250), and cardiovascular fitness (CVF) using a 20-meter shuttle run test (n=1,319).

Results: In **study 1**, epoch length influenced the volume of activity recorded; however, the direction and magnitude of the bias depended on activity intensity and volume. In **study 2**, girls accumulated less moderate-to-vigorous PA (MVPA) and more sedentary time compared with boys, except during physical education. Fewer girls than boys met PA guidelines during school, recess, and lunch. Similarly few boys and girls (< 3%) met PA guidelines during physical education. In **study 3**, PA was beneficially associated with small, but not large, artery compliance. Bouted MVPA was not associated with small or large artery compliance. In **study 4**, activity was associated with CVF in children. However, the association between bouted MVPA and CVF was not independent of total MVPA. In **study 5**, girls and boys randomized to intervention schools had 31-37% greater CVF at the end of year one compared with children attending control schools; the magnitude was clinically relevant, but not statistically significant after adjusting for school clusters. There was no between-group difference across year two.

Conclusions: Objective measures of activity improve the relation between PA and cardiovascular health thus future research should standardize methods and use accelerometers to assess children's activity whenever possible. Children undertake little PA during school, particularly during physical education. Whole school PA interventions may enhance the cardiovascular health of children; however, generalist teachers require training and support for sustained effects. Long term prospective trials of activity (assessed by accelerometry) and targeted PA interventions that control for school clusters would fill a notable gap in the paediatric literature.

Preface

The overall study was designed and implemented under the leadership of Heather McKay and PJ Naylor; data were collected by the Action Schools! BC measurement team. Ethical approval was obtained from the University of British Columbia Behavioural Research Ethics Board (B05-0505) and the University of Victoria Human Research Ethics Board (07-05-149f).

A version of chapter 4 is being prepared for submission (Association of epoch length with measurement of children's physical activity and sedentary time). I defined the research question specific to this part, processed, cleaned and analyzed the data, and wrote the initial draft of the manuscript. Heather McKay provided detailed editorial feedback on the manuscript. Darren Warburton also edited the manuscript.

A version of chapter 5 has been published (Nettlefold L, McKay HA, Warburton DER, McGuire KA, Bredin SSD, Naylor PJ (2010). The challenge of low physical activity during the school day: at recess, lunch and in physical education. British Journal of Sports Medicine doi:10.1136/bjsm.2009.068072). Copyright permission was obtained to include this work in the thesis. I coordinated physical activity (accelerometry) data processing and generated the final physical activity data spreadsheet. I helped define the research question, cleaned and analyzed the data, and wrote the initial draft of the manuscript. All co-authors reviewed and edited the published manuscript.

A version of chapter 6 is being prepared for submission (The association of physical activity and sedentary time with arterial compliance in young children). This sub study was designed and implemented under the leadership of Darren Warburton and Shannon Bredin. I coordinated physical activity (accelerometry) data processing and generated the final physical activity data spreadsheet. I helped define the research question, analyzed and cleaned the data, and wrote the initial draft of the manuscript. Darren Warburton and Heather McKay edited the manuscript.

A version of chapter 7 is being prepared for submission (Physical activity and cardiovascular fitness in children: is bouted activity important?). I coordinated physical activity (accelerometry) data processing and generated the final physical activity data spreadsheet. I defined the research question, cleaned and analyzed the data, and wrote the initial draft of the manuscript. Heather McKay provided detailed editorial feedback. Darren Warburton also edited the manuscript.

A version of chapter 8 is being prepared for submission (Changes in cardiovascular fitness following dissemination of the AS! BC model). I helped define the research question, cleaned and analyzed the data, and wrote the initial draft of the manuscript. Heather McKay guided the direction and provided detailed editorial feedback on the manuscript. PJ Naylor and Darren Warburton also edited the manuscript.

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List of abbreviations and symbols

Abbreviation	Definition
Δ	Delta (change)
AEE	Activity energy expenditure
BEACHES	Behaviors of Eating and Activity for Children's Health - Evaluation System
BMI	Body mass index
BSA	Body surface area
C_1	Large artery compliance
C_2	Small artery compliance
CANPLAY	The Canadian Physical Activity Levels Among Youth Survey
CCHS	Canadian Community Health Survey
CHMS	Canadian Health Measures Survey
CI	Confidence interval
CO	Cardiac output
CON	Control group
CVF	Cardiovascular fitness
d	Days
D	Diameter (of an artery)
dias	Diastolic
EE	Energy expenditure
ET	Ejection time
h	Wall thickness (of an artery)
H_0	Null hypothesis
HBSC	Health Behaviour in School-Aged Children study
hr	Hours
HR	Heart rate
HDL	High density lipoprotein cholesterol
INT	Intervention group
kg	Kilogram
kJ	Kilojoule
LDL	Low density lipoprotein cholesterol
LPA	Light physical activity
m	Metre
MAP	Mean arterial pressure
MET	Metabolic equivalent
min	Minute

Abbreviation	Definition
MPA	Moderate physical activity
MRI	Magnetic resonance imaging
MVPA	Moderate to vigorous physical activity
OR	Odds ratio
P	Pressure (within an artery)
p25	25^{th} Percentile
p75	75^{th} Percentile
PA	Physical activity
PAQ-C	Physical Activity Questionnaire for Children
PDAY	Pathological Determinants of Atherosclerosis in Youth study
PE	Physical education
R	Systemic vascular resistance
SBP	Systolic blood pressure
sec	Seconds
SD	Standard deviation
SE	Standard error
SED	Sedentary time
SES	Socio-economic status
SOFIT	System for observing fitness instruction time
SOPARC	System for observing play and recreation in communities
SOPLAY	System for observing play and leisure activity in youth
SRT	Shuttle run test (e.g., Leger's 20 m shuttle run test)
SV	Stroke volume
sys	Systolic
VO_2 max	Maximal aerobic power
VPA	Vigorous physical activity
wk	Week
yr	Years

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Although there are many lonely hours during graduate school, it would be impossible to write a thesis alone. The long list of individuals who have helped me along the way begins with my co-supervisors Dr. Heather McKay and Dr. Darren Warburton. Thank you for being such strong role models and for teaching me so much, about so many things, so patiently. I have learned so much about being a researcher through your insightful questions, thoughtful answers, and careful guidance. I would also like to thank my three committee members - Dr. Maureen Ashe, Dr. Shannon Bredin and Dr. PJ Naylor - who were incredibly helpful and supportive throughout my time here at UBC.

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1 Introduction[1]

Cardiovascular diseases are a leading cause of death, disability, and illness both in Canada [1] and worldwide [2]. In recent decades, coronary heart disease mortality has declined more than 40% in Canada [3] and approximately 30% in the United States [4] and the European Union [3]. Despite reductions in mortality, the societal burden of cardiovascular disease remains high as more individuals survive with clinical cardiovascular conditions. For example, in Canada the relative increase in the prevalence of heart disease was 27% among low income and 37% among low-middle income Canadians from 1994-2005 [5]. In the United States over 1/3 of adults (2006 data) are living with cardiovascular disease [4].

Because of the high prevalence, cardiovascular disease is the largest contributor to health care costs in Canada [1]. A Health Canada report estimated direct and indirect costs attributable to cardiovascular disease of approximately $18.5 billion in 1998 [6]; equivalent to $21.2 billion in 2004 [7]. Even in British Columbia, where the prevalence of cardiovascular disease risk factors is lowest in all of Canada [5], costs related to cardiovascular disease were estimated at $2.2 billion [1]. In its yearly update on heart disease and stroke in America, the American Heart Association estimated a total cost of $503.2 billion for 2010 [4]. Thus, interventions that reduce the incidence and/or prevalence of cardiovascular disease may be a viable option to reduce the economic impact of this disease on our health care system.

Although the major burden of cardiovascular disease is experienced during adulthood, the disease process commences in childhood [8,9]. Consequently, interventions aimed at reducing future cardiovascular disease should be initiated early in life. Approximately 50% of North American children exhibit one or more cardiovascular disease risk factors [10] and in a sample of nearly 250 elementary school children from the Greater Vancouver Area in British Columbia 9% had four or more risk factors [11]. These statistics are worrisome because the severity of cardiovascular disease increases with increasing numbers of risk factors [9]. Furthermore, many risk factors such as cardiovascular fitness [12], physical activity [13], sedentary behaviour [14], body mass index (BMI) [15], hypertension [16] and clustered cardiovascular risk [17], show some degree of tracking across childhood and into adolescence and adulthood. In addition, there has been a secular increase in the prevalence of cardiovascular disease risk factors such as low cardiovascular fitness [18] unfavorable body composition (i.e., increased skinfold thickness) [19,20] obesity [20,21] and blood pressure [22].

[1] A glossary of key terms used throughout this thesis is located in Appendix A.

Physical activity and sedentary behaviours play a particularly important role as risk factors for cardiovascular disease because they are independent risk factors [23-25] and also mediate levels of other risk factors [26,27]. Furthermore, the prevalence of insufficient physical activity in Canada is equal to or greater than all other modifiable risk factors for cardiovascular disease [28] and is associated with yearly costs of $5.7 million (2001 data) in Canada [29]. In adults, high levels of physical activity [25,30-32] and cardiovascular fitness [33] are associated with lower cardiovascular morbidity and mortality. In children, the absence of data on cardiovascular events and mortality means that research is limited to the use of surrogate outcome variables. Consequently, cross-sectional and longitudinal relationships between physical activity, sedentary behaviour, cardiovascular fitness, and future cardiovascular disease risk in youth are less well defined.

The challenge of defining these complex relationships is attributable in part to how difficult it is to accurately measure physical activity and sedentary behaviours [34,35]. While physical activity and sedentary time are elusive measures in any population, the challenges are magnified in children because of their sporadic and unstructured activity patterns [36-38] and the multitude of changes (biomechanical, cognitive, and physiological) that occur during growth [35]. However, it is imperative that we derive accurate measures of physical activity and sedentary behaviour to more clearly delineate associations between physical activity, sedentary time, and health; understand temporal trends; and evaluate the effect of physical activity interventions [39]. Objective measures of physical activity and sedentary time, such as accelerometry, enhance the quality and extend the scope of physical activity outcomes [34]. Considerable advances in the field of accelerometry have been made; however, there remain many important limitations and methodological questions.

Until recently, the only objectively measured physical activity data from a nationally representative sample of Canadian children was from pedometers. Physical activity levels of Canadian children were alarmingly low and fewer than 20% of boys and 10% of girls achieved the equivalent of 90 minutes of physical activity per day [40]. In addition, sedentary time was high; average screen time reached 4-5 hours/day in Canadian youth aged 10–16 years [41] – much higher than the 2 hour/day limit recently recommended by the Canadian Society for Exercise Physiology [42]. New research from the Canadian Health Measures Survey, where physical activity and sedentary time were measured using accelerometers, confirmed these low activity levels. Only 9% of boys and 4% of girls accumulated 60 minutes of moderate to vigorous physical activity (MVPA) at least 6 days per week and children and youth were sedentary for over 8 hours/day [43]. Given the established links between physical activity, sedentary behaviour, and health in adults, interventions that promote childhood physical activity and discourage sedentary time may be an effective strategy to improve health status and reduce future risk of cardiovascular disease.

Interest in childhood physical activity and inactivity has increased dramatically worldwide and a tremendous number of physical activity interventions have been developed to address the issue. School-based interventions have a number of advantages over community or home-based strategies. First, most children attend school; therefore, the accessible population includes those from a range of socioeconomic and ethnic backgrounds who might be difficult to involve otherwise [44,45]. Second, school children are a 'captive' audience for approximately 30 hours/week and are subject to curriculum-mandated physical and health education [45]. School-based physical activity interventions have improved several aspects of youth health including duration of physical activity and cardiovascular fitness [46]. However, the evidence to date comes predominantly from studies of intervention *efficacy* (i.e., under well-controlled experimental conditions). Only a few interventions have addressed *effectiveness* (i.e., as research is disseminated and translated into practice [47]), an essential next step to better understand health at a population level [48].

The aim of this thesis is to evaluate the relation between physical activity, sedentary behaviour, and cardiovascular health in children. In Chapter 2 I provide relevant background information, from which I derived 5 research questions, related objectives, and hypotheses that target gaps in the current literature. In Chapter 3 I describe the study design and the cohort of children that were measured to address the 5 research questions. In Chapters 4 to 8 I discuss the findings related to my research questions. Specifically, in Chapter 4 I address the question 'What is the effect of accelerometer epoch length on the measurement and classification of children's activity intensity and pattern?'. In Chapter 5 I address the question 'What is the prevalence of sedentary behaviour, light physical activity and MVPA, and what are the activity patterns of girls and boys during the school day?'. In Chapter 6 I investigate the cross-sectional association between physical activity, sedentary behaviour, and arterial compliance. In Chapter 7 I investigate the cross-sectional association between physical activity, sedentary behaviour, and cardiovascular fitness. Finally, in Chapter 8 I address the question 'What is the effect after two-years of a widely disseminated school-based physical activity model (Action Schools! BC) on cardiovascular fitness?'. I conclude the main body of the thesis in Chapter 9 with an integrated discussion, share my final thoughts and suggest areas for future research in the field of childhood physical activity and cardiovascular health.

2 Literature review, objectives and hypotheses

This chapter begins with a brief overview of the physiology of cardiovascular disease and the protective nature of physical activity for cardiovascular health. I describe physical activity and sedentary behaviour patterns in children and different means to assess habitual activity. I then review the published literature on school-based interventions that target children's physical activity or sedentary behaviour. Where possible, I focus on the highest levels of evidence, such as systematic reviews, meta-analyses and randomized controlled trials. Failing these sources of evidence, I supplement the review with data from cross-sectional and longitudinal studies. Where there is little, or only weak evidence in children, I refer to published adult data. I conclude the chapter by defining the scope of the thesis and outline the objectives and hypotheses for the research that is described in detail in the subsequent research chapters.

2.1 Cardiovascular health & disease in children

In this section I first discuss arterial structure and function in health. Next, I define cardiovascular disease and describe its physiology and progression. Finally, I review important risk factors for cardiovascular disease.

2.1.1 Arterial structure and function in health

The arterial system serves to transform pulsatile blood flow generated through left ventricular contraction into a steady flow of oxygenated blood that is conducted and directed to the periphery of the body [49]. Structurally this is achieved by varying the composition, and therefore the elasticity, of the arterial wall along the length of the vascular tree [50]. Pulsatile blood flow is buffered within the large, elastic arteries (e.g., the aorta and carotid arteries) located proximal to the heart. As their name suggests, these arteries contain a large proportion of elastic fibres (Figure 2-1). This enables: 1) passive expansion during systole to store ejected blood, and 2) elastic recoil during diastole to continue moving blood to the periphery [51]. For this reason, these are also called *capacitance* arteries. Smaller, more distal arteries have a larger proportion of smooth muscle (Figure 2-1), allowing biomechanical and biochemical stimuli to alter vascular tone and therefore regulate blood flow around the body [49]. These muscular arteries are also called *conduit* arteries.

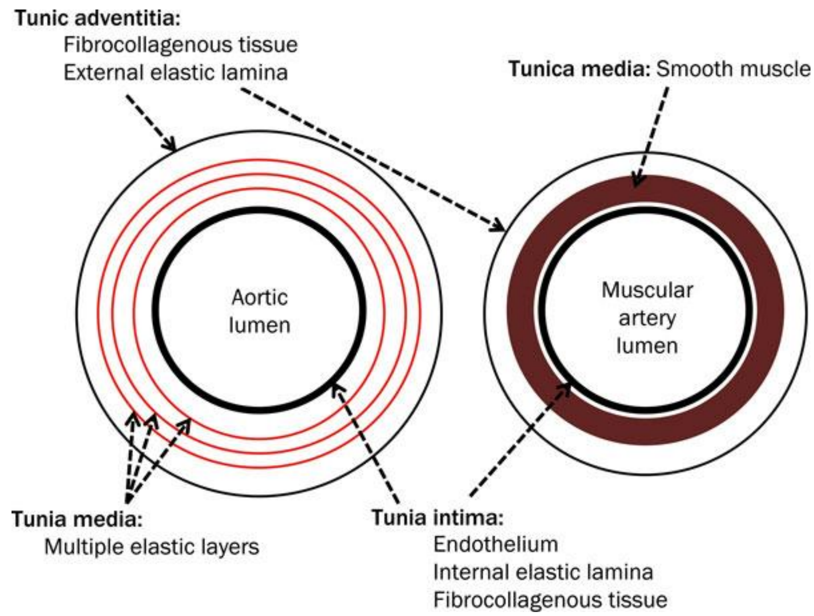

Figure 2-1. Cross section of an elastic (left) and muscular (right) artery [51]**.**
Reprinted by permission from Macmillan Publishers Ltd: Acta Pharmacologica Sinica advance online publication, 30 Aug 2010 (doi: 10.1038/aps.2010.123).

In cross section, both elastic and muscular arteries are composed of three layers (Figure 2-1). The outermost layer, the tunica adventitia, is composed of connective tissue as well as blood vessels and nerves [49]. The tunica media, located interior to adventitia is where the structural differences between elastic and muscular arteries are apparent; multiple concentric sheets of elastic fibres are located within the media of elastic arteries whereas smooth muscle cells comprise the bulk of the media in muscular arteries [51]. The innermost layer, the intima, interfaces with the lumen of the vessel and consists of a single layer of endothelial cells.

The inner endothelial layer plays a crucial role in vascular physiology [52]. A healthy endothelium is metabolically active and has the following characteristics: 1) it acts as a selective permeability barrier, 2) it is non-thrombogenic and non-adherent, 3) it regulates local vasomotor tone (and thus blood flow) by producing vasoactive molecules, 4) it produces growth regulatory molecules and cytokines, 5) it produces connective tissue matrix macromolecules and, 6) it can oxidize lipoproteins as they are transported into the vessel wall. Dysfunction of the endothelial layer is one of the earliest markers of cardiovascular disease.

2.1.2 Definition and physiology of cardiovascular disease

The term cardiovascular disease most often refers to coronary artery disease and atherosclerosis – the progressive stiffening and narrowing of medium and large arteries due to the deposition of fatty plaques along the vessel wall. The atherosclerotic process results in deleterious changes to both the structure and function of the vasculature and is the root cause of most cardiovascular morbid events [53]. Atherosclerosis is now widely acknowledged as an inflammatory disease. A detailed review of the molecular biology of the atherosclerotic process is beyond the scope of the current work; however, it has been the subject of several reviews (e.g., [52,54-57]) and the key points are summarized here.

Atherosclerotic lesions exist along a continuum of severity from an initial fatty streak to an advanced fibrotic lesion (Figure 2-2). The initiation and progression along this continuum is explained by the response-to-injury hypothesis of Ross [52,57,58] (Figure 2-3). The process is initiated when a healthy endothelial layer (Figure 2-3A) is subjected to damaging biochemical or biomechanical stimuli (e.g., oxidized lipoproteins, non-laminar blood flow; Figure 2-3B). The resulting endothelial dysfunction is characterized by increased expression of adhesion molecules, which attract and bind leukocytes to the vascular wall, on the endothelial cell surface. Endothelial permeability to leukocytes (monocytes and T-cells) and lipids increases and these molecules migrate into the sub-endothelial space (Figure 2-3C). Within the vessel wall monocytes differentiate into macrophages and consume lipids and oxidized lipoproteins to create foam cells and a fatty streak. The macrophages and endothelial cells release growth factors, cytokines, and other inflammatory mediators that promote smooth muscle cell migration and proliferation within the sub-endothelial space (Figure 2-3D). The fatty streak progresses to an intermediate fibro-fatty lesion as more lipid collects and smooth muscle cells begin to secrete a connective tissue (elastin, collagen, proteoglycan) matrix (Figure 2-3E). As lesion growth proceeds, a fibrous cap is formed that shields the thrombotic core of the lesion from the circulating blood (Figure 2-3F). If the interior of the lesion is exposed to the blood contained within the lumen of the vessel (either due to a loss of endothelial cells or a gap in the endothelial layer) a thrombus is formed which can get lodged in a narrow vessel and stop blood flow. Because changes to vascular structure and function occur prior to clinical manifestation of cardiovascular disease, they are important early screening factors.

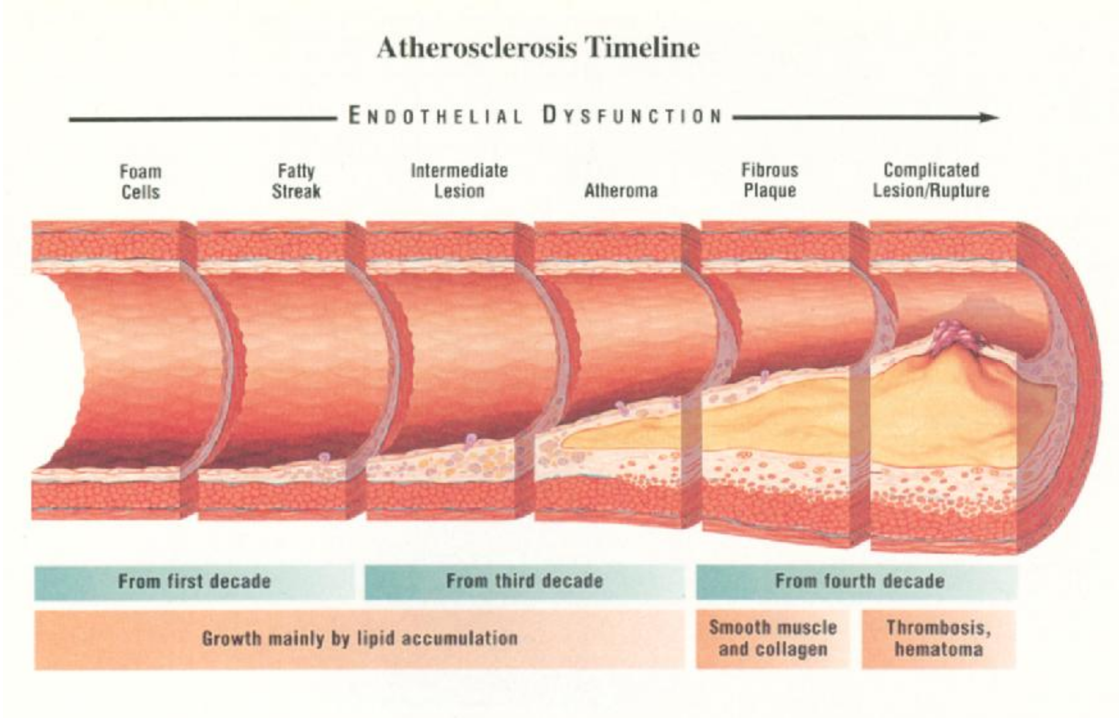

Figure 2-2. Timeline and progression of the atherosclerosis process across four decades [59,60]**.** *This figure illustrates the progression from foam cells to the development of a complicated lesion across four decades. The development of an atheroma, fibrous plaque, and complicated lesion are clearly discernible within the endothelium in the later stages. Reprinted from the American Journal of Cardiology, 82 (10), Pepine CJ, The effects of angiotensin-converting enzyme inhibition on endothelial dysfunction: Potential role in myocardial ischemia, S23-S27, Copyright (1998), with permission from Elsevier. Reprinted from Circulation, 1995, 92(5), Stary HC, A definition of advance types of atherosclerotic lesions and a histological classification of atherosclerosis: A report from the committee on vascular lesions of the council on arteriosclerosis, American Heart Association, 1355-1374, with permission from Wolters Kluwer Health.*

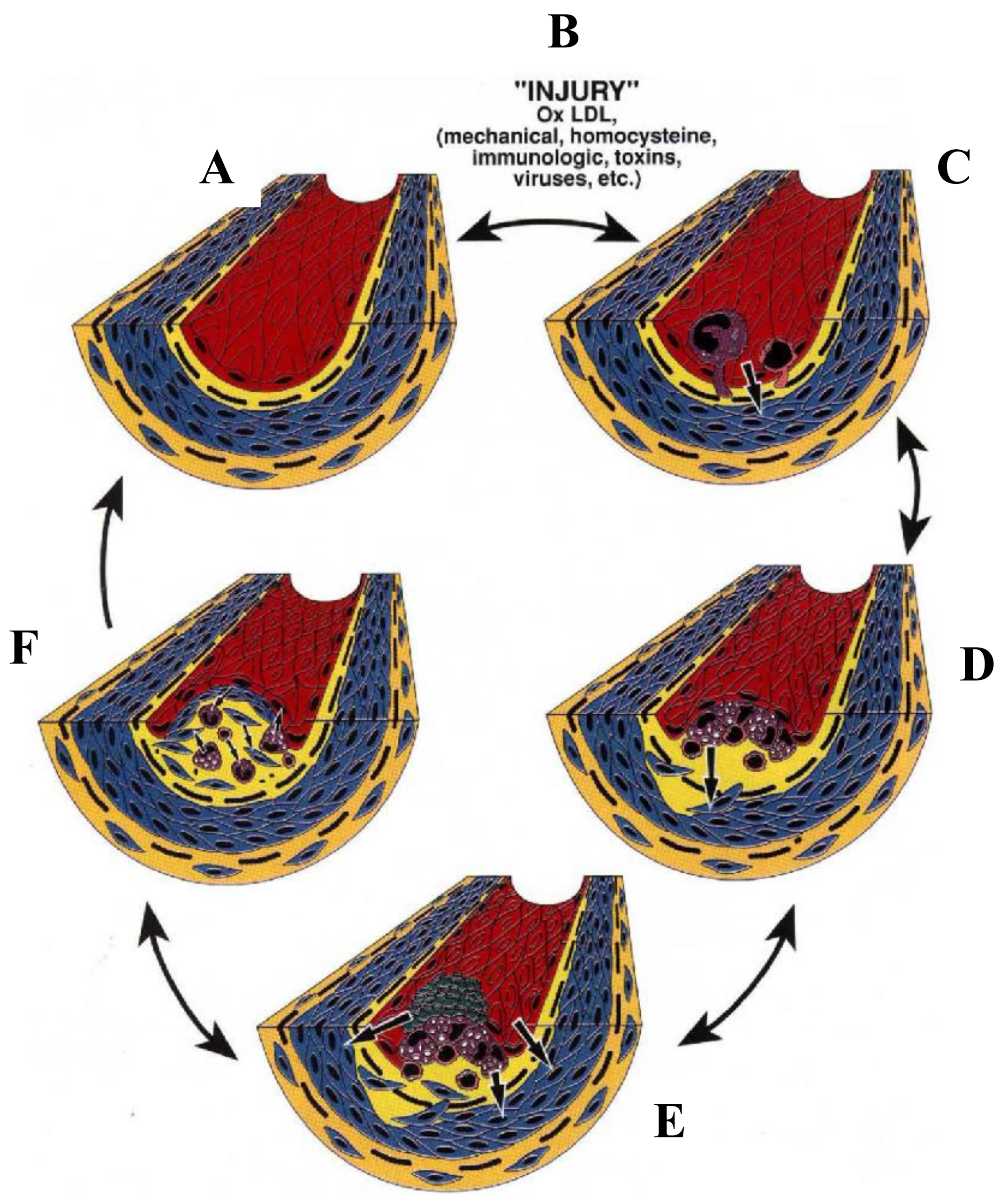

Figure 2-3. The response-to-injury hypothesis of atherosclerosis [52].
A) Initial healthy artery; B) Biochemical or biomechanical injury leads to endothelial dysfunction; C) Leukocytes attach to newly expressed adhesion molecules on the luminal surface of endothelial layer. Leukocytes migrate into sub-endothelial space; D) Macrophages consume lipid to create fatty streak, smooth muscle cells begin to migrate; E) Progression to a fibro-fatty lesion; F) Fibrous cap shields thrombotic core of the lesion. Reproduced by permission from Macmillan Publishers Ltd: Nature 362, Ross R, The pathogenesis of atherosclerosis: a perspective for the 1990s, 801 – 809, Copyright (1993).Ox LDL, oxidized low density lipoprotein.

2.1.3 The cardiovascular disease process begins in childhood

The majority of symptomatic cardiovascular disease is observed during adulthood; however, it is now widely acknowledged that the antecedents of the disease process are present in childhood (Figure 2-2). For example, post-mortem evaluations revealed preliminary atherosclerotic lesions (fatty streaks) amongst young children and adolescents (2-15 years) in the Bogalusa Heart Study. The extent of lesions observed was related to the number of risk factors for cardiovascular disease [9]. In a review on the topic, McGill et al. [8] concluded that the anatomical location of fatty streaks in youth corresponds to the location of more advanced lesions in older individuals. This suggests that fatty streaks are the precursors of adult cardiovascular disease. Indeed, fatty streaks and raised atherosclerotic lesions share many similarities in their structural composition [8].

In addition to evidence of sub-clinical vascular disease, risk factors known to be associated with cardiovascular disease in adults are also prevalent, albeit to a lesser degree, in children. Large data sets, such as the Bogalusa Heart Study [61], the Danish Youth and Sport Study [17] and the European Youth Heart Study [62] have shown that cardiovascular disease risk factors cluster in children. Furthermore, clustered risk tracks from childhood to young adulthood [17,61]. In combination with the post-mortem findings of preliminary atherosclerotic lesions, the early presence of risk factors provides a strong argument for early prevention of cardiovascular disease.

2.1.4 Risk factors and risk markers for cardiovascular disease

A challenge of studying cardiovascular disease in children is that cardiovascular events (e.g., fatal or non-fatal myocardial infarction) are rare in young people. Thus, research in children requires that surrogate end-points, risk markers, and risk factors be used as outcome variables. Cardiovascular events are typically the clinical, later stage manifestation of the atherosclerotic process within the vasculature. Therefore, intima-media thickness is a commonly used surrogate endpoint as it is thought to represent early stage, subclinical disease. Carotid intima-media thickness is a marker of carotid atherosclerosis [63,64] and an important predictor of future cardiovascular events [65,66] and subsequent carotid plaque [67]. A recent systematic review showed that a 0.1 mm difference in common carotid artery intima-media thickness was associated with a 15% increased risk of myocardial infarction (hazard ratio = 1.15) and an 18% increased risk of stroke (hazard ratio = 1.18) [65].

Many other variables associated with increased risk of cardiovascular disease were used as surrogate outcomes in research. In the next section I focus only upon measures that are central to my thesis.

That is, the evidence as it pertains to arterial stiffness, cardiovascular fitness, physical activity, and sedentary behaviour as indicators of cardiovascular health. These variables are notable as they are non-invasive, predict later cardiovascular health, and are relatively easy to assess in children. Although other risk factors such as obesity, hypertension, and biochemical variables play an important role in atherosclerosis and cardiovascular health, they are not central to my thesis and thus I mention them only briefly. In this next section I review each measure with respect to its: 1) relationship to cardiovascular events and mortality in adults, 2) relationship to carotid intima-media thickness and atherosclerotic plaques in adults (and children where possible), 3) cross-sectional relationship with cardiovascular health in children and, 4) longitudinal relationship with cardiovascular health in children.

2.1.4.1 Arterial stiffness as a risk marker for cardiovascular disease

Arterial stiffness is an important measure of overall vascular health as it integrates aspects of arterial structure and function, the atherosclerotic burden and the subclinical vascular effect of prevalent risk factors [68,69]. For this reason it can be considered a risk *marker* of atherosclerotic burden (as opposed to a risk *factor* [70,71]). Arterial stiffness occurs when the physiological processes that balance the proportion of collagen and elastin in the vessel wall become dysregulated [51]. At the cellular level, stiffened vessels have increased collagen, fragmented elastin, as well as structural and functional abnormalities in the endothelial and sub-endothelial layers [51,72,73].

The consequences of vascular stiffening can be described using a propagative model of arterial pressure wave transmission [50]. Left ventricular contraction generates a forward moving pressure wave that travels through the arterial system. These pressure waves are reflected backwards at branch points in the vascular tree. In healthy elastic arteries, these backward waves augment vascular pressure during diastole. With stiffening of the large arteries located proximal to the heart, the vasculature is unable to stretch and accommodate the stroke volume ejected by the left ventricle, thus increasing systolic blood pressure [74]. As the smaller vessels located in the periphery of the body stiffen, systemic vascular resistance increases and the pressure wave generated through left ventricular contraction travels forward more quickly. This results in an earlier reflection from downstream branch points and increases blood pressure during systole as opposed to diastole (Figure 2-4) [75]. Stiffening of the peripheral vasculature appears to play a major role in hypertension; large artery elasticity was similar between hypertensive and normotensive individuals whereas small artery elasticity was reduced in the hypertensive group [76]. In summary, vascular stiffness increases left ventricular afterload and systolic blood pressure, decreases diastolic blood pressure and widens pulse pressure. The increased afterload forces the heart to work harder and decreases coronary perfusion [75]. Increased systolic blood pressure and pulse pressure damage the microvasculature; these small vessels rely on pressure dampening to reduce blood pressure to a more appropriate level [77]. Increased pulse pressure may enhance the atherosclerotic process and increase the chance of lesion rupture [77].

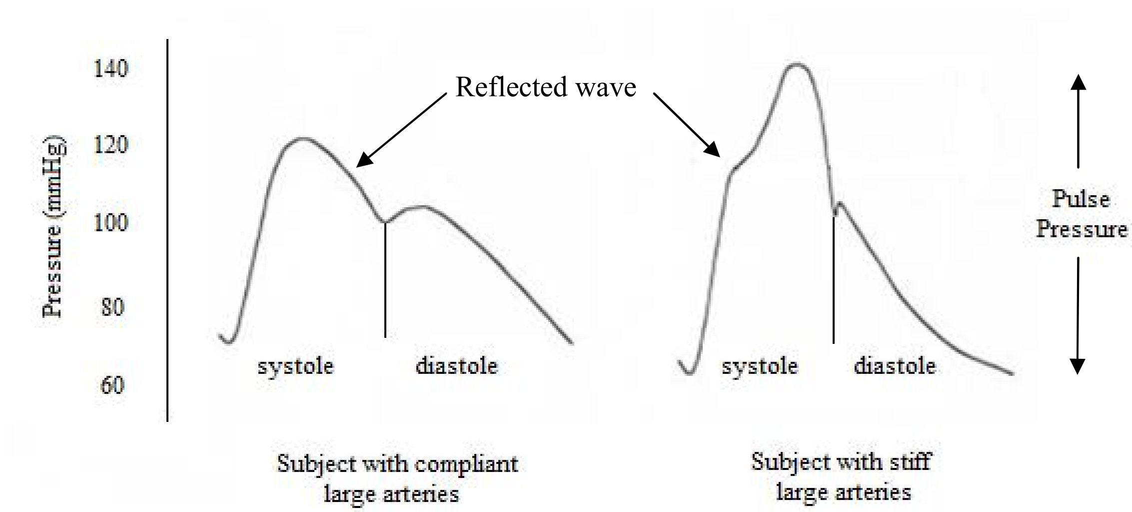

Figure 2-4. Differences in arterial pressure wave in healthy (those with compliant large arteries) and unhealthy (those with stiff large arteries) individuals [78]**.**
In individuals with stiff arteries, the reflected wave returns sooner and augments blood pressure during systole. This reduces blood pressure during diastole and results in a wider pulse pressure. Reprinted from Arteriosclerosis, Thrombosis, and Vascular Biology, 23, Oliver JJ, Webb DJ, Noninvasive assessment of arterial stiffness and risk of atherosclerotic events, 554-566, Copyright (2003), with permission from Wolters Kluwer Health.

Measurement of arterial stiffness requires less skill than measuring intima-media thickness and may be less painful for some participants than measures of endothelial function that require lengthy occlusion of the vasculature [69]. Thus, arterial stiffness is an ideal variable to assess in large cohort studies and in children. Investigations that reported arterial stiffness used a variety of definitions and techniques, each of which provides slightly different information about the vasculature (Table 2-1). For example, *regional* arterial stiffness can be assessed via pulse wave velocity, *local* arterial stiffness via ultrasound, and *systemic* arterial stiffness via pulse contour analysis [50]. In adults, pulse wave velocity is considered the gold standard measure of arterial stiffness because of its anatomical relevance (central vasculature) and its predictive ability for cardiovascular disease [75]. However there are advantages and disadvantages to each method: pulse wave velocity provides no information on arterial geometry and is crucially dependent on accurate distance measures; ultrasound techniques require a high degree of technical skill; and pulse contour analysis provides only *indirect* information on arterial stiffness [50]. Ultimately, the final choice depends on the research question, time and space constraints, training and personnel requirements, and equipment costs [75]. Given the relative paucity of data in children, no gold standard has been established in this population [79]. Thus, the choice of methodological approach is based on evidence from adults and opportunistic conditions. In the following sections, I focus on literature that used arterial compliance as the indicator of arterial stiffness where possible as it is the method used in this thesis. However, due to the limited volume of work in this area, I also discuss findings from studies that collected and reported data using methods listed in Table 2-1.

Table 2-1. The different measures of arterial stiffness commonly reported in the literature [78]**.**

Variable	Definition	Formula
Compliance	Absolute change in vessel diameter (or area) for a given change in pressure	$\frac{\Delta D \text{ (or area)}}{\Delta P}$
Capacitative compliance (C_1); large artery	Relationship between decline in pressure and decline in volume in the arterial tree during the exponential component of diastolic pressure decay (said to reflect large artery compliance)	$\frac{\Delta V}{\Delta P}$
Oscillatory compliance (C_2); small artery	Relationship between oscillating pressure change and oscillating volume change around the exponential pressure decay during diastole (said to reflect small artery compliance)	$\frac{\Delta V}{\Delta P}$
Distensibility	The relative change in vessel diameter (or area) for a given change in pressure	$\frac{\Delta D}{\Delta P \cdot D}$
Elastic modulus	The pressure change required for (theoretical) 100% stretch from resting diameter (inverse of distensibility)	$\frac{\Delta P \cdot D}{\Delta D}$
Pulse wave velocity	The speed with which the pulse wave travels along a length of artery	$\frac{\text{Distance}}{\Delta \text{time}}$
Stiffness index	The ratio of the natural logarithm of systolic/diastolic blood pressure to the relative change in diameter	$\frac{\ln (P_{sys}/P_{dias})}{[\frac{(D_{sys}-D_{dias})}{D_{dias}}]}$
Young's modulus (incremental elastic modulus)	Elastic modulus per unit area (accounts for wall thickness)	$\frac{\Delta P \cdot D}{\Delta D \cdot h}$

D, diameter; P, pressure; V, volume; sys, systolic; dias, diastolic; h, wall thickness; Reprinted from Arteriosclerosis, Thrombosis, and Vascular Biology, 23, Oliver JJ, Webb DJ, Noninvasive assessment of arterial stiffness and risk of atherosclerotic events, 554-566, Copyright (2003), with permission from Wolters Kluwer Health.

Adult data demonstrate a clear link between arterial stiffness and cardiovascular disease. In addition, reduced small artery compliance predicted future cardiovascular events [80] and a recent meta-analysis of 17 studies showed that aortic pulse wave velocity also predicted future cardiovascular events and all-cause mortality [81]. Arterial stiffness was also associated with atherosclerotic plaque load whether estimated via coronary angiography [82], carotid intima-media thickness, or lumbar spine x-ray for calcified plaques [83]. Furthermore, adults with diffuse atherosclerotic plaques had lower small and large artery compliance compared to those with focal or no plaques [82]. In a large, population-based cohort of elderly participants (The Rotterdam Study) there was a strong association between quartiles of carotid intima-media thickness and aortic plaque severity and measures of arterial stiffness (pulse wave velocity and common carotid distensibility) [83].

Evidence from clinical populations also supports a link between arterial stiffness and cardiovascular disease. Small artery compliance was reduced in adults with hypertension and post-menopausal women with symptomatic coronary artery disease [76]; small and large artery compliance was reduced in adults with diabetes [82]; and aortic pulse wave velocity was increased in adults with peripheral artery disease [83]. Studies in youth revealed reduced arterial compliance, reduced arterial distensibility, and increased stiffness index in children with type 1 diabetes compared with healthy controls [84]; reduced arterial distensibility, increased pulse wave velocity, and augmentation index in children with type 2 vs. type 1 diabetes [85]; and increased stiffness index in Chinese children with metabolic syndrome compared with healthy controls [86]. Arterial stiffness was also associated with weight status in youth. Body mass index ($r = 0.34$), waist circumference ($r = 0.32$), and percent body fat ($r = 0.32$) were associated with increased pulse wave velocity in healthy children [87] and obese children had increased elastic modulus [88] and decreased carotid distensibility [89] compared to non-obese children. To my knowledge, no longitudinal study has yet examined whether arterial stiffness predicts future cardiovascular health or disease in children.

2.1.4.2 Cardiovascular fitness as a risk factor for cardiovascular disease

Cardiovascular fitness is considered an important marker of overall health as it demonstrates successful integration of the cardiovascular, respiratory, and musculoskeletal systems [90,91]. Of concern, a recent review of data from 27 countries showed a secular decline in cardiovascular fitness of 0.36% per year in youth from 1958-2003 [18]; this suggests that the overall cardiovascular health of contemporary children is worse than their predecessors.

The strongest evidence for the link between cardiovascular fitness and cardiovascular disease comes from longitudinal studies of adults where cardiovascular events or all-cause mortality were the measured endpoints. In a recent meta-analysis, Warburton et al. [32] calculated that fit individuals had a 45% lower risk of all-cause mortality and up to 50% lower risk of cardiovascular disease compared with unfit individuals (Figure 2-5). In another meta-analysis conducted by Kodama et al. [33], men and women with higher cardiovascular fitness had a 13% lower risk of all-cause mortality and a 15% lower risk of cardiovascular mortality per 1 metabolic equivalent (MET) increase in maximal aerobic power (e.g., 1 km/hour higher running speed). Further, men who improved their cardiovascular fitness over time reduced their risk of mortality compared to those men who remained unfit [90,92]. To illustrate, in a classic study by Blair et al., of nearly 10,000 men, each 1-minute increase in treadmill time was associated with an 8% lower risk of mortality over a mean follow up period of 5 years [92]. Encouragingly, men who moved out of the least fit quartile by follow up had a 44% lower risk of mortality compared with those who were unfit at both examinations [92].

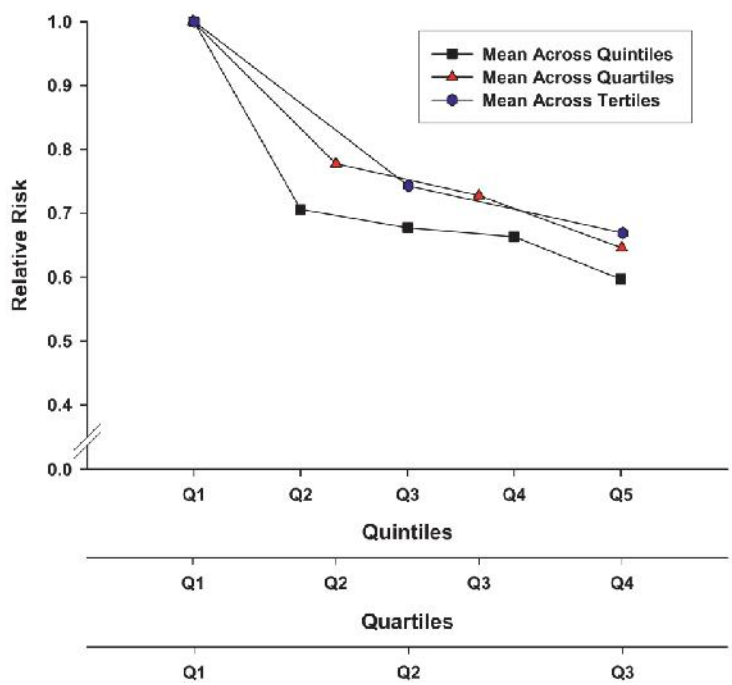

Figure 2-5. Mean relative risk for all-cause mortality decreases across physical activity/fitness categories [32]**.**
This figure illustrates the reduction in relative risk for all-cause mortality across tertiles, quartiles, and quintiles of physical activity/fitness. Risk reduction with increased physical activity/fitness is greatest at the lowest end of the activity/fitness spectrum. Reprinted from: International Journal of Behavioral Nutrition and Physical Activity, 2010, 7:39 Warburton DER, Charlesworth, Ivey A, Nettlefold L, Bredin SSD, A systematic review of the evidence for Canada's physical activity guidelines for adults (doi:10.1186/1479-5868-7-39) under the terms of the Creative Commons Attribution License.

Cardiovascular fitness was also linked to surrogate markers of cardiovascular disease (such as atherosclerosis) in adults; however, to date only male data are available. In Finnish men, carotid intima-media thickness was inversely associated with cardiovascular fitness in a cross-sectional analysis [93,94] and was associated with a slower progression of atherosclerosis in a population-based 4-year longitudinal study (n=854 men aged 42-60 years) [94]. Cross-sectional findings were replicated in a much larger study of nearly 10,000 Korean men; the fittest individuals had a 33% lower risk of carotid atherosclerosis than the least fit [95].

While mortality data in children are non-existent, there is evidence that highlights the importance of cardiovascular fitness as a marker of cardiovascular health in youth. The relation between cardiovascular fitness and single cardiovascular disease risk factors in youth are weak (generally r = 0.1 - 0.2) [96]. However, more robust findings are observed when researchers evaluated clustered cardiovascular disease risk as the outcome variable. For example, data from the European Youth Heart Study (approximately 1,700 boys and girls aged 9 and 15 years) [97] and a Portuguese cohort (n=1,461 boys and girls aged 8-15 years) [10] suggested that cardiovascular disease risk factors 'clustered' (i.e., are not independently distributed). Further, three times more youth than expected (assuming a binomial distribution) displayed four risk factors and eight times more youth than expected presented with five risk factors [97]. Additional data from these cohorts and the Danish Youth and Sport Study [17] showed that clustered cardiovascular risk is more likely to appear in the least fit group compared with the most fit group [97-103]. In one such study children in the least fit quartile were 13 times more likely to present with clustered cardiovascular risk than children in the most fit quartile [99]. Unlike the European Youth Heart Study, the Copenhagen School-Child Intervention Study did not observe clustering of cardiovascular disease risk factors. This is perhaps attributable to the younger age of participants (6-7 years); however, the least fit quartile of children was still two times more likely to have three or more risk factors than the most fit quartile [104].

In addition to cross-sectional associations between cardiovascular fitness and cardiovascular health there is also evidence from longitudinal studies that supports the relation between childhood cardiovascular fitness and cardiovascular health 1-23 years later. In their recent systematic review, Ruiz et al. [105] examined data from 20 longitudinal cohort studies that evaluated the relationship between cardiovascular fitness and cardiovascular health over follow up periods of 1-23 years. Overall there was 'strong' evidence (defined as consistent findings in three or more high quality studies) that supported the notion that high cardiovascular fitness in childhood and adolescence was associated with healthier blood lipid profiles, lower blood pressure and lower total or central adiposity later in life. There was ‘moderate’ evidence (defined as consistent findings in two high-quality studies) that supported a link between youth cardiovascular fitness and reduced incidence of metabolic syndrome and arterial stiffness. Furthermore, improved fitness was associated with improved cardiovascular disease risk factors. While comprehensive, the review was limited by the diversity in research methods – cardiovascular fitness was measured using many different protocols and there were wide variations in outcome variables reported (e.g., continuous vs. dichotomous) and length of follow up.

Not all longitudinal studies reported a significant relation between cardiovascular fitness and future risk for cardiovascular disease. Of interest, an 8-year follow up of 235 adolescents (aged 16-19 years at baseline) in the Danish Youth and Sport Study found no evidence that adolescent cardiovascular fitness predicted later clustered cardiovascular disease risk [17]. In light of the strong links between low cardiovascular fitness and clustered cardiovascular disease risk in cross-sectional studies of youth, it is somewhat surprising that this relationship was not maintained. This is particularly striking in the Danish Youth and Sport Study as clustered cardiovascular disease risk tracked over that same period (Odds ratio = 6.0 for a case at baseline to be a case at follow up). Thus, most of the evidence that links clustered cardiovascular disease risk to cardiovascular fitness stems from the European Youth Heart Study, which suggests that these relationships need to be explored further in other cohorts.

Since the publication of the systematic review by Ruiz et al. [105], three longitudinal studies reported on the association between cardiovascular fitness and cardiovascular disease risk factors in youth [106-108]. These investigations generally agreed that cardiovascular fitness in youth predicted BMI at follow up intervals of 1-2 years [106], 5 years [107] and 27 years [108]. However, it remains unclear whether fitness predicts other risk factors such as blood pressure and components of the blood lipid profile. Cardiovascular fitness at age 9 years was not related to total cholesterol, systolic or diastolic blood pressure 5 years later [107]. Further, cardiovascular fitness at age 13 years predicted diastolic blood pressure and triceps skinfolds over 12 years (aged 25 years at follow up) but only predicted systolic blood pressure and high density lipoprotein (HDL) cholesterol over 2 years (aged 15 years at follow up); total cholesterol and triglycerides showed cross-sectional, but not longitudinal, associations with cardiovascular fitness [108]. In general, the predictive value of childhood cardiovascular fitness for adult cardiovascular health decreased with length of follow up; no risk factors for cardiovascular disease at age 40 years were associated with fitness at age 13 years [108].

2.1.4.3 *Physical activity and sedentary behaviour as risk factors for cardiovascular disease*

Physical activity is described very broadly as any body movement produced by the skeletal muscles that increases energy expenditure above resting levels (defined as 1.0 metabolic equivalent; MET), whether it is for leisure or non-leisure purposes [109]. Exercise is physical activity that is planned and structured with the aim of improving one or more aspects of health [109]. At the opposite end of the spectrum, sedentary behaviours are those that do not require energy expenditure above resting levels [110]. There is abundant epidemiological evidence that demonstrated a protective (and independent) effect of physical activity on cardiovascular health and all-cause mortality in adults. Two recent systematic reviews and meta-analyses estimated that the risk reduction associated with being physically active in adulthood was 30-35% for cardiovascular disease, all-cause and cardiovascular mortality [32,111]. The relationship between physical activity and these outcomes was not linear; a greater reduction in risk was observed between sedentary and moderately active individuals compared with moderately and highly active individuals. Thus, even small amounts of physical activity were beneficial in low active populations [30,32] (Figure 2-5).

The physical activity and cardiovascular health field has shifted and expanded in recent years to examine the relation between sedentary behaviour (distinct from the absence of physical activity) and health. Although fewer data are available, published reports indicated a link between sedentary time and risk of cardiovascular and all-cause mortality in men and women [23,24,112,113] (Table 2-2). The relation was linear [24], independent of physical activity [23,24] and the dose-response relation was observed even among physically active individuals [23]. However, physically active individuals were at lower risk of cardiovascular mortality compared with inactive individuals even when their sedentary time was high [112].

Table 2-2. Studies that evaluated the relation between sedentary behaviour and cardiovascular disease or cardiovascular mortality in adults.

First Author, Study, Country	Population	Measurement	Results
Katzmarzyk [23] 1981 Canada Fitness Survey Canada	n=17,013 Aged 19-90 yr Men and women Follow up: 12 yr	Sitting time (questionnaire) none, ¼ of time, ½ of time, ¾ of time, almost all of the time PA (12 month recall) 'Active' (≥7.5 MET·h/wk) 'Inactive' (<7.5 MET·h/wk) Mortality Canadian Mortality Database	HR (95% CI) for CVD mortality by sitting time category (multivariate adjusted): None: 1.00 (referent) ¼ time: 1.01 (0.77-1.31) ½ time: 1.22 (0.94-1.60) ¾ time: 1.47 (1.09-1.96) Almost all: 1.54 (1.09-2.17) *P* for trend <0.0001 Conclusion: Dose-response relationship is independent of PA
Dunstan [24] AusDiab Australia	n=8,800 Aged ≥ 25 yr Men and women Follow up: 6.6	TV viewing time (7 day recall) <2 hr/d, ≥2 to <4 hr/d, ≥4 hr/d Exercise time (questionnaire) 0 hr/wk, >0 to 2.49 hr/wk, ≥2.5 hr/wk	HR (95% CI) for CVD mortality per 1 hr/d (multivariate adjusted): 1.18 (1.03-1.35) Conclusion: Linear relationship between TV time and mortality
Warren [112] Aerobic Center Longitudinal Study United States	n=7,744 Aged 20-89 yr Men only Follow up: 21 yr	Sedentary time (questionnaire, sum of TV time and time spent in car) Quartiles of average $hr \cdot wk^{-1}$ PA (questionnaire) 'Active' – 4 categories 'Inactive' – 4 categories	HR (95% CI) for CVD mortality by quartile of sedentary time (multivariate adjusted): Q1 (lowest):1.00 (referent) Q2: 1.09 (0.77-1.54) Q3: 1.33 (0.96-1.83) Q4 (highest): 1.37 (1.01-1.87) *P* for trend <0.04 Conclusion: Dose-response relationship is independent of PA
Manson [113] Women's Health Initiative Observational Study United States	n=73,743 Aged 50-79 yr (at entry) Women only Follow up: 3 yr	Sedentary time (questionnaire) Time spent sitting (hr/d) Time spent lying down or sleeping (hr/d) PA (questionnaire) MET·h/wk	RR (95% CI) of CVD by categories of sedentary time (multivariate adjusted): < 4 hr/d: 1.00 (referent) ≥ 16 hr/d sitting: 1.68 (1.07-2.64) 12-15 hr/d lying down or sleeping: 1.38 (1.01-1.87) Conclusion: Prolonged sitting increases risk

PA, physical activity; HR, hazard ratio; RR, relative risk; MET, metabolic equivalent.

Despite the well-accepted associations between physical activity and cardiovascular events/mortality, the relation between physical activity and indicators of sub-clinical vascular disease (i.e., carotid atherosclerosis and intima-media thickness) is less clear. A systematic review of 20 studies [114] reported that while many cross-sectional studies observed an inverse relation between physical activity and carotid intima-media thickness, exercise training studies did not consistently decrease or slow the progression of carotid atherosclerosis and thickening in more physically active individuals. Since publication of that review there have been at least six additional published papers whose findings were similarly inconsistent. For example, the Multi-Ethnic Study of Atherosclerosis demonstrated univariate inverse associations between total physical activity, MVPA, intentional exercise and walking pace and intima-media thickness of the common and internal carotid arteries in 6,500 adults aged 45-84 years [115]. However, with the exception of walking pace, these associations were attenuated and became non-significant after adjustment for confounding variables (age, race, test site, education, income, and smoking). Other recent studies reported no association between carotid intima-media thickness and exercise time in older adults [116] or physical activity in youth [117]; an inverse association between carotid intima-media thickness and walking pace in older adults [118]; greater vascular ‘roughness’ (used as an indicator of irregularity in carotid wall thickness) but no greater intima-media thickness in physically inactive compared with physically active adults [119]; and a smaller increase in carotid intima-media thickness in 44 obese children aged 6-11 years who participated in a 6-month exercise intervention, compared with non-exercising controls [120].

Very few studies have examined the relation between sedentary time and sub-clinical vascular health. A study of 614 men and women aged 30-60 years measured sedentary-light physical activity and reported that it was independently associated with increased carotid intima-media thickness at baseline but not after 3 years of follow up [121]; participation in vigorous physical activity predicted smaller increases in carotid intima-media thickness. When self-report data were used in place of objective data from accelerometers there were no associations between intima-media thickness and sedentary time or physical activity in this population [121] or another group of similarly aged adults [122].

Kadoglou et al. [114] proposed several reasons for the inconsistent associations between physical activity, sedentary behaviour, and carotid intima-media thickness (as an index of vascular health). First, most studies assessed these behaviours by questionnaire, which are susceptible to recall error and response bias [123]. Second, intima-media thickness is commonly measured at the carotid artery; however, physical activity may influence predominantly muscular arteries (e.g., femoral) with a smaller effect on elastic arteries (e.g., carotid). Finally, differences in the populations assessed, differences in how intima-media thickness was measured and differences in length of follow up time may all contribute to variations in reported findings.

In children, mortality data and indicators of atherosclerosis are lacking. Therefore, investigators used clustered cardiovascular risk as a surrogate outcome. Data were predominantly from the European Youth Heart Study cohort [62,98,100,103,124,125], although several other cohorts performed similar analyses [10,17,126]. Physical activity was most often associated with clustered cardiovascular risk [62,100,103,124-126], although not in every case [10,17,98]. However, of the three studies that did not report an association with cardiovascular risk one found that a higher percentage of boys in the most physically active quartile had no risk factors [10]. In other studies the association between physical activity and clustered cardiovascular risk was independent of adiposity [62,100,103,125], cardiovascular fitness [62,100], and TV time [125]. Further, the association persisted when total physical activity was assessed using accelerometry (counts per minute [62,100,103,124,125]) as sedentary, light, moderate, vigorous physical activity [103] or bouted physical activity [126].

Seven longitudinal studies predicted future cardiovascular health from physical activity during youth:

- The Cardiovascular Health in Young Finns Study [127]
- The Amsterdam Growth and Health Longitudinal Study [128]
- The Leuven Longitudinal Study on Lifestyle, Fitness and Health [129]
- The Northern Ireland Young Hearts Study [130]
- The Danish Youth and Sports Study [131]
- The Muscatine Study [132]
- The Oslo Youth Study [108]

These studies all measured physical activity and evaluated risk factors for cardiovascular disease in youth and at a later stage (5-25 years). For the most part, youth physical activity was not associated with cardiovascular health in adulthood [108,128-130,132]. Exceptions were the Danish Youth and Sports Study and the Cardiovascular Risk in Young Finns Study. In the former, decreased physical activity over an 8-year period was associated with increased cardiovascular risk factors (percent body fat in men and blood lipids in women) [131]. In the latter study, individuals who were consistently active over a 6 year period had a better cardiovascular health profile than those who were consistently inactive [127].

The challenge of accurately assessing physical activity across the life span likely plays a role in the null association described above. Section 2.3 contains an overview of different physical activity measurement techniques. Briefly, all seven studies mentioned above assessed physical activity using self-report questionnaires. This subjective approach may introduce bias given the difficulty to accurately recall and capture physical activity, and the propensity to overestimate one's activity level [123]. Physical activity outcomes reported included leisure time [108,127], everyday physical activity [130], vigorous physical activity (sweat episodes) over the previous 3 days [132], physical activity over the previous 3 months [128], sports participation over the past year [129], and transportation and sport activity over the past year [131]. Interestingly, a recent study that measured physical activity objectively (via accelerometry) observed an association between physical activity at age 15 and indicators of insulin resistance 6 years later [133].

2.1.4.4 Other important risk factors for cardiovascular disease

Obesity: Many studies showed that obesity, regardless of how it was defined, was associated with an increased risk of cardiovascular disease in adults. For example, a 5 unit increase in BMI increased the risk of vascular disease by 40% and mortality by 30% in a collaborative analysis of nearly 900,000 men and women [134]. In addition, individuals with high waist and/or hip circumference, waist-to-hip ratio [135], relative weight (percentage of desirable rate, based on life insurance tables), and/or weight gain [136] were at an elevated risk for myocardial infarction and incident cardiovascular disease. These findings are supported by data that linked obesity to the presence of atherosclerotic lesions. In the Pathological Determinants of Atherosclerosis in Youth study, BMI was positively associated with the presence of coronary fatty streaks and raised lesions in 15-34 year old boys and men. In comparison, subcutaneous abdominal fat, but not BMI, was associated with the presence of coronary fatty streaks in same age women [137]. BMI and waist circumference were associated with carotid intima-media thickness in healthy young adults in the Bogalusa Heart Study [138].

In longitudinal investigations [139-147] and a systematic review [105], childhood BMI was associated with increased risk of premature mortality from endogenous causes [139], all-cause and cardiovascular mortality [141] future cardiovascular events [140], increased carotid intima-media thickness in adulthood [142-145] and predicted individual cardiovascular risk factors [146] and clustered cardiovascular risk [147] in adulthood. However, whether there is an *independent* effect of childhood obesity on cardiovascular health remains controversial, as the association is likely due in part to the high tracking of BMI from childhood into adulthood [148].

Hypertension: Blood pressure has a graded association with cardiovascular disease [149,150] and hypertension is widely acknowledged as a key cardiovascular risk factor [151]. Elevated blood pressure predicted cardiovascular events [152] cardiovascular disease [153] and cardiovascular mortality in adults [154]. Elevated mean arterial pressure (≥ 110 mmHg) was associated with the extent of coronary artery and abdominal aorta lesions (percent surface area involved) in young adults who had an autopsy as part of the Pathological Determinants of Atherosclerosis in Youth study [8]. In the Bogalusa Heart Study, systolic and diastolic blood pressures were positively correlated with intima-media thickness [138].

Children's systolic blood pressure predicted intima-media thickness [144] and levels of other risk factors (blood pressure, lipids, glucose) [146] during adulthood. Few studies examined the relation between childhood blood pressure and subsequent mortality. In one study that did, there was an association between childhood hypertension, but not systolic or diastolic blood pressure (measured on a continuous scale), and premature mortality from endogenous causes [139].

Biochemical variables: Many blood serum variables were associated with increased risk for cardiovascular disease. In recent years, through collaboration across studies, large merged data sets were created. This, in turn, allowed researchers to detect relations between postulated risk factors and cardiovascular disease. These meta-analyses represent the best evidence to date and support that cardiovascular risk increased with higher levels of low density lipoprotein (LDL) cholesterol [151], triglycerides [155], total cholesterol [156], fibrinogen [157], C-reactive protein [158], lipoprotein-a [159], and lipoprotein-associated phospholipase A_2 [160]. Conversely, high levels of high density lipoprotein (HDL) cholesterol protected against cardiovascular disease [161]. Low HDL and elevated levels of the other serum factors were also associated with the presence of arterial fatty streaks and lesions [8] and with intima-media thickness [138]. In longitudinal investigations, childhood levels of LDL cholesterol [144,145], non-HDL cholesterol [162], and apolipoproteins [163] predicted carotid intima-media thickness in adulthood. However, not all studies agree; in a recent study, childhood cholesterol did not predict premature mortality [139].

Diabetes, glucose, and insulin: Diabetes is an independent risk factor for cardiovascular disease [151]. In a sample of middle-aged men who were assessed over a 33 year interval, those with glucose intolerance were 33% more likely to die from cardiovascular causes than normo-glycemic men [164]. However, two recent studies were unclear regarding indicators of glucose handling. Sawar et al. [165] reported significant associations between fasting glucose, post-load glucose, and glycosylated hemoglobin with incident cardiovascular disease in a meta-analysis of 50,000-250,000 participants (sample size depended on the outcome). In contrast, a prospective study (mean follow up of 4.6 years) examined 3,200 British women aged 60-79 years [166]. They observed an association between fasting insulin, insulin sensitivity, and cardiovascular disease, but cardiovascular disease was not associated with fasting glucose or glycosylated haemoglobin. In the Bogalusa Heart Study there was no association between glucose or insulin and intima-media thickness in young adults (mean age 32 years) [138]. Finally, a longitudinal study explored childhood predictors of premature mortality and found that children with the lowest glucose tolerance were 73% more likely to die prematurely than children with the highest glucose tolerance [139].

2.2 Associations between physical activity, sedentary behaviour, and other cardiovascular risk factors

In this section, I discuss the relation between physical activity, sedentary behaviour, and the indicators of cardiovascular health relevant to this thesis (arterial stiffness and cardiovascular fitness). A brief section also highlights the complex relationships between physical activity, sedentary time, cardiovascular fitness and obesity. Physical activity and sedentary behaviour are important modifiable risk factors for cardiovascular disease because they have independent effects and mediate levels of other important risk factors [23-27]. In a prospective study of 27,000 women aged ≥ 45 years, 59% of the protective effect of physical activity was explained by changes in established risk factors; 40% was attributed to ‘unknown factors’ (Figure 2-6) [26].

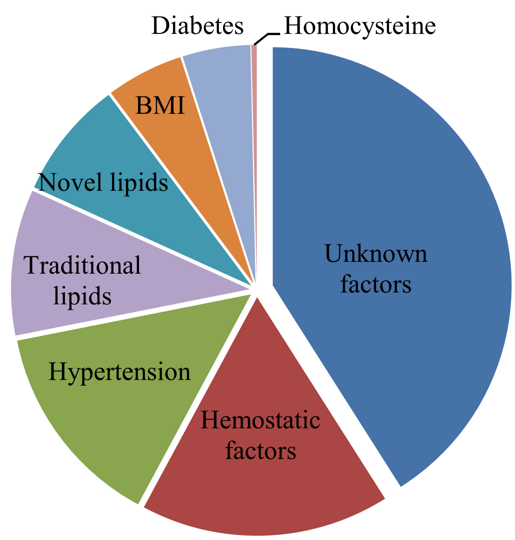

Figure 2-6. Percent reduction in CVD events attributable to the effect of physical activity on other risk factors (figure from [167] **based on data from** [26]**).**
Cardiovascular events included nonfatal myocardial infarction, nonfatal ischemic stroke, percutaneous coronary intervention, coronary artery bypass grafting, or cardiovascular death. With kind permission from Springer Science+Business Media: European Journal of Applied Physiology, Impact of inactivity and exercise on the vasculature in humans, 108, 2010, pp. 845-875, Thijssen DHJ, Maiorana AJ, O’Driscoll G, Cable NT, Hopman MTE, Green DJ, Figure 1. Based on data from Circulation, 116(19), Mora S, Cook, N, Buring JE, Ridker PM, Lee IM, Physical activity and reduced risk of cardiovascular events: potential mediating mechanisms, 2110-2118, Copyright (2007), with permission from Wolters Kluwer Health.

2.2.1 What is the relation between physical activity or sedentary behaviour and arterial stiffness?

While adult physical activity generally provided a benefit for arterial stiffness (discussed below), there is a paucity of data that describe the relation between arterial stiffness and sedentary behaviour. Physically active adults demonstrated less age-related arterial stiffening than their sedentary peers [168,169]. However, there was substantial variability between studies in the sample population and how arterial stiffness and physical activity were measured and reported. Studies that used objective measures of physical activity (pedometers or accelerometers) in middle-aged [170] and elderly [171,172] cohorts reported weak, but statistically significant, inverse associations with pulse wave velocity [171,172], stiffness index, and Young's elastic modulus [170] in the carotid artery. Most studies, however, used questionnaires to assess leisure time, sport, and occupational physical activity levels. Of these, the Atherosclerosis Risk in Communities cohort (> 10,000 individuals aged 45-64 years) was the largest. Self-reported occupational physical activity and vigorous sports activity (but not leisure time or total sports activity) demonstrated weak associations with carotid distensibility [173]. In other studies with smaller cohorts, the stiffness index was inversely related to moderate and vigorous physical activity [174]; pulse wave velocity was inversely related to leisure-time physical activity (in men) and sports physical activity (in men and women) [130]. Elastic modulus was lower [175] and augmentation index was higher [176] in those with high leisure time physical activity (above the median) compared with those who had low leisure time physical activity; there was no effect of physical activity group on pulse wave velocity [176]. No studies investigated the relation between sedentary behaviour and arterial stiffness.

Similar to studies of sedentary behaviour, few studies examined the relation between physical activity and arterial stiffness in children. Cross-sectional analyses of youth aged 9-12 years demonstrated no association between arterial compliance [177] or carotid distensibility [89], and physical activity (weekly self-report questionnaire). In contrast, Schack-Nielsen et al. [178] observed an inverse relation between pulse wave velocity and physical activity (24-hr recall questionnaire). To my knowledge, the only study of children that measured physical activity objectively (pedometers) found a weak ($r = -0.08$), but statistically significant, inverse relation between 7-day physical activity level and pulse wave velocity [87]. However, pedometers are unable to capture the intensity or pattern of physical activity so it was not possible to determine the relation of these factors with arterial stiffness. No studies investigated the relation between sedentary behaviour and arterial stiffness in children.

One longitudinal study [179] and one exercise intervention [120] provide data that support these cross-sectional reports. The Amsterdam Growth and Health Longitudinal Study measured habitual physical activity (structured interview; n = 373) on eight occasions from age 13-36 years. At age 36 years, individuals in the middle and upper tertile of the stiffness index, engaged in 19.5 and 26.5 fewer minutes of vigorous physical activity per week, on average, compared with those in the lowest tertile throughout the 24 year follow up (adjusted for sex, height, time, smoking and alcohol consumption). In contrast, there was no association between light to moderate physical activity and arterial stiffness at age 36 years [179]. A 3-month intervention designed for pre-pubertal obese children (age 8.9 ± 1.5 years) was comprised of 60 minutes of exercise after school, 3 times per week; it did not improve arterial stiffness in the exercise group compared with the control group [120]. However, the arterial stiffness (reported as elastic modulus) of those in the intervention group who continued to attend classes for three more months (n = 18) decreased by 6 months while those in the control group had increased arterial stiffness. Thus, it seems important to explore the time course of these vascular changes.

The mechanism whereby physical activity *intensity* influenced arterial stiffness is not known. The most common approach was to assess deliberate MVPA as lighter intensity physical activity is more challenging to assess via self-report. To date, only three adult studies measured physical activity objectively (using accelerometers) and only one of these partitioned physical activity into different intensities [172]. High quantities of light physical activity were inversely associated with pulse wave velocity independent of time spent in MVPA, but only in the oldest (mean age 63 years) and least fit group.

2.2.2 What is the relation between physical activity or sedentary behaviour and cardiovascular fitness?

It is well established that there is a positive relation between physical activity and cardiovascular fitness in adults [180,181] (Figure 2-7). The relationship is roughly linear [182,183], although large individual differences in the response to exercise training that are attributed (at least in part) to genetics have been reported [184-186]. A classic study of brothers, mono- and dizygotic twins suggested that the effect of genes is approximately 40% for maximal aerobic power (VO_2 max) expressed per kilogram of body weight [187]. More recent data reported that heritability, which includes genetic and environmental factors, was estimated to be at least 50% for VO_2 max [188].

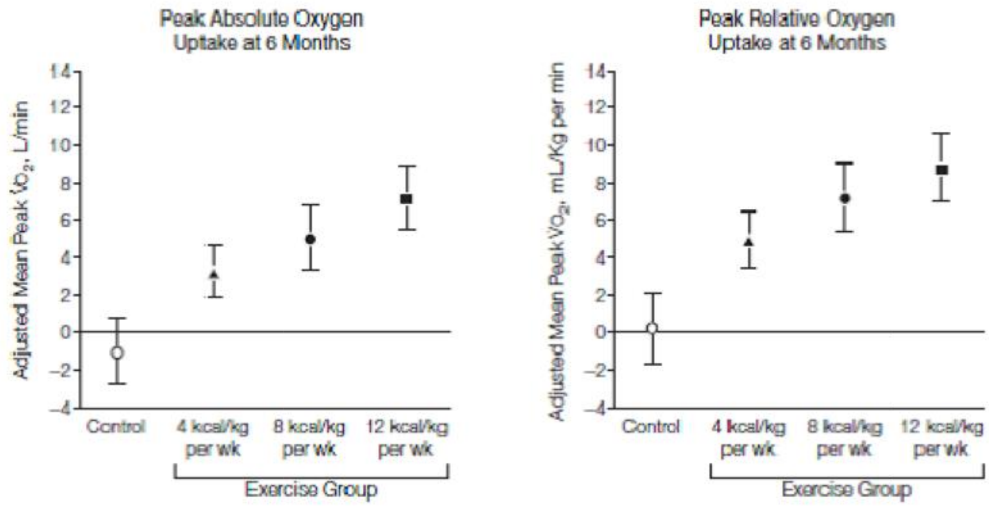

Figure 2-7. The relation between exercise dose and improvement in cardiovascular fitness [182]**.** *The relationship is approximately linear in adults as illustrated by these data from sedentary overweight or obese women taking part in a randomized controlled exercise intervention. Adapted from: Journal of the American Medical Association, 297 (19), Church TS, Earnest CP, Skinner JS, Blair SN, Effects of Effects of Different Doses of Physical Activity on Cardiorespiratory Fitness Among Sedentary, Overweight or Obese Postmenopausal Women With Elevated Blood Pressure: A Randomized Controlled Trial, pp. 2081-2091, Copyright © (2007) American Medical Association. All rights reserved.*

In contrast, the relation between physical activity and children's cardiovascular fitness is not well established. A review by Morrow and Freedson [189] reported weak correlations between physical activity and cardiovascular fitness in children and adolescents (0.16-0.17). They offered poor measures of physical activity (i.e., inaccurate and/or unreliable; predominantly by questionnaire), generally high cardiovascular fitness (e.g., average 5% improvement in response to training [190]) or a true lack of association in this population as possible reasons for the weak association. To further explain this final point, children frequently engage in physical activity that is unstructured and sporadic [36,37] and this type of activity may be insufficient to enhance fitness. More recent studies measured physical activity objectively (predominantly using accelerometers). However, there was still considerable variability in the precise methods used to assess cardiovascular fitness and in how physical activity was reported. For example, cardiovascular fitness has been evaluated using treadmill endurance time [191], maximal oxygen consumption ($\dot{V}O_2$ peak or max) on a cycle ergometer [192-197] or treadmill [126,198-202], and using the 20 m shuttle run test [203-207]. Common physical activity outcomes from accelerometers are total physical activity (accelerometer counts/min) as well as time spent in sedentary behaviours, light physical activity, moderate physical activity, vigorous physical activity, and MVPA. However, despite standard nomenclature, how intensity levels are defined (i.e., accelerometer count thresholds), data collection methods (e.g., epoch), and post collection processing (e.g., definitions of non-wear time) are not standardized which makes it challenging to compare across studies.

Table 2-3 summarizes the associations between cardiovascular fitness and objectively measured physical activity (accelerometry, pedometry, doubly labelled water) in cross-sectional studies. I excluded those studies that dichotomized physical activity (i.e., into high and low groups) [205,206] or did not report associations in a manner that I was able to summarize [196]. Overall, physical activity explained only a small portion of the variance in cardiovascular fitness in children. Some studies found significant associations between physical activity and fitness only in girls [201], only in boys [198], or only when the two sexes were pooled [204]. In the latter study, correlations between cardiovascular fitness and physical activity were non-significant but in opposite directions for girls and boys when analyzed separately ($r = 0.26$ in boys, $r = -0.11$ in girls and $r = 0.21$ for the whole group) [204]. Kristensen et al. [196] reported that cardiovascular fitness was associated with total physical activity (average counts/minute) in 9 year old boys and girls and 15 year old girls, but not 15 year old boys. Vigorous physical activity was more strongly associated with cardiovascular fitness than lighter intensity physical activity [193,195,199,203], but this was not universal [126,191,192,198,204]. A series of studies by Dencker et al. demonstrated a closer association between cardiovascular fitness and vigorous physical activity than with moderate physical activity or MVPA [193,195]. However, vigorous physical activity explained only a small additional portion of the variance in cardiovascular fitness after total body fat, maximal heart rate and sex were added to the prediction model. [194]. Only two studies reported an association between cardiovascular fitness and MVPA when MVPA was accumulated in 5 [126,200] or 10 minute [126] bouts.

Few studies examined the relation between cardiovascular fitness and objectively measured sedentary time or light physical activity. Studies that used subjective measures of sedentary time (child and/or parent reported TV/internet time) reported inconsistent associations between sedentary behaviour and cardiovascular fitness [208-210]. There was a weak association between parent/child reported TV time and 1 mile run/walk time [209] and children classified into a high TV group were less fit at baseline and 2.4 times more likely to be unfit after 2 years [208]. However, in 129 girls (mean age 14.8 years) there was no association between cardiovascular fitness (1 mile run time) and sedentary behaviour (television and internet time) [210].

Table 2-3. Pearson product moment correlation coefficient (r) or coefficient of determination (r^2) between cardiovascular fitness and categories of physical activity/sedentary behaviour (measured objectively) in children and adolescents.

Category	Boys	Girls	Combined boys and girls
Total activity	Total counts: r = 0.64 [191] Total steps: r = 0.50 [191] Counts/minute: r = 0.23 [193] Counts/minute, age 9: [196] Steps/day: r = 0.16 [197] Counts/minute: r = 0.17^A [198] AEE: r = 0.30 NS [201]	Total counts: r = 0.55 [191] Total steps: r = 0.58 [191] Counts/minute: r = 0.23 [193] Counts/minute: r = 0.05^A [198] AEE: r = 0.45 [201] Steps/day: r = 0.23 [197]	Total counts: r = 0.66 [191] Total steps: r = 0.59 [191] Heart rate: r = NS [191] Counts/minute: $r^2 = 0.22^B$ [192] Counts/day: r = 0.15^C [126] Counts/minute: r = 0.12^D [200] Counts/10 seconds: r = 0.12^E [202] Counts/minute: r = 0.28 [207]
Sedentary time	r = -0.0 NS^A [198] r = -0.04 NS [201] r = -0.14 NS [204]	r = -0.06 NS^A [198] r = -0.32 [201] r = -0.12 NS [204]	r = -0.12^C [126] r = -0.12 NS [204] r = 0.11 NS [207]
Light physical activity	r = 0.06 NS^A [198]	r = 0.04 NS^A [198]	r = 0.10^C [126] r = 0.031 NS [207]
Moderate physical activity	r = 0.61 [191] r = 0.15 NS [193] r = 0.28^A [198]	r = 0.65 [191] r = 0.13 NS [193] r = 0.14 NS^A [198]	r = 0.66 [191] $r^2 = 0.21^B$ [192] r = 0.14^F [195] r = 0.30 [199] r = 0.09^C [126] r = NS^H [203] r = 0.020 NS [207]
MVPA	r = 0.27^A [198] r = -0.07 NS [201]	r = 0.12 NS^A [198] r = 0.25 NS [201]	$r^2 = 0.21^B$ [192] r = 0.25^F [195] r = 0.28^H [203] r = 0.31 [207]

Category	Boys	Girls	Combined boys and girls
Vigorous physical activity	r = 0.53 [191] r = 0.32 [193] r = 0.16[A] [198] r = 0.22 NS [204]	r = 0.54 [191] r = 0.30 [193] r = 0.07[A] [198] r = -0.10 NS [204]	r = 0.61 [191] r^2 = 0.21[B] [192] r^2 increased by 1% (to 0.65)[I] [194] r = 0.38[F] [195] r = 0.45 [199] r = 0.11[C] [126] r = 0.23 [204] r = 0.48[H] [203] r = 0.39[J] [207]
Very vigorous physical activity	r = 0.26 NS [204]	r = -0.11 NS [204]	r = 0.21 [204] r = 0.28[J] [207]
Bouted MVPA **(5 min)**	Bout frequency : r = 0.46 [211] Bout intensity : r = 0.32 [211] Bout duration : r = 0.36 [211]	No studies	Number of bouts: r = 0.14[C] [126] Accumulated minutes: r = 0.16[C] [126] Accumulated minutes: r = 0.24[D] [200]
Bouted MVPA **(10 min)**	No studies	No studies	Number of bouts: r = 0.15[C] [126] Accumulated minutes: r = 0.16[C] [126]

Significance is at $p<0.05$ for all studies; MVPA, moderate to vigorous physical activity; [A] *Adjusted for BMI* [198]*;* [B] *Adjusted for age, sex, study* [192]*;* [C] *Adjusted for age, gender & BMI z score* [126]*;* [D] *Adjusted for sex* [200]*;* [E] *Adjusted for HDL, fatness and sex* [202]*;* [F] *Adjusted for sex* [195]*;* [G] *Adjusted for sex, race, sex by race interaction, age* [199]*;* [H] *Adjusted for age, sex, maturity* [203]*;* [I] *Adjusted for total body fat, max HR and gender* [194]*;* [J] *Square root transformed variable* [207]*; NS, not significant.*

2.2.3 Associations between physical activity, sedentary time, and obesity

Many cross-sectional investigations support a beneficial association between physical activity, cardiovascular fitness, and adiposity or obesity in youth [191,212-216]. However, these data are unable to address whether low physical activity leads to obesity or whether obesity leads to reduced physical activity levels. Longitudinal data are more limited but a recent review of prospective studies reported that physical activity may not be a key predictor of future adiposity [217]. In spite of this, a short review by Lee and colleagues [218] suggested that being physically active or fit attenuated or eliminated the health risks of obesity. This review supports the authors' previous findings that 'fit and fat' individuals are at lower risk of mortality than those who are 'unfit and lean' [219,220]. The precise intensity and pattern of activity required to prevent excess weight gain and obesity is unclear; however cross sectional data have shown that indices of adiposity in children were more strongly associated with vigorous physical activity than moderate activity or sedentary time [221]. Additionally, children who accumulated more MVPA in extended periods (bouts) were less likely to be overweight than children who accumulated most of their MVPA sporadically [222].

2.2.4 Proposed physiological mechanisms that explain the effect of physical activity and sedentary behaviour on cardiovascular risk profile

Despite clear epidemiological evidence that supports a protective effect of increased physical activity [32,111] and decreased sedentary behaviour [23,24,112,113] on cardiovascular disease, the physiological mechanisms that drive this association are not well understood. In a large prospective study of women aged ≥45 years, 60% of risk reduction associated with physical activity was attributed to altered levels of other known cardiovascular risk factors such as blood pressure and components of the lipid profile (Figure 2-6) [26]. Thus, 40% of reduced risk associated with physical activity was unexplained. Arterial stiffness (as an index of vascular health) and cardiovascular fitness are both cardiovascular disease risk factors associated with physical activity. Although they were not measured, they may be among the 'unknown factors" that contribute to risk reduction in the aforementioned study [26]. In addition, the detrimental metabolic effects of physical *inactivity* and sedentary time are distinct from the beneficial metabolic effects of physical activity [223]. Indeed, sedentary time was associated with many of the cardiovascular risk factors (e.g., BMI, blood pressure, plasma glucose, blood lipids) identified by Mora et al. (Figure 2-6; [26]) after accounting for physical activity [27,224].

2.2.4.1 How does physical activity improve cardiovascular fitness?

Physical activity (typically structured aerobic exercise of at least moderate intensity) improves cardiovascular fitness (i.e., maximal aerobic power) through several mechanisms and the physiology is well described and has been reviewed previously [225]. To summarize, oxidative metabolism is enhanced through increased mitochondrial proteins and glycolytic enzymes. Functionally this delays the onset of metabolic acidosis, increases oxidation of free fatty acids, and decreases glycogen depletion and carbohydrate utilization during sub-maximal exercise, thus postponing fatigue. Capillary number and density increase as does maximal blood flow through the muscle; this provides a greater surface area for exchange of metabolites and lengthens the transit time of blood. Thus, skeletal muscle oxygen uptake (arterio-venous difference) is enhanced. Left ventricular size and contractility increase; these factors contribute to an increased stroke volume, a lower heart rate during sub-maximal exercise and a greater maximal cardiac output. Hemoglobin content of the blood increases which permits a greater oxygen carrying capacity. The response to catecholamines is blunted which contributes to the decreased heart rate during sub-maximal exercise and a lower lactate production [225].

2.2.4.2 How do physical activity and sedentary behaviour affect vascular health?

The rapid (occurring within days or weeks) functional and structural vascular changes observed with routine physical activity appear to be stimulated by repeated episodes of increased shear stress [28,167,226]. Systemic vascular vasodialatory capacity increases, independent of changes in other risk factors [28], through increased expression and activation of nitric oxide synthase [167]. Further, there is some evidence to support reduced sympathetic tone after exercise training [226]. Structurally, arteries undergo outward remodelling which leads to an increased vessel diameter [167,227]. In large arteries, exercise may yield structural changes that increase the elasticity of the arterial wall [114], although the precise mechanism is unknown [168]. Data from adults suggest that the impact of physical activity and exercise is more pronounced on central (i.e., elastic) arteries than peripheral (i.e., muscular) arteries [168]. For example, average steps per day and amount of MVPA over a one-year period were inversely related to pulse wave velocity of the central vasculature but not of the peripheral vasculature in 200 Japanese adults (aged 65-84 years) [171]. Further, a 16-week walking/jogging intervention in 17 sedentary Japanese men (aged 31 – 64 years) reduced aortic, but not leg pulse wave velocity [228].

The role of sedentary behaviour on vascular health comes primarily from studies in individuals subjected to extreme physical inactivity (i.e., prolonged bed rest, post-spinal cord injury, space flight). Vascular changes that occurred with physical inactivity were distinct from changes associated with physical activity. This suggests that these behaviours ‘are not simply the opposite ends of a linear spectrum of physiological adaptation’ [167]. Physical inactivity leads to rapid (within weeks) structural changes in the vasculature. This may be in response to reduced blood flow with little variation in shear stress, and subsequent decreased arterial diameter (inward remodelling) [167,227].

2.2.5 Summary

While research in adults has established a clear link between physical activity and cardiovascular health, there is a paucity of conclusive evidence regarding this relation in children. Only a few studies evaluated the relation between physical activity and vascular health in youth. While more studies examined the link between physical activity and cardiovascular fitness there is little information about the role of physical activity *patterns* on these key cardiovascular health variables in children.

2.3 Measurement of physical activity and sedentary behaviour in children

In this section I first define the dimensions of physical activity and sedentary behaviour and then review tools commonly used to measure these behaviours in children.

2.3.1 Defining physical activity, sedentary behaviour and their dimensions

Physical activity is described very broadly as any body movement produced by skeletal muscles that increases energy expenditure above resting levels (defined as 1.0 metabolic equivalent; MET), whether it is for leisure or non-leisure purposes [109]. At the opposite end of the spectrum, sedentary behaviours are those that do not require energy expenditure above resting levels [110]. The spectrum of activity from sedentary behaviour through to vigorous physical activity can be partitioned into categories defined as multiples of the resting metabolic rate. In my thesis, I define sedentary behaviour, light, moderate, and vigorous physical activity as activities that expend < 1.5 METs, 1.5-2.9 METs, 3.0-5.9 METs and ≥ 6.0 METs, respectively. I adopt these definitions as they are frequently used in the literature [110,229].

Accurate measures of physical activity and sedentary behaviours are essential to delineate the relation between physical activity and health, measure the prevalence of these behaviours in a population, and assess the effectiveness of interventions [39]. However, physical activity and sedentary behaviours are both complex constructs and there is no true gold standard measure for either [229,230]. For example, there are several dimensions of physical activity and sedentary behaviour and each can be measured and reported in a number of ways (Table 2-4).

Table 2-4. Dimensions of physical activity and sedentary behaviour commonly reported.

Dimension of Activity	How it has been reported in the literature
Frequency	- Number of sessions/week - Number of days/week where a specific criteria was achieved (i.e., 5 days where 30 minutes was achieved)
Intensity	- Steps/minute (pedometer) - Average or percentage of maximal heart rate - Counts/minute (accelerometer) - Activity at a given intensity (i.e., sedentary behaviour, light physical activity, moderate physical activity, vigorous physical activity)
Duration	- Minutes/day - Minutes/week - Number of years of participation
Type	- Name of activity (e.g., walking, cycling) - Broad category (e.g., aerobic, resistance)
Volume	- METs/week - kcal/wk
Accumulation patterns	- Total minutes - Minutes accumulated in bouts - Number of activity bouts - Number of breaks in activity (i.e., breaks in sedentary time)
Context	- Location of activity (e.g., indoors vs. outdoors) - Presence of other participants

MET, metabolic equivalents; kcal, kilocalorie.

2.3.2 Overview of tools used to assess physical activity

A number of different measurement tools are commonly used to assess physical activity. This may partially explain differences between studies as to the relation between physical activity or sedentary behaviour and various health outcomes. These measurement approaches have been extensively reviewed [34,35,231-233] and are generally divided into criterion (doubly labelled water, calorimetry, direct observation), objective (heart rate, pedometers, accelerometers) and subjective (questionnaires, diaries, interviews) methods. In this section I briefly describe each measurement technique and summarize their key features in Table 2-5. I provide more detail about the two methods I used for this thesis (accelerometry and self-report questionnaire) in sections 2.3.2.4 and 2.3.2.5.

2.3.2.1 Overview of criterion methods

Doubly labelled water: The doubly labelled water technique is considered the gold standard to measure energy expenditure in free-living individuals over a period of several days to several weeks and this approach is often used to validate other measurement tools [234,235]. Briefly, participants consume water containing a known amount of labelled hydrogen and oxygen isotopes. Energy expenditure is calculated using an estimate of the carbon dioxide produced and the uptake of oxygen as a means to evaluate the loss of hydrogen and oxygen isotopes from the body [234,235]. The carbon dioxide produced is estimated by comparing the rate at which oxygen isotope is lost (through carbon dioxide and water) with the rate at which hydrogen isotope is lost (through water only). Oxygen uptake is estimated from an assumed respiratory quotient based on analysis of a participant's food intake (diary) or using respiratory gas exchange (i.e., indirect calorimetry). However, there is potential for error to be introduced depending on how oxygen uptake is estimated [234]. That said, this is an accurate and reliable approach, although it is expensive to perform and does not provide information on physical activity patterns.

Calorimetry: Calorimetry measures an individual's energy expenditure over a period from several hours (indirect and direct calorimetry) to several days (direct calorimetry only) [232,233]. Direct calorimetry estimates energy expenditure by precisely measuring heat produced (through evaporation, radiation, convection, and conduction) when a participant is isolated within a sealed measurement chamber. Indirect calorimetry estimates energy expenditure by measuring the oxygen and carbon dioxide content of inspired and expired gas.

Direct observation: There are at least eight validated observational systems that are used to categorize the intensity of children's physical activity through direct observation [232]. For each of these, trained investigators categorize the intensity of all activities using an established coding system. This is undertaken in intervals ranging from 3 seconds to 1 minute to evaluate the context and pattern of physical activity. Many of these systems use the same physical activity codes; however, the specific context in which physical activity occurs is unique. For example, SOFIT (System for Observing Fitness Instruction Time) is used to assess physical education classes, SOPLAY (System for Observing Play and Leisure Activity in Youth) is used to assess free play settings (i.e., recess or lunch), SOPARC (System for Observing Play and Recreation in Communities) is used to assess activity in parks and other recreational settings, and BEACHES (Behaviours of Eating and Activity for Children's Health – Evaluation System) is used to assess activity at home [236]. This is an expensive approach that imposes considerable investigator burden. There is also potential for those being measured to react and behave differently than they would normally.

2.3.2.2 Overview of objective methods

Heart rate: Heart rate monitors are used to quantify time spent in activity of various intensities. This is possible because of the approximately linear relationship between heart rate and oxygen consumption [232]. However, factors other than activity (e.g., caffeine and stress) can affect heart rate and thus this approach may not be appropriate to measure time spent in lighter intensity activity [237].

Pedometers: Pedometers are spring-loaded devices most often worn at the hip. The spring-loaded mechanism allows pedometers to count the total number of steps taken during the wear period. Most pedometers are not time stamped; therefore, it is not possible to gather information about time of day or activity intensity [232,238].

Accelerometers: Accelerometers are currently the most commonly used objective measure of physical activity. They are typically comprised of a piezoelectric element that generates a voltage proportional to the imposed acceleration [239]. Accelerometers are usually worn at the hip and thus provide an estimate of the acceleration of the body's centre of mass. Accelerometer data are time stamped and therefore provide valuable information about the pattern of physical activity throughout the day. However, accelerometers are unable to assess activities where the hip is relatively stationary (e.g., cycling), swimming (devices are usually not waterproof), or the increased energy expenditure associated with walking uphill or carrying a load [240]. Although accelerometers are commonly used to estimate amount and intensity of physical activity, more recently they have also been used to quantify sedentary time [241]. I provide more detail in section 2.3.2.4 regarding accelerometry methods commonly used to assess children.

2.3.2.3 Overview of subjective methods

Questionnaires, diaries and interviews: Subjective measures of physical activity and sedentary behaviour (e.g., screen time; time spent in screen-based sedentary behaviours such as time spent watching television, using a computer or playing video games) are commonly used in large epidemiological trials. This is based upon their relatively low cost, which permits large number of individuals to be assessed [231]. Typically participants (or a proxy such as a parent) are asked (through a questionnaire or an interviewer) to estimate one or more aspects of their physical activity or sedentary behaviours (e.g., frequency, intensity, duration, and/or type) during a specific time period. Energy expenditure (i.e., volume of physical activity, often expressed in METs or kcal) can be estimated from a list of activities undertaken by the participant [242].

Whether self-reported physical activity questionnaires are a valid and reliable means to assess children's activity levels has spurred much debate for several reasons. First, children tend to engage in physical activity that is transient and short in duration [36-38]. Thus, it may be difficult for them to remember their activities and to quantify them accurately for later reporting. Second, children are less cognitively developed and may be unable to recall the duration and intensity of physical activities. Third, participants may over or under-report physical activity (i.e., reporting bias) [232,243]. A recent systematic review concluded that 72% of 'indirect' (subjective) measures of physical activity were overestimates compared with 'direct' (objective) measures [243]. More detail is provided in section 2.3.2.5 regarding the physical activity questionnaire used to assess children in the current study.

Table 2-5. Measurement tools commonly used to assess physical activity in children [231].

	Can it assess free-living physical activity?	Invasiveness and burden	Cost	Dimensions assessed	Length of measurement	Accuracy
Doubly labeled water	Yes	Not invasive	Very expensive	Total EE	Usually 7-14 days	Very accurate
Calorimetry	No, laboratory-based	Bulk equipment and invasive with use of mask	Very expensive	Total EE, intensity, frequency, duration	Short term; up to 24 hours in a metabolic chamber	Very accurate
Accelerometry	Yes	Not invasive	Moderate	Activity counts, intensity, frequency, duration, EE can be predicted	1-14 days; Usually up to 7 days	Accurate during flat locomotion and for sedentary activities
Pedometry	Yes	Not invasive	Inexpensive	Total steps, total day physical activity	1-14 days	Accurate during most walking speeds
Heart rate monitoring	Yes	Can be bulky	Moderate	Intensity, frequency, duration, EE can be predicted	1-14 days; usually 4 days	Good at higher activity intensities but poor at low activity intensities
Combined heart rate and movement	Yes	Not invasive	Moderate to expensive	Intensity, frequency, duration, EE can be predicted	1-14 days	Should be accurate across all intensity levels
Questionnaires	Yes	Not invasive	Inexpensive	Type, possibly frequency and duration of sports and leisure activities and to rank EE	From 1 day to habitual	Only suitable in those over 10 years of age
Activity diaries	Yes	Very time consuming	Inexpensive	Total EE, type, duration, frequency	4-7 days	Only in older adolescents
Direct Observation	No, controlled environment	High investigator burden	Very expensive	Type, duration, frequency	Short term in controlled environments; less than 24 hours	Accurate in short term

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2.3.2.4 *Using accelerometry to assess children's physical activity*

There are many brands of accelerometers, however, ActiGraph accelerometers (formerly Computer Science Applications; CSA) were most commonly used in studies that assessed children's physical activity. ActiGraph is a uniaxial accelerometer with inter- and intra-instrument variability of 1-5% [244,245]. This brand demonstrated good validity (against doubly labelled water, indirect and direct calorimetry, direct observation, heart rate monitoring, and other motion sensors) in youth [246]. Reliable estimates of habitual physical activity were obtained with at least 3-4 days of monitoring [247-249]. The number of hours of wear time per day contributed less to overall reliability [248]; however, the vast majority of studies have used a minimum criterion of 10 hours/day.

To translate raw accelerometer data into a variable that is more accessible (e.g., minutes of MVPA vs. accelerometer counts) the user applies cut points derived from calibration studies. I summarize the calibration studies (for ActiGraph/CSA monitor) performed in children, along with derived cut points and/or equation in Table 2-6. Most calibration studies used earlier models of the CSA/ActiGraph to develop cut points in small samples of children. They commonly used 1-minute epochs to generate threshold values. The prediction equations generated from these models did not accurately predict energy expenditure [250]. This is likely due to misclassification of activity intensity. By definition, a regression line is fit through the midpoint of the data with some data overestimated and other data underestimated. However, accelerometry was a useful tool to estimate time spent in activities of a specified intensity [250-252]. Three studies used receiver operating characteristic curve analysis to generate threshold values [253-255] as a means to minimize the misclassification of activity [256]. Two studies developed cut points for pre-school children only [253,255], and one of the pre-school models derived cut points for sedentary time [253].

Table 2-6. A summary of paediatric studies that generated calibration equations for ActiGraph accelerometers.

Study	Methods	Thresholds/Equation
Reilly [253]	- CSA/ActiGraph 7164 and direct observation of time in nursery - n=30 children aged 3-4 yr - Receiver operator characteristic analysis to determine optimal sensitivity and specificity	Sedentary < 1100 counts/minute
Trost/Freedson [257]	- CSA/ActiGraph 7164 and indirect calorimetry during treadmill exercise (two walking speeds and one running speed) - n=50 children in development group; n=30 children in validation group; all aged 6-17 yr - Regression modelling to predict METs	METs = 2.757 + (0.0015 * counts/min) – (0.08957 * age [yr]) – (0.000038 * counts/min * age [yr]) For a 10 year old: Sedentary < 254 counts/minute Light = 255-1016 counts/minute Moderate = 1017-3694 counts/minute Vigorous ≥ 3695 counts/minute
Eston [258]	- CSA/ActiGraph 7164 and indirect calorimetry during treadmill exercise (two walking speeds and two running speeds) and three unstructured activities (playing catch, hopscotch, sitting and colouring) - n=30 children aged 8-10 yr - Regression modelling to predict VO_2 (scaled to body weight$^{-0.75}$)	For the average body weight of 30 kg [252]: 3 METs = 500 counts/minute 6 METs = 4000 counts/minute 9 METs = 7600 counts/minute
Trost [259]	- CSA/ActiGraph 7164 and indirect calorimetry during treadmill exercise (two walking speeds and one running speed) - n=30 children aged 10-14 yr	EE (kcal/min) = -2.23 + 0.0008*counts/minute + 0.08*body mass[kg]
Puyau [260]	- CSA/ActiGraph 7164 and room calorimetry (with heart rate telemetry) during a structured protocol of sedentary (Nintendo, arts and crafts, quiet playtime), light (aerobic warm up, walking at 2.5 miles/hr), moderate (Tae Bo exercise, standing play) and vigorous activities (jogging at 4.5-6.0 miles/hr, jump rope) - n=26 children aged 6-16 yr - Regression modelling to predict AEE	AEE (kcal/kg/minute) = 0.0183 + 0.000010*counts/minute Sedentary < 800 counts/minute Light < 3200 counts/minute Moderate < 8200 counts/minute Vigorous ≥ 8200 counts/minute

Study	Methods	Thresholds/Equation
Treuth [261]	- CSA/ActiGraph and indirect calorimetry during free living activities rest, watching TV, playing computer game, sweeping, slow walking, brisk walking, step aerobics, cycling, basketball, stair climbing, running) - n=74 girls aged 13-14 yr - Random coefficient regression modelling	MET=2.01 + 0.00171*counts/30 sec Sedentary < 50 counts/30 sec (< 100 counts/minute) Light = 51-1499 counts/30 sec (101-2999 counts/minute) Moderate = 1500-2600 counts/30 sec (3000-5200 counts/minute) Vigorous > 2600 counts/30 sec (> 5200 counts/minute)
Mattocks [251]	- CSA/Actigraph 7164 and indirect calorimetry during free living activities (lying, sitting, slow walking, brisk walking, jogging, hopscotch) - n=163 children in development group; n=83 children in validation group; all aged 12 yr - Random intercepts modelling, adjusted for age and gender	EE (kJ/kg/min) = -0.933 + 0.000098 counts/minute + 0.091*age [yr] – 0.0422*gender [male=0, female=1] 3 METs = 2306 counts/minute 4 METs = 3581 counts/minute 6 METs = 6130 counts/minute
Pate [262]	- Actigraph (model not specified) and indirect calorimetry during structured (watching TV, walking, running) and unstructured activities (20 minutes of self-selected indoor and outdoor activities) - n=30 children aged 3-5 yr - Random coefficient regression modelling	Maximal aerobic power = 10.0714 + 0.02366*counts/15sec Moderate = 420 counts/15 sec (1680 counts/minute) Vigorous = 842 counts/15 sec (3368 counts/minute)

Study	Methods	Thresholds/Equation	
Sirard [255]	- ActiGraph and direct observation during 5 structured activities (sitting and talking, fast walking, sitting and playing, slow walking, jogging) - n=16 children aged 3-5 yr in development group; n=281 children in validation group - Receiver operator characteristic analysis to determine optimal sensitivity and specificity for 4 categories of activity intensity	Sedentary: 3yr: 0-301 counts/15 sec 4yr: 0-363 counts/15 sec 5 yr: 0-398 counts/15 sec Light: 3 yr: 302-614 counts/15 sec 4yr: 364-811 counts/15 sec 5 yr: 399-890 counts/15 sec Moderate: 3 yr: 615-1230 counts/15 sec 4yr: 812-1234 counts/15 sec 5 yr: 891-1254 counts/15 sec Vigorous: 3 yr: ≥ 1231 counts/15 sec 4yr: ≥ 1235 counts/15 sec 5 yr: ≥ 1255 counts/15 sec	 (0-1204 counts/minute) (0-1452 counts/minute) (0-1592 counts/minute) (1205-2456 counts/minute) (1453-3244 counts/minute) (1593-3560 counts/minute) (2457-4920 counts/minute) (3245-4936 counts/minute) (3561-5016 counts/minute) (≥ 4921 counts/minute) (≥ 4937 counts/minute) (≥ 5017 counts/minute)
Evenson [254]	- CSA/ActiGraph 7164 and indirect calorimetry during free living sedentary (resting, watching DVD, colouring) light (slow walking), moderate (climbing stairs, basketball, brisk walking) and vigorous (cycling, jumping jacks, running) activities - n=33 children aged 5-8 yr - Receiver operator characteristic analysis to determine optimal sensitivity and specificity for sedentary, moderate and vigorous activities	Sedentary = 0-25 counts/15 sec Light = 26-573 counts/15 sec Moderate = 574-1002 counts/15 sec Vigorous ≥ 1003 counts/15 sec	(<100 counts/minute) (101-2292 counts/minute) (2293-4008 counts/minute) (≥ 4009 counts/minute)

EE, energy expenditure; AEE, activity energy expenditure.

2.3.2.5 Physical Activity Questionnaire for Children (PAQ-C)

The Physical Activity Questionnaire for Children (PAQ-C) is a 7-day recall questionnaire that assesses MVPA during the school year. The PAQ-C shows good internal consistency [263,264], acceptable test-retest reliability [263] and was validated in a sample of Canadian children aged 8-13 years against accelerometry, other self-report techniques, a recall interview and a fitness test [265]. However, a recent study of 1,000 children (mean age 10.7 years) from the southwestern United States showed that validity of the PAQ-C varied by race. They reported significant associations between fitness (measured using a step test) and PAQ-C score in white children but not in African American or Hispanic children [266].

The original version of the PAQ-C did not assess sedentary behaviours. We added items related to sedentary behaviours from a 7-day recall questionnaire used in the Middle-School Physical Activity and Nutrition (M-SPAN) program [267].

2.3.3 Summary

The accurate evaluation of physical activity and sedentary behaviours is challenging – especially in children. It becomes increasingly so given there is no 'gold standard' technique that is capable of capturing the multiple dimensions of these two constructs. Accelerometers have proven to be a viable objective tool with acceptable reliability and validity; however, there are many methodological decisions that must be made regarding the specific data collection and processing methods. To date, there are also no universally accepted (standard) guidelines for accelerometry data processing.

2.4 Physical activity & sedentary behaviour in childhood

In this section I summarize current Canadian and international physical activity and sedentary behaviour guidelines for children. Following this, I review the prevalence of physical activity and sedentary behaviour in children and describe trends in these data.

2.4.1 Physical activity & sedentary behaviour guidelines for children

Many government and non-government organizations have developed evidence-based physical activity guidelines for children (Table 2-7). Current national [268-272] and international [273,274] guidelines recommend that youth accumulate 60 minutes of MVPA/day. This compares to previous versions of the guidelines that recommended lower [275] or higher [276,277] amounts of MVPA. Generally, recommendations are similar which is not surprising given that they are based on essentially the same research base. However, subtle differences exist. For example, one guideline recommends 60 minutes of MVPA/day, *on average* (i.e., some days with fewer than 60 minutes are acceptable as long as the time is made up on other days) [268] whereas others recommend accumulating 60 minutes of MVPA *every day* [269-271,273,274]. Further, some guidelines included information on how a child should progress towards the suggested target if currently inactive (e.g., increase by 10% per week) [270,278] and what types of activities they might include in their everyday routine (e.g., aerobic, strength, flexibility) [268,270-274].

Several organizations have also included statements concerning screen time. Australian [269] and American [279] physical activity guidelines recommend that children should limit screen time to a maximum of 2 hours/day. Canadian [280] and American [281] Paediatric Societies both recommend no more than 1-2 hours/day of screen time. To my knowledge, these screen time guidelines were not formulated through a rigorous systematic review of the literature, but are supported in part by recent studies [282,283]. Most recently (February 2011), the Canadian Society for Exercise Physiology released the first set of systematic evidence-based sedentary behaviour guidelines. These guidelines call for a maximum of 2 hours of recreational screen time/day and minimizing other sedentary behaviours such as motorized transportation and extended sitting time [42].

It is certain that physical activity and sedentary time guidelines will evolve further as the field advances. This is particularly likely with respect to minimal and optimal doses of physical activity [284] and evidence-based limits on total sedentary time [223]. For example, two recent studies disagree with current physical activity guidelines. In children who achieved the target of 60 minutes of MVPA/day, cardiovascular risk factors still clustered [62] and despite improved metabolic health, BMI or fatness did not improve [285]. In contrast, adolescents who achieved 60 minutes of MVPA/day were likely to have greater cardiovascular fitness [206]. In adults, different types and doses of physical activity may be required to achieve a specific health goal [181]. Janssen [268] postulated that this might also hold true for children. As to screen time guidelines, in adolescents the recommended 2 hours/day may be conservative as the risk for metabolic syndrome [282] or overweight (by waist circumference) [283] did not increase until average screen time exceeded 3 hours/day. It seems vital that internationally accepted evidence-based guidelines be created as a means to compare across different populations and across countries around the world.

Table 2-7. Physical activity and sedentary time guidelines for children (adapted from Janssen [284]**).**

Country (reference)	Age group	Evidence base	Recommendations
Physical Activity			
Canada [268]	5-17 yr	Systematic review	- Children and youth 5-17 years of age should accumulate an average of at least 60 minutes per day and up to several hours of at least moderate intensity physical activity. Some of the health benefits can be achieved through an average of 30 minutes per day - More vigorous intensity activities should be incorporated or added when possible, including activities that strengthen muscle and bone - Aerobic activities should make up the majority of the physical activity. Muscle and bone strengthening activities should be incorporated on at least 3 days of the week
United States [271]	5-19 yr	Systematic review	- School-age youth should participate daily in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate, enjoyable and minimizes the risk of injuries - Children should include resistance exercise, vigorous aerobic exercise and weight loading activities on 3 or more days per week
Australia [278]	≤ 19 yr	Systematic review	- All children and youth should engage in physical activity of at least moderate intensity for 60 minutes or more on a daily basis - Children and youth should avoid extended periods of inactivity through participation in sedentary activities such as television watching, video, computer games and surfing the internet - Children and youth who currently do little activity should participate in physical activity of at least moderate intensity for at least 30 minutes daily, building up to undertaking 60 minutes daily
United Kingdom [272]	5-18 yr	Systematic review	- Children and adolescents aged 5–16 years should accumulate at least 60 minutes of moderate-to vigorous intensity activity per day, including vigorous-intensity aerobic activities that improve bone density and muscle strength.
Ireland [270]	2-18 yr	Existing physical activity guidelines and expert opinion	- All children and young people should be active, at a moderate to vigorous level, for at least 60 minutes every day - Include muscle-strengthening, flexibility and bone-strengthening exercises times a week - Children who are not active should start off slowly

Country (reference)	Age group	Evidence base	Recommendations
World Health Organization [274]	5-17 yr	Systematic review	- Children and young people aged 5-17 years old should accumulate at least 60 minutes of moderate to vigorous intensity physical activity daily - Physical activity of amounts greater than 60 minutes daily will provide additional health benefits - Most of daily activity should be aerobic. Vigorous intensity activities should be incorporated, including those that strengthen muscle and bone, at least 3 times/week
European Union [273]	not defined	Strong *et al.* [279]	- School-aged youth should participate in 60 minutes or more of moderate to vigorous physical activity daily, in forms that are developmentally appropriate, enjoyable, and involve a variety of activities - The full dose can be accumulated in bouts of at least 10 minutes - Specific types of activity according to the needs of the age group should be addressed: aerobic, strength, weight bearing, balance, flexibility, motor development
Screen Time/Sedentary time			
Canada [42]	5-11 yr 12-17 yr	Systematic review	- Limit recreational screen time to no more than 2 hours per day; lower levels are associated with additional health benefits. - Limit sedentary (motorized) transport, extended sitting and time spent indoors throughout the day.
Canada [280]	Not specified	Not discussed	- Television watching should be limited to less than 1-2 hours/day
United States [281]	>2 yr	Not discussed	- Limit children and adolescent's total media time (with entertainment media) to no more than 1-2 hours of quality programming/day
Australia [286-288]	0-2 yr 2-12 yr 12-18 yr	Not discussed	- No television for children under 2 years - Maximum of 2 hours/day for those older than 2 years

Adapted, with permission, from Applied Physiology, Nutrition, and Metabolism, 32(Supplement 2), Janssen I, Physical activity guidelines for children and youth, S109-S121 © 2008 NRC Canada or its licensors.

2.4.2 Prevalence of physical activity and sedentary behaviour in children

I have previously discussed the challenge of accurately assessing physical activity and sedentary behaviours in children. Clearly, the tool used to assess these outcomes will play a central role in achieving an accurate estimate of the prevalence of physical activity and sedentary behaviour. To illustrate, when physical activity was assessed by accelerometry fewer than 5% of American adults achieved the recommended daily amount [289]. However, when self-report questionnaires were used, 45% of Americans met the recommended daily amount of physical activity [290]. Typically, self-report measures overestimate children and youth's physical activity compared with objective measures [243]. Self-report and objective measures of sedentary time are seldom compared as they measure different aspects of behaviour. Self-report data tend to focus upon one aspect of sedentary behaviour, such as TV or screen time, whereas objective tools measure total sedentary time.

Further, even with the same measurement tool, if different measurement criteria are adopted levels of physical activity will be different. When researchers applied accelerometer cut points from two previously published calibration studies, prevalence estimates (i.e., percentage meeting physical activity guidelines) ranged from 35% to 100% in a sample of 45 children aged 8-11 years [291]. Finally, and in a similar vein, when different physical activity guidelines were applied the percentage of American children deemed physically active ranged from 3% to > 90% [292].

2.4.2.1 How active are Canadian children?

Although seemingly a simple question the answer proves elusive as: 1) standardized data are not available and 2) the criteria used to define children as 'physically active' typically do not align with Canada's physical activity guidelines [284]. For example, previous versions of Canada's physical activity guidelines for children recommended 90 minutes of physical activity per day [276,277] whereas reports of the prevalence of physical activity in children used 60 minutes/day [293], 3.0 kcal/day/kg [294], 1, 2, or 3 hours/day [295], or various step counts/day [40]. Historically, most estimates of physical activity prevalence in Canadian youth used self-report [293,294] or parent-reports [295] of physical activity. Generally, using self-report or proxy measures, physical activity levels were low (fewer than 50% of youth achieved sufficient physical activity [293,294]). More recently, physical activity was assessed on a population level in Canada using pedometers [40] or accelerometers [43]. These data are summarized in Table 2-8.

Table 2-8. Recent population-based studies assessing the prevalence of physical activity in healthy Canadian children.

Study	Population	Measurement of physical activity	Results		
HBSC [293] 2001-2002	Age: 10-16 years n=5,890 Cross-National survey (34 countries)	In-class questionnaire. How many days in the past week and in a typical week they achieve 60 minutes of physical activity. "Active" if 60 minutes on ≥ 5 days	Total group: 44.9%		
CCHS [294] 2003	Age: 12 years and older n=3,315,567 (Here 12-19 years)	Telephone and home interviews. Total leisure time physical activity energy expenditure is estimated based on type, frequency and duration of activities (previous 3 months) and body mass "Physically active" defined as 3.0 kcal/day/kg	Total group: 47.3% physically active Boys: 54.6% physically active Girls: 39.5% physically active 12-14 years: 50.0% 15-19 years: 45.6%		
CCHS [295] 2004	Age: 6 years and older (Here 6-11 years)	Proxy report by parent. Physical activity over last 3 months (type of activities, frequency and duration)	Total group: 83.9% > 1 hr/day 42.6% > 2 hr/day 9.8% > 3 hr/day	Boys: 86.7% > 1hr/day 48.6% > 2hr/day 13.5% > 3hr/day	Girls: 80.8% > 1hr/day 36.2% > 2hr/day 5.9% > 3 hr/day
CANPLAY [40] 2005-2007	Age: 5-19 years n=11,669	7 day pedometry Three thresholds applied 1) BMI-referenced (15,000 steps/day for boys and 12,000 steps/day for girls) 2) Equivalent to 150 minutes physical activity/week (15,000 steps/day for both boys and girls) 3) Equivalent to 90 minutes physical activity/day (16,500 steps/day for both boys and girls)	Ave step counts Boys – 12,259 steps/day Girls – 10,906 steps/day Boys > girls Younger > older Prevalence estimates (by age and sex) in Figure 2-8		

Study	Population	Measurement of physical activity	Results	
CHMS [43] 2007-2009	Age: 6 to 19 years n=1,608	Accelerometer (ActiCal) Valid files had 4 days of ≥ 10 wear hours/day Several thresholds applied (two selected for this table) 1) MVPA guideline: 60 min/day, 6 days a week 2) Step guideline: 13,500 steps/day (approximately 60 min MVPA/day)	Average MVPA (min/day) Boys: 6-10 yr: 69 min/day 11-14 yr: 59 min/day 15-19 yr: 53 min/day 9.0% met MVPA guideline Average steps/day Boys: 6-10 yr: 13,217 11-14 yr: 11,857 15-19 yr: 11,267 6.7% met step guideline	 Girls: 6-10 yr: 58 min/day 11-14 yr: 47 min/day 15-19 yr: 39 min/day 4.1% met MVPA guideline Girls: 6-10 yr: 11,745 11-14 yr: 10,351 15-19 yr: 9,204 2.8% met step guideline

CHMS, Canadian Health Measures Survey; CCHS, Canadian Community Health Survey; HBSC, Health Behaviour in School-Aged Children; CANPLAY, Canadian Physical Activity Levels Among Youth.

The Canadian Physical Activity Levels Among Youth study (CANPLAY) used pedometers to assess physical activity in a national sample of 11,000 youth [40]. Not surprisingly, the estimated number of children who engaged in recommended levels of physical activity was lower than in previous studies that used self-report to assess children's physical activity (Figure 2-8, Table 2-8). The Canadian Health Measures Survey used accelerometers to measure physical activity in a nationally representative sample of 1,600 youth aged 6-19 years. Similar to the CANPLAY study, physical activity levels were lower than previous studies that assessed activity levels via self-report (Table 2-8).

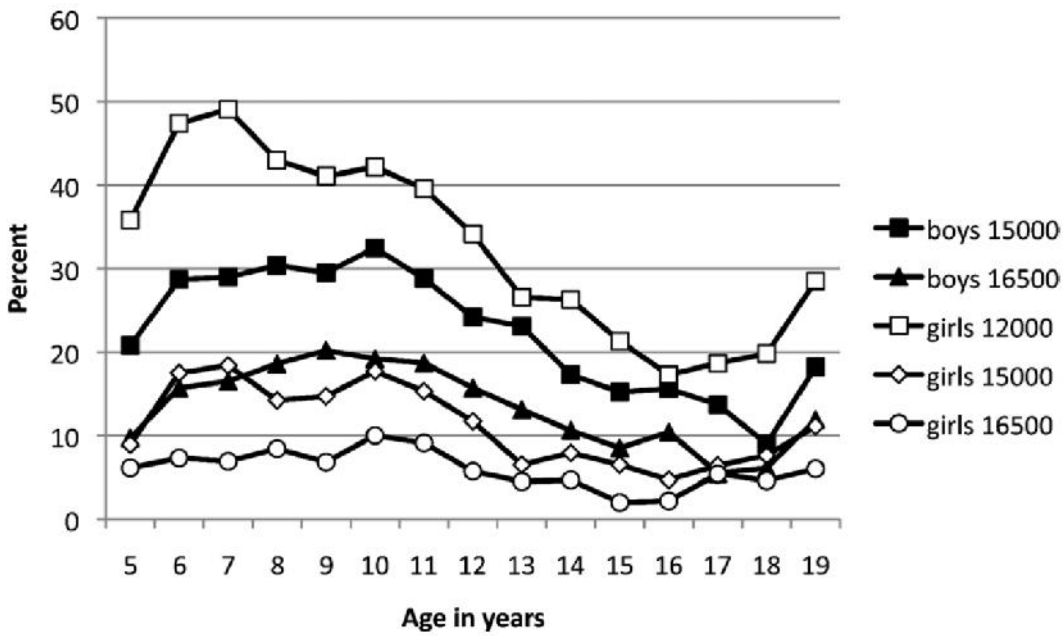

Figure 2-8. Percentage of boys and girls meeting equivalent of youth recommended daily steps reprinted from [40]**.**
The criteria for being physically active were: 1) BMI-referenced steps (12,000 steps/day for girls, 15,000 steps/day for boys), 2) the equivalent of 150 minutes of moderate to vigorous physical activity (15,000 steps/day) and 3) the equivalent of Canadian physical activity guidelines (90 minutes/day; 16,500 steps/day). Reprinted from Medicine & Science in Sports & Exercise, 2010, 42(9), Craig C, Cameron C, Griffiths J, Tudor-Locke C, Descriptive epidemiology of youth pedometer-determined physical activity, pp. 1639-1643, with permission from Wolters Kluwer Health.

Important patterns are apparent within this data set. First, physical activity levels were higher for boys compared with girls when the same step count thresholds were applied (Figure 2-8). This finding is supported by other studies [126,229,257,293,296-304]. However, maturity level of the child can easily confound the relation between physical activity and sex. That is, children of the same chronological age may vary substantially in their level of biological maturity [305]. Further, on average, girls reach puberty approximately 2 years in advance of boys (12 vs. 14 years) [306] and when data are aligned on physical maturity, instead of chronological age, sex differences disappear [307,308]. However, sex differences in physical activity levels have been reported even among preschool children [309]. A second important pattern is that physical activity levels (reported as steps per day) decreased with age in both boys and girls (Figure 2-8, Figure 2-9). Cross-sectional and longitudinal studies support this observation [257,294,297,301,302,310,311]. Physical activity assessed using accelerometers estimated that the decrease from age 9 to 15 years was approximately 40 minutes of MVPA/year [297].

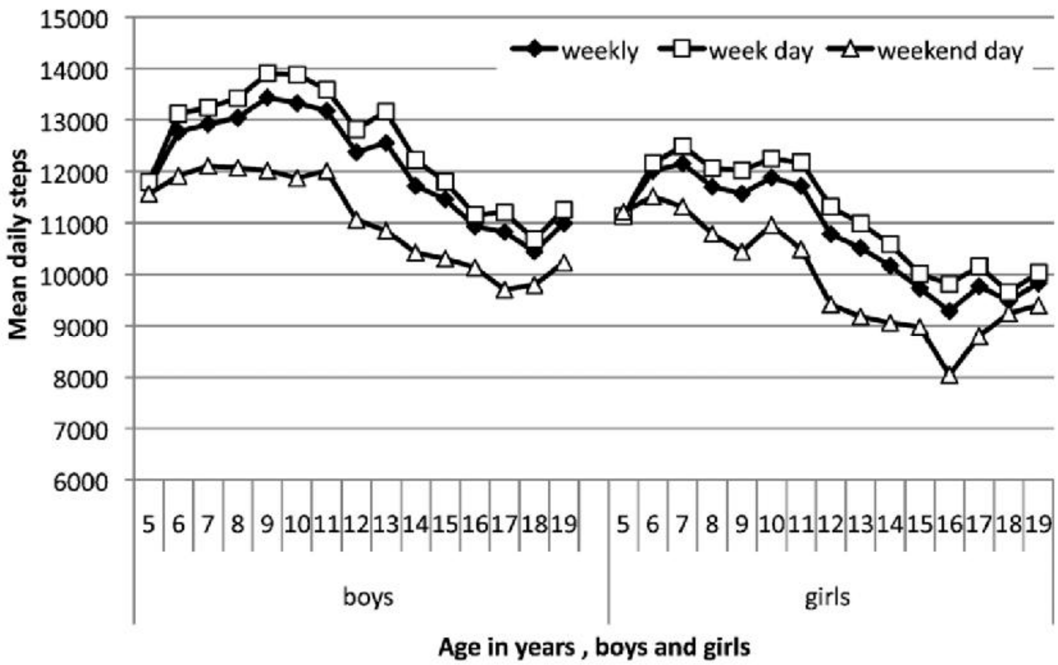

Figure 2-9. Mean steps/day in boys and girls, by age [40]**.**
This figure illustrates the decline in physical activity levels that occurs with age and the differences in physical activity levels between boys and girls of the same chronological age. Reprinted from Medicine & Science in Sports & Exercise, 2010, 42(9), Craig C, Cameron C, Griffiths J, Tudor-Locke C, Descriptive epidemiology of youth pedometer-determined physical activity, pp. 1639-1643, with permission from Wolters Kluwer Health.

2.4.2.2 How active are Canadian children compared to children from other countries?

In a comparison of 34 countries, Canada had the third highest percentage of (self-reported) physically active youth, following the United States and Ireland [293]. More recently, estimates of physical activity using accelerometry were obtained from a representative sample (n=1,778) of children and youth aged 6-19 years in the United States [289]. Results showed that 42% of American children aged 6-11 years and 8% of adolescents aged 12-17 years met physical activity guidelines of 60 minutes of MVPA/day [289]. It is difficult to compare these American data to the recently published Canadian Health Measures Survey data [43] for several reasons. First, different accelerometers were used in each study, which means that the cut points are based on entirely different calibration studies. Second, prevalence estimates in the American sample were based on participants with one or more valid wear days whereas in the Canadian sample, prevalence estimates were based on individuals with at least four valid wear days. Physical activity data from other countries were not obtained from nationally representative cohorts.

2.4.2.3 Is there evidence for a secular decline in physical activity?

With well-documented secular increases in overweight and obesity [21,312,313] and decreases in cardiovascular fitness [18] there is significant interest in determining whether these changes are a result of declining physical activity levels. The answer remains unclear. Some studies reported decreased physical activity levels in youth [314,315] whereas others found no change [316] or increased [317,318] amounts of physical activity over time. This is a difficult question to address given the differences in measurement protocols and reported outcome variables between studies. Additional study is required to clarify temporal trends.

2.4.2.4 How sedentary are Canadian children?

Nationally representative data for screen time were collected as part of the 2000-2001 Health Behaviour in School Aged Children study. Within that cohort of 7,000 youth (grades 6-10), boys accumulated 4.8 hr/day and girls 4.1 hours/day of screen time. In addition, fewer than 20% of the participants met the Canadian Paediatric Society guidelines [280] of less than 2 hours of entertainment screen time/day [41]. A large proportion of American youth also spend excessive amounts of time engaged in sedentary screen time behaviours. An estimated 44% [319] to 47% [320] of youth exceed the guideline of 2 hours/day. Until recently, estimates of total sedentary time were not available for the Canadian population. However, the recently published Canadian Health Measures Survey data revealed that Canadian children and youth spend 8.6 hours/day sedentary (approximately 62% of waking hours) [43].

2.4.2.5 What is the link between physical activity and sedentary behaviour?

Intuitively one might think that as physical activity levels increase, sedentary time decreases and vice versa. However, it is possible for children to be physically active (i.e., meeting physical activity guidelines) and still engage in large amounts of sedentary time. For example, a recent study showed that the most active group of children was also the most sedentary [321]. Another study showed that exceeding 2 hours/day of screen time was not consistently associated with reduced physical activity [322]. A meta-analysis of 52 studies showed only a weak (but negative) relationship between TV time and physical activity [323]. Of interest, a study in Canadian adolescents (mean age 15 years) found no relationship between 'unproductive' sedentary time (TV viewing or video games) and physical activity. However, they observed a positive relation between 'productive' sedentary time (homework or part time work) and physical activity [324].

2.4.2.6 Patterns of physical activity and sedentary behaviour in children

Tempo and accumulation of physical activity: Tempo and accumulation refer to the pattern in which physical activity is accrued. That is, whether physical activity is accumulated in short bursts or in more prolonged bouts. Children tend to participate in physical activity that is intermittent. Estimates of bout duration ranged from 3 seconds for vigorous physical activity [36] to approximately 20 seconds for less intense activity [37,38]. There were small [37] or not significant [38] sex differences in average bout duration (at least up to age 11 years). Sleap and Warburton [325] reported that 95% of children aged 5-11 years engaged in at least one 5 minute bout of MVPA. However, only 21% engaged in at least one 20 minute bout of MVPA. In contrast, a small study by Baquet et al. [37] found that no children engaged in bouts of MVPA lasting at least 10 minutes. The number of 5 and 10 minute bouts of moderate physical activity [300] and vigorous physical activity [257] decreased with age. Although a relatively new study examined the accumulation pattern of sedentary behaviour in adults, expressed as breaks in sedentary time [326], these data are as yet unavailable for children.

Day-to-day variability in physical activity: Children typically engaged in more physical activity on weekdays than weekends or free days [296,297,302-304,311,327]. In addition, children were less active in the evening compared with during school and after school periods [302]. Physical activity levels on Friday were more similar to weekends than weekdays [303]. However, these data were not entirely consistent. One study observed this pattern emerge in boys only [311] while another suggested that day-to-day physical activity patterns were age dependent. Weekends were a more important source of MVPA for younger children (boys in grade 1-6 and girls in grade 1-3) whereas weekdays were more important for older children (boys grade 10-12 and girls grade 7-12) to accumulate MVPA. There was no difference in accumulation of weekday vs. weekend MVPA in the grade 7-9 boys or grade 4-6 girls (Figure 2-10) [247]. There is an approximate difference of 16% between the amount of MVPA accrued on weekdays as compared with weekend days [302].

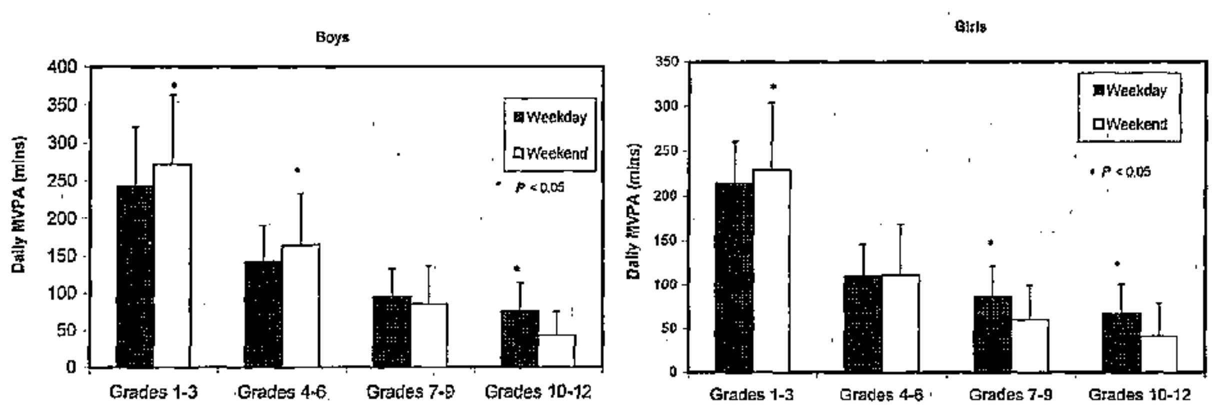

Figure 2-10. Weekday vs. weekend MVPA in boys (left panel) and girls (right panel) [247].
This figure illustrates the difference in moderate to vigorous physical activity (MVPA) between weekdays and weekend days by age and sex. In grade 1-6 boys and grade 1-3 girls, more MVPA is accumulated on weekend days than weekdays. There is no difference between weekend days and weekdays for grade 7-9 boys or grade 4-6 girls. In grade 10-12 boys and grade 7-12 girls, more MVPA is accumulated on weekdays than weekend days. Reprinted from Medicine & Science in Sports & Exercise, 2000, 32(2), Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC, Using objective physical activity measures with youth: How many days of monitoring are needed?, pp. 426-431, with permission from Wolters Kluwer Health.

Seasonal Variation in physical activity: There appears to be seasonal variation in physical activity levels across many, but not all regions [328]. Children accrued significantly more minutes of MVPA in the spring and/or summer compared with fall or winter [328]. In contrast, improvements in physical fitness during the school year with no change over the summer holiday have been reported [329]. A detailed analysis of physical activity assessed with accelerometers showed that the frequency of physical activity bouts varied more than the duration or intensity of activity bouts across winter and summer seasons in southwest England [327]. Two small studies reported that there may [330] or may not [331] be a seasonal effect on the amount of MVPA accumulated during school recess time.

2.4.3 Summary

It is challenging, if not impossible, to compare children's physical activity levels between studies because of methodological differences. A number of factors influence physical activity prevalence estimates. These include the measurement tool selected and the physical activity guideline used to determine if the recommended level of physical activity has been achieved. In addition, many reports of children's physical activity used self-report data, which may not be reliable or accurate. Finally, self-report data typically does not capture light activity or sedentary time, both of which are important determinants of heath, independent of physical activity.

2.5 School-based interventions that promote physical activity and/or reduce sedentary behaviour to improve cardiovascular fitness

2.5.1 Why target schools for physical activity interventions?

Schools are important vehicles to effectively address childhood health issues including low physical activity and cardiovascular fitness. First, most children attend school and therefore spend approximately 30 hours/week in that environment. During school, children are a ‘captive’ audience and receive physical and health education which are typically mandated as part of the curriculum, at least at the elementary school level [44,45]. Second, schools house children from a wide range of socioeconomic and cultural backgrounds and curriculum, school policy and environmental changes can be used to promote healthy living [44,45]. Third, physical activity accrued during the school day contributes to overall physical activity levels. In one study, approximately 70% of daily MVPA was accumulated at school [332], although lower amounts have also been reported [333]. Further, children who are inactive during the school day (e.g., on days where no physical education is provided) fail to compensate by increasing after school physical activity [334,335]. Finally, in addition to purported health benefits, opportunities to participate in physical activity during the school day also help students focus in the classroom [336].

Despite these many benefits, there are a number of barriers to health promotion in the school setting and schools may not be living up to their potential to enhance children’s health. For example, curricular time devoted to physical education is declining [337] and in British Columbia, as many as 74% of schools do not meet the minimum 10% of instructional time designated for physical education [338]. Further, time spent in MVPA during physical education [339-342] and recess breaks [343,344] are often lower than recommended (50% of physical education time [345] and 40% of recess time [343] spent in MVPA).

2.5.2 School-based interventions that target physical activity and/or sedentary behaviour

Research interest in children’s physical activity has increased dramatically in recent years and a large number of school-based interventions have been developed to target physical activity and/or sedentary behaviour. These school-based interventions have been systematically reviewed; most evaluated the effect of school-based physical activity interventions on either physical activity outcomes or weight status (overweight or obesity). Only one review examined the effect of school-based interventions on cardiovascular fitness [46] and no review included any index of vascular health other than blood pressure (e.g., arterial stiffness). Relevant reviews are summarized in Table 2-9. I excluded reviews with a focus on obesity from Table 2-9 as it was not a focus of this thesis. However, these reviews are summarized briefly in Appendix B. Meta-analyses have not been performed for physical activity or cardiovascular fitness outcomes in school-based intervention trials due to large differences in the intervention and the outcome variables reported.

The overall conclusions of the reviews vary and in some cases are inconclusive [346] owing to; 1) different research questions, 2) different methodologies used in the studies being reviewed and, 3) a limited number of high quality studies. For example, Jago [347] focused on non-curricular interventions whereas the review by Dobbins et al. [46] included any intervention implemented within schools. Salmon et al. [348] separated interventions by physical activity measurement technique (subjective vs. objective) and found that interventions using objective measures of physical activity were more likely to report significant findings than studies using subjective measures. In general, school based interventions increased physical activity duration and cardiovascular fitness [46] and in-school physical activity [347,349]. However, interventions did not improve out of school physical activity [46,349]. Multi-component interventions and those that targeted physical education, activity breaks, and families were more effective than curriculum-only interventions [348].

Table 2-9. Recent reviews that evaluated the impact of school-based physical activity interventions on physical activity and/or fitness.

Study	Research question	Results/conclusion
Dobbins [46]	What is the effectiveness of school-based interventions in promoting physical activity and fitness in children and adolescents? Searched articles up to July 2007	In general there was a positive effect on: - Duration of physical activity - TV viewing - $\dot{V}O_2$ max - Blood cholesterol In general there was no effect on: - Leisure time physical activity rates - Systolic and diastolic blood pressure - BMI - Pulse rate
van Sluijs [346]	What is the effectiveness of interventions to promote physical activity in children and adolescents? Searched articles up to December 2006	In general there was an inconclusive effect of: - School-based interventions - School plus family or community interventions
Salmon [348]	What is the effectiveness of interventions reporting physical activity outcomes in children and adolescents? Searched articles from January 1985 to June 2006	In general there was a positive effect of: - School-based interventions that included physical education, activity breaks or that included family strategies In general there was no effect of: - Curriculum-only interventions
Jago [347]	Are non-curricular interventions effective at promoting physical activity? Searched articles from 1970 to 2002	In general there was a positive effect on: - MVPA during break periods (i.e., recess) In general there was no effect on: - Travel to school patterns
Stone [349]	Are interventions to increase physical activity in schools (and other community settings – not discussed here) for children effective? Searched articles from 1980 to 1997	In general there was a positive effect on: - Knowledge and attitudes - Physical activity in physical education class In general there was no consistent effect on: - Out of school physical activity

$\dot{V}O_2$ max, maximal aerobic power; BMI, body mass index.

The many excellent and comprehensive reviews of school-based physical activity interventions form the basis of my literature review (Table 2-9). However, given their focus on physical activity outcomes, many interventions that report cardiovascular fitness as the primary outcome were excluded. Only one review evaluated the effect of school-based interventions on cardiovascular fitness [46] and this included only five studies, three were in adolescents. These studies reported fitness as VO_2 max or used heart rate recovery as a proxy of VO_2 max. School-based interventions in children commonly evaluated cardiovascular fitness using other measurement techniques such as the 20 m shuttle run protocol or a timed run. To address this gap I summarize all school-based intervention studies that reported any index of cardiovascular fitness as an outcome in Table 2-10. I include interventions aimed at healthy children and exclude those that targeted a specific population (e.g., interventions aimed solely at overweight or obese children) and adolescents. I also include physical activity outcomes where available.

Table 2-10 is organized so that studies that reported significant differences in cardiovascular fitness between intervention and control groups appear first (in reverse chronological order). These are followed by studies that reported no significant change in cardiovascular fitness (also in reverse chronological order). To more easily compare the magnitude of change between studies, I calculated the percentage change in fitness between groups (where possible). At least four additional school-based physical activity interventions are currently in process that also measured children's cardiovascular fitness. They are, Lekker Fit! [350], (S)Partners for Heart Health [351], Activity Knowledge Circuit [352], and the Lifestyle of our kids (LOOK) study [353]. I provide some details of these interventions in Table 2-10, although results are not yet available. Two of these studies had only small subject numbers and employed a quasi-experimental design [351,352]. Thus, they are of lower quality compared with the randomized controlled design utilized by the other two studies.

Table 2-10. School-based interventions conducted with children that reported cardiovascular fitness and physical activity or sedentary behaviour as outcome variables.

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Interventions with a significant effect on cardiovascular fitness			
Kriemler [354] KISS Switzerland	**Sample:** 540 children aged 7-11 yr **Randomization:** 15 schools randomized to INT (n=9) or CON (n=6) **Intervention:** INT: PE lessons prepared by PE specialists - 3 lessons taught by generalist teacher, 2 taught by PE specialist; 3-5 activity breaks during academic lessons (2-5 min each); daily PA homework (~10 min) CON: Usual practice (3 PE classes/wk)	**Duration:** 1 school yr **CVF:** 20 m SRT (laps) **PA:** Accelerometer **Statistics:** Mixed linear model with random effects for school class	**Mean difference in CVF at follow-up:** INT > CON (p=0.04) **Percent increase in CVF:** INT: +21% CON: +16% Difference (INT > CON): +5% **Mean difference in total PA at follow-up:** Total PA: INT=CON (p=0.31) In school PA: INT>CON (p=0.003) **Percent increase in in-school PA:** INT: +8% CON: -8% Difference (INT > CON): +16%
Resaland [355] Sogndal school-intervention study Western Norway	**Sample:** 259 children in 4th grade from 2 consecutive yr **Group allocation:** 1 INT school and 1 CON school, located in different municipalities **Intervention:** INT: 60 min daily PA lesson planned by expert PE teacher in conjunction with researcher and taught by classroom teacher. PA lesson consisted of MVPA (e.g., ball games, brisk walking, active play, skiing, etc.) CON: 2*45 min PE class/week (usual practice)	**Duration:** 2 school yr **CVF:** $\dot{V}O_2$ peak from treadmill test **PA:** Not measured **Statistics:** ANCOVA	**Mean difference in CVF change (adjusted):** INT > CON: +3.6 (2.5 to 4.6) ml/kg/min (p<0.001) **Percent increase in CVF:** INT: +8.8% CON: +0.8% Difference (INT > CON): +8%

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Walther [356] Germany	**Sample:** 188 children aged ~11 yr **Randomization:** 7 classes randomized to INT (n=4) or CON (n=3). An additional 2 classes (not randomized from another school that focused on competitive sports) served as another reference group. **Intervention:** INT: 45 min of exercise training/day (225 min/wk); at least 15 min endurance training/day CON: 45 min of exercise twice a week (90 min/wk) Sports group: 540 min exercise training/wk; frequent sporting events	**Duration:** 1 school yr **CVF:** Graded treadmill test with indirect calorimetry for VO_2 max (ml/min/kg) **PA:** Not measured **Statistics:** Adjusted for clustering using the ICC	**Mean difference in CVF at follow-up:** INT vs. CON +3.7 (0.3 to 7.2) mL/min/kg (p=0.032) **Percent increase in CVF:** INT: +29% CON: +18% Difference (INT-CON): +11%
Reed [357] **Naylor** [358] AS! BC Canada	**Sample:** 269 children aged 9-11 yr **Randomization:** 8 schools randomized to INT (n=6) or CON (n=2). **Intervention:** INT: Schools created individualized Action Plans to increase PA across 6 Action Zones; in the Classroom Action Zone teachers delivered 15 min of MVPA daily (additional 75 min/wk) CON: Usual practice of PE and PA	**Duration:** 1 school yr **CVF:** 20 m SRT (laps) **PA:** Pedometer and PAQ-C (pre-post changes not reported) **Statistics:** Adjusted for clustering using a variance inflation factor	**Mean difference in CVF (INT-CON) at follow-up:** +6 laps (p<0.05) **Percent increase in CVF:** Difference (INT-CON): +20% (p<0.05)

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Sallis [359] SPARK USA	**Sample:** 955 children in the 4th and 5th grade **Randomization:** 7 schools assigned to INT1 (n=264 children), INT2 (n=331 children) or CON (n=360 children) **Intervention:** INT1: PE specialists taught the SPARK PE (3*30 min/wk or health and skill fitness) and self-management (1*30 min/wk) program INT2: Generalist teachers were trained to deliver SPARK PE and self-management CON: Usual PE program	**Duration:** 2 school yr **CVF:** timed 1 mile run (sec) PA**:** Self-reported, accelerometer, direct observation in PE class (SOFIT) **Statistics:** Adjusted for clustering using the ICC	**Mean difference in CVF (run time) at follow-up:** Boys: NS Girls: INT1 < CON (p=0.03) **Percent improvement in CVF (run time; girls):** INT1: -28% INT2: -13% CON: -21% **Mean difference in PA at follow-up (vs. CON):** MVPA in PE: INT1 > INT2 > CON (p<0.001) INT1: + 22.4 vs. CON INT2: + 7.5 min vs. CON **Mean difference in out of school PA at follow-up (vs. CON):** NS

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Vandongen [360] Australia	**Sample:** 1,147 children aged 10-12 yr **Randomization:** 30 schools randomized to 6 groups 1) Fitness 2) fitness + school nutrition 3) school nutrition 4) school + home nutrition 5) home nutrition 6) control **Intervention:** INT: - Fitness: 6*30 min classroom sessions; 15 min activity daily (target HR of 150-170 bpm) - School nutrition: 10*60 min lessons to improve knowledge and attitudes - Home nutrition: 5 nutrition messages delivered through comics aimed at children and parents; homework sheets CON: usual practice	**Duration:** 1 school yr **CVF:** 1.6 km run (min); 20 m SRT (laps) **PA:** Not measured **Statistics:** No mention of controlling for clustering	**Mean difference in CVF at follow-up (min and laps):** Boys: Fitness, Fitness + School nutrition > Control (significant) Girls: Fitness, Fitness + School nutrition > Control (significant) **Percent increase in CVF (20 m SRT):** Fitness (girls): +12% Fitness + school nutrition (girls): +14% Control (girls): -3% Fitness (boys): +8% Fitness + school nutrition (boys): +13% Control (boys): +4.2%
Arbeit [361] Heart Smart USA	**Sample:** 530 children in the 4th and 5th grade **Randomization:** 4 schools randomized to INT (n=2) or CON (n=2) **Intervention:** INT: cardiovascular health curriculum, modification of school lunch, exercise program (12 lessons and aerobic activities delivered by PE staff; yearlong fitness program integrated into PE curriculum CON: usual practice	**Duration:** 1 school yr **CVF:** 1 mile run/walk (time) **PA:** not measured **Statistics:** No mention of controlling for clustering	**Difference in percent change in CVF (INT vs. CON):** Grade 4 boys: +1.4% (NS) Grade 4 girls: -7% (NS) Grade 5 boys: -17% ($p<0.01$) Grade 5 girls: -14% (NS)

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Manios [362,363] Based on 'Know your body' Greece	**Sample:** A random sample of ~400 children (yr 2 follow-up) and 1,000 children (yr 6 follow-up) **Group assignment:** All schools in two counties of Crete were assigned to INT, schools in one other county were assigned to CON. **Intervention:** INT: multi-component workbooks, classroom modules (13-17 h/yr for health and nutrition, 4- h/y for fitness and activity), playground fitness sessions of moderate intensity CON: Usual practice; children allowed to play freely during PE sessions with no structured program	**Duration:** 2 and 6 yr follow-up **CVF:** 20 m SRT (stages) **PA:** Parent reported MVPA (yr 2), self-reported MVPA (yr 6) **Statistics:** No mention of controlling for clustering (yr 2); mixed linear model with random effect for school (yr 6)	**Mean difference in CVF at follow-up:** yr 2: 0.4 shuttle run stages INT > CON ($p<0.005$) yr 6: 1.2 shuttle run stages INT > CON ($p<0.0001$) **Percent increase in CVF:** yr 2 INT: +113% yr 2 CON: +68% Difference (INT > CON): +45% yr 6 INT: +163% yr 6 CON: +66% Difference (INT > CON): +97% **Mean change in PA from baseline to 6 yr follow-up:** INT:+281.3 (22) min CON:+174.5 (25.7) min Difference: INT > CON ($p<0.05$)
Harrell [364] CHIC USA	**Sample:** 1,274 children aged 7-11 yr **Randomization:** 12 schools randomly assigned to INT or CON **Intervention:** INT: Curriculum developed by American Heart Association delivered by classroom teachers (2 times/wk for 8 wks), PA intervention (24 lessons that included a warm up, 20 min of aerobic activities and a cool down)	**Duration:** 8 wk **CVF:** Predicted VO_2 max from submaximal cycle test **PA:** Self-reported **Statistics:** Used survey regression to account for clustering within the school	**Mean difference in CVF at follow-up:** INT vs. CON: +1.73 (0.80 to 2.66) ml/kg/min **Percent increase in CVF:** INT: +8% CON: +4% Difference (INT > CON): +4%

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Interventions with no significant effect on cardiovascular fitness			
De Meij [365] JUMP-in The Netherlands	**Sample:** 2,848 children aged 6-12 yr **Group allocation:** 9 INT schools from two city districts (these schools were planning to start the intervention); 10 CON schools (comparable, from geographically separated city districts); majority of students with low SES. **Intervention:** INT: Multi-component intervention including pupil follow up system (monitoring and referral if needed); school sport clubs (makes use of existing local opportunities); 'the class moves!' (PA breaks during lessons); 'this is your way to move!' (workbooks for children and parents); parental information services (meetings, courses, activities; additional services for at risk children (extra PE lessons, consultation at hospital) CON: Usual practice	**Duration:** 2 school yr **CVF:** 20 m SRT modified to 18 m (laps) **PA:** Accelerometer **Sports Participation:** Interview **Statistics:** Multilevel model to account for clustering within individual and school	**Mean difference in CVF at follow-up:** INT vs. CON: +0.02 laps (-0.26 to 0.29) (NS) **Mean difference in PA at follow-up:** INT vs. CON: 40 counts/min (-27 to 106) (NS) **Mean difference in organized sport participation at follow-up:** INT vs. CON: OR=2.8 (2.18 to 3.62) ($p<0.05$) **Sports participation and CVF (vs. always inactive)** Joined sports: +0.2 (0.06 to 0.3) Remained in sports: +0.38 (0.2 to 0.5) Stopped sports: +0.18 (-0.06 to 0.4) (NS)

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Boyle-Holmes [366] EPEC USA	**Sample:** 1,195 children aged 8-12 yr **Group allocation:** 8 schools with PE teachers implementing the intervention were compared to 8 schools teaching the usual PE curriculum **Intervention:** INT: 51 lessons/grade (2*30 min/wk) that focus on motor skills and PA in a progressive manner CON: usual practice (2-3 40 min classes/wk)	**Duration:** 2 school yr **CVF:** 20 m SRT (converted to VO_2 max (ml/min/kg) **PA:** Self-reported **Statistics:** Multilevel regression that accounted for clustering within schools	**Mean difference in CVF at follow-up (adjusted):** INT vs. CON: +0.27 ml/min/kg (NS) **Mean difference in PA MET score at follow-up (adjusted):** 4th grade INT vs. CON: +124.42 (p=0.01) 5th grade INT vs. CON: -26.01 (NS)
Graf [367] CHILT Germany	**Sample:** 615 children aged 7 at baseline **Group assignment:** 12/18 randomly selected schools agreed to be allocated to INT, 5 randomly selected schools agreed to be allocated to CON **Intervention:** INT: Health education lessons (1*20-30 min/wk), PA breaks during lessons (1*5 min in the morning), train PE teachers to optimize PE class	**Duration:** 4 school yr **CVF:** 6 min run (meters) **PA:** Not measured **Statistics:** No mention of controlling for clustering	**Mean difference in CVF at follow-up:** INT vs. CON: +21.7 m (-0.5 to 43.8) p=0.055
Stock [368] Healthy Buddies Canada	**Sample:** 383 children in kindergarten to 7th grade **Group assignment:** 1 INT school, 1 CON school **Intervention:** INT: 21 lessons taught to grade 4-7 students over school year (1*45 min/wk) - these students then taught their ‘buddy’ (kindergarten-grade 3 students) a 30 min lesson; each buddy pair participated in weekly PA sessions together (2*30 min/wk)	**Duration:** 1 school yr **CVF:** 9 min run **PA:** not measured **Statistics:** Mixed effects model with class as the cluster	**Mean difference in CVF at follow-up:** INT vs. CON: NS

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Verstraete [369] Based on SPARK Belgium	**Sample:** 764 children in 4th and 5th grade **Randomization:** 16 schools randomized to INT (n=8) or CON (n=8) **Intervention:** INT: Health-related PE (SPARK PE) taught by PE specialists, classroom health lessons (SPARK self-management) implemented by research staff, extracurricular (recess and after school) PA promotion program (provided game equipment, organized activities 1/wk)	**Duration:** 2 school yr **CVF:** 20 m SRT **PA:** accelerometer, self-reported LTPA **Statistics:** Linear mixed model to account for clustering within schools	**Mean difference in CVF at follow-up (unadjusted):** INT vs. CON: +0.51 min (NS) **Mean difference in PA at follow-up (unadjusted):** MPA: INT vs. CON: +15.5 min ($p<0.01$) MVPA: INT vs. CON: +16.4 min ($p<0.01$)
Donnelly [370] USA	**Sample:** 338 children from 3rd to 5th grade **Group allocation:** 1 INT school and 1 CON school **Intervention:** INT: School food service modifications, PA intervention (3*30-45 min/wk of aerobic exercises such as hopping skipping and games) CON: Usual PE program and food service	**Duration:** 2 school yr **CVF:** 1 mile walk/run (min); $\dot{V}O_2$ max in subsample (ml/min/kg) **PA:** Self-reported **Statistics:** Repeated measures ANOVA	**Mean difference in CVF (1 mile walk/run time; average of 4 measures):** INT < CON (significant but p value not reported) Significant between-group difference only observed at start of yr 2; NS at end of 2 yr intervention. **Mean difference in CVF ($\dot{V}O_2$ max):** NS

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Luepker [371] CATCH USA	**Sample:** 5,106 children initially in 3rd grade **Randomization:** 96 schools were randomized to INT1 (n=28), INT2 (n=28) or CON (n=40). **Intervention:** INT1: Modifications to school food service (decrease fat and sodium in school lunch), PE intervention (train classroom teachers to increase MVPA to 40% of class time), classroom curriculum (A total of 82, 30-40 min lessons delivered by trained classroom teachers over the 3 year intervention addressing psychosocial factors, eating behaviors and PA patterns) INT2: INT1 plus home curriculum (19 activity packets over 3 years) CON: Usual practice	**Duration:** 3 school yr **CVF:** 9 min distance run **PA:** Self-reported habitual PA, direct observation in PE class (SOFIT) **Statistics:** Mixed model to account for clustering at school level	**Mean difference in CVF at follow-up:** INT vs. CON: +16 yards (NS) **Mean difference in MVPA/d at follow-up:** INT vs. CON: -9.3 min (NS) **Mean difference in VPA/d at follow-up:** INT vs. CON: +12.1 min (p<0.003) **MVPA during PE class** INT > CON (p=0.02) **VPA during PE class** INT > CON (p=0.04)
Trevino [372] Bienestar Heath Program USA	**Sample:** 1,419 children in 4th grade **Randomization:** 27 schools randomized to INT (n=13) or CON (n=14) **Intervention:** INT: Health and PE class (5*45 min/wk; 1 day for health education and 4 days for PA); optional after school meeting for students to reinforce learning (1*60 min/wk); evening parent meetings (every second month); food service education for staff (1*30 min/month) and students (1/wk)	**Duration:** 1 school yr **CVF:** Modified Harvard step test (PA score=exercise time[sec]*100/(HR_0+HR_1+HR_2), where HR_n is the heart rate measured at min *n* post exercise **PA:** Not measured **Statistics:** Mixed models to account for clustering within schools	**Mean difference in CVF at follow-up:** INT vs. CON: +1.87 (-1.44 to 5.17) (p=0.04) **Percent increase in CVF:** INT: +3% CON: -1% Difference (INT > CON): +4%

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Interventions in progress			
Jansen [350] Lekker Fit! The Netherlands	**Sample:** For adequate power (to detect a difference in BMI) 2,778 children in 20 schools are required. The children are aged 6-12 yr **Randomization:** 20 schools randomized to INT or CON **Intervention:** INT:3 PE sessions/wk taught by a PE specialist; optional participation in organized sport and play activities outside school hours; cooperation with sports clubs to encourage membership; score card with results of fitness testing compared to reference scores; 3 classroom lessons taught by classroom teacher addressing nutrition, active living and healthy lifestyle choices; meetings for parents CON: Usual practice (2 PE sessions/wk)	**Duration:** 2 school yr **CVF:** 20 m SRT **PA:** self-reported **SED:** self-reported screen time **Statistics:** Multilevel regression analysis	Not yet available
Carlson [351] (S)Partners for Heart Health	**Sample:** For adequate power 180 children are required. The children are in 5th grade. **Group assignment:** 4 schools allocated to INT (n=2) or CON (n=2). Two PE classes from each school will participate **Intervention:** INT: 8 lessons (uses existing health curriculum: Jump Into Foods & Fitness) taught by school PE teacher and university student partners; mentoring partnership after each lesson (and ongoing between lessons) between 5th grade students and university students; monthly newsletters for staff and parents	**Duration:** 1 school yr **CVF:** 20 m SRT **PA:** Pedometer **Statistics:** Not described	Not yet available

First Author Study name Country	Description of sample and physical activity intervention	Methods	Results (Mean [SE; p_{25}, p_{75}; or 95% CI] or Odds Ratio [95% CI])
Knox [352] Activity Knowledge Circuit Wales	**Sample:** For adequate power 160 students are required. The children are aged 11-14 yr **Group allocation:** INT (year 8 students), CON (maturation-matched students from year 7 and 9) **Intervention:** INT: Increase PA by 2 hr/wk by walking 3200m twice a week during lessons. Each curriculum subject (except PE) will deliver up to 4 walking lessons during the intervention. During walking lessons, short tasks (<60 sec) are set up every 400-800 m; PE class (2/wk) are conducted normally CON: Usual practice	**Duration:** 18 wk **CVF:** 20 m SRT **PA:** Self-reported **Statistics:** Multiple regression and t-tests (clustering not discussed)	Not yet available
Telford [353] LOOK Australia	**Sample:** 800 children aged 7-8 yr at baseline, followed until age 11-12 yr **Randomization:** 30 schools randomized to INT or CON **Intervention:** INT: 2*50 min/wk PE lesson delivered by PE specialist as part of the mandated 120 min/wk CON: Usual practice (120 min/wk PE)	**Duration:** 4 yr **CVF:** 20 m SRT **PA:** Pedometer **Statistics:** Multilevel models to account for clustering within schools and repeated measures on the participants	Not yet available

20 m SRT, 20 m shuttle run test; CON, control group; INT, intervention group; CVF, cardiovascular fitness; PA, physical activity; SE, standard error; CI, confidence interval; ICC, intraclass correlation coefficient; PE, physical education; SOFIT, system for observing fitness instruction time; EPEC, Exemplary Physical Education Curriculum; SPARK, Sports, play and active recreation for kids; CATCH, Child and Adolescent Trial for Cardiovascular Health; MVPA, moderate to vigorous physical activity; VPA, vigorous physical activity; CHIC, Cardiovascular Health in Children; SES, socio-economic status; OR, odds ratio; KISS, Kinder-Sportstudie; LOOK, Lifestyle Of Our Kids.

Most school-based physical activity interventions were administered over ≤ one school year [351,352,354,356,357,360,361,364,368,372], although others were administered across six [362], four [353,367], three [371] or two [350,355,359,365,366,369,370] years. Either trained generalist or physical education specialist teachers delivered the interventions and were compared against a control group where no intervention was delivered. Only one intervention compared both specialist and trained generalist teachers to a control group [359]. In that study, children taught by physical education specialists engaged in greater amounts of MVPA during physical education class than students taught by trained teachers (+7 min) or the control group (+22 min). Girls taught by physical education specialists improved their cardiovascular fitness (1 minute faster run time) significantly more than did girls in the control group. There was no difference in cardiovascular fitness between girls taught by physical education specialists compared with trained generalist teachers or in boy's cardiovascular fitness between any group [359].

Some interventions required demanding changes to the school schedule such as two [354] or three [355,356] additional physical education lessons per week; introduction of physical education specialists [353,354,359,369] or additional classroom lessons for health education [360,362,364,367,368,371]. However, there was often very limited information about the control group's activities so it was difficult to determine the extent of change required. In general, interventions delivered and evaluated over a shorter timeframe appeared more likely to report a significant positive effect on fitness compared with interventions delivered and evaluated over a longer timeframe (Figure 2-11).

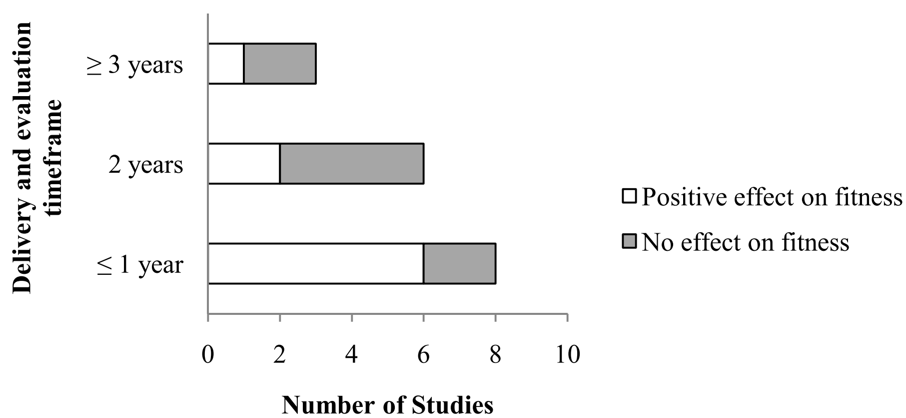

Figure 2-11. Relation between the duration of an active intervention and the effect of the intervention (positive/null) on cardiovascular fitness.
This figure suggests that interventions delivered and evaluated over one school year or less are more likely to report a positive effect on cardiovascular fitness than those delivered over two or more years.

2.5.3 Summary

Many excellent school based interventions may have been hampered by the length or breadth of the evaluation. For example, school-based physical activity interventions often extended across only one academic year (or less) with a follow-up, similarly, after one school year (or less). Thus, the long-term efficacy and sustainability of most interventions is unknown. Further, most studies evaluated program *efficacy,* but not *effectiveness*. Thus, whether school based interventions can be effective in a 'natural setting', outside of an experimental environment so to speak, is unknown. Only two interventions (SPARK and CATCH; Table 2-10) were broadly disseminated and re-evaluated using a high quality design [373,374]. JUMP-in was also re-evaluated [365] after an initial small pilot study [375], but the effectiveness trial was not randomized.

In closing – there is a need for dissemination trials, characterized by long intervention and follow up periods and prior pilot/consultation phases and well-designed dissemination strategies. It is through these effectiveness trials that we may be better able to bridge the gap and translate knowledge and practice. Currently, we do not know whether well designed intervention studies are able to produce change at the population level [48,376].

2.6 Rationale, objectives and hypotheses

I provided a brief summary at the end of major sections within this chapter as a means to identify important gaps in the current literature related to children's physical activity and cardiovascular health. While it is beyond the scope of this thesis to address all of these unanswered questions, in this section I pose five research questions that address current gaps in the literature and that form the basis of this thesis.

2.6.1 Study 1: The association of accelerometer epoch length with the measurement and classification of children's activity intensity and pattern

Rationale

Studies of children using objective measures of physical activity and sedentary time are becoming commonplace. However, the user must make many methodological decisions when using accelerometers to assess physical activity and sedentary time. One such decision is the choice of an appropriate epoch length (e.g., 15 second vs. 1 minute). This is particularly important as it is made *prior* to data collection and has implications regarding the assessment of children's sporadic activity patterns (Chapter 4).

Objectives

To compare measurement in 15 second vs. 60 second epochs with respect to children's:

1) MVPA (average minutes/day; average minutes/day accumulated in bouts)
2) sedentary time (average minutes/day; average minutes/day accumulated in bouts)
3) light physical activity (average minutes/day)
4) moderate physical activity (average minutes/day)
5) vigorous physical activity (average minutes/day)

Hypotheses

1) Light physical activity, moderate physical activity and MVPA will be different when recorded using 15 vs. 60 second epochs.

   H_0: Light physical activity, moderate physical activity and MVPA will be similar when recorded using 15 vs. 60 second epochs.
2) More sedentary time and vigorous physical activity will be recorded using 15 second vs. 60 second epochs.

   H_0: Sedentary time and vigorous physical activity will be similar between 15 and 60 second epochs.
3) More bouted activity will be recorded using 60 second vs. 15 second epochs.

   H_0: Bouted activity will be similar between 15 and 60 second epochs.

2.6.2 Study 2: What is the prevalence of sedentary behaviour, light physical activity and what are the activity patterns of girls and boys during the school day?

Rationale

Most physical activity research focuses upon MVPA given its well documented health benefits in adults [32,111] and children [62,100,103,124-126]. Recently, studies of adults highlighted the important negative effects of sedentary behaviour on metabolic risk factors [24,27,223,326] and the positive benefits of light physical activity on plasma glucose, arterial stiffness, and energy balance [172,377,378]. However, we know very little about the effect of these activity intensities on children's health. It therefore seems important to focus upon how sedentary behaviour and light activity might affect the cardiovascular health of children and to tease out significant time points during the school day as a context where children spend substantial amounts of time (Chapter 5).

Objectives

1) Describe the amount of sedentary time, light physical activity, and MVPA accrued during a typical school day (whole school day, classroom, recess, lunch, scheduled physical education)
2) Compare activity intensity for boys and girls during each of these school day time periods
3) Describe whether girls and boys are achieving the recommended amount of MVPA during recess (40% of recess and lunch breaks; United Kingdom [343]), physical education (50% of physical education class; United States [345]), and across the whole school day (30 minutes accumulated during the school day; Canada: BC Ministry of Education [379])
4) Determine whether there is a difference in the proportion of boys and girls achieving the recommended guidelines during each of the time periods that comprise a typical school day

Hypotheses

1) Girls will accrue more sedentary time, less light physical activity, and less MVPA compared with boys.

   H_0: Girls will not accrue more sedentary time, less light physical activity, or less MVPA compared with boys.
2) On average, children will not achieve physical activity guidelines across all time periods.

   H_0: On average, children will achieve physical activity guidelines across all time periods.
3) A smaller proportion of girls compared with boys will meet physical activity guidelines.

   H_0: The proportion of girls meeting guidelines will not be smaller than the proportion of boys.

2.6.3 Study 3: The cross-sectional association of physical activity and sedentary time with arterial compliance in young children

Rationale

Historically, researchers used subjective measures of physical activity, such as questionnaires, to understand the relation between physical activity and health. This relation is often weak in children; however, evidence suggests that the link between physical activity and health outcomes is stronger when physical activity is measured objectively instead of with a subjective method such as self-report [268,380]. For example, the link between physical activity and metabolic syndrome was only significant when objective measures of physical activity were used in place of subjective measures [268]. Furthermore, subjective measures of physical activity are unable to 'deconstruct' *how* physical activity is undertaken (e.g., bouts) and at what *intensity*, across an average day. Very few studies linked the pattern and intensity of children's activity with health outcomes [211,222] and none have explored the relation with more specific measures of cardiovascular health such as arterial compliance (Chapter 6).

Objectives

1) Describe the cross-sectional relation between arterial compliance and objectively measured physical activity (total physical activity, total MVPA, bouted MVPA, light physical activity, moderate physical activity, and vigorous physical activity) and sedentary time.
2) Evaluate whether MVPA accumulated in bouts is associated with arterial compliance independent of the total volume of MVPA.

Hypotheses

1) Physical activity will be positively associated with arterial compliance.

   H_0: Physical activity will not be positively associated with arterial compliance.
2) Sedentary time will be negatively associated with arterial compliance.

   H_0: Sedentary time will not be negatively associated with arterial compliance.
3) Bouted MVPA will be positively associated with arterial compliance independent of total MVPA.

   H_0: Bouted MVPA will not be positively associated with arterial compliance independent of total MVPA.

2.6.4 Study 4: The cross-sectional association of physical activity with cardiovascular fitness in children: are activity bouts important?

Rationale

In adults, there is a positive relation between MVPA and cardiovascular fitness [180,181]. However, whether this relation extends to children has been debated as physical activity explains only a small portion of the variance in cardiovascular fitness in children [229]. Recently, MVPA accumulated in bouts of at least 5 or 10 minutes predicted risk of overweight beyond total MVPA [222]. To date, three studies have observed significant associations between cardiovascular fitness and MVPA accumulated in 5 [126,200,211] or 10 minute [126] bouts. However, none of these studies evaluated the magnitude of the association *independent* of the total volume of MVPA (Chapter **7**).

Objectives

1) Describe the cross-sectional relation between cardiovascular fitness and objectively measured physical activity (total physical activity, total MVPA, bouted MVPA, light physical activity, moderate physical activity, and vigorous physical activity) and sedentary time.
2) Evaluate whether MVPA accumulated in bouts is associated with cardiovascular fitness independent of the total volume of MVPA

Hypotheses

1) Physical activity will be positively associated with cardiovascular fitness.
   H_0: Physical activity will not be positively associated with cardiovascular fitness.
2) Sedentary time will be negatively associated with cardiovascular fitness.
   H_0: Sedentary time will not be negatively associated with cardiovascular fitness.
3) Bouted MVPA will be positively associated with cardiovascular fitness independent of total MVPA.
   H_0: Bouted MVPA will not be positively associated with cardiovascular fitness independent of total MVPA.

2.6.5 Study 5: Is a novel school-based physical activity model (Action Schools! BC) an effective means to enhance cardiovascular fitness in children? A randomized controlled effectiveness trial

Rationale

A substantial number of excellent school-based physical activity intervention trials assessed the *efficacy* (i.e., effect under well-controlled experimental conditions) of the intervention on health outcomes in children. However, very few studies evaluated the *effectiveness* (i.e., as research is disseminated and translated into practice) once it was disseminated on a wide-scale and in a more natural school setting. Furthermore, most studies evaluated the effect of an intervention over a single school year. Action Schools! BC was evaluated in an efficacy pilot study from 2003-2004 and reported positive outcomes for physical activity [358], cardiovascular fitness [357], and bone health [381]. This study will contribute to the current literature by establishing the effectiveness of the Action Schools! BC model after province-wide dissemination over 2 school years (Chapter 8).

Objectives

1) Evaluate changes in cardiovascular fitness in boys and girls in response to the dissemination of a school-based physical activity model (AS! BC) across year one and year two of the intervention dissemination trial.

Hypotheses

1) Cardiovascular fitness will increase significantly more in girls and boys attending schools randomly assigned to the intervention arm compared with children attending schools randomly assigned to the control arm in i) year one and ii) year two of the intervention trial.

   H_0: Cardiovascular fitness will not increase significantly more in girls and boys attending schools randomly assigned to the intervention arm compared with children attending schools randomly assigned to the control arm in i) year one and ii) year two of the intervention trial.

3 Study and cohort description

This section describes research methods common to each research question. This includes a brief description of the AS! BC model, an overview of the cohort of students included in this thesis as well as a description of the measurement protocols. Methods and statistical analyses unique to each research question appear within the appropriate chapter.

3.1 The Action Schools! BC model

Action Schools! BC (AS! BC) is a flexible, school-based physical activity model that was developed in response to reports of escalating levels of physical inactivity and obesity in children from British Columbia, all of Canada and around the world [21,312-314]. Action Schools! BC provides elementary schools with the tools and support required to create customized action plans that promote physical activity and healthy living. The vision of AS! BC is twofold: First, that "physical activity and healthy eating are integrated into the fabric of schools and maintained through partnerships with family and community" and second, that "long-term, measurable and sustainable health benefits are achieved" [382]. Action Schools! BC targets four health outcomes (Figure 3-1); however, for the purposes of this thesis I will focus on the cardiovascular health component.

Figure 3-1. Action Schools! BC has four health targets: bone health, cardiovascular health, muscular health and psychosocial health.
Images © Action Schools! BC (2006).

3.1.1 The development of Action Schools! BC

The development of the AS! BC model began in December 2002 as described previously by Naylor et al. [383]. AS! BC applied a socioecological approach (Figure 3-2) to promote healthy living within the elementary school context [383]. As applied to health behaviours, ecological models highlight the important influences and interactions in the social, environmental, and political environments, in addition to personal attributes. By considering these additional sources of influence, interventions designed with ecological theory in mind are more comprehensive, and hopefully, more likely to effect change [384].

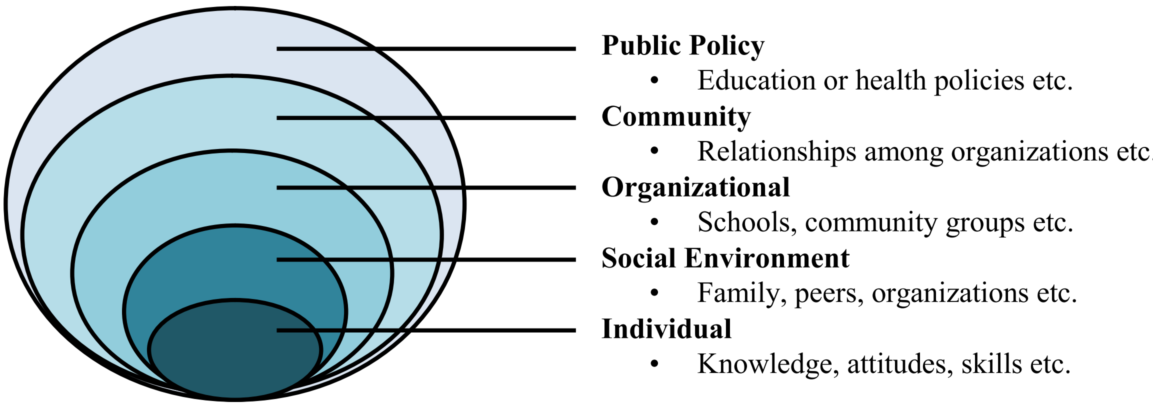

Figure 3-2. Socioecological model showing multiple levels of influence on an individual's behaviour (based on McLeroy et al. [385]**)**

Action Schools! BC took a multi-sector approach (health, education etc.) to address these multiple levels of influence. First, a research partnership with five provincial agencies (BC Ministry of Education; BC Ministry of Health; BC Ministry of Tourism, Sport, and the Arts; Provincial Health Services Authority; and 2010 Legacies Now) was established. Then, committees that made horizontal (across sectors) and vertical (from practitioners to policy makers; Appendix C) connections were convened to guide model development and implementation [383] (Figure 3-3).

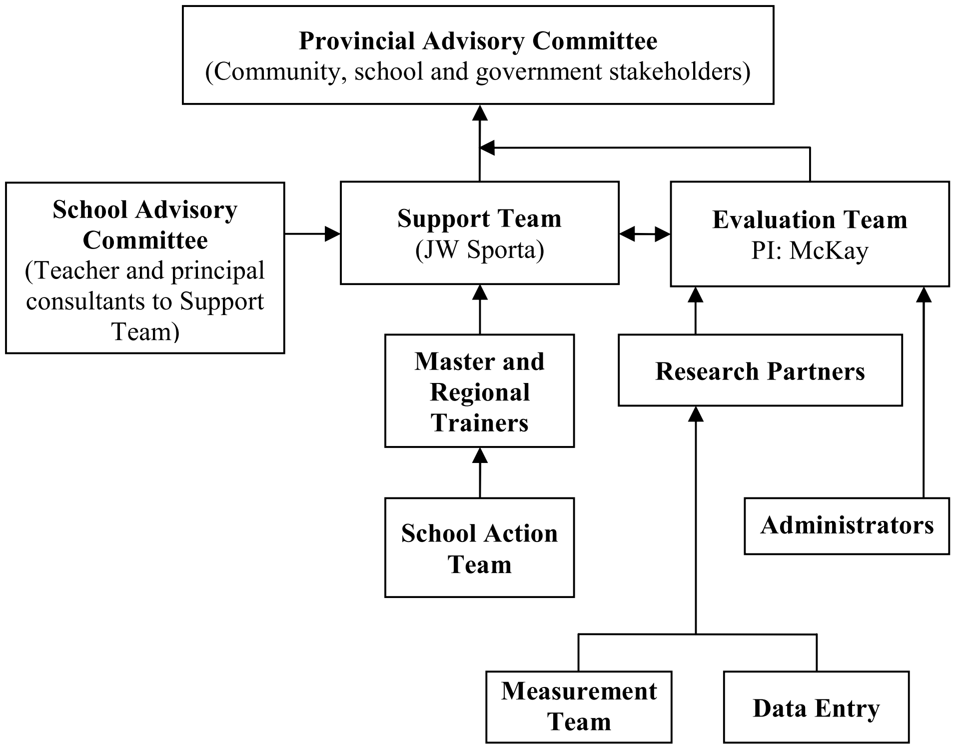

Figure 3-3. Organizational structure of AS! BC during development of the model [386]**.** *Reprinted, from HM MacDonald (2006) Effectiveness of a school-based physical activity intervention for increasing bone strength in children: Action Schools! BC. University of British Columbia, with permission.*

The **Provincial Advisory Committee** included individuals from community, school, and government stakeholder groups. This committee provided feedback on initial model development and implementation strategies, particularly with respect to potential barriers. These individuals were then able to communicate the final model to their respective stakeholder groups. The **AS! BC Support Team** was comprised of experts hired from JW Sporta, a consulting company with 25 years in the school system where they developed and implemented a school-based sport skill program. This team (with researchers) led development and implementation of the AS! BC model by initially reviewing the 'best practice' physical activity literature. The support team convened a **School Advisory Committee** that was comprised of teachers and principals who provided feedback on development and implementation strategies. Finally, the **Evaluation Team** was composed of researchers with expertise in target health outcomes. This team designed and implemented the multiple outcome evaluation (study design, research methods, data collection, data analysis, and dissemination of key findings etc.).

3.1.2 The implementation of Action Schools! BC

A unique aspect of the AS! BC model is its *flexibility*. Action Schools! BC is a 'framework for action' that promotes and supports increased physical activity across six Action Zones (Table 3-1). Instead of being curriculum based, teachers and schools can choose one or more areas that they wish to target for additional physical activity. A short description of each Action Zone and a sample activity from one of the planning resources [382] is provided in Table 3-1. The only prescriptive component of AS! BC is 'Classroom Action' where teachers are asked to provide an additional 15 minutes of physical activity during class time each day for a total of 75 minutes/week. In conjunction with scheduled physical education, ultimately the AS! BC model aims to achieve the goal of 150 minutes of physical activity/week.

Table 3-1. The six Action Zones of Action Schools! BC [382].

Action Zone	Description	Sample Action Idea
SCHOOL ENVIRONMENT	Makes healthy choices the easy choices by creating safe and inclusive school environments, and supporting healthy living policy.	Provide bike racks or create bike storage in a safe location on the school grounds.
SCHEDULED PHYSICAL EDUCATION	Provides an annual physical education calendar of ideas and best practice resources that support the Ministry of Education prescribed learning outcomes for scheduled physical education	Teach the skills of a variety of activities – team and individual sports, traditional and alternative pursuits, gymnastics, dance, yoga.
CLASSROOM ACTION	Provides creative, alternative classroom physical activity ideas that complement physical and health education, and build healthy bodies and minds.	Integrate nutrition, physical activity and healthy living into the daily routine of the class.
FAMILY AND COMMUNITY	Fosters the development of partnerships with families and community practitioners to benefit from the wealth of resources available to promote and encourage healthy living.	Support students gaining community activity experiences such as rock climbing, skating, skiing, swimming, hiking, or curling.
EXTRA-CURRICULAR	Supports a variety of opportunities for students, staff and families to engage in healthy living before and after school, and during lunch and recess.	Create clubs that are accessible and fun for all students (e.g., climbing club, skipping club, kilometer club).
SCHOOL SPIRIT	Cultivates school spirit by encouraging physical activity, supporting healthy eating choices, and celebrating the benefits of healthy living for the whole school.	Organize physical activity events for students and school staff (e.g., Terry Fox Run).

Content © Action Schools! BC (2006).

Implementation of AS! BC occurs through structured channels (Figure 3-3) using a number of key resources (Table 3-2). First, schools convene a **School Action Team** which includes one or more persons committed to promoting healthy living in the school. The School Action Team (or a teacher/administrator at the school) completes a School Health Inventory (Appendix D) and works with the AS! BC Support Team to develop an action plan that outlines yearly physical activity and healthy living goals across the six Action Zones (Appendix E).

Next, teachers are trained to deliver the Classroom Action component of the model at a workshop coordinated and facilitated by the AS! BC Support Team and **Master or Regional Trainers**. Master and Regional Trainers are elementary school teachers (generalist and physical education specialists) who are passionate about the initiative and want to be involved at the community level. Training of Master and Regional Trainers occurs during the summer at the AS! BC Summer Institute. Classroom Action workshops are designed to introduce generalist teachers to the AS! BC model and build skills and confidence to deliver physical activity. Release time is provided by the Ministry of Education to allow teachers to attend an AS! BC workshop. After training, teachers receive a classroom action bin (Figure 3-4, Appendix F) filled with playground balls, chalk, videos, skipping ropes, exercise bands, hand grippers, and accompanying written resources [382,387,388] that support their customized Action Plan. The AS! BC Support Team provides resources, on-going consultation and communicates with schools and the research team throughout the school year.

Figure 3-4. The components of an Action Schools! BC Action Bin.
See Appendix F for a list of the Action Bin contents.

Table 3-2. Resources that support the Action Schools! BC model [389]**.**

Resource	**Description**
Action Pages [387]	A resource directory using curriculum organizers to link teachers, coaches, or community instructors with recommended and available resources from across Canada.
Planning Guide for Schools and Teachers [382]	A set of inventories and worksheets that guide teachers and the School Action Team to identify school priorities and create their Action Plan. The Planning Guides provide sample goal statements, action ideas, lesson plans, and recommended resources for each of the six AS! BC Action Zones. An annual physical education calendar is also included.
AS! BC Classroom Action Resource	A model to help teachers integrate more physical activity opportunities throughout the school day.
Classroom Action Bin	A storage bin for the classroom filled with playground balls, videos, skipping ropes, exercise bands, strength grippers, and written resources (such as the Action Pages and Planning Guides) that support the Action Plan (Appendix F).
Action Plan	Integrates the efforts and actions of teachers, school administrators, families, and community practitioners to achieve goals in six Action Zones. The School Action Plan is used to record a school's goal statements and actions for each of the six Action Zones. Action Plans should be completed every year (Appendix E).
AS! BC Workshops	AS! BC workshops introduce the initiative to the generalist teacher, build capacity, contribute to the school culture, and nurture sustainability by providing a motivational and practical in-service for school staff, administrators, and other members of the school community. The workshops also provide an opportunity to promote success stories from other Action Schools and encourage school staff to request subsequent workshops to enhance their ability to promote healthy living. AS! BC workshops are delivered by the Support Team or Master or Regional Trainers.
AS! BC Website	The website hosts information about the intervention and research programs, downloadable planning templates and resources, media coverage and promotional pieces, and links (www.actionschoolsbc.ca)

3.2 Action Schools! BC pilot investigation

The AS! BC model was evaluated in a pilot study between February 2003 and June 2004. Schools that volunteered to be a part of the pilot investigation were randomized to one of three study arms: Intervention level 1 ('liaison' schools), intervention level 2 ('champion' schools), or control. The two intervention arms differed only in the amount of facilitation provided to the schools after teacher training (approximately 2-4 hours/week for liaison schools and 0.5-1 hour/week for champion schools). At level 1 schools an AS! BC facilitator worked with a self-selected teacher champion to complete school health inventories and provided individual mentorship to teachers at the school. At level 2 schools the self-selected teacher champion completed school health inventories and there was less frequent contact with an AS! BC facilitator for individual teachers. Control schools maintained their regular school activities.

At follow up, the amount of physical activity delivered at intervention schools was higher than at control schools; however, there were no differences between the two intervention arms [389]. Compared with children attending control schools, children attending intervention schools experienced beneficial changes in physical activity [358], cardiovascular fitness [357], and bone health [381] with no deleterious effects on academic performance [390]. These positive outcomes encouraged funding and supported dissemination of the model across the province of British Columbia.

3.3 Action Schools! BC dissemination evaluation

For dissemination, the AS! BC model was modified slightly from its previous format into one more conducive to widespread implementation and evaluation. Specifically, there was only one intervention arm, which was modelled after the ‘champion’ arm of the pilot study. Details for the provincial dissemination evaluation of AS! BC are provided in the remainder of this chapter. This investigation was approved by the human research ethics boards at the University of British Columbia (B05-0505) and the University of Victoria (07-05-149f).

3.3.1 Study design

The dissemination of AS! BC was evaluated using a cluster randomized controlled trial of 30 elementary schools (n=1,529 consented children) from four (out of five) provincial health authorities. The evaluation took place over two school years (Sept 2005 - Jun 2007); measurement was conducted at the beginning and end of each school year (Time (T)1, Fall 2005; T2, Spring 2006; T3, Fall 2006; T4, Spring 2007; Figure 3-5).

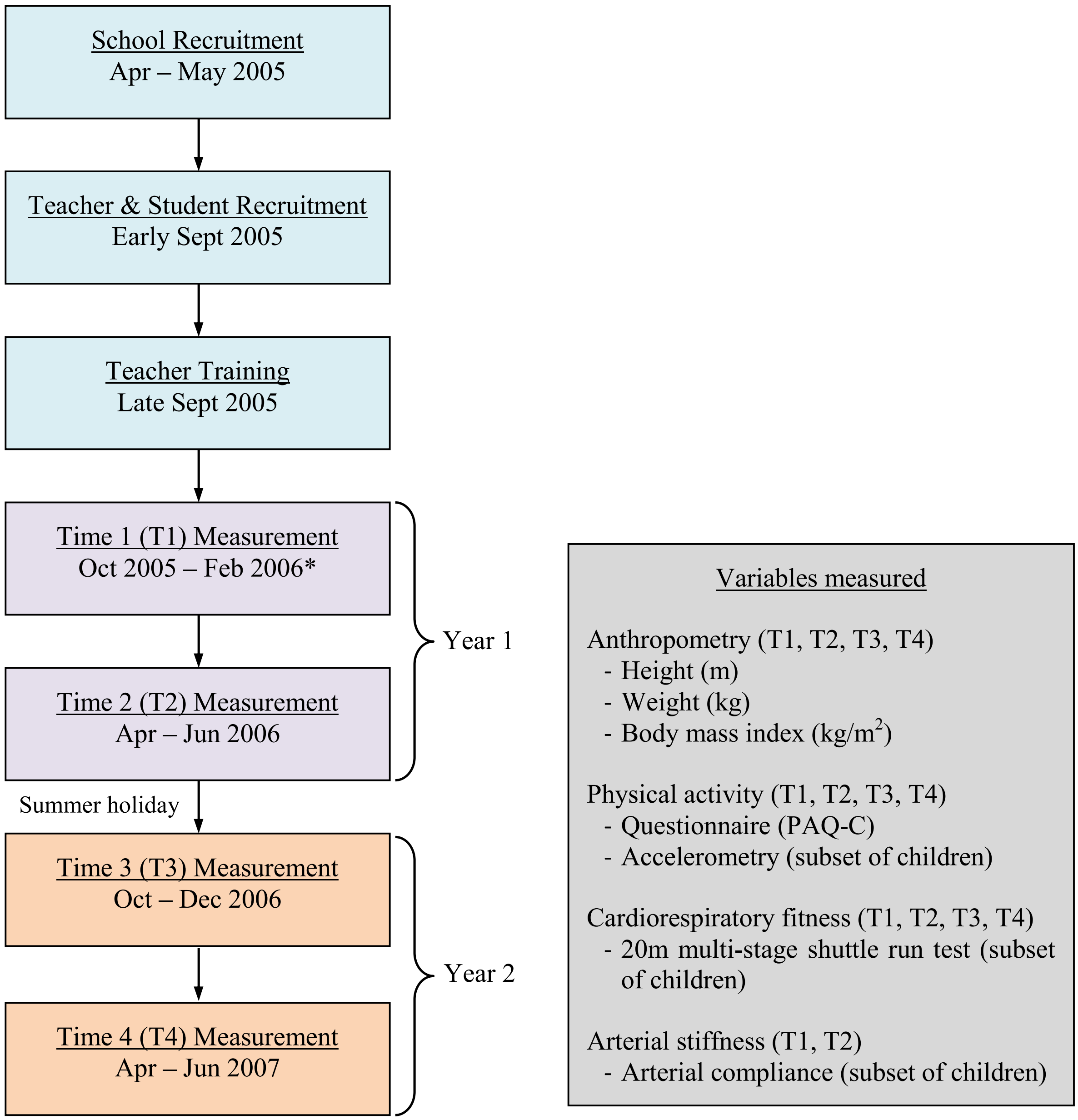

Figure 3-5. Timeline of AS! BC dissemination evaluation and measurements conducted at each time point.

**There was a province wide teacher's strike that disrupted this measurement period (T1); PA, physical activity; PAQ-C, physical activity questionnaire for children.*

3.3.2 School and teacher recruitment

School and teacher recruitment was initiated in April 2005. The recruitment process included 1) presentations of the study to school districts and/or principals at relevant meetings; 2) letters of invitation to schools and teachers (Appendix G); and 3) a second letter to volunteer schools inviting grade 4 and 5 teachers to participate in the evaluation process (Appendix H). Of the 87 schools assessed for eligibility, 30 schools including 2,401 students met our inclusion criteria (not currently participating in AS! BC or any other physical activity or healthy eating program). Eligible schools were stratified by size (> 300 or < 300 students) and geographic location (4 regions) and randomly assigned to control (14 schools) or intervention (16 schools) conditions (Figure 3-6).

3.3.3 Student recruitment and consent

In September 2005, the study was presented to grade 4 and 5 students whose teachers had agreed to participate in the evaluation. All students who participated in regular physical education classes and provided parental consent (Appendix I) were eligible to participate in the evaluation. Importantly, as the AS! BC model was incorporated as part of regular school programming all students took part in the intervention, regardless of whether they consented to be evaluated.

3.3.4 Sample sizes

The data used in this thesis are a sub-sample of a larger data set, therefore sample size calculations were not performed for the individual research questions. A total of 1,529 children (747 intervention, 782 control) from 30 schools consented to participate in the AS! BC evaluation. Anthropometry and physical activity (by questionnaire) were assessed in children from all 30 schools; other variables, such as cardiovascular fitness, physical activity (accelerometry) and arterial stiffness (arterial compliance) were measured in children from a subset of schools. A flow chart outlining the number of students who consented to each part of the evaluation is provided in Figure 3-6.

3.3.5 My role in the dissemination evaluation

The two-year dissemination trial was already underway when I began my thesis work. Thus I was not involved in data collection during year one (T1 and T2). During year two I was team leader and bore responsibility for the accelerometry portion of the evaluation. This entailed learning accelerometry methodology and software, distributing accelerometers to participants, collecting, screening, processing and cleaning accelerometry data during T3 and T4 measurement periods. I planned the accelerometry data cleaning procedure, processing, and variable extraction for accelerometry data across all four time points in conjunction with a research trainee. I also performed final data checks on the T1 and T2 processed data. Other data that are included in my thesis were collected and entered into the database by members of the Cardiovascular Physiology and Rehabilitation Laboratory (University of British Columbia), the Cognitive and Functional Learning Laboratory (University of British Columbia), and/or the AS! BC measurement team. However, prior to data collection at T3 I attended training sessions with the other members of the AS! BC measurement team and was trained for all AS! BC measurement protocols, including those contained within my thesis. I also attended and observed the training of master and regional teacher trainers at the AS! BC Summer Institute.

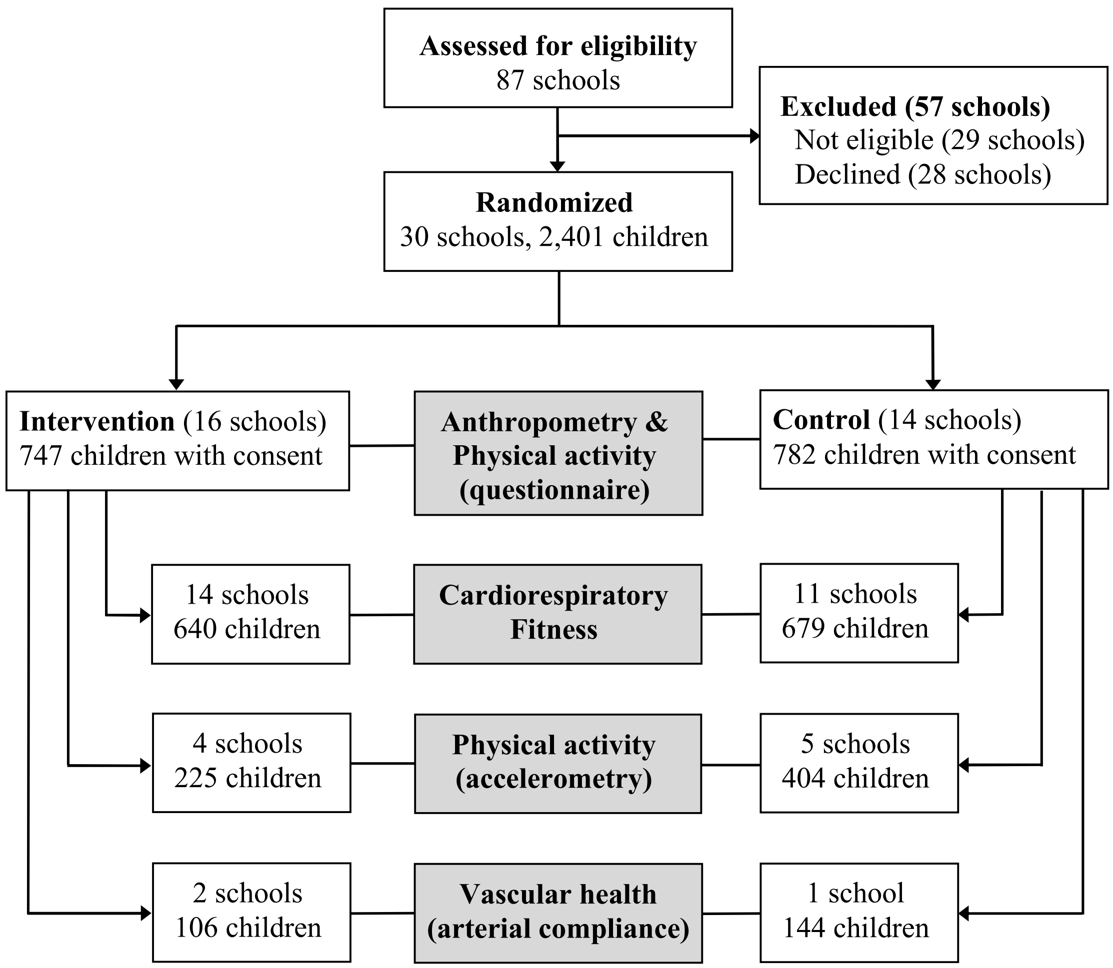

Figure 3-6. Number of children who consented for the various components of the AS! BC evaluation relevant to the current work.
The number of children lost to follow up and analyzed to address specific research questions are presented within each research chapter.

3.4 Measurements

All data were collected in the school by a team of trained research personnel. Children were excused from their classroom in small groups for measurement, which took place in school gymnasia, common spaces, or outdoors.

3.4.1 Anthropometry

Anthropometry was undertaken at each time period (T1, T2, T3, T4). Standing height (without shoes) was measured in duplicate to the nearest millimetre using a portable stadiometer (Seca Model 214, Hanover, MD). Gentle traction was applied to the mastoid processes while the head was maintained in the Frankfort plane. Body mass was measured in duplicate to the nearest 0.1 kg using an electronic scale (Seca Model 840, Hanover, MD). If measures of height or body mass differed by more than 4 mm or 0.2 kg respectively a third measure was taken. The average of the two closest values or the median of three equidistant values were used for analysis. Body mass index was calculated as body mass divided by height squared (kg/m^2).

3.4.2 Questionnaires

3.4.2.1 Health history questionnaire

A health history questionnaire (Appendix J) was completed by parents of all consented students at baseline (T1) to determine ethnicity and any medical conditions that would prevent the child from participating in regular physical activity. Ethnicity was classified based on the birthplace of both parents or all four grandparents. Most children were identified as Caucasian (57%) while the remainder were classified as Asian (25%), North American Aboriginal (10%), or other/mixed ethnicity (9%).

3.4.2.2 Physical Activity Questionnaire for Children (PAQ-C)

Physical activity was assessed at each of the four measurement periods (T1, T2, T3, T4) using a modified version of the PAQ-C [263,265] (Appendix K). The PAQ-C is a valid and reliable tool for assessing leisure time physical activity over the previous 7 days in elementary school-aged children. The questionnaire was modified by adding an estimate of activity *time* to question 1 and by adding questions about the child’s daily activities both within and outside school (questions 11-23). Children completed the questionnaire with the help of a research assistant who was able to prompt children with cues and examples (i.e., recess is 15 minutes long, lunch is usually 30 minutes).

The following physical activity variables were calculated and were considered as covariates:

1. General physical activity score (PAQ-C score): This variable ranges from 1 (low active) to 5 (high active); mean scores were calculated across nine questions (1-8, 11) based on self-reported frequency and intensity of physical activity. This is the original scoring tool of the PAQ-C.
2. Out of school physical activity: A score for out of school physical activity was created using the sum of three questions (5-7). Possible out of school physical activity scores range from 3 (low active) to 15 (high active).

3.4.2.3 Teacher physical activity logs

Teachers were asked to complete weekly physical activity logs outlining the physical activity that their class engaged in (Appendix L). This included scheduled physical education time as well as additional physical activity such as Classroom Action and physical activity-related field trips.

3.4.3 Blood pressure

Blood pressure and heart rate were measured in duplicate using an automated blood pressure monitor (BPM-100, VSM Medtech Ltd, Vancouver, Canada). Blood pressure was measured on the left arm using an appropriately sized cuff according to the procedures established by the Canadian Society for Exercise Physiology [391]. Children were asked to sit quietly in a chair with feet flat on the ground, back supported, and left elbow and forearm resting palm up on a table. If blood pressure was greater than 120/80 mmHg (95th percentile in this population) a third measure was taken after a 5 minute rest. If the third measure was above 120/80 mmHg (approximately the 95th percentile in this age group) the child was not permitted to participate in the cardiovascular fitness testing [392].

3.4.4 Cardiovascular fitness

Cardiovascular fitness was measured in children from 25 schools using a multistage 20 m shuttle run protocol [393]. The 20 m shuttle run is a valid [393,394] and reliable [393] tool to estimate cardiovascular fitness in field-based research. Children ran in groups of 4-6 back and forth along a marked 20 m course. The cadence was set by an audio recording with an audible signal that sounded at the end of each 20 m shuttle. A research assistant ran alongside students to assist with pacing. The test began at a running speed of 8.5 km/hr and increased 0.5 km/hr every min. Criteria for ending the test were: 1) the child was experiencing undue discomfort and could no longer continue despite verbal encouragement, 2) the child was unable to maintain the set cadence, or 3) the child failed to complete two consecutive 20 m shuttles at the target pace. We recorded the total number of laps completed and the corresponding speed was used in conjunction with their age in the following equation to estimate $\dot{V}O_2$ max (mL/kg/min):

$$\dot{V}O_2\,max = 31.025 + (3.238 \cdot speed) - (3.243 \cdot age) + (0.1535 \cdot speed \cdot age)$$

[Equation 1]

Where speed is the speed at the last lap and age is the integer age in years (rounded down). Cardiovascular fitness is reported both as number of laps completed and as estimated $\dot{V}O_2$ max (mL/kg/min).

3.4.5 Accelerometry

3.4.5.1 Accelerometry data collection

Physical activity data were collected in a subset of participants from nine schools using GT1M ActiGraph accelerometers (ActiGraph LLC, Florida). The GT1M is a small (3.8 x 3.7 x 1.8 cm) solid-state accelerometer that detects vertical acceleration signals in the range of 0.05 to 2.00 G's. The signal is band limited to the frequency range of 0.25-2.50 Hz. This frequency detects normal human motion and excludes motion from other sources (such as riding in a vehicle) [395]. Accelerometer activity counts are summed over a user-specified epoch (interval), which was set at 15 seconds for the purposes of this investigation.

A research assistant distributed accelerometers and a log sheet (to record monitor on and off times; Appendix M) to participants at their schools and provided instruction on correct wear. Accelerometers were attached to an elastic belt that was worn around the child's waist with the accelerometer positioned at the iliac crest (Figure 3-7). Participants were asked to wear the monitor during waking hours and to remove it only for sleeping, bathing, showering, and swimming. With the exception of one school at T1 (where monitors were distributed on a Friday and collected 4 days later at the end of the day (a Tuesday) and one school at T4 (where monitors were distributed on a Monday and collected 8 days later (a Tuesday) all monitors were distributed on a Wednesday and collected 5 days later (the following Monday; T1 and T2) or 6 days later (Tuesday; T3 and T4) morning. Accelerometers were programmed to begin operating at the beginning of the first school day (typically a Wednesday). However, data from the first day were excluded to eliminate between-school differences in distribution time and any initial reactivity by children to the monitor.

Figure 3-7. ActiGraph worn on the waist with an elastic belt.

3.4.5.2 Accelerometry data reduction and processing

Following the wear period, accelerometer data were downloaded to a computer and each file was individually screened in Microsoft Office Excel version 2003 or 2007 (Microsoft Corporation, Redmond, WA) for spurious data (i.e., extremely high values representing monitor saturation) and patterns (i.e., extended periods of the same count value). Participants had to accumulate at least 10 hours of wear time on at least 3 days for their data to be considered for further data processing [248]. The rationale for combining individuals with 3 or 4 days of valid data in the analyses is provided in Appendix N. All data processing was performed using custom written software (KineSoft software, Saskatoon, Canada) designed to standardize and optimize accelerometer data [396]. This software summarizes the raw (15 second) accelerometer data into user-specified outcome variables (described below).

To distinguish non-wear periods from true sedentary time (i.e., when extended periods of zeros in the data file were due to monitor removal as opposed to being stationary) the method of Esliger et al. [396] was adopted; that is, the mean length and 95% confidence interval of motionless bouts that were unexplained by the participant's log sheet were calculated. This value was 25 ± 3 minutes; therefore, periods of continuous zeros ≥ 30 minutes were considered biologically implausible and these data were excluded from the analysis.

Physical activity intensity was determined using age-specific cut points (physical activity intensity thresholds) and the participant's age on the day the monitor was distributed [257]. These cut points were developed and validated in a group of 80 children aged 6 to 17 years, through a laboratory-based calibration study. Regression analysis was used to relate treadmill exercise intensity (via respiratory gas exchange measures) and accelerometer counts (raw accelerometry units) [397]. The regression equation is:

$$METs = 2.757 + (0.0015 \cdot counts \cdot min^{-1}) - (0.08957 \cdot age) - (0.000038 \cdot counts \cdot minute{-}1 \cdot age$$

[Equation 2]

Where METs is the metabolic equivalent, counts/minute is the raw accelerometer data and age is the integer age in years (rounded down). This equation accounted for 90% of the variance in measured MET level with a correlation of 0.86 between measured and predicted MET values [257,397]. The equation was not designed to predict counts/minute below 3.0 METs therefore two key assumptions were made in order to calculate thresholds for lower MET values: 1) At all ages 1.0 METs was assumed equal to zero counts/min and 2) 1.5 METs was assumed equal to 0.25 the count value at 3.0 METs.

For this thesis, MVPA (≥ 3.0 METs), sedentary time (< 1.5 METs), light physical activity (1.5-2.9 METs), moderate physical activity (3.0-5.9 METs) and vigorous physical activity (≥ 6.0 METs) were defined as the primary physical activity outcomes of interest. The equivalent accelerometer cut points for these MET values for students included in the evaluation are shown in Table 3-3. Using the KineSoft software the following variables were calculated and extracted:

1. MVPA, sedentary time, light physical activity, moderate physical activity, and vigorous physical activity (average minutes per day) (Chapters 4, 6, 7).
2. Sedentary time and MVPA accumulated in bouts (average bouted minutes/day). The bout durations were 0-5 minutes, 5-10 minutes, 10-20 minutes, and ≥ 20 minutes (Chapters 4, 6, 7).
3. MVPA, light physical activity, and sedentary behaviour at specific times during the school day (average minutes per day in each specified window of time). The specific time periods of interest were the whole school day, classroom time, recess, lunch, and scheduled physical education (Chapter 5).

Table 3-3. Age-specific cut point ranges (counts/15 second epoch) for activity intensity categories.

	Age				
	8	**9**	**10**	**11**	**12**
MVPA	≥ 201	≥ 226	≥ 254	≥ 284	≥ 316
SED	< 50	< 57	< 64	< 71	< 79
LPA	50-200	57-225	64-253	71-283	79-315
MPA	201-827	227-874	255-923	284-976	316-1033
VPA	≥ 828	≥ 875	≥ 924	≥ 977	≥ 1034

MVPA, moderate to vigorous physical activity (≥ 3.0 METs); SED, sedentary time (< 1.5 METs); LPA, light physical activity (1.5-2.9 METs); MPA, moderate physical activity (3.0-5.9 METs); VPA, vigorous physical activity (≥ 6.0 METs) These ranges were calculated using the regression equation of Freedson et al. [397] *and Trost et al.* [257].

3.4.6 Arterial compliance

Arterial compliance was used as an index of vascular health. Compliance was measured non-invasively using the HDI/Pulsewave CR 2000 system (Eagan, MN, USA). This device acquires radial artery waveforms from the right arm using applanation tonometry. Applanation tonometry is ideal for use in large studies and with children because it requires little in the way of technical expertise and can be done relatively quickly in a field setting [75]. The radial waveform is calibrated with simultaneous measures of brachial blood pressure via an automated oscillometric blood pressure cuff on the left arm. Children rested supine for at least 5-10 minutes prior to measurement. The sensor was positioned over the radial artery and adjusted until an adequate waveform was obtained. The child's height and weight were entered into the device and 30-second recordings of arterial waveforms were acquired.

I will briefly describe arterial pulse pressure waveforms here before describing how compliance measures were derived. A sample arterial waveform is provided in Figure 3-8. Blood is ejected from the left ventricle into the arterial system when the aortic valve opens, resulting in a rapid increase in arterial pressure (P_1). The backward reflection of earlier waveforms from peripheral branch points produces a secondary increase in pressure (P_2). Aortic valve closure yields a brief pressure fluctuation (the dicrotic notch) and signifies the end of systole and the beginning of diastole. After aortic valve closure, pressure in the arteries decreases until the next left ventricular ejection.

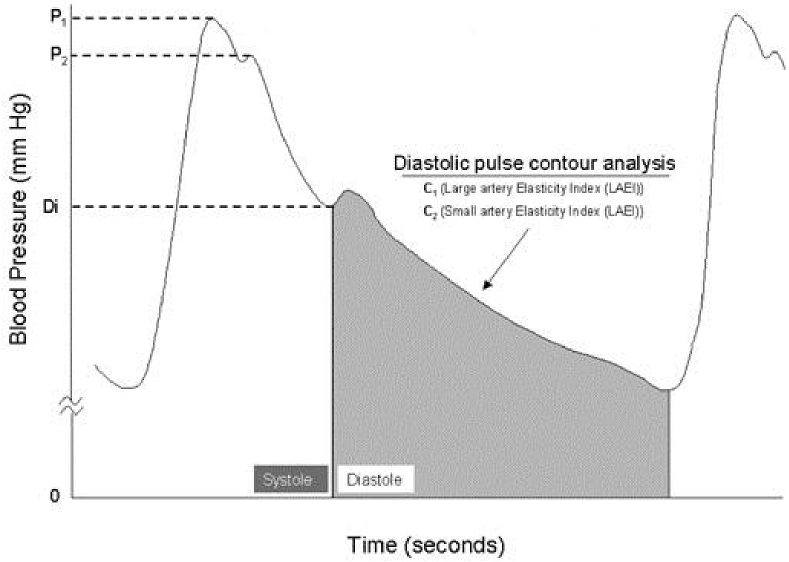

Figure 3-8. Diastolic pulse contour analysis of the radial artery waveform [398]**.**
P_1, initial increase in arterial pressure (caused by left ventricular contraction); P_2, secondary increase in arterial pressure (caused by reflection of earlier waveforms from peripheral branch points); Di, dicrotic notch (caused by aortic valve closure). Adapted by permission from Macmillan Publishers Ltd: American Journal of Hypertension, Duprez DA, Kaiser DR, Whitwam W, Finkelstein S, Belalcazar A, Patterson R, Glasser S, Cohn J, Determinants of radial artery pulse wave analysis in asymptomatic individuals, copyright (2004).

The HDI/Pulsewave software models the diastolic portion of the mean arterial waveform obtained over the 30-second interval using a third order equation (modified Windkessel model) [76]. The equation partitions the diastolic wave into an exponential decay (representing large artery or capacitive compliance) and an oscillatory decay (representing small artery or oscillatory compliance). The equation is [76]:

$$P\,(t) = \underbrace{A_1 \exp(-A_2 t)}_{A} + \underbrace{A_3 \exp(-A_4 t)\cos(A_5 t + A_6)}_{B} \qquad \textbf{[Equation 3]}$$

Where *P* is the diastolic pressure at time *t* relative to aortic valve closure. The A_i parameters are fit with a parameter-estimating algorithm. The first part of the equation (A) models the exponential decay while the second part of the equation (B) models the oscillatory decay [399].

After optimization of A_i parameters, values for large (C_1) and small (C_2) arterial compliance are calculated using the following formulae [400]:

$$C_1 = \frac{2A_4[A_2+A_4)^2+A_5^2]}{[R \cdot A_2 \cdot (2A_4+A_2)(A_4^2+A_5^2)]} \quad \textbf{[Equation 4]}$$

$$C_2 = \frac{1}{R \cdot (2A_4+A_2)} \quad \textbf{[Equation 5]}$$

Where C_1 and C_2 are large (capacitive) and small (oscillatory) artery compliance respectively, A_i are parameters from the third order model that describe the diastolic portion of the arterial pulse wave and R is an estimate of systemic vascular resistance.

Systemic vascular resistance can be estimated using the following equation [400]:

$$R = \frac{MAP}{CO} \quad \textbf{[Equation 6]}$$

Where R is systemic vascular resistance, MAP is mean arterial pressure (calculated by integrating the area under the pulse wave curve) and CO is cardiac output.

Cardiac output can be estimated as the product of heart rate (measured) and stroke volume calculated using the following equation [76]:

$$SV = -6.6 + (0.25 \cdot ET) - (0.62 \cdot HR) + (40.4 \cdot BSA) - (0.51 \cdot Age) \quad \textbf{[Equation 7]}$$

Where SV is stroke volume, ET is ejection time (ms), HR is heart rate (beats/min), BSA is body surface area (mm^2), and age is in years.

The non-invasive derivation of arterial compliance has been validated against invasive measures of brachial artery compliance [76] as well as the stroke volume to pulse pressure ratio and MRI-determined aortic distensibility [401]. Furthermore, these measures are repeatable over short (3-60 minutes), medium (7-14 days), and longer (5-177 days) intervals [76,402]. Small (mL/mmHg x 100) and large (mL/mmHg x 10) arterial compliance are the primary vascular outcome variables.

3.4.7 Statistical analyses

All statistical analyses were performed using Stata version 10.1 (StataCorp, College Station, TX). For each research question the data were checked for normality and outliers using box plots and scatter plots. To check for potential data entry errors the data of outliers were verified (and corrected where necessary). Outliers were not removed from the analysis except where data were physically or physiologically implausible (e.g., reporting more minutes of physical activity than are possible during one day). The specific statistical analysis used to address each research question is presented within each research chapter.

4 The association of accelerometer epoch length with the measurement and classification of children's activity intensity and pattern[2]

SYNOPSIS: The selection of an appropriate epoch length is a critical decision with important implications for data resolution and measurement of physical activity patterns, particularly in children. Many investigations have used a one-minute epoch during measurement; however, this may not accurately capture sporadic behaviours. This chapter explores the relation between epoch length and the measurement and classification of activity intensity and patterns in children.

4.1 Introduction

Our ability to accurately measure and classify physical activity is essential both for population-level surveillance and to examine the relation between physical activity intensity and selected health outcomes [39]. It is especially challenging to measure physical activity in children because their activity tends to be sporadic and short in duration [36,37]. Accelerometers are commonly used to objectively measure the amount and intensity of physical activity, however, a number of different methods have been used to assess physical activity using accelerometry. Therefore, one focus of this thesis is to explore how the choice of epoch length influences estimates of children's physical activity. For example, longer epochs (e.g., 60 seconds) may result in poor estimates of physical activity when short periods of high intensity activity are interspersed with longer periods of less intense physical activity within the same measurement interval [403]. Thus, longer epochs may flatten the overall intensity of physical activity and may fail to adequately represent children's transient, intermittent bouts of activity [36,37].

To date, four studies [403-406] have examined the influence of epoch length on physical activity outcomes in children; three studies specifically reported the influence of epoch length on MVPA. Of these, one noted that children undertook more MVPA when physical activity was assessed with shorter (15 second) epochs [403], another, that children undertook more MVPA when physical

[2] Original data from Chapter 4 are being used to prepare a manuscript (Nettlefold L, McKay HA, Naylor PJ, Warburton DER. Association of epoch length with measurement of children's physical activity and sedentary time).

activity was assessed with longer (60 second) epochs [404], and the third study found no difference in the amount of MVPA undertaken when physical activity was measured with short (1 second) versus long (60 second) epochs [406]. Similar discrepancies are noted for sedentary time [403,404], light physical activity (LPA) [404,406], and moderate physical activity (MPA) [404-406].

The health benefits of *total* MVPA in children are now well established [268,279]. However, an emerging area of research focuses on the pattern of MVPA accumulation (e.g., extended 'bouts' of MVPA vs. single epochs) and the influence of bouted MVPA and/or sedentary behaviour on selected health outcomes. For example, in youth (aged 8-17 years), MVPA accumulated in bouts of at least 5 or 10 minutes reduced the odds of a child being overweight, independent of the total volume of MVPA [222]. In adults, sedentary behaviour increased all-cause and cardiovascular mortality risk [23,24] and was unfavourably associated with cardiometabolic risk factors [407]. Further, the number of breaks in sedentary time was beneficially associated with indicators of metabolic health such as waist circumference, BMI, triglycerides and plasma glucose [326]. Despite these established relationships, only one small (n=16) investigation [405] examined the influence of epoch length on measurement of MVPA patterns (i.e., bouts) and none have examined the influence of epoch length on measurement of sedentary behaviour patterns.

Thus, the primary objectives of this study were to evaluate a cohort of children to determine the association of epoch length (15 second vs. 60 second) with; 1) volume (i.e., minutes/day) of MVPA, sedentary time, LPA, MPA, and vigorous physical activity (VPA), and, 2) patterns (i.e., minutes/day accumulated in bouts) of MVPA and sedentary time. We hypothesized that when children's physical activity is measured using a 15 second epoch 1) the volume of sedentary time and vigorous physical activity will be greater, compared with a 60 second epoch, and 2) the volume of bouted activity (bouted sedentary time and MVPA) will be lower, compared with a 60 second epoch.

4.2 Methods

The recruitment process is described in detail in Chapter 3. Children (n=629) at nine schools in the larger investigation consented to participate in this component (physical activity measurement via accelerometry).

Briefly, we assessed anthropometry using standard methods and used accelerometry to evaluate physical activity; specific details are provided in Chapter 3. Physical activity data were collected in 15 second epochs and reintegrated to create 60 second epochs using custom software (Epoch Conversion

Tool, Saskatoon, Canada). Both 15 second and 60 second data files were processed using KineSoft software, version 3.3.49 (Saskatoon, Canada).

We used KineSoft software to extract the following physical activity variables: MVPA (≥ 3.0 METs; minutes/day), sedentary time (SED; < 1.5 METs; minutes/day), LPA (1.5-2.9 METs; minutes/day), MPA (3.0-5.9 METs; minutes/day) and VPA (≥ 6.0 METs; minutes/day). We also extracted patterns of accumulated MVPA and sedentary time (minutes per day in bouts). We considered four different 'bouts' of physical activity: 0-5 minutes, 5-10 minutes, 10-20 minutes, and ≥ 20 minutes. We developed the following margins of tolerance for interruptions in defined bouts of physical activity (i.e., when physical activity intensity fell outside the specified boundaries). For bouts 0-5 minutes in length, interruptions were not permitted. For bouts 5-10 minutes in length we permitted a 30 second interruption (15 second data only). For bouts 10-20 minutes in length we permitted a 1 minute interruption and for bouts ≥ 20 minutes in length we permitted a 2 minute interruption. Data from 15 second and 60 second epochs are denoted with subscript 15 and 60 respectively (i.e., $MVPA_{15}$ and $MVPA_{60}$).

Statistical analyses

We used Stata Version 10.1 (StataCorp, College Station, TX) to perform all statistical analysis. The strength of the relation between physical activity variables measured in 15 second or 60 second epochs was assessed using Pearson product moment correlation coefficients. We determined the mean difference between physical activity variables measured in 15 second vs. 60 second epochs (i.e., agreement at the *group* level) with paired t-tests; alpha was set at 0.01 to account for multiple tests.

To assess agreement between physical activity collected in 15 second and 60 second epochs on an *individual* level we used Bland Altman plots [408]. Bland Altman plots reflect the difference (bias) between methods (physical activity in 15 second epochs minus physical activity in 60 second epochs) against the mean values from the two methods. When data points were scattered evenly across the plot (i.e., there was no relationship between the bias and the mean), we calculated the mean bias and 95% limits of agreement. However, visual inspection of the Bland-Altman plots revealed a relationship between the bias and the mean for most variables. This relation was confirmed through Spearman rank correlation coefficients between the bias and mean (significant at $p<0.01$). To manage the relation between the bias and the mean we expressed the bias as a ratio of 15 second: 60 second data (similar effect to log-transforming data [408]). We then calculated the mean bias and 95% limits of agreement for the ratio between the two methods. For those variables where the ratio approach did not remove the significant association between the bias and the mean, we applied a regression model to the original bias vs. mean plot [408]. Briefly, the regression line fit through the original Bland Altman plot describes the mean bias for the physical activity variable across the range of activity. This equation was also used to calculate 95% limits of agreement. Finally, to illustrate the magnitude of the effect across the range of physical activity we observed, we calculated the predicted bias for participants with the lowest and highest value for each physical activity variable.

4.3 Results

Participants

The sample size and reasons for participant exclusion are illustrated in Figure 4-1. Of 629 participants recruited, 68 were not measured (absent from school, moved between consent and measurement, incomplete consent process). Of the 561 participants who were measured, we excluded 255 (accelerometer malfunction, non-standard wear interval, insufficient wear time). Therefore, 306 participants (159 girls) are included in the present analysis. Table 4-1 provides the descriptive characteristics of participants. There were no differences in age or anthropometric variables between girls and boys or between those who were (n=306) and were not (n=255) included (data not shown).

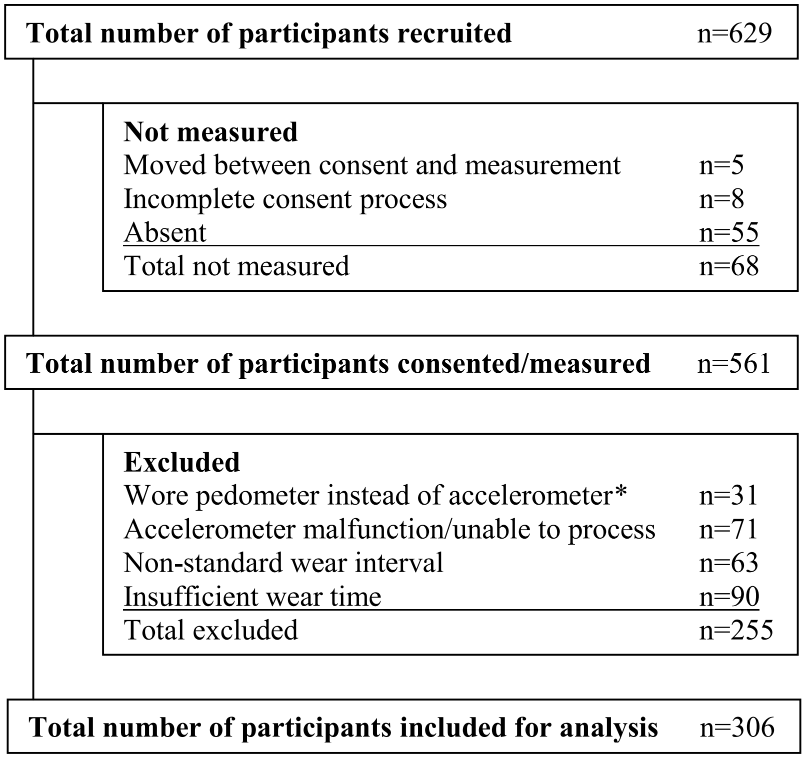

Figure 4-1. Sample size and flow of participants through the study.
**Some children wore a pedometer because of an insufficient number of accelerometers (due to late returns from previous school).*

Table 4-1. Descriptive characteristics of participants including age and anthropometric variables.

	Sample size	Mean value (SD)
Age (y)	n=306	9.9 (0.6)
Height (cm)	n=299	140.4 (7.2)
Body mass (kg)	n=300	36.2 (8.9)
BMI (kg/m^2)	n=299	18.2 (3.4)

Data are presented as mean (SD). BMI, body mass index. There were no significant differences between girls and boys therefore the pooled data are presented.

Moderate to vigorous physical activity

There was a very strong correlation between $MVPA_{15}$ and $MVPA_{60}$ (r = 0.99; Table 4-2). At the *group* level there was significant bias in $MVPA_{15}$ versus $MVPA_{60}$; however, the magnitude of the difference was small (-1.9 minutes/day) and likely not clinically significant (Table 4-2). For agreement at the *individual* level, we noted a clear relationship between the bias and the mean (Spearman's rho = -0.74; Figure 4-2A) that we were unable to manage by expressing the data as a ratio. Therefore, we present the regression equation that describes the bias along with 95% limits of agreement (Table 4-3). We also present predicted bias for the least and most active child in the cohort (Table 4-3).

Table 4-2. Mean values (SD) for 15 second and 60 second epochs and the bivariate Pearson product moment correlation between them. The group level effect (bias), 95% confidence intervals (CI), and significance levels were calculated using paired t-tests.

	15 second epoch Mean (SD)	60 second epoch Mean (SD)	Bivariate Correlation	Bias (95% CI) (p value)
Categories of physical activity intensity				
MVPA (min/day)	123.1 (37.4)	125.0 (44.5)	0.99	-1.9 (-3.0, -0.1) p<0.001
SED (min/day)	546.8 (63.8)	486.5 (71.7)	0.98	60.4 (58.6, 62.1) p<0.001
LPA (min/day)	119.0 (21.8)	179.1 (32.4)	0.94	-60.1 (-61.7, -58.5) p<0.001
MPA (min/day)	104.0 (28.9)	113.9 (38.7)	0.97	-9.9 (-11.3, -8.5) p<0.001
VPA (min/day)	19.1 (11.8)	11.1 (9.6)	0.96	8.0 (7.5, 8.4) p<0.001
Length of bouted MVPA (min/day)				
0-5 min	109.3 (30.6)	75.2 (21.0)	0.90	34.0 (32.3, 35.7) p<0.001
5-10 min	3.6 (3.5)	16.9 (9.0)	0.44	-13.3 (-14.2, -12.4) p<0.001
10-20 min	6.8 (7.8)	17.4 (12.2)	0.61	-10.6 (-11.7, -9.5) p<0.001
≥ 20 min	3.4 (7.3)	15.0 (17.7)	0.70	-11.6 (-13.2, -10.1) p<0.001
Length of bouted SED time (min/day)				
0-5 min	200.9 (43.9)	97.9 (22.9)	0.93	103.0 (100.3, 105.7) p<0.001
5-10 min	25.5 (7.9)	54.2 (13.2)	0.59	-28.7 (-29.9, -27.5) p<0.001
10-20 min	84.2 (20.4)	88.0 (20.4)	0.72	-3.7 (-5.4, -2.0) p<0.001
≥ 20 min	234.8 (89.6)	238.4 (87.1)	0.97	-3.6 (-6.0, -1.2) p=0.003

Bias calculated as 15 second minus 60 second data. SED, sedentary; LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity; MVPA, moderate-to-vigorous physical activity.

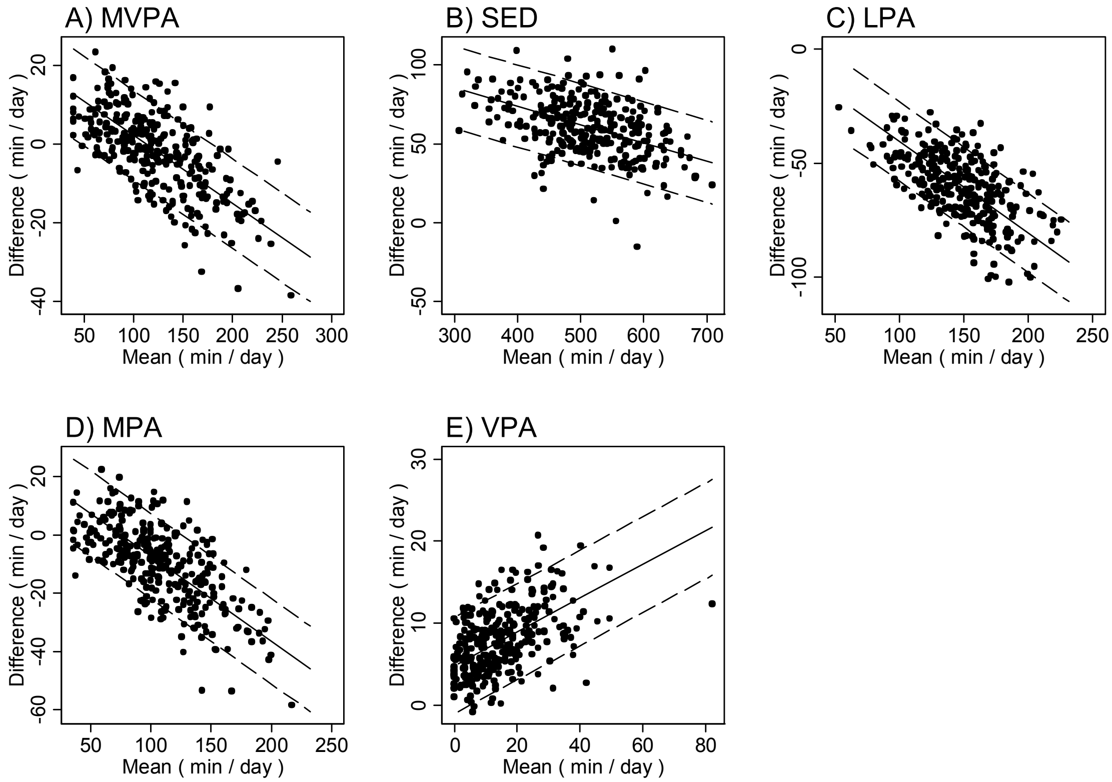

Figure 4-2. Bland Altman plots for five categories of physical activity intensity with regression-based bias (solid line) and 95% limits of agreement (dashed lines).

The intensity categories were: (A) moderate to vigorous physical activity (MVPA), (B) sedentary time (SED), (C) light physical activity (LPA), (D) moderate physical activity (MPA), and (E) vigorous physical activity (VPA). The equation for the bias and the magnitude of the 95% limits of agreement are located in Table 4-3. Difference was calculated as 15 second minus 60 second epochs.

Table 4-3. Regression equations for predicted bias and 95% limits of agreement to assess agreement between 15 second and 60 second epochs on an individual level.

	Equation for bias	95% LOA	Predicted bias at lowest mean value	Predicted bias at highest mean value
Categories of physical activity intensity				
MVPA (min/day)	Bias = 19.6 - 0.17*Ave	± 11.4	12.7	-28.8
SED (min/day)	Bias = 120.8 - 0.12*Ave	± 26.0	37.9	83.9
LPA (min/day)	Bias = -0.17 - 0.40*Ave	± 17.5	-26.1	-92.9
MPA (min/day)	Bias = 22.0 – 0.29*Ave	± 14.7	11.5	-46.0
VPA (min/day)	Bias = 4.9 + 0.20*Ave	± 5.8	5.1	21.7
Length of bouted MVPA				
0-5 min	Bias = -1.9 + 0.39*Ave	± 22.3	10.2	59.7
5-10 min	Bias = -1.6 – 1.1*Ave	± 10.1	-1.6	-34.0
10-20 min	Bias = -4.0 – 0.54*Ave	± 16.3	-4.0	-31.3
≥ 20 min	Bias = -2.8 - 0.96*Ave	± 15.5	-2.8	-81.4
Length of bouted sedentary time				
0-5 min	Bias = 6.0 +0.65*Ave	± 22.1	40.6	156.5
5-10 min	Bias = -4.0 - 0.62*Ave	± 17.5	-11.3	-50.5
10-20 min#	Bias = -3.7	± 29.9	--	--
≥ 20 min#	Bias = -3.6	± 41.7	--	--

The individual level influence of epoch length was assessed by fitting a regression line through each Bland-Altman plot. The regression equation represents the predicted bias between 15 second and 60 second epochs across the range of activity for each variable. This equation was used to predict bias for the child with the lowest and highest volume of each activity variable. The equation for bias is the regression equation describing the solid line in Figure 4-2, Figure 4-3, and Figure 4-4; 95% LOA, 95% limits of agreement; Ave, average of 15 and 60 second physical activity data; SED, sedentary (1.0-1.5 METs); LPA, light physical activity (1.5-2.9 METs); MPA, moderate physical activity (3.0-5.9 METs); VPA, vigorous physical activity (≥ 6.0 METs); MVPA, moderate-to-vigorous physical activity (≥ 3.0 METs); #There was no relation between the difference and the mean therefore standard bias (line with a slope of 0) and 95% limits of agreement were computed.

Sedentary time

We noted a strong correlation between SED_{15} and SED_{60} (r = 0.98; Table 4-2). At the *group* level an average of 60 minutes more of sedentary time (p<0.001) was recorded using 15 second compared with 60 second epochs (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean (Spearman's rho = -0.52; Figure 4-2B) that was not removed by expressing data as a ratio. Therefore, we present the regression equation that describes the bias and 95% limits of agreement (Table 4-3). We also present the predicted bias for participants with the lowest and highest values for sedentary time (Table 4-3).

Light physical activity

We noted a strong correlation between LPA_{15} and LPA_{60} ($r = 0.94$; Table 4-2). At the *group* level there was, on average, 60 fewer minutes of light physical activity ($p<0.001$) when 15 second epochs were used compared with 60 second epochs (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean (Spearman's rho = -0.76; Figure 4-2C). This relationship did not persist when data were expressed as a ratio; light physical activity recorded in 15 second epochs was 66% ± 8% of the physical activity value recorded for LPA in 60 second epochs (data not shown). We also provide the regression equation that describes the bias and 95% limits of agreement, as well as the predicted bias for participants with the lowest and highest volume of light physical activity (Table 4-3).

Moderate physical activity

There was a strong correlation between MPA_{15} and MPA_{60} ($r = 0.97$; Table 4-2). At the *group* level, 10 fewer minutes of moderate physical activity ($p<0.001$), on average, were recorded using 15 second compared with 60 second epochs (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean (Spearman's rho = -0.78; Figure 4-2D) that was not removed by expressing data as a ratio. We provide the regression equation that describes the bias and 95% limits of agreement, as well as the predicted bias for participants with the lowest and highest values for moderate physical activity (Table 4-3).

Vigorous physical activity

There was a strong correlation between VPA_{15} and VPA_{60} ($r = 0.96$; Table 4-2). At the *group* level 8 more minutes of vigorous physical activity ($p<0.001$), on average, were recorded using 15 second compared with 60 second epochs (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean (Spearman's rho = 0.69; Figure 4-2E) that was not removed by expressing data as a ratio. We provide the regression equation that describes the bias and 95% limits of agreement, as well as the predicted bias for participants with the lowest and highest values for vigorous physical activity (Table 4-3). Visual inspection of the plot revealed a potentially influential data point (mean vigorous physical activity approximately 80 minutes/day; Figure 4-2E). Excluding data from this individual did not substantially affect the correlation, bias at the group level, or bias at the individual level (data not shown).

Moderate to vigorous physical activity accumulated in bouts

There were moderate to high correlations between bouted $MVPA_{15}$ and $MVPA_{60}$ (r = 0.44-0.90; Table 4-2). At the *group* level, significantly more MVPA was accumulated in bouts of 0-5 minutes using the 15 second epoch compared with the 60 second epoch (p<0.001, Table 4-2). Significantly fewer minutes of MVPA were accumulated in bouts of 5-10 minutes, 10-20 minutes, and ≥ 20 minutes using 15 second compared with 60 second epochs (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean of bouted MVPA for all four bout durations (Spearman's rho = 0.67, -0.76, -0.5, and -0.91, for 0-5 minute, 5-10 minute, 10-20 minute, and ≥ 20 minute bouts respectively; Figure 4-3. For MVPA accumulated in bouts of 0-5 minutes, the relationship between the bias and the mean did not persist when data were expressed as a ratio. Specifically, bouted MVPA (0-5 minute bouts) recorded in 15 second epochs was 46% ± 37% of the value recorded for MVPA in 60 second epochs (data not shown). We provide regression equations that describe the bias and 95% limits of agreement, as well as the predicted bias for participants with the lowest and highest volume of MVPA accumulated in bouts (Table 4-3).

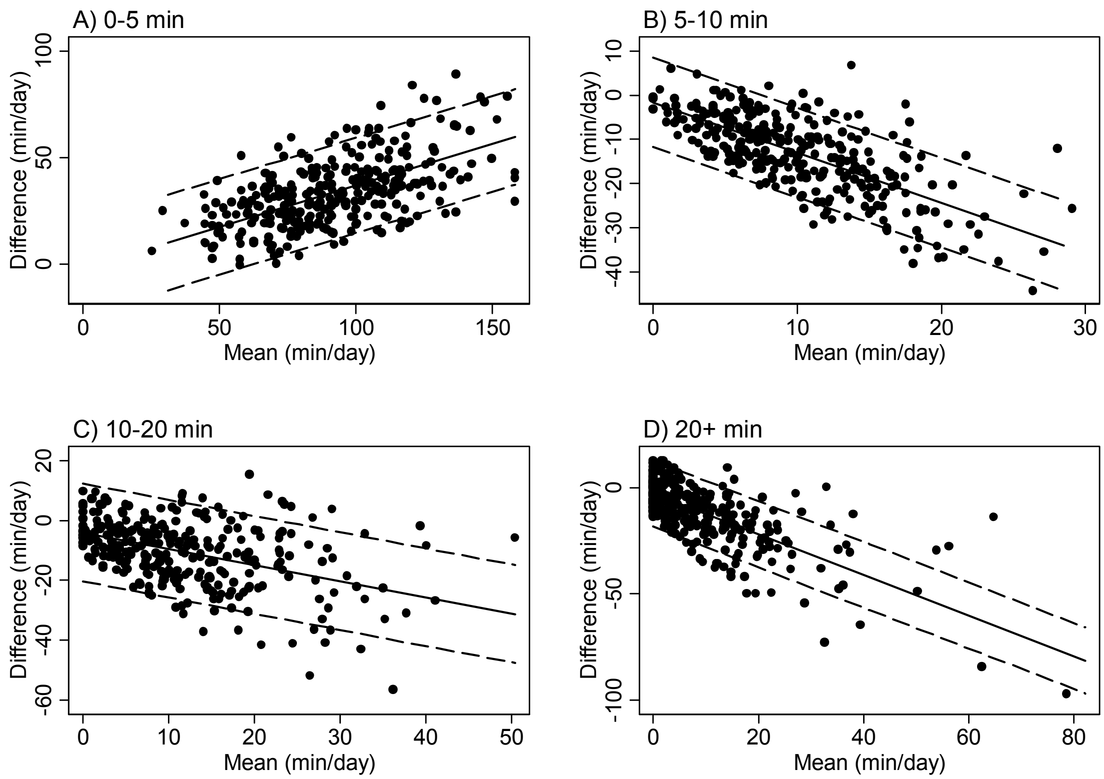

Figure 4-3. Bland Altman plots for moderate to vigorous physical activity accumulated in bouts with regression-based bias (solid line) and 95% limits of agreement (dashed lines).
Bout lengths were: (A) 0-5 minutes, (B) 5-10 minutes, (C) 10-20 minutes, and (D) ≥ 20 minutes. The equation for the bias and the magnitude of the 95% limits of agreement are located in Table 4-3. Difference was calculated as 15 second minus 60 second epochs.

Sedentary time accumulated in bouts

There were moderate to high correlations between bouted SED_{15} and SED_{60} (r = 0.59-0.97; Table 4-2). At the *group* level, significantly more sedentary time was accumulated in bouts of 0-5 minutes using the 15 second epoch compared with the 60 second epoch (p<0.001, Table 4-2). Significantly fewer minutes of sedentary time were accumulated in bouts of 5-10 minutes, 10-20 minutes and ≥ 20 minutes using 15 second compared with 60 second epochs (p<0.003, Table 4-2).However, the magnitude of the difference for 10-20 minute and ≥ 20 minute bouts was small and likely not physiologically relevant (Table 4-2). At the *individual* level, there was a clear relationship between the bias and the mean of bouted MVPA for 0-5 minute (Spearman's rho = 0.89) and 5-10 minute (Spearman's rho = -0.50) bouts whereas there was no such relationship for the 10-20 minute (Spearman's rho = 0.01) or ≥ 20 minute (Spearman's rho = 0.13) bouts (Figure 4-3). The relationship between the bias and the mean for bouts of sedentary time 0-5 minutes and 5-10 minutes was not removed by expressing data as a ratio. Therefore, we provide regression equations that describe the bias and 95% limits of agreement, as well as the predicted bias for participants with the lowest and highest volume of sedentary time accumulated in bouts of 0-5 minutes and 5-10 minutes (Table 4-3). The standard Bland Altman approach was used to compute bias and 95% limits of agreement for bouts of sedentary time 10-20 minutes and ≥ 20 minutes (Table 4-3).

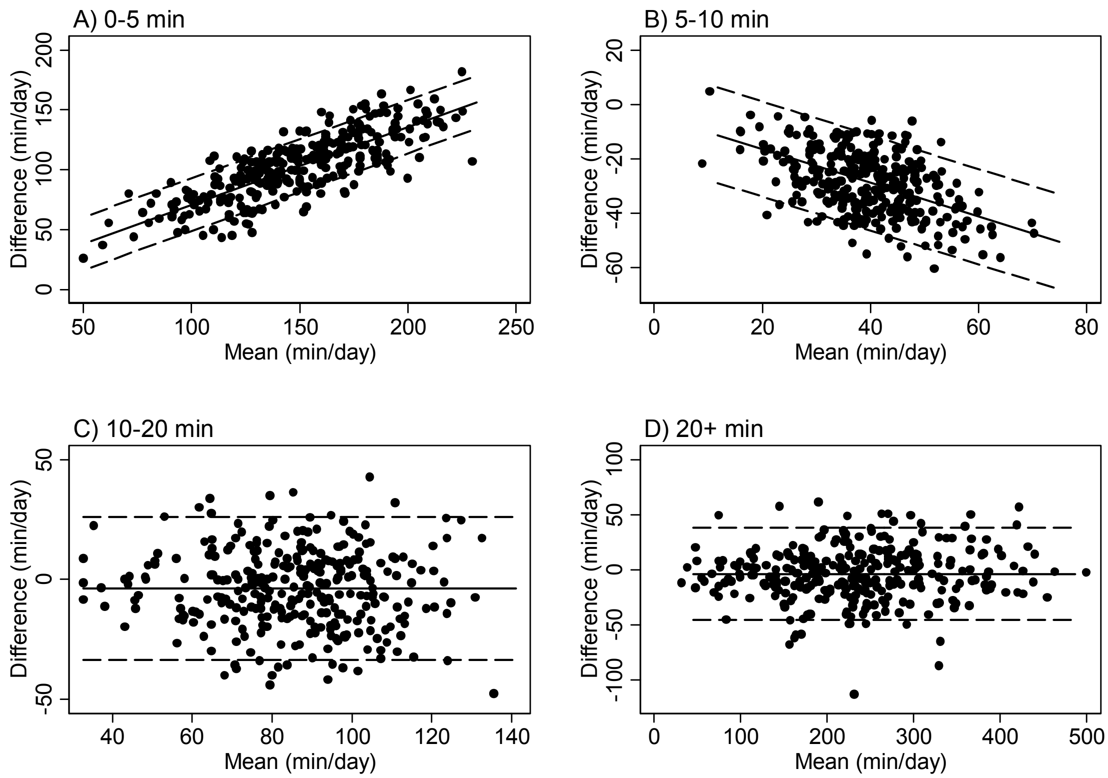

Figure 4-4. Bland Altman plots for sedentary time accumulated in bouts with bias (solid line) and 95% limits of agreement (dashed lines).
Bout lengths were: (A) 0-5 minutes, (B) 5-10 minutes, (C) 10-20 minutes, and (D) ≥ 20 minutes. Bias and 95% limits of agreement were calculated via regression for 0-5 minute and 5-10 minute bouts, and by standard approaches for 10-20 minute and ≥ 20 minute bouts. The equation for the bias and the magnitude of the 95% limits of agreement are located in Table 4-3. Difference was calculated as 15 second minus 60 second epochs.

Summary of results

The overall trends for the influence of epoch length on physical activity measurement at the group and individual level are summarized in Table 4-4.

Table 4-4. Summary of the overall trends of the influence of epoch length on physical activity measurement for each variable. The table highlights the epoch length (in seconds) that recorded the most activity at the group and individual level within each intensity and bout category.

	Group level (paired t-test)	Individual level (Bland-Altman)	
		Least active children	**Most active children**
Categories of physical activity intensity (min/day)			
MVPA	60	15	60
SED	15	15	15
LPA	60	60	60
MPA	60	15	60
VPA	15	15	15
Bouted MVPA (min/day)			
0-5 min	15	15	15
5-10 min	60	60	60
10-20 min	60	60	60
≥ 20 min	60	60	60
Bouted SED (min/day)			
0-5 min	15	15	15
5-10 min	60	60	60
10-20 min	60	60	60
≥ 20 min	60	60	60

MVPA, moderate to vigorous physical activity; SED, sedentary time; LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity.

4.4 Discussion

It is generally well accepted that children engage in short, sporadic bursts of physical activity as opposed to sustained bouts [36,37]. Estimates of activity bout duration range from 3 seconds for vigorous physical activity [36] to 20 seconds for less intense activity [37,38]. However, many studies that measured children’s physical activity used accelerometers with a 60 second measurement interval (epoch). To enhance our understanding of the relation between childhood physical activity and overall health and fitness, we report the implications of choosing shorter versus longer epochs to assess children’s physical activity.

Our findings extend the existing literature that examined the effect of epoch length on estimates of children’s physical activity in two ways. First, the influence of epoch length on bouted MVPA has only been explored once in a sample of 16 children [405]; bouted sedentary time has not been reported previously. This is notable as bouted MVPA and sedentary time are important determinants of health, independent of the total volume of physical activity [222,326]. Second, we demonstrated that the influence of epoch length varies with total amount of physical activity and quantify this effect for the first time by reporting regression-based bias and limits of agreement.

Only two of four previous studies of children's physical activity used Bland Altman plots to examine agreement between epoch lengths [404,406]. It seems important to examine outcomes at the *individual* level (using Bland Altman plots) as analysis at the *group* level (i.e., using paired t-test) obscured valuable information. Thus, Bland-Altman plots should be considered a critical component of physical activity studies that compare multiple methodologies. Rowlands [406] used the Bland Altman approach and reported that the influence of epoch length differed by physical activity level. However, the authors did not adjust the calculated bias and 95% limits of agreement using a regression approach, possibly because of the small sample size (n = 25). Thus, the reported limits of agreement were likely too wide [406,408]. In contrast, Edwardson and Gorely [404] used the Bland Altman approach but found no relationship between the bias and mean physical activity level of participants. The reasons for the discrepant findings are unclear as there were many similarities between studies (e.g., age of the children, sample size, accelerometer manufacturer). However, there were also some notable differences. For example, we defined 'non-wear time' as 30 minutes of consecutive zeros, whereas Edwardson and Gorley [404] used a 20 minute criterion. These discrepancies may explain, in part, the differences between studies.

Total and bouted MVPA

Clear evidence links MVPA to health benefits in children [268,279] and new research shows that bouted MVPA may contribute to health independent of the total volume of MVPA [222]. Thus, accurate measurement of this variable is essential. Previous studies demonstrated mixed results regarding the influence of epoch length on measures of MVPA. A large study of boys and girls (n = 311) aged 7-11 years measured more MVPA with a 5 second epoch than a 60 second epoch [404]. One small study measured more MVPA when a shorter epoch was applied [403] whereas another reported no influence of epoch length on MVPA [406].

At the *group* level, the influence of epoch length on the total volume of MVPA was of a lesser magnitude (-1.9 minutes) than in previous studies (-5 minutes [404] and +10 minutes [403]). However, at the *individual* level, the magnitude of the bias varied with the amount of MVPA undertaken by children. Specifically, children with low mean values for MVPA tended to record greater MVPA per day using 15 second epochs whereas children with high mean values for MVPA tended to record greater MVPA per day using 60 second epochs. The predicted bias ranged from +12.7 minutes (15 second > 60 second) for the least active child to -28.8 minutes (15 second < 60 second) for the most active child. Nilsson et al. [405] theorized that there would be less bias in sedentary participants (i.e., the influence of epoch length would be weaker) as sedentary activity patterns include fewer transitions between low and high intensity activity. However, given their small sample size (n=16 children) they were unable to investigate this theory [405]. Of interest, our data support their hypothesis; in our cohort the magnitude of the bias for the most active child was more than twice that of the least active child (28.8 minutes vs. 12.7 minutes).

The nature of children's physical activity patterns may also explain why low and high active children experienced bias in opposite directions. As the definition of MVPA is broad (≥ 3 METs) it is possible that the least and most active children accumulate activity of different intensities *within* the MVPA category. That is, less active children may accumulate MVPA predominantly from the low end of the category (e.g., 3-4 METs) while more active children may accumulate a greater volume of higher intensity MVPA (e.g., 5-6 METs and above). If low active children tend to accumulate low intensity MVPA (e.g., 3-4 METs), their MVPA may get re-classified as light activity when averaged with longer periods of light activity or sedentary time. Thus, low active children would register greater volumes of MVPA with the *shorter* epoch. In contrast, if high active children tend to accumulate high intensity MVPA (e.g., 5-6 METs and above), their sedentary and light activity may get re-classified as MVPA when averaged with short epochs of high intensity MVPA. Thus, high active children would register greater volumes of MVPA with the *longer* epoch. However, this is purely speculative as we do not know the average intensity of MVPA bouts in low or high active children.

A 40 minute per day range in the amount of physical activity recorded is substantial given this represents 66% of the daily recommended level for children. However, in our cohort, children generally achieved recommended levels of physical activity [268] regardless of epoch length (> 95% met physical activity guidelines of 60 minutes per day). Nevertheless, different estimates of MVPA based on epoch lengths may alter the reported relationship between MVPA and other indices of health. Most studies that reported the relation between objectively measured physical activity and cardiovascular health in children measured physical activity using a 60 second epoch (e.g., the European Youth Heart Study [62,103,124,409]). It is important to better understand the *clinical* implications of different estimates of MVPA that arise due to epoch length. However, we did not address this in the current study

Recent research demonstrated that bouted MVPA was independently associated with overweight in youth [222]. However, only one previous study evaluated the influence of epoch length on the volume of MVPA accumulated in bouts. In that study, MVPA accumulated in bouts ≥ 10 minutes was lower for shorter compared with longer epochs. However, researchers reported only a group level effect and did not calculate limits of agreement. In the present study we observed 10-15 minutes less MVPA in bouts of 5-10 minutes, 10-20 minutes, and ≥20 minutes when using a shorter (15 second) epoch compared with a longer (60 second) epoch. This represents a difference of 60-80% between the two epoch lengths and reinforces the need to gain a better understanding of how these different estimates of bouted MVPA will impact upon the relation with health outcomes.

Bouted and unbouted sedentary time

The association of sedentary time to metabolic risk [27,224,326], cardiovascular and all-cause mortality in adults [23,24,112,113], and cardiovascular disease risk factors in youth [103,410,411] has garnered increased attention of late. However, only two previous studies analyzed the influence of epoch length on the measurement of sedentary time [403,404]. At the *group* level, Edwardson and Gorley [404] also reported more total sedentary time with a shorter epoch. The magnitude of the difference was similar to our present finding [404]. In contrast, Reilly et al [403] reported no difference in sedentary time with epoch length. The discrepancy in outcome between our study and that of Reilly et al. [403] is likely explained by several important methodological differences. First, children in the Reilly et al. study were 5-6 years old, whereas children in our study were older (8-11 years). Second, the cut points used to classify sedentary time were dramatically different. Reilly et al. [403] used a cut point of < 1100 counts/min developed using data obtained from a sample of 3-4 year old children. We defined sedentary time as physical activity < 1.5 METs and applied the age-specific formula developed by Trost who derived cut points from data obtained from 6-17 year old youth [257]. Cut points for sedentary activity in our sample ranged from 200-283 counts/minute.

At the *individual* level, virtually all children recorded more sedentary time with 15 second compared with 60 second epochs. The 95% limits of agreement were wide (± 26 minutes) and indicate relatively poor agreement between the two epoch lengths. Specifically, there was a shift towards more measured sedentary time (60 minutes more) and *less* light physical activity (60 minutes less) when a 15 second epoch was used compared to a 60 second. This demands further study given the associations between sedentary time [224], light physical activity [378,412] and cardiovascular health.

As neither of the previous studies assessed the influence of epoch length on bouted sedentary activity we addressed this question in the current study and found that epoch length was of critical importance for short bouts of sedentary time but had less impact as the bouts grew longer. Twice as much sedentary time accumulated in bouts of 0-5 minutes was measured with the 15 second epoch compared with the 60 second epoch (200 minutes vs. 100 minutes). Although evidence-based guidelines for *total* sedentary time are not currently available, a difference of 100 minutes per day seems substantial. This finding represents an important first step to better understanding the relation between bouted sedentary time and an array of health outcomes.

Light, moderate, and vigorous physical activity

We also observed substantial diversity in the results for light, moderate and vigorous activity. In previous studies, values for light activity (< 3 METs) were either the same [406] or lower [404] when measured with short as compared with long epochs. Similar to our findings, Edwardson [404] reported substantially less light physical activity with shorter epochs. We also noted substantial variation across the range of mean light physical activity. Specifically, the predicted bias ranged from -26 minutes in the child who undertook the lowest volume of light activity to -93 minutes in the child who undertook the highest volume of light activity. Clearly, this large range does not instil a large degree of confidence in this measure. That said, our findings support Nilsson [405] who hypothesized that less active participants would display lower bias than would active participants. This was thought to be due to fewer transitions between low and high intensity activity.

Differences have also been reported for moderate activity (approximately 3-6 METs). Specifically, similar [405] or lower [406] values were reported for shorter as compared with longer epochs. For vigorous activity (approximately 6-9 METs) values were both higher [405] and lower [406] for shorter as compared with longer epochs. More intense physical activity (9-12 METS) demonstrated similar values for shorter versus longer epochs [406]. However, estimated activity ≥ 9 METs [405] and ≥ 12 METs [406] was higher when shorter epoch lengths were used. Further, as all studies assessed only small numbers of children (n=16-32), used different brands of accelerometers, different epoch lengths and different definitions for physical activity intensity it is difficult to compare across them [403,405,406].

We observed a similar magnitude as reported previously for the *group* level effect for moderate and vigorous activity [404]. However, at an *individual* level there was substantial bias and values ranged from +12 minutes to -46 minutes for moderate physical activity and +5 minutes to +21 minutes for vigorous physical activity for children who recorded the least and most amounts of moderate and vigorous physical activity, respectively. Again, these data support Nilsson's theory that estimates for low active children will be less affected by epoch length compared with more active children [405].These data once again highlight the need to consider epoch length when measuring any intensity of physical activity. Importantly, even those categories of intensity that display relatively small group level effects such as moderate and vigorous physical activity (< 10 minutes/day in this cohort) demonstrate large effects at the individual level.

Limitations

We acknowledge that our study has several limitations. First, we did not undertake direct observation of participants so are unable to determine the accuracy of 15 second or 60 second epochs using direct observation as the criterion. However, a recent study [413] that measured physical activity using accelerometry and direct observation reported that 5 second accelerometry data were most closely matched to data acquired through direct observation. This offers further support for shorter epoch lengths when assessing children given the sporadic nature of children's physical activity [36,37]. Second, the physiological relevance of the four bout lengths selected in this study are unknown as our study did not address this. Third, we applied cut points to accelerometry data files to estimate minutes of physical activity. Had we applied different cut points, we would have obtained different estimates of physical activity [291]. However, it is likely that the relative effect of epoch length would remain. Fourth, our sample consisted only of children aged 8-11 years therefore our results cannot be generalized to younger or older populations.

Conclusion

Previous studies suggested that epoch length might be a trivial concern in physical activity studies that report outcomes for variables with low mean bias (at the *group* level). However, we demonstrated that a small effect at the group level does not preclude large *individual* differences when different epoch lengths are used to assess children's physical activity. Thus, it seems imprudent to compare across studies where different epoch lengths were used. Results should also be interpreted in light of the substantial differences in the influence of epoch length on children with estimates of low versus high physical activity levels. Future research should aim to clarify the *accuracy* of different epoch lengths and evaluate whether the choice of epoch length alters observed relationships with health outcomes, with the ultimate goal of standardizing methodologies across studies

5 The prevalence of sedentary behaviour, light physical activity, and moderate to vigorous physical activity during the school day in girls and boys [3]

SYNOPSIS: Most school-based physical activity research in children has focused on activity of at least moderate to vigorous intensity. Consequently, we know very little about patterns of sedentary behaviour and light physical activity in this environment. This chapter examines the spectrum of activity intensity (sedentary, light and moderate to vigorous), measured objectively via accelerometry, occurring across the school day in elementary school girls and boys.

5.1 Introduction

Compelling evidence supports a beneficial relationship between MVPA and a variety of chronic disease risk factors in school-aged children [279]. Physical activity in children decreases adiposity in those who are overweight, decreases blood pressure in those with hypertension [279] and enhances skeletal [381] and cardiovascular [357] health. Over the last several decades increasing numbers of children around the world have been classified as overweight or obese [414]. Although the root of obesity is complex, evidence suggests that low physical activity and increased sedentary behaviour may be partially responsible [293,415].

The school environment is an attractive option for delivering health-promoting physical activity. Children spend approximately 30 hours/week in school and boys and girls from a range of socioeconomic backgrounds and ethnicities that might be difficult to access otherwise are included [44,45]. However, schools may not be living up to their potential. While physical education and recess are likely opportunities for school physical activity, evidence suggests that curricular time devoted to physical education is declining [337]. Furthermore, MVPA during physical education is lower [339-342] than recommended [345], and differs by sex [339,416]. Moderate to vigorous

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[3] A version of Chapter 6 has been published. Nettlefold, L., McKay, H.A., Warburton, D.E.R., McGuire, K.A., Bredin, S.S.D., Naylor, P.J. (2010). The challenge of low physical activity during the school day: at recess, lunch and in physical education. British Journal of Sports Medicine *doi:10.1136/bjsm.2009.068072*

physical activity during recess is also lower than recommended [343,344] although this finding is not consistent [417].

Beyond the well-known benefits of MVPA for cardiovascular [279,357], skeletal [279,381] and mental health [279] and the focus on MVPA in school-based studies [339,343,344,416,418], light physical activity may also provide benefits by contributing to daily energy expenditure [110]. Additionally, sedentary time is an independent risk factor for all-cause and cardiovascular mortality in adults [23,419]. Very few studies have described the spectrum of physical activity intensity from sedentary to MVPA during the school day. Moreover, those investigations included only boys [342], did not distinguish between sedentary behaviour and light physical activity [420] or examined only recess [342,420], lunch [420], and/or physical education [342].

A number of studies demonstrated that habitual MVPA is lower in girls compared with same age boys [257]. However, few studies have investigated *when* during the school day these differences occurred and whether there is also a gender difference in sedentary behaviour and light physical activity. Therefore, the objectives of this chapter were to:

1) *describe* the amount of sedentary time, light physical activity and MVPA undertaken by elementary school girls and boys throughout a typical school-day (whole school-day, classroom time, recess, lunch and scheduled physical education)
2) *compare* whether activity intensity differed between girls and boys during each time interval
3) *describe* compliance with recommended school day MVPA guidelines throughout a typical school-day
4) *compare* whether guideline compliance differed between girls and boys during each time interval

We hypothesized that girls would accumulate more sedentary behaviour and less physical activity (light physical activity and MVPA) compared with boys and that a smaller proportion of girls compared with boys would meet physical activity guidelines.

5.2 Methods

The recruitment process is described in detail in Chapter 3. Children (n=629) at nine schools consented to participate in this component (physical activity measurement via accelerometry) of the larger investigation.

Anthropometric and physical activity data (accelerometry and teacher's physical activity logs) were collected and processed as described in chapter 3. At the one school in T1 where accelerometers were distributed on Friday morning and collected Tuesday afternoon, a full school day was constructed using the latter half of Friday (12:45 PM to end of day) and the beginning of Tuesday (start of day to 12:45).

Accelerometry data were processed using KineSoft software, version 2.0.94 (Saskatoon, Canada) to extract minutes of sedentary time, light physical activity and MVPA during 1) the whole school day (approximately 9AM-3PM), 2) regular class time (recess, lunch and scheduled physical education excluded), 3) recess, 4) lunch, and 5) scheduled physical education. Data for a time segment were discarded if participants were missing data during that time period (i.e., motionless bouts longer than 30 minutes). Therefore, the sample size for time periods varied (Figure 5-1). To account for between-school variation in the length of each time period I expressed time spent in activity at each level of intensity as 1) total minutes accumulated and 2) as a proportion of the total time.

To ascertain whether physical education had taken place as scheduled, I crosschecked physical education schedules with weekly teacher activity logs. If a teacher reported physical education as per the schedule, the class was deemed "verified". If a teacher's log did not match the physical education schedule, or if activity logs were not completed, the class was deemed "un-verified". I used only "verified" classes in these analyses.

The guidelines applied for school day physical activity were:

1) 30 minutes of MVPA accumulated during the school day (Canada: BC Ministry of Education [379])
2) 40% of the recess and lunch breaks in MVPA (United Kingdom [343]
3) 50% of physical education class in MVPA (United States [345])

Statistical analyses

Statistical analyses were performed using Stata Version 10.1 (StataCorp, College Station, TX). I used independent t-tests to compare basic descriptive characteristics between included and excluded (owing to insufficient accelerometry data) participants and one way ANOVA weighted by the number of days of data per child to compare the intensity of girls' and boys' activity during each time period. I used Chi-square tests to evaluate associations between gender and guideline achievement. Results were considered significant at $p<0.05$.

5.3 Results

Participants

Sample sizes and reasons for participant exclusion are provided in Figure 5-1. Of the 629 children who were recruited, 68 were not measured (moved between consent and measurement, absent, incomplete consent) (Figure 5-1). Of the 561 measured participants, I excluded those who had malfunctioning accelerometers, insufficient data or an invalid school day (i.e., school holiday). On four measurement dates there were insufficient accelerometers for all children and although pedometers were provided for these children their data were excluded (Figure 5-1). Final sample sizes were 380 for lunch; 379 for whole school-day, classroom and recess; and 216 for physical education. There were 272 participants (150 girls, 122 boys) with two valid school days and 108 participants (48 girls, 60 boys) with one valid school day. There were 46 participants (22 girls, 24 boys) with two verified physical education classes and 170 participants (91 girls, 79 boys) with one verified physical education class.

Descriptive characteristics

Several participants were not measured for height (n=7) or body mass (n=6). Age, height, and body mass were similar between the 198 included girls and the 91 excluded girls (Table 5-1). Age and BMI were similar between the 182 included boys and the 90 excluded boys. However, included boys were shorter (-2.3 cm, 95 % CI -4.2 to -0.5 cm) and weighed less (-3.2 kg, 95% CI -5.8 to -0.6 kg) (data not shown) than excluded boys.

Table 5-1. Descriptive characteristics including age and body composition for participants.

	Sample Size (girls, boys)	Girls	Boys
Age (y)	(198,181)	10.0 (0.6)	9.9 (0.6)
Height (cm)	(194, 179)	140.6 (7.6)	140.3 (6.8)
Body mass (kg)	(195, 179)	35.6 (7.8)	36.3 (9.5)
Body Mass Index (kg/m^2)	(194, 179)	17.9 (2.8)	18.3 (3.7)

Values are presented as mean (SD).

Total number of participants recruited
n=629

Not measured

Absent	n=55
Moved between consent and measurement	n=5
Consent process incomplete	n=8
Total not measured	n=68

Total number of participants consented and measured
n=561

Excluded from further analyses

Wore pedometer instead of accelerometer	n=31
Accelerometer malfunctioned	n=23
Insufficient data for inclusion (<3 days)	n=125
No week day measured (school holiday)	n=2
Total excluded	n=181

Total number of participants included for lunch period analyses n=380

Excluded from recess and whole school-day analyses

Motionless bout during recess/school day	n=1

Total number of participants included for recess and whole school-day analyses n=379

Excluded from PE class analyses

No PE class scheduled during wear interval	n=61
PE class not verified by teacher's logs	n=103
Total excluded	n=164

Total number of participants included for PE class analyses
n=216

Figure 5-1. Flow of participants and reasons for exclusion from the analysis.
PE, physical education class.

Whole school-day activity

The school day ranged in length from 345 to 387 minutes. Girls accumulated less MVPA and more sedentary behaviour compared with boys (Table 5-2). Accumulated light physical activity was similar between girls and boys (Table 5-2). Overall the compliance with school-day physical activity guidelines of 30 minutes/day was high (>90%). Approximately 5% fewer girls than boys met the recommended target (Figure 5-2).

Table 5-2. Physical activity profile for girls and boys during the whole school day (includes recess, lunch and physical education times where applicable).

	Girls (n=197)	Boys (n=182)	Difference (95% CI)	*p* value
MVPA (min)	52.9 (16.8)	63.5 (21.4)	-10.6 (-14.5, -6.8)	<0.001
Proportion in MVPA (%)	14.4 (4.5)	17.3 (5.6)	-2.9 (-3.9, -1.8)	<0.001
LPA (min)	54.1 (13.3)	56.4 (11.9)	-2.3 (-4.8, 0.3)	0.08
Proportion in LPA (%)	14.8 (3.7)	15.4 (3.2)	-0.6 (-1.3, 0.1)	0.08
Sedentary (min)	260.1 (28.8)	246.2 (25.0)	13.9 (8.5, 19.4)	<0.001
Proportion in sedentary (%)	70.8 (7.2)	67.3 (7.1)	3.5 (2.1, 5.0)	<0.001

Values are presented as mean (SD). Difference calculated as girls-boys (95% CI; confidence interval). MVPA, moderate to vigorous physical activity; LPA, light physical activity.

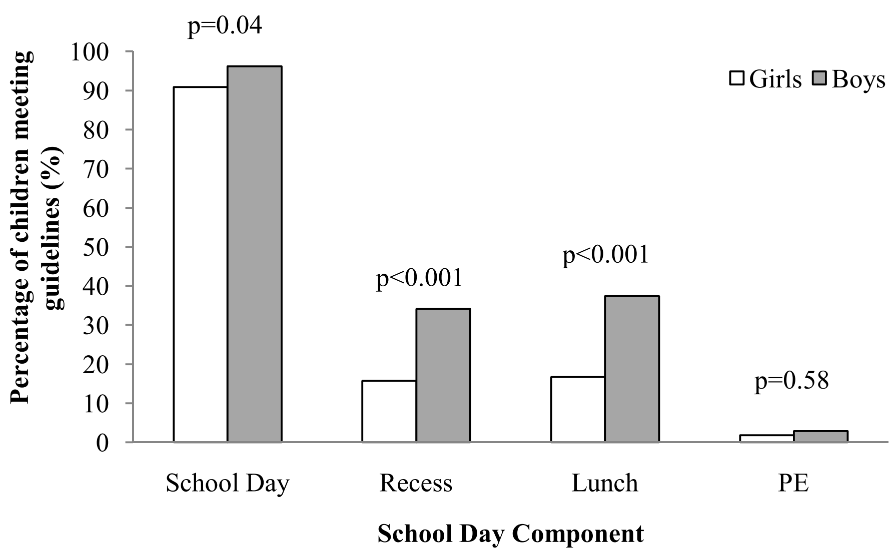

Figure 5-2. Percentage of students meeting recommended guidelines for physical activity during school.

Physical activity guidelines applied were: 1) at least 30 min MVPA during the school day; 2) 40% of recess time in MVPA; 3) 40% of lunch time in MVPA; 4) 50% of physical education class in MVPA.
p values <0.05 represents a significant gender difference in guideline compliance; PE, physical education.

Classroom activity

Regular class time excluded recess, lunch, and physical education class (if applicable) and ranged in length from 240 to 322 minutes. Girls accumulated less MVPA, less light physical activity, and more sedentary time compared with boys (Table 5-3).

Table 5-3. Physical activity profile for girls and boys during regular class time only (excludes recess, lunch, and physical education times where applicable).

	Girls (n=197)	Boys (n=182)	Difference (95% CI)	*p* value
MVPA (min)	33.8 (12.3)	39.9 (15.1)	-6.2 (-8.9, -3.4)	<0.001
Proportion in MVPA (%)	12.0 (4.5)	14.1 (5.2)	-2.1 (-3.1, -1.1)	<0.001
LPA (min)	38.6 (10.6)	41.1 (10.0)	-2.5 (-4.6, -0.4)	0.02
Proportion in LPA (%)	13.7 (3.8)	14.6 (3.4)	-0.9 (-1.6, -0.1)	0.02
Sedentary (min)	209.7 (29.2)	200.3 (24.9)	9.4 (3.9, 14.9)	<0.001
Proportion in sedentary (%)	74.2 (7.4)	71.2 (7.3)	3.0 (1.5, 4.5)	<0.001

Values are presented as mean (SD). Difference calculated as girls-boys (95% CI; confidence interval). MVPA, moderate to vigorous physical activity; LPA, light physical activity.

Recess activity

Recess ranged in length from 15 to 25 minutes. Girls accumulated less MVPA and more sedentary time compared with boys (Table 5-4). The amount and percent of light physical activity accumulated was similar between girls and boys (Table 5-4). Approximately 18% fewer girls than boys met the recommended physical activity guidelines for recess break activity (Figure 5-2).

Table 5-4. Physical activity profile for girls and boys during recess.

	Girls (n=197)	Boys (n=182)	Difference (95% CI)	*p* value
MVPA (min)	3.8 (3.3)	5.3 (4.3)	-1.6 (-2.3, -0.8)	<0.001
Proportion in MVPA (%)	19.6 (16.0)	27.9 (22.0)	-8.3 (-12.1, -4.4)	<0.001
LPA (min)	3.1 (1.5)	3.3 (1.6)	-0.2 (-0.5, 0.1)	0.28
Proportion in LPA (%)	16.8 (7.7)	17.8 (8.4)	-1.0 (-2.6, 0.7)	0.24
Sedentary (min)	11.8 (4.1)	10.1 (4.8)	1.7 (0.84, 2.6)	<0.001
Proportion in sedentary (%)	63.7 (20.5)	54.4 (24.7)	9.2 (4.7, 13.8)	<0.001

Values are presented as mean (SD). Difference calculated as girls-boys (95% CI; confidence interval). MVPA, moderate to vigorous physical activity; LPA, light physical activity.

Lunch activity

Lunch ranged in length from 35 to 50 minutes. Girls accumulated less MVPA and more sedentary time compared with boys (Table 5-5). The amount and percent of light physical activity accumulated was similar between girls and boys (Table 5-5). Approximately 21% fewer girls than boys met the recommended physical activity guidelines for lunch break activity (Figure 5-2).

Table 5-5. Physical activity profile for girls and boys during lunch.

	Girls (n=198)	Boys (n=182)	Difference (95% CI)	*p* value
MVPA (min)	12.5 (5.3)	15.6 (7.5)	-3.1 (-4.4, -1.8)	<0.001
Proportion in MVPA (%)	27.9 (12.0)	34.7 (16.3)	-6.9 (-9.7, 4.0)	<0.001
LPA (min)	9.3 (2.7)	8.9 (2.6)	0.4 (-0.1, 0.9)	0.14
Proportion in LPA (%)	20.6 (5.7)	19.8 (5.8)	0.8 (-0.4, 1.9)	0.19
Sedentary (min)	23.3 (6.8)	20.5 (7.5)	2.9 (1.4, 4.3)	<0.001
Proportion in Sedentary (%)	51.6 (14.3)	45.5 (16.4)	6.1 (3.0, 9.2)	<0.001

Values are presented as mean (SD). Difference calculated as girls-boys (95% CI; confidence interval). MVPA, moderate to vigorous physical activity; LPA, light physical activity.

Scheduled physical education class activity

Scheduled physical education ranged in length from 30 to 45 minutes/class. The amount and percent of MVPA, light physical activity and sedentary time accumulated was similar between girls and boys (Table 5-6). Similar numbers of girls and boys met the recommended physical activity guidelines for physical education class (Figure 5-2).

Table 5-6. Physical activity profile for girls and boys during scheduled physical education.

	Girls (n=113)	Boys (n=103)	Difference (95% CI)	*p* value
MVPA (min)	5.2 (5.5)	4.6 (5.3)	0.6 (-0.8, 2.1)	0.39
Proportion in MVPA (%)	13.0 (12.9)	11.4 (12.5)	1.5 (-1.9, 5.0)	0.37
LPA (min)	5.6 (3.5)	5.6 (4.1)	0.0 (-1.0, 1.0)	0.98
Proportion in LPA (%)	14.0 (8.0)	14.1 (9.5)	-0.1 (-2.4, 2.3)	0.94
Sedentary (min)	28.8 (7..6)	29.1 (7.6)	-0.3 (-2.4, 1.7)	0.77
Proportion in Sedentary (%)	73.0 (18.4)	74.5 (18.3)	-1.5 (-6.4, 3.5)	0.56

Values for girls and boys are presented as mean (SD). Difference calculated as girls-boys (95% CI; confidence interval). MVPA, moderate to vigorous physical activity; LPA, light physical activity.

5.4 Discussion

This study extends the existing literature by reporting sedentary time and light physical activity in addition to MVPA across the entire elementary school day. The hypotheses of lower physical activity levels and guideline compliance in girls held true, with the exception of scheduled physical education class. Similar to previous studies [311,421,422] girls accumulated fewer minutes of MVPA than boys across the school day. Two novel findings were 1) girls accumulated more sedentary time than boys and, 2) girls and boys engaged in similar amounts of light physical activity except in the classroom where boys were more active. Girls were also less likely than boys to meet current physical activity recommendations during the school day, at recess, and at lunch.

Whole school day and classroom activity

The findings for MVPA are similar to three previous studies that have assessed school day physical activity in girls and boys. Mota et al. [422] measured MVPA in children aged 8-15 years across an assumed 9:00AM to 2:59PM school day. The total amount of MVPA reported (46 minutes for girls and 63 minutes for boys) is similar to the amount we measured. Gidlow et al. [333] reported accelerometer counts/min across the school day in children aged 3-16 years. Although they did not compare girls and boys statistically, average counts/min were 382 for girls and 493 for boys. Our data also support an investigation in 6th grade students where boys accumulated nearly 2,000 more steps during the school day than girls [423]. Our finding that girls and boys engaged in similar amounts of light physical activity and that girls were more sedentary than boys suggests that girls are replacing MVPA with sedentary time rather than participating in a greater proportion of lighter intensity physical activity.

Interestingly, classroom physical activity behaviours also differed between the sexes. Previous investigations have not isolated classroom physical activity however we observed that girls were also less active (light physical activity and MVPA) and more sedentary compared to boys during classroom lessons. This speaks to the need for targeted classroom-based physical activity models that engage both sexes.

Current guidelines suggest that children should engage in at least 30 minutes of MVPA during the school day [44,45,379]. The vast majority of children (>90%) in our study achieved this goal. However, 5% fewer girls compared with boys were achieving the recommended amount of MVPA.

Recess and lunch activity

The percent time this cohort spent in MVPA during recess (20-28%) and lunch (30-35%) is similar to a previous study of 5-10 year old children from the UK [343]. However other studies have reported MVPA engagement of 63-78% in 3rd-5th grade children [417] and 50% in 6-12 year old boys [342]. Most previous studies [343,417,424-426] but not all [344] reported less MVPA in girls compared with boys. To our knowledge only one previous study reported light physical activity and sedentary time in addition to MVPA during recess [342]. Boys (aged 6-12 years) accumulated substantially less sedentary time and engaged in more light physical activity compared with boys in our study [342].

The differences between studies may be partially due to; 1) how physical activity was measured, 2) the study sample, 3) school policies and, 4) climate and geography. First, while we used accelerometers to quantify MVPA, Beighle et al. [417] used pedometers (Walk4Life) with an activity time function. This device groups physical activity intensities together whereas we report different intensity levels separately. Wickel and Eisenmann [342] defined non-wear as 20 minutes of consecutive zeros in comparison to our definition of 30 minutes and used different thresholds to classify physical activity intensity. This may yield different estimates of sedentary time [427] and physical activity levels [291].

Second, we recruited children from schools whereas Wickel and Eisenmann [342] recruited boys from local youth sport programs. A positive relationship between MVPA during sport practice and unstructured physical activity (i.e., total physical activity excluding youth sport, recess and physical education) suggests that children who are active during sport practice are also active during other aspects of their lives (such as recess and lunch). Additionally, our age range (8-11 years) is narrower than previous studies (6-12 years) [342]. It is well-documented that on average older children are less active than younger children [257].

Third, school policies that define the length or structure of recess and lunch may also explain differences between studies. In our study recess was 15-25 minutes long and lunch ranged from 35-50 minutes. We do not know how school policy specifically influenced physical activity during these periods (e.g., whether children had to sit and eat prior to playing outside). These data were also not provided in previous studies.

Fourth, there were also differences in the geography and climate where studies were conducted. This study was conducted in Vancouver, Canada during the winter months (November – February) whereas previous studies were conducted in the southwestern United States during spring (May) [417], central United States (month not reported) [342], the northwest of England during summer, fall, and spring (June, July-March) [343,424,426] and Portugal during spring/summer (May and June) [344].

Current recommendations suggest that 40% of recess and lunchtime should be spent in MVPA [343]. Fewer girls than boys achieved this recommendation; 16% of girls and 34% of boys met the guidelines during recess and 17% of girls and 37% of boys met the guidelines during lunch. This differs from two previous studies from the UK: First, among 5-10 year old children only 4% of girls and 15% of boys met the guidelines [343]. Second, among 6-10 year old children 44% of normal weight boys, 30% of overweight boys, 22% of normal weight girls and 34% of overweight girls met the guidelines [426].

Taken together, these findings highlight the need to provide more and/or facilitated opportunities for physical activity during school breaks. Environmental variables such as equipment availability, access to suitable play areas and high levels of adult supervision are associated with higher levels of physical activity [428]; therefore these factors may be useful targets for intervention.

Scheduled physical education class activity

The percent time this cohort spent in MVPA during physical education class (11-13%) is substantially lower than previous studies that report 37-40% of physical education class in MVPA [339,340,342]. This cohort also engaged in less light physical activity and more sedentary time than a previous study in 6-12 year-old boys [342]. The physical education curriculum in British Columbia prescribes learning outcomes in three areas: 1) Active Living (includes knowledge and participation), 2) Movement Skills, and 3) Safety, Fair Play & Leadership [429]. Therefore, it is possible that the physical education classes we measured were addressing different (non-physical activity) aspects of the curriculum.

There were several differences between previous investigations of physical education activity and ours. First, in other studies physical education specialists taught all [416,423] or a majority [339] of physical education classes. In our study all physical education classes were taught by the regular classroom (in most cases a generalist) teacher. SPARK (Sports and Active Recreation for Kids), a school-based physical education program showed that specialist teachers were more effective at increasing time students spent in MVPA compared with trained generalist teachers (40 minutes vs. 33

minutes weekly; [359]). Thus, it appears that despite focused training for generalist teachers, the need for advanced specialization in physical education may be necessary to effectively enhance children's physical activity levels during physical education. Second, several previous investigations used direct observation (System for Observing Fitness Instruction Time; SOFIT) rather than accelerometry to classify physical activity intensity [339,416]. With SOFIT student-level physical activity is estimated by coding children's body position (lying, sitting, standing, walking, vigorous). The 'vigorous' category includes any activity that is more intense than walking but does not distinguish beyond that.

Our findings did not support our hypothesis of less MVPA and more light physical activity and sedentary time in girls compared with boys or previous studies where 3rd [339], 4th [430] and 5th [416] grade boys were more active in physical education than girls, on average. However, our results support two studies reporting no gender differences in accelerometer counts per min in 5th grade [431] and step counts [423] in 6th grade girls and boys during physical education class.

Guidelines for physical activity during physical education class [345] suggest that 50% of physical education time should be spent in MVPA. In our study, less than 5% of girls and boys met these recommended guidelines (Figure 5-2). This is the only setting during the school-day where activity levels were similar between boys and girls, most likely due to mandatory participation. These findings highlight the need to evaluate either the nature of the physical education curriculum or the delivery of it, if the goal is to optimize physical activity opportunities for children within physical education. This also suggests that schools might benefit from a complimentary (to physical education) school-based physical activity model where children are provided physical activity opportunities *outside* of structured physical education. This concept has been used recently in several interventions [389,432-434].

Limitations of the present study

We acknowledge several limitations. First, we did not assess physical maturity. Previous research suggests that sex differences in physical activity levels are eliminated after controlling for maturity [308]. As girls mature earlier than boys, they may be less physically active compared with same-age boys. Second, although we cross-checked school physical education schedules with teacher's physical activity logs and excluded those data that were not supported by teacher logs or where there were discrepancies, teacher data may have been recorded incorrectly. Third, we did not directly observe the activities reported by teachers. Fourth, we applied cut points to estimate minutes of physical activity from accelerometer data. Previous research suggests different cut points can yield different estimates of physical activity [291]. However, while the number of minutes within physical activity intensity categories may change with different cut points, the relative differences between boys and girls would likely remain true (i.e., more sedentary time and less MVPA in girls compared to boys).

Conclusion

The propensity for sedentary behavior in girls rather than MVPA or light physical activity may have negative health implications. Thus, school-based models that provide facilitated opportunities for physical activity and effectively engage girls should become a priority for schools. There is little known about sex-specific behaviors that might explain these differences. Therefore, future studies that examine social or biological factors that influence sex differences in physical activity are needed to inform both the design and implementation of school-based physical activity models.

Despite these sex differences a majority of children were meeting the whole school-day physical activity guidelines. Although many (63%-85%) children were not meeting the recess and lunch MVPA guidelines, the extremely high proportion not meeting the physical education class MVPA guidelines (approximately 97%) is especially troubling. Perhaps this serves as a call to action for school systems that have replaced physical education instruction by specialist teachers with generalist teachers to; 1) provide additional training or, 2) consider alternate or complimentary (to physical education) models of physical activity that provide children with more targeted opportunities to be more physically active during the school-day.

6 The cross-sectional association of physical activity and sedentary time with arterial compliance in young children[4]

SYNOPSIS: Arterial compliance, defined as the change in arterial volume relative to the change in arterial pressure, is an important marker of vascular health. In adults, physical activity has beneficial effects on arterial compliance; however, there are few data available in youth. This chapter explores the cross-sectional relation between physical activity, sedentary time, and arterial compliance in children. This is the first study to examine the relation between activity levels and arterial compliance in children using objectively measured physical activity and sedentary behaviour.

6.1 Introduction

Physical activity protects against cardiovascular and all-cause mortality in adults [32,111] and against clustered cardiovascular risk in youth [62,100,103,124-126]. Sedentary behaviours are also linked to increased risk of cardiovascular and all-cause mortality in adults [23,24,112,113] and to cardiovascular risk factors such as overweight [283] and blood pressure [411,435] in youth. While the physiological mechanisms that underpin the association between physical activity, sedentary behaviour, and cardiovascular health are not fully understood [26], research suggests that the beneficial effect of physical activity and the negative effect of sedentary time may be partly explained by their effects on arterial structure and function [168,436].

Arterial compliance provides insight into the structural and functional changes that precede atherosclerosis and cardiovascular events [76]. Consequently, arterial compliance is an important early marker of vascular health. In general, there is a beneficial relation between arterial compliance and physical activity in adults. Sedentary young adults had lower arterial compliance than their endurance-trained counterparts [437] and physically active adults demonstrated less age-related arterial stiffening than their sedentary peers [168,436]. In contrast, the relation between arterial

[4] Original data from chapter 6 are being used to prepare a manuscript (Nettlefold L, McKay HA, Naylor PJ, Bredin SSD, Warburton DER. The cross-sectional association of physical activity and sedentary time with arterial compliance in young children).

compliance and physical activity in youth is unclear. In children aged 9-12 years, arterial compliance was not related to physical activity measured using a weekly self-report questionnaire [177]. However, physical activity was linked to other indicators of children's vascular health, such as endothelial function [438] and pulse wave velocity [87] when physical activity was measured objectively. This suggests that weak estimates of physical activity in the previous study [177] may have obscured an association between physical activity and arterial compliance.

Accelerometers are now recommended widely to measure physical activity because they are less susceptible to recall bias and more likely to capture the sporadic activity patterns of children [439]. In addition, accelerometers provide information about characteristics of physical activity behaviour that are challenging to assess via questionnaire, such as accumulation patterns (i.e., activity accrued in extended bouts), sedentary time, and light intensity activity [439]. Emerging research suggests that these characteristics have important effects on youth health. For example, MVPA accumulated in bouts reduced risk of overweight independent of the total volume of MVPA [222] and bouts of light physical activity were beneficially associated with microvascular function [211].

Previous investigations were unable to evaluate the importance of sedentary time, light physical activity, and bouted MVPA to vascular stiffness because of limitations with the tool used to measure physical activity [87,177,438]. Accordingly, the aim of this investigation was to explore the relation of physical activity and sedentary behaviour (measured via accelerometry) with arterial compliance in children. Specific objectives were: 1) to evaluate the relation between physical activity intensity (MVPA, sedentary time, light, moderate, and vigorous physical activity) and arterial compliance in children and 2) to evaluate whether MVPA accumulated in bouts predicts arterial compliance beyond the total volume of MVPA. Our hypotheses were: 1) MVPA, light, moderate, and vigorous physical activity would be positively associated with arterial compliance, 2) sedentary time would be negatively associated with arterial compliance, and 3) MVPA accumulated in bouts would predict arterial compliance beyond the total volume of MVPA.

6.2 Methods

The recruitment process is described in detail in Chapter 3. Children (n=248) at three schools in the larger investigation consented to participate in this component (arterial compliance measurement and physical activity measurement via accelerometry).

Briefly, we assessed anthropometry using standard methods and arterial compliance using applanation tonometry; specific details are provided in Chapter 3. We used accelerometry to evaluate physical activity. Physical activity data were collected in 15 second epochs and processed using KineSoft software, version 2.0.94 (Saskatoon, Canada).

We used KineSoft software to extract the following physical activity variables: MVPA (≥ 3.0 METs; minutes/day), sedentary time (< 1.5 METs; minutes/day), light physical activity (1.5-2.9 METs; minutes/day), moderate physical activity (3.0-5.9 METs; minutes/day), and vigorous physical activity (≥ 6.0 METs; minutes/day). We also extracted patterns of accumulated MVPA (minutes/day in bouts). We considered four different 'bouts' of physical activity: 0-5 minutes, 5-10 minutes, 10-20 minutes, and ≥ 20 minutes. We developed the following margins of tolerance for interruptions in defined bouts of physical activity (i.e., when physical activity intensity fell outside the specified boundaries). For bouts 0-5 minutes in length, interruptions were not permitted. For bouts 5-10 minutes in length we permitted a 30 second interruption (15 second data only). For bouts 10-20 minutes in length we permitted a 1 minute interruption and for bouts ≥ 20 minutes in length we permitted a 2 minute interruption.

Statistical analyses

Stata Version 10.1 (StataCorp, College Station, TX) was used for all statistical analyses. Descriptive data are reported as mean (standard deviation) or median (25^{th}, 75^{th} percentile). Differences between girls and boys on all descriptive variables were assessed using unpaired t-tests (for normally distributed data) and Wilcoxon rank-sum test (for abnormally distributed data). Bivariate associations between arterial compliance and physical activity variables were assessed using partial correlation (controlling for body surface area) [440]. Hierarchical regression was used to evaluate the contribution of physical activity variables to large and small arterial compliance after controlling for body surface area, systolic blood pressure, and BMI. Overall model fit was assessed using cumulative r^2 and the independent contribution of physical activity was assessed using the change in r^2 when each physical activity variable was added to the base model. We tested assumptions of normality, linearity, and homoscedasticity using model residuals. The level of significance was set *a priori* at $p<0.05$.

6.3 Results

Descriptive characteristics

The flow of participants through the study and reasons for missing data are shown in Figure 6-1. After excluding participants without physical activity (n=96) and arterial compliance (n=47) data, 105 children (43 boys, 62 girls) were retained for further analysis. Descriptive characteristics for the 105 children with complete data are shown in Table 6-1. There were no differences in descriptive characteristics between boys and girls; therefore, the data were pooled for all subsequent analyses.

Total number of participants recruited n=248

No physical activity data	
Moved between consent and measurement	n=1
Incomplete consent process	n=1
Absent	n=24
Wore a pedometer*	n=9
Accelerometer malfunction	n=8
Insufficient data (<3 valid days)	n=53
Total	n=96

Total with valid physical activity data n=152

No arterial compliance data n=47

Total with physical activity and arterial compliance data n=105

Figure 6-1. Flow of participants through the study.
**Some children wore a pedometer because of an insufficient number of accelerometers (due to late returns from previous school).*

Table 6-1. Descriptive characteristics for children with complete arterial compliance and accelerometry data.

	Boys (n=43)	Girls (n=62)	Combined (n=105)
Anthropometrics and age			
Age (yr)	9.8 (0.6)	9.9 (0.6)	9.9 (0.6)
Height (cm)	138.2 (6.5)	139.9 (7.6)	139.2 (7.2)
Weight (kg)	33.8 (6.6)	34.3 (7.1)	34.1 (6.9)
BMI (kg/m^2)	17.6 (2.4)	17.4 (2.3)	17.5 (2.4)
Vascular measures			
Large artery compliance (mL/mmHg*10)	9.4 (4.0)	9.4 (4.1)	9.4 (4.0)
Small artery compliance (mL/mmHg*100)	5.6 (2.4)	5.3 (1.7)	5.4 (2.0)
Systolic blood pressure (mmHg)	105.2 (6.8)	108.6 (8.2)	107.2 (7.8)
Diastolic blood pressure (mmHg)	55.7 (6.5)	58.2 (5.6)	57.2 (6.1)
Mean arterial pressure (mmHg)	74.9 (4.7)	77.0 (6.7)	76.2 (6.0)
Physical Activity (accelerometry)			
Total physical activity (counts/min)	468.6 (141.4)	474.6 (158.6)	472.1 (151.1)
MVPA (min/day)	124.8 (40.6)	123.7 (37.9)	124.1 (38.9)
Sedentary (min/day)	539.9 (58.4)	538.5 (77.3)	539.1 (69.9)
Light physical activity (min/day)	116.0 (23.5)	121.0 (21.7)	119.0 (22.5)
Moderate physical activity (min/day)	105.2 (32.1)	104.8 (29.4)	105.0 (30.4)
Vigorous physical activity (min/day)	19.6 (11.3)	18.8 (10.3)	19.1 (10.7)
Bouted MVPA (0-5 min bouts; min/day)	103.0 (31.1)	106.9 (30.0)	105.3 (30.4)
Bouted MVPA (5-10 min bouts; min/day)	11.7 (8.8)	9.8 (6.8)	10.6 (7.7)
Bouted MVPA (10-20 min bouts; min/day)	6.4 (0.0, 11.8)	2.5 (0.0, 9.6)	3.4 (0.0, 10.3)
Bouted MVPA (≥20 min bouts; min/day)	0.0 (0.0, 5.9)	0.0 (0.0, 0.0)	0.0 (0.0, 5.1)

Values are mean (SD) or median (p25, p75). There were no differences between boys and girls for any variable; BMI, body mass index; MVPA, moderate to vigorous physical activity.

Upon visual inspection, three participants (2 girls) had values for large arterial compliance that appeared to be outliers (22-25 mL/mmHg*10; 3-4 standard deviations above the mean). Subsequent regression models supported this with large residuals for these data points. Furthermore, their leverage and influence (Cook's distance) statistics exceeded critical values. Thus, data from these individuals were excluded from subsequent regression models. The sample mean (standard deviation) for large artery compliance decreased from 9.4 (4.0) to 9.0 (3.2) mL/mmHg*10 when these data were excluded. The sample mean (standard deviation) for small artery compliance did not change appreciably.

Bivariate association between arterial compliance, physical characteristics, and physical activity

Partial correlation coefficients (adjusted for body surface area) between physical characteristics, physical activity variables and arterial compliance are shown in Table 6-2. Large artery compliance was positively associated with height ($r = 0.24$) and average sedentary time ($r = 0.22$) and negatively associated with weight ($r = -0.27$) and BMI ($r = -0.26$). When data from the three outliers were excluded the partial correlation between large artery compliance and sedentary time was no longer significant ($p=0.29$). The partial correlation between large artery compliance and other physical activity variables also decreased substantially when data from the three outliers were excluded (Table 6-2).

Small artery compliance was positively associated with MVPA ($r = 0.20$), light physical activity ($r = 0.24$), and moderate physical activity ($r = 0.20$). Minutes of MVPA accumulated in bouts of 5-10 minutes were also positively correlated with small artery compliance ($r = 0.22$). The positive association between total physical activity (accelerometer counts/minute) and small artery compliance was borderline significant ($r = 0.19$, $p=0$ .05). Excluding data from the three outliers had virtually no effect on the partial correlation between physical characteristics, physical activity, and small artery compliance (Table 6-2). However, for consistency with the analyses for large artery compliance, subsequent regression models excluded these outliers.

Table 6-2. Partial correlation coefficients among physical characteristics, physical activity, and arterial compliance measurements (adjusted for body surface area).

	Large artery (C_1)		Small artery (C_2)	
	n=105	n=102[§]	n=105	n=102[§]
Age (yr)	0.15 (p=0.13)	0.19 (p=0.06)	0.11 (p=0.29)	0.10 (p=0.33)
Height (cm)	0.24 (p=0.02)*	0.21 (p=0.03)*	-0.03 (p=0.78)	-0.04 (p=0.71)
Weight (kg)	-0.27 (p=0.01)*	-0.27 (p=0.01)*	-0.05 (p=0.58)	-0.05 (p=0.65)
BMI (kg/m^2)	-0.26 (p=0.01)*	-0.24 (p=0.01)*	-0.03 (p=0.75)	-0.02 (p=0.81)
Total physical activity (counts/min)	-0.16 (p=0.12)	-0.01 (p=0.89)	0.19 (p=0.05)	0.20 (p=0.05)
MVPA (min/day)	-0.17 (p=0.08)	-0.03 (p=0.74)	0.20 (p=0.04)*	0.21 (p=0.03)*
Sedentary (min/day)	0.22 (p=0.03)*	0.11 (p=0.29)	-0.07 (p=0.50)	-0.08 (p=0.44)
Light physical activity (min/day)	-0.15 (p=0.13)	0.00 (p=0.99)	0.24 (p=0.02)*	0.26 (0.01)*
Moderate physical activity (min/day)	-0.19 (p=0.05)	-0.05 (p=0.61)	0.20 (p=0.04)*	0.21 (p=0.03)*
Vigorous physical activity (min/day)	-0.09 (p=0.34)	0.03 (p=0.80)	0.17 (p=0.08)	0.17 (p=0.09)
Bouted MVPA (0-5 min) (min/day)	-0.16 (p=0.10)	-0.03 (p=0.77)	0.18 (p=0.07)	0.19 (p=0.05)
Bouted MVPA (5-10 min) (min/day)	-0.12 (p=0.21)	-0.06 (p=0.55)	0.22 (p=0.03)*	0.20 (0.048)*
Bouted MVPA (10-20 min) (min/day)	-0.04 (p=0.72)	0.08 (p=0.42)	0.11 (p=0.26)	0.11 (p=0.26)
Bouted MVPA (≥ 20 min) (min/day)	-0.18 (p=0.08)	-0.14 (p=0.15)	-0.00 (p=0.98)	-0.00 (p=0.97)

*BMI, body mass index; MVPA, moderate to vigorous physical activity. *p<0.05*

§ Upon visual inspection, three participants had large arterial compliance data that appeared to be outliers (3-4 standard deviations above the mean). Subsequent regression models supported this with large residuals for these data points. Furthermore, their leverage and influence (Cook's distance) statistics exceeded critical values. We calculated the partial correlations with (n=105) and without (n=102) these three individuals for both large and small artery compliance.

Multivariate associations

The results of the hierarchical linear regression are shown in Table 6-3. The base model consisted only of potential confounding variables (body surface area, BMI, and systolic blood pressure). The base model explained 32-35% of the variance for both small and large artery compliance. Subsequent models consisted of the base model plus one physical activity variable. None of the physical activity variables explained any additional variance in large artery compliance. For small artery compliance, MVPA, light physical activity, and moderate physical activity explained 2.6 - 4.7% of the variance beyond that explained by body surface area, BMI, and systolic blood pressure. Total physical activity (accelerometer counts/minute) and MVPA accumulated in bouts of 0-5 or 5-10 minutes approached statistical significance (p=0.067, 0.091 and 0.093 respectively) and explained an additional 2% of the variance in small artery compliance beyond the base model. Sedentary time did not explain any additional variance in small artery compliance beyond the base model; however, when average wear hours per day was also introduced in to the model the r^2 change increased from 0.2% to 2.8% and was statistically significant (p=0.04; data not shown). Average wear hours/day was not a significant predictor in any other model.

Table 6-3. Results of the hierarchical linear regression to determine the unconfounded effect of physical activity on small and large artery compliance (n=102).

	Large Artery (C_1) §		Small Artery (C_1) §	
	r^2 change (p value)	Cumulative r^2	r^2 change (p value)	Cumulative r^2
Base model				
Body surface area, BMI, systolic blood pressure	----	0.320	----	0.345
Base model + physical activity variables				
Model 1: Base model + total MVPA (min/day)	0.001 (p=0.754)	0.321	0.026* (p=0.047)	0.371
Model 2: Base model + total physical activity (counts/min)	0.001 (p=0.682)	0.322	0.022 (p=0.067)	0.367
Model 3: Base model + sedentary (min/day)	0.017 (p=0.113)	0.338	0.002 (p=0.587)	0.347
Model 4: Base model + light physical activity (min/day)	0.000 (p=0.820)	0.321	0.047* (p=0.007)	0.392
Model 5: Base model + moderate physical activity (min/day)	0.001 (p=0.682)	0.322	0.027* (p=0.042)	0.373
Model 6: Base model + vigorous physical activity (min/day)	0.000 (p=0.983)	0.320	0.014 (p=0.149)	0.359
Model 7: Base model + MVPA accumulated in bouts of 0-5 min (min/day)	0.001 (p=0.761)	0.321	0.019 (p=0.091)	0.364
Model 8: Base model + MVPA accumulated in bouts of 5-10 min (min/day)	0.006 (p=0.344)	0.327	0.019 (p=0.093)	0.364
Model 9: Base model + MVPA accumulated in bouts of 10-20 min (min/day)	0.008 (p=0.276)	0.329	0.015 (p=0.139)	0.360
Model 10: Base model + MVPA accumulated in bouts of ≥20 min (min/day)	0.007 (p=0.323)	0.327	0.002 (p=0.617)	0.347

The dependent variable was either large or small artery compliance. The first block consisted of body surface area, BMI, and systolic blood pressure. The second block consisted of one physical activity variable. BMI, body mass index; MVPA, moderate to vigorous physical activity.

§ *Upon visual inspection, three participants had large arterial compliance data that appeared to be outliers (3-4 standard deviations above the mean). Subsequent regression models supported this with large residuals for these data points. Furthermore, their leverage and influence (Cook's distance) statistics exceeded critical values and when data for these participants were excluded, the r^2 for the base large artery compliance model increased from 0.215 to 0.320. As a result, model parameters (for both large and small artery compliance) are based on a sample of 102 participants.*

Total MVPA versus bouted MVPA

Neither total nor bouted MVPA were associated with large artery compliance in the previous bivariate or multivariate analyses. Therefore, the relative importance of total vs. bouted MVPA in large artery compliance was not assessed. The associations were somewhat stronger for small artery compliance. Therefore, to evaluate whether MVPA accumulated in bouts predicted small artery compliance beyond total minutes of MVPA, the two variables were introduced into the hierarchical model in separate blocks (Table 6-4). The inclusion of bouted MVPA was not significant and explained between 0 and 0.2% additional variance. The full model with coefficients for all covariates, and adjusted r^2 is provided in Appendix O.

Table 6-4. Results of the hierarchical linear regression to determine the independent effect of bouted MVPA on small artery compliance after controlling for body surface area, BMI, systolic blood pressure and total MVPA (n=102).

	Small Artery (C_1)	
	r^2 change (p value)	**Cumulative r^2**
Base model		
Body surface area, BMI, systolic blood pressure	----	0.345
Base model + physical activity variables		
Model 1: Base model + MVPA	0.026* (p=0.047)	0.371
Model 2: Model 1 + MVPA accumulated in bouts of 0-5 min (min/day)	0.002 (p=0.571)	0.373
Model 3: Model 1 + MVPA accumulated in bouts of 5-10 min (min/day)	0.001 (p=0.722)	0.372
Model 4: Model 1 + MVPA accumulated in bouts of 10-20 min (min/day)	0.002 (p=0.565)	0.373
Model 5: Model 1 + MVPA accumulated in bouts of ≥20 min (min/day)	0.000 (p=0.997)	0.371

The dependent variable was small artery compliance. The first block consisted of body surface area, BMI, and systolic blood pressure. The second block consisted of MVPA (min/day). The third block consisted of one of the bouted MVPA variables. BMI, body mass index; MVPA, moderate to vigorous physical activity.

§ *Upon visual inspection, three participants had large arterial compliance data that appeared to be outliers (3-4 standard deviations above the mean). Subsequent regression models supported this with large residuals for these data points. Furthermore, their leverage and influence (Cook's distance) statistics exceeded critical values. As a result, model parameters are based on a sample of 102 participants.*

6.4 Discussion

This is the first investigation to use an objective measure of physical activity to examine the relation between physical activity, sedentary time, and arterial compliance in children. There are three novel findings. First, objectively measured physical activity, but not sedentary time, was beneficially associated with small artery compliance in healthy children. In this cohort of children aged 8-11 years, physical activity explained an additional 2.6 - 4.7% of the variance beyond that captured by body surface area, BMI, and systolic blood pressure with the largest amount of additional variation explained by the average amount of light physical activity/day. Second, objectively measured physical activity was not associated with large artery compliance. Third, MVPA accumulated in bouts did not predict arterial compliance independent of total MVPA. These data extend our previous findings which showed that physical fitness was associated positively with arterial compliance [177].

Physical activity and arterial compliance

Our findings align with research in adults suggesting that sedentary individuals have lower arterial compliance than their endurance-trained counterparts [437] and that physically active individuals demonstrate less age-related arterial stiffening than their sedentary peers [168,436]. Our previous work in children demonstrated a positive association between physical fitness and arterial compliance, but no association between questionnaire-derived physical activity and arterial compliance in a group of similarly aged children [177]. This highlights the importance of 'robust' exposure measures such as objectively measured physical activity or physical fitness in these types of investigations.

Despite no directly comparable research in youth, our results support previous investigations that reported beneficial associations between objectively measured physical activity and endothelial function [438] or carotid-femoral pulse wave velocity [87] in youth. Despite using objective measures of physical activity (doubly labeled water [438] and 7 day pedometry [87]), the methodologies applied in those two studies do not allow researchers to examine physical activity in the same type of detail as accelerometry. For instance, while both provide an estimate of total volume of activity (energy expenditure and number of steps) neither provides any information about intensity or patterns of physical activity. This is unfortunate because novel research suggests that bouted activity [222,326], light physical activity [378], and sedentary behaviour [224] are important determinants of health.

Light physical activity has emerged as a very important facet of physical activity behaviour. However, to date it has received relatively little attention in comparison to the more widely studied MVPA. Here we show that light intensity activity is associated with small artery compliance, both in bivariate and multivariate analyses. Light physical activity was also associated with microvascular health in boys [211] and pulse wave velocity in adults [172]. It is encouraging that vascular health is associated with light physical activity to the same degree as MVPA because it implies that even individuals who fall short of current MVPA guidelines may still achieve vascular health benefits through light physical activity.

The physiology by which physical activity may improve arterial compliance in children is unclear and there are likely many biological pathways involved. However, the mechanisms by which regular exercise and physical activity reduce age-related arterial stiffening in adults offer some hypotheses. Physical activity and exercise increase blood flow, which induces sheer stress on the vessel wall. Repeated episodes of increased shear stress appear to stimulate the functional and structural vascular changes observed with routine physical activity [28,167,226]. Oxidative stress is reduced and systemic vascular vasodialatory capacity increases through increased expression and activation of nitric oxide synthase [167,168]. Resting sympathetic activity may be decreased which leads to reductions in vascular tone [226,441]. Structurally, arteries undergo outward remodelling which leads to an increased vessel diameter [167,227]. Given the positive association we observed between light physical activity and small artery compliance, it suggests that even the small increases in blood flow and shear stress that would be expected with light intensity activity may improve vascular health. Additionally, given that obesity [440], metabolic syndrome [86], and diabetes [85] are associated with poor vascular health, the beneficial effect of light physical activity on the vasculature may be mediated through the association of light physical activity with daily energy expenditure and energy balance [442], and/or an association with metabolic risk factors such as plasma glucose level [378].

Small versus large arterial compliance

The absence of a relation between physical activity and large artery compliance may be due, at least in part, to structural and functional differences between the large capacitance arteries and the smaller conduit arteries. In large arteries, such as the aorta, compliance is determined by vascular structure. These arteries contain high quantities of elastin and collagen and structural changes, such as elastin fragmentation and increased collagen, lead to decreased compliance [72,443]. In contrast, the compliance of smaller, muscular arteries is determined through a combination of structure and function. The layer of smooth muscle cells found in these arteries is susceptible to structural changes, such as concentric smooth muscle thickening, and infiltration of collagen and other molecules. However, the compliance of smaller arteries is also influenced by functional changes, such as a reduced response to the vasoactive substances of the endothelium [443]. The association of physical activity with small, but not large, artery compliance suggests that the beneficial effects of physical activity may be realized through improvements to vascular function. Indeed, previous research demonstrated that physical activity is associated with endothelial function in healthy youth [438,444] and youth with type 1 diabetes [445].

Total versus bouted MVPA

From a health promotion perspective, it is important to determine whether physical activity accumulated in bouts is important beyond the total volume of activity. Previous editions of Canada's physical activity guidelines for children encouraged MVPA to be accumulated in bouts of 5 to 10 minutes [276,277]. However, the latest revision removed this statement due to a paucity of research in this area [268]. Further exploration of the relative importance of physical activity bouts is required to inform future physical activity guidelines.

Recent evidence in youth has shown that MVPA accumulated in bouts reduces the risk of overweight independent of the total volume of physical activity [222]. In contrast, the present work found only limited evidence that MVPA accumulated in bouts was related to arterial compliance. In fact, when total MVPA was entered into the model first, there was no additional effect of bouted MVPA. This suggests that the total volume of MVPA is more important than the pattern in which it is accrued. From a physiological perspective, perhaps it is the *frequency* of bouts (of any duration) that increase blood flow, and hence shear stress, that are important to produce vascular benefits. Indeed previous work in young boys demonstrated that the frequency of bouts of at least light intensity was associated with microvascular health [211]. Future research might consider not only the volume of activity accumulated in bouts, but also the number of activity bouts.

We only considered MVPA accumulated in bouts; however, other aspects of activity bouting may be important to consider in the future. Research in adults found that those who engaged in shorter bouts of sedentary time had a healthier metabolic profile than those who were sedentary for prolonged periods [326]. In the present analyses, average sedentary time per day was not associated with arterial compliance; however, we did not assess the influence of either bouted sedentary time or the number of sedentary bouts. Given that many metabolic risk factors are also predictors of arterial compliance in adults [446], it is possible that bouted sedentary time or the number of sedentary bouts might be better associated with arterial compliance than average sedentary time per day. Unlike Stone et al. [211], who observed an association between the number of bouts of at least light intensity and microvascular health, we did not assess the frequency of light activity bouts. However we did observe that light physical activity was the physical activity variable most strongly associated with small artery compliance in this cohort of children. This adds to the growing evidence that suggests that a more detailed analysis of light activity is warranted.

Of clinical importance, our findings support the most recent revision of Canada's physical activity guidelines where there is no recommendation that specifically relates to patterns of physical activity [268]. An important caveat is that MVPA accrued in bouts of at least 5 minutes was low in this cohort; 40% of children did not engage in any bouts of MVPA 10-20 minutes in length and 72% did not engage in any bouts of MVPA greater than 20 minutes in length. Thus, the high prevalence of zeros in the data may have hampered our analyses.

Limitations

There are several limitations that should be acknowledged. First, this is a relatively small sample of children and this may have limited our ability to detect associations between some variables of interest. Indeed, there are several instances that suggest a trend in the data that did not reach statistical significance. A post-hoc calculation of the sample size required to achieve statistical significance given the current r^2 values is provided in Appendix P. To increase statistical power in this study, data from girls and boys were pooled. Previous work reported that prepubertal girls had stiffer central and peripheral arteries compared with prepubertal boys [447]. However, in postpubertal girls and boys, there was no difference in large artery stiffness and *boys* actually had stiffer peripheral arteries [447]. This suggests that the higher concentration of sex steroids present after puberty, as well as the increase in body size [448] modulate arterial stiffness in both girls and boys. The goal of this study was not to evaluate gender differences in arterial compliance; however, it is unknown whether the relationship between arterial compliance and physical activity is different in prepubertal girls and boys. A larger sample of girls and boys would be required to evaluate this question. However, it is possible that the increased vascular stiffness previously observed in prepubertal girls compared with prepubertal boys [447] is related to the generally lower levels of physical activity observed in girls compared with boys [40,126,229,257,293,296-304].

A second limitation of this study is the cross-sectional nature of the data. We cannot conclude that low volumes of physical activity cause reduced small artery compliance; longitudinal data are necessary to clarify this association. Third, although evidence in adults suggests that low arterial compliance predicts cardiovascular events [80], we do not know the long-term health implications of low arterial compliance during childhood. Fourth, many children did not accumulate any MVPA in bouts, particularly in the longer categories. Thus, the quantity and distribution of the bouted physical activity data may have been inadequate to detect an association.

Conclusion

Our data support the need for robust measures of physical activity patterns, such as that obtained via accelerometry, in health research. Future research, particularly the influence of activity bout frequency on vascular health and the effect of a physical activity intervention on arterial compliance, is warranted.

7 Physical activity and cardiovascular fitness in children: are bouts of activity important? [5]

SYNOPSIS: This chapter explores the relation between objectively measured physical activity, sedentary time, and cardiovascular fitness in children. In particular, this chapter aims to investigate whether moderate to vigorous physical activity accumulated in bouts predicts cardiovascular fitness beyond the total volume of activity. A thorough understanding of physical activity patterns that promote cardiovascular fitness is essential given the importance of cardiovascular fitness as a determinant of health.

7.1 Introduction

Cardiovascular fitness is a key component of overall health in children and adults [90,91]. In epidemiological investigations, cardiovascular fitness was associated with a reduced risk of all-cause and cardiovascular mortality in adults [32,33] and reduced risk of clustered cardiovascular risk in children and adolescents [17,99-101]. In adults, MVPA was positively associated with cardiovascular fitness [180,181]. However, evidence to support a strong relation between MVPA [229], exercise training [190] and cardiovascular fitness in children is equivocal. This relates in part to the challenge of adequately capturing the unique pattern of children's physical activity and relating these patterns to short and longer term health benefits.

For adults, current physical activity guidelines recommend that aerobic exercise be accumulated in bouts of at least 10 minutes to achieve health benefits, including improved cardiovascular fitness [32,272,449]. For children, although 60 minutes/day of physical activity is recommended, there is currently a paucity of evidence to support *how* those minutes should be accrued [268,272,274,279]. Specifically, not knowing whether or how bouts of physical activity contribute to children's cardiovascular fitness is a limitation of current physical activity guidelines [268]. Previous research in youth (aged 8-17 years) found that MVPA accumulated in bouts of at least 5 or 10 minutes reduced risk of overweight independent of total MVPA [222]. However, to date, only three studies examined

[5] Original data from chapter 7 are being used to prepare a manuscript (Nettlefold L, McKay HA, Naylor PJ, Warburton DER. Physical activity and cardiovascular fitness in children: is bouted activity important?)

the association between cardiovascular fitness and MVPA accumulated in 5 [126,200,211] or 10 minute [126] bouts. Significant associations between bouted MVPA and cardiovascular fitness were noted, however, the magnitude of these associations *independent* of the total volume of MVPA was not assessed.

Therefore, the primary aim of this study was to evaluate the independent contribution of total MVPA and bouted MVPA to cardiovascular fitness in children. A secondary aim was to report the relation between cardiovascular fitness and other indices of physical activity (total physical activity, sedentary time, light physical activity, moderate physical activity, and vigorous physical activity). We hypothesized that bouted MVPA would be an independent predictor of cardiovascular fitness in children.

7.2 Methods

The recruitment process is described in detail in Chapter 3. Children (n=629) attending nine schools consented to participate in this component (physical activity measurement via accelerometry) of a larger study (n=1,529 students; attending 30 schools).

Briefly, we assessed anthropometry using standard methods. We assessed cardiovascular fitness using a multistage, 20 m shuttle run test [393]; specific details are provided in chapter 3. We used an objective measure (accelerometry) to determine level of physical activity; epoch length was set at 15 seconds. We used KineSoft software (version 2.0.94; Saskatoon, Canada) to extract the following physical activity variables: MVPA (≥ 3.0 METs; minutes/day), sedentary time (SED; < 1.5 METs; minutes/day), light physical activity (1.5-2.9 METs; minutes/day), moderate physical activity (3.0-5.9 METs; minutes/day), vigorous physical activity (≥ 6.0 METs; minutes/day), and bouted MVPA (minutes/day accumulated in bouts of 0-5 minutes, 5-10 minutes, 10-20 minutes, and ≥ 20 minutes). For bouted activity we developed the following margins of tolerance for interruptions in defined bouts of physical activity (i.e., when physical activity intensity fell outside the specified boundaries). For bouts 0-5 minutes in length, interruptions were not permitted. For bouts 5-10 minutes in length we permitted a 30 second interruption. For bouts 10-20 minutes in length we permitted a 1 minute interruption and for bouts ≥ 20 minutes in length we permitted a 2 minute interruption. Detailed methods are provided in Chapter 3.

Statistical analyses

We used Stata Version 10.1 (StataCorp, College Station, TX) for all statistical analyses. Descriptive data are reported as mean (SD; standard deviation) or median (25^{th}, 75^{th} percentile). We used unpaired t-tests to assess differences in age and anthropometric variables between included and excluded participants. Differences between boys and girls for age, anthropometry, cardiovascular fitness, and physical activity were assessed using unpaired t-tests (normally distributed data) or Wilcoxon rank-sum test (Mann-Whitney; skewed data). Based on previous research, we hypothesized that boys would have greater cardiovascular fitness than girls [194]; therefore, analyses were conducted separately for girls, for boys and the whole group. We used Pearson product moment and Spearman rank correlation coefficients to examine the bivariate association between cardiovascular fitness and physical activity variables. We used hierarchical linear regression to evaluate the unique contribution of physical activity to cardiovascular fitness after controlling for age, BMI, and sex (sex included only in analysis of pooled data). We assessed the fit of the overall model using cumulative r^2 and the independent contribution of physical activity using the r^2 change as each physical activity variable was added to the base model. We tested assumptions of normality, linearity, and homoscedasticity using model residuals.

Some participants did not engage in any 10-20 minute or ≥ 20 minute bouts of MVPA; therefore, we created a dichotomous variable for 1) children who accrued *no* vs. *any* MVPA in 10-20 minute bouts (i.e., all MVPA was accrued in bouts of < 10 minutes or ≥ 20 minutes) and 2) children who accrued *no* vs. *any* MVPA in ≥ 20 minute bouts (i.e., all MVPA was accrued in bouts of < 20 minutes). We used linear regression to compare the cardiovascular fitness of these two groups, adjusted for age, sex, BMI and the total volume of MVPA (minutes/day). The level of significance for all analyses was set *a priori* at $p<0.05$.

7.3 Results

The flow of participants through the study and reasons for missing data are provided in Figure 7-1. After excluding participants with missing or invalid physical activity (n=247), cardiovascular fitness (n=12), and BMI (n=4) data, we retained 366 children (173 boys) for further analysis. There was no difference in age or height for participants who were included versus those who were excluded. However, excluded participants were 1.6 kg heavier (95% confidence interval 0.5, 3.2) and had a BMI 0.6 kg/m^2 higher (95% confidence interval 0.0007, 1.2) than included participants (data not shown).

Descriptive characteristics are provided in Table 7-1. Cardiovascular fitness (number of laps), vigorous physical activity, and MVPA accumulated in bouts of 5-10, 10-20, and ≥ 20 minutes were positively skewed. Thus, the median (with 25th and 75th percentiles) is reported in Table 7-1 and differences between boys and girls were assessed using Wilcoxon rank-sum (Mann-Whitney) tests. All other variables were normally distributed (Table 7-1). Thus, these variables are reported as mean (standard deviation) and differences between boys and girls were assessed using unpaired t-tests. Boys had 30% higher cardiovascular fitness (6 laps) and accrued more MVPA (19 minutes/day) and vigorous activity (6 minutes/day) than did girls. On average, children wore the accelerometer for 13.1 (1.0) hours/day; 55% of children had 4 valid days of accelerometry data and 45% had 3 valid days.

Total number of participants recruited n=629

No physical activity data	
Moved between consent and measurement	n=5
Incomplete consent process	n=8
Absent	n=55
Wore a pedometer*	n=31
Accelerometer malfunction	n=23
Insufficient data (<3 valid days)	n=125
Total	n=247

Total with valid physical activity data n=382

No cardiovascular fitness data (absent) n=12

No measure of BMI n=4

Total with complete data n=366

Figure 7-1. Flow of participants through the study and reasons for missing data.
**Some children wore a pedometer because of an insufficient number of accelerometers (due to late returns from previous school).*

Table 7-1. Mean (SD) or median (p25, p75) values for descriptive characteristics of boys and girls including age, anthropometric variables, cardiovascular fitness, and physical activity.

	Boys (n=173)	Girls (n=193)	Combined (n=366)
Age and anthropometrics			
Age (yr)	9.9 (0.6)	9.9 (0.6)	9.9 (0.6)
Height (cm)	140.3 (6.8)	140.5 (7.6)	140.4 (7.2)
Weight (kg)	36.2 (9.5)	35.5 (7.7)	35.8 (8.6)
BMI (kg/m^2)	18.2 (3.6)	17.8 (2.8)	18.0 (3.2)
Cardiovascular fitness			
Number of laps completed	26 (17, 40) *	20 (14, 31)	23 (15, 34)
Estimated $\dot{V}O_2$ max (mL/kg/min)	47.4 (4.5) *	46.1 (3.5)	46.7 (4.0)
Physical Activity (accelerometry)			
MVPA (min/day)			
Total MVPA	134.6 (39.8) *	116.0 (34.1)	124.8 (38.0)
Bouted MVPA (0-5 min bouts)	106.7 (27.7)	101.1 (27.0)	103.7 (27.4)
Bouted MVPA (5-10 min bouts)	11.5 (6.2, 16.7) *	7.9 (4.0, 12.1)	9.5 (4.8, 15.0)
Bouted MVPA (10-20 min bouts)	7.8 (3.3, 13.3) *	2.7 (0.0, 7.8)	4.0 (0.0, 10.5)
Bouted MVPA (≥20 min bouts)	0.0 (0.0, 7.0) *	0.0 (0.0, 0.0)	0.0 (0.0, 5.2)
Total physical activity (cpm)	512.1 (151.3) *	445.8 (134.6)	477.2 (146.3)
Sedentary (min/day)	534.2 (62.9)	545.0 (68.2)	539.9 (65.9)
Light physical activity (min/day)	119.7 (22.4)	120.5 (21.9)	120.1 (22.1)
Moderate physical activity (min/day)	111.7 (30.1) *	99.3 (26.9)	105.2 (29.1)
Vigorous physical activity (min/day)	20.3 (13.3, 29.4) *	14.5 (9.7, 21.9)	17 (10.5, 25.5)

*Values are mean (SD) or median (p25, p75); BMI, body mass index; $\dot{V}O_2$ max, maximal aerobic power; cpm, accelerometer counts/minute; MVPA, moderate to vigorous physical activity;*significantly different from girls (p<0.05).*

Bivariate association between cardiovascular fitness and physical activity

Table 7-2 describes the associations between cardiovascular fitness (number of laps) and physical activity variables. Age, but not BMI, was significantly associated with all physical activity variables; therefore, age-adjusted correlations are also provided. Pearson product moment and Spearman rank correlation coefficients were similar (in direction and magnitude); therefore, I report only Pearson Product Moment correlation coefficients (Spearman Rank correlation coefficients are provided in Appendix Q). Sedentary time was negatively associated with cardiovascular fitness. With the exception of light physical activity, all other physical activity variables were positively associated with cardiovascular fitness (Table 7-2).

Physical activity variables predict cardiovascular fitness; but predictors differ by sex

Results from the hierarchical linear regression are provided in Table 7-3. Cardiovascular fitness served as the dependent variable. The first block of independent variables (the base model) entered into the model included age, BMI, and sex (where appropriate). The base model explained 9.2% to 12.6% of the variance in cardiovascular fitness. Subsequent models were comprised of the base model plus one physical activity variable. In the model for boys only and the combined model (boys and girls), sedentary time and all physical activity variables except light physical activity were significant predictors of cardiovascular fitness. In the girls only model, light physical activity, 10-20 minute bouts of MVPA, and ≥ 20 minute bouts of MVPA did not significantly predict cardiovascular fitness.

Bouted MVPA is not associated with cardiovascular fitness independent of total MVPA

To evaluate whether bouted MVPA was a significant *independent* predictor of cardiovascular fitness bouted MVPA and total MVPA were entered separately into the hierarchical linear regression model (Table 7-4). Bouted MVPA (of any length) was not a significant independent predictor of cardiovascular fitness and explained only 0-0.9% of additional variance. The full model with coefficients for all covariates and adjusted r^2 is provided in Appendix Q.

Sixteen children (5 boys) did not accumulate any MVPA in bouts of 5-10 minutes, 126 children (36 boys) did not accumulate any MVPA in bouts of 10-20 minutes, and 266 children (100 boys) did not accumulate any MVPA in bouts ≥ 20 minutes. Age and BMI were similar between children with *no* MVPA in bouts of 10-20 minutes compared with children with *any* MVPA in bouts of 10-20 minutes. Similarly, BMI was not different between children with *no* MVPA in bouts ≥ 20 minutes compared with children with *any* MVPA in bouts of ≥ 20 minutes. Children with *no* MVPA in bouts ≥ 20 minutes were significantly older than children with *any* MVPA in bouts ≥ 20 minutes; however, the differences were small (approximately 2 months). The proportion of girls with *no* 10-20 minute or ≥ 20 minute bouts of MVPA was significantly greater than the proportion of boys with *no* 10-20 minute or ≥ 20 minute bouts of MVPA (chi-square, $p<0.001$).

Cardiovascular fitness was similar in children with *any* 10-20 minute bouts of MVPA compared with children with *no* 10-20 minute bouts of MVPA (Figure 7-2). Cardiovascular fitness was greater in children with *any* bouts of MVPA ≥ 20 minutes compared with children with *no* bouts of MVPA ≥ 20 minutes (Figure 7-2). The performance difference between groups was approximately 5.8 laps (95% CI 2.4, 9.2) (Figure 7-3). All models were adjusted for age, BMI, sex, and total MVPA.

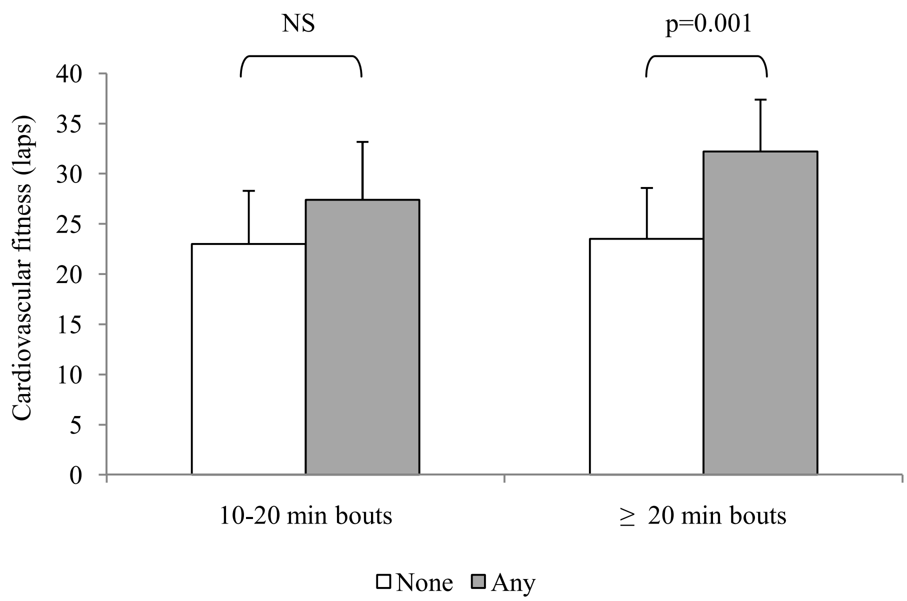

Figure 7-2. Cardiovascular fitness (unadjusted values) in children who accumulated no or any 10-20 minute bouts and ≥ 20 minute bouts of MVPA.
There was no significant difference in cardiovascular fitness between children with ***no*** *or* ***any*** *MVPA in bouts of 10-20 minutes. After adjusting for age, sex, BMI and total MVPA, children with* ***any*** *MVPA in bouts ≥ 20 minutes ran 5.8 laps more (95% CI 2.4, 9.2) than children with* ***no*** *MVPA in bouts ≥ 20 minutes (see also Figure 7-3); (NS, not significant).*

Table 7-2. Pearson Product Moment correlation coefficients (unadjusted and age-adjusted) between cardiovascular fitness (number of laps) and physical activity variables.

	Boys (n=173)		Girls (n=193)		Combined (n=366)	
	Unadjusted	**Age-adjusted**	**Unadjusted**	**Age-adjusted**	**Unadjusted**	**Age-adjusted**
MVPA (min/day)						
Total MVPA	0.22 (p=0.004)	0.25 (p=0.001)	0.16 (p=0.03)	0.19 (p=0.007)	0.23 (p<0.001)	0.26 (p<0.001)
Bouted MVPA (0-5 min)	0.13 (p=0.1)	0.16 (p=0.04)	0.13 (p=0.07)	0.16 (p=0.02)	0.14 (p=0.006)	0.17 (p=0.001)
Bouted MVPA (5-10 min)	0.15 (p=0.06)	0.16 (p=0.04)	0.14 (p=0.05)	0.16 (p=0.02)	0.18 (p<0.001)	0.20 (p<0.001)
Bouted MVPA (10-20 min)	0.23 (p=0.002)	0.25 (p=0.001)	0.11 (p=0.13)	0.12 (p=0.1)	0.24 (p<0.001)	0.25 (p<0.001)
Bouted MVPA (≥20 min)	0.19 (p=0.01)	0.20 (p=0.007)	0.08 (p=0.28)	0.09 (p=0.23)	0.20 (p<0.001)	0.21 (p<0.001)
Total physical activity (cpm)	0.27 (p<0.001)	0.29 (p<0.001)	0.21 (p=0.004)	0.22 (p=0.002)	0.27 (p<0.001)	0.29 (p<0.001)
Sedentary time (min/day)	-0.20 (p=0.01)	-0.22 (p=0.005)	-0.13 (p=0.07)	-0.17 (p=0.02)	-0.17 (p<0.001)	-0.20 (p<0.001)
Light physical activity (min/day)	0.03 (p=0.68)	0.04 (p=0.59)	0.07 (p=0.34)	0.08 (p=0.28)	0.04 (p=0.40)	0.05 (p=0.31)
Moderate physical activity (min/day)	0.19 (p=0.01)	0.22 (p=0.004)	0.13 (p=0.06)	0.17 (p=0.02)	0.20 (p<0.001)	0.23 (p<0.001)
Vigorous physical activity (min/day)	0.22 (p=0.003)	0.25 (p=0.001)	0.19 (p=0.008)	0.21 (p=0.004)	0.25 (p<0.001)	0.27 (p<0.001)

cpm, accelerometer counts per minute; MVPA, moderate to vigorous physical activity. Spearman rank correlation coefficients are provided in Appendix Q.

Table 7-3. Hierarchical linear regression models to demonstrate the independent contribution of total physical activity and bouted MVPA to cardiovascular fitness (controlled for age, BMI, and sex).

	Boys (n=173)		**Girls (n=193)**		**Combined (n=366)**	
	r^2 change (p value)	**Cumulative r^2**	**r^2 change (p value)**	**Cumulative r^2**	**r^2 change (p value)**	**Cumulative r^2**
Base model						
Age, BMI, sex [a]	----	0.094	----	0.092	----	0.126
Base model + physical activity variables						
MVPA (min/day)						
Total MVPA	0.073 (p<0.001)	0.167	0.034 (p=0.007)	0.126	0.061 (p<0.001)	0.178
Bouted MVPA (0-5 min)	0.037 (p=0.008)	0.130	0.025 (p=0.021)	0.117	0.029 (p<0.001)	0.155
Bouted MVPA (5-10 min)	0.025 (p=0.029)	0.119	0.021 (p=0.034)	0.113	0.023 (p=0.002)	0.148
Bouted MVPA (10-20 min)	0.056 (p=0.001)	0.150	0.011 (p=0.135)	0.103	0.034 (p<0.001)	0.160
Bouted MVPA (≥20 min)	0.034 (p=0.012)	0.127	0.010 (p=0.156)	0.102	0.023 (p=0.002)	0.149
Total physical activity (cpm)	0.084 (p<0.001)	0.178	0.042 (p=0.003)	0.134	0.052 (p<0.001)	0.186
Sedentary (min/day)	0.041 (p=0.005)	0.134	0.023 (p=0.028)	0.115	0.029 (p<0.001)	0.155
Light physical activity (min/day)	0.008 (p=0.22)	0.102	0.005 (p=0.311)	0.097	0.006 (p=0.114)	0.132
Moderate physical activity (min/day)	0.058 (p=0.001)	0.151	0.029 (p=0.013)	0.121	0.042 (p<0.001)	0.168
Vigorous physical activity (min/day)	0.063 (p<0.001)	0.157	0.033 (p=0.008)	0.125	0.048 (p<0.001)	0.174

[a] *Sex only included in the base model for the combined analysis of girls and boys; MVPA, moderate to vigorous physical activity; cpm, accelerometer counts/minute.*

Table 7-4. Hierarchical linear regression models to demonstrate the independent contribution of bouted MVPA to cardiovascular fitness (controlled for age, BMI, sex and total MVPA).

	Boys (n=173)		Girls (n=193)		Combined (n=366)	
	r^2 change (p value)	Cumulative r^2	r^2 change (p value)	Cumulative r^2	r^2 change (p value)	Cumulative r^2
Base model						
Age, BMI, sex [a], total MVPA	----	0.167	----	0.126	----	0.178
Base model + bouted MVPA variables (min/day)						
Bouted MVPA (0-5 min)	0.003 (p=0.408)	0.170	0.002 (p=0.491)	0.129	0.004 (p=0.165)	0.182
Bouted MVPA (5-10 min)	0.002 (p=0.531)	0.169	0.001 (p=0.726)	0.127	0.000 (p=0.789)	0.178
Bouted MVPA (10-20 min)	0.009 (p=0.176)	0.176	0.001 (p=0.734)	0.127	0.006 (p=0.116)	0.184
Bouted MVPA (≥20 min)	0.003 (p=0.444)	0.170	0.001 (p=0.581)	0.128	0.004 (p=0.209)	0.182

Cardiovascular fitness served as the dependent variable. The first block of independent variables (the base model) entered into the model included age, BMI, sex (where appropriate), and total MVPA. Subsequent models were comprised of the base model plus one bouted MVPA variable. BMI, body mass index; MVPA, moderate to vigorous physical activity. The full model with coefficients for all covariates and adjusted r^2 is provided in Appendix Q.

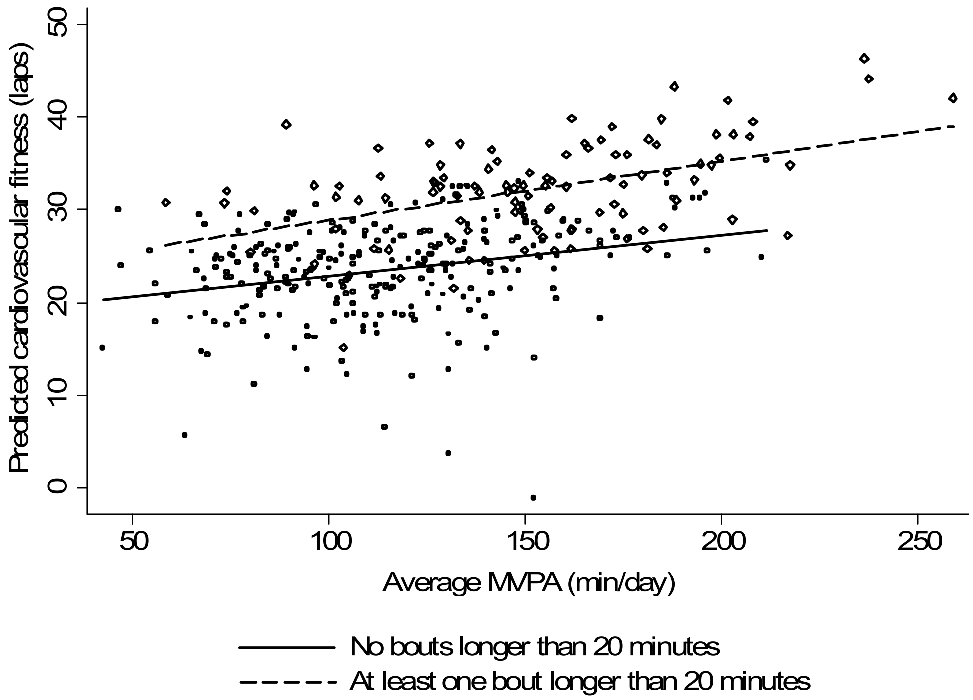

Figure 7-3. The relation between cardiovascular fitness and total MVPA in children who accrued no (solid line) or any (dashed line) MVPA in bouts ≥ 20 minutes.

Children who engaged in any bouts of MVPA ≥ 20 minutes ran 5.8 laps more,(95% CI 2.4, 9.2), on average, compared with children who engaged in no bouts of MVPA ≥ 20 minutes (controlled for age, sex, BMI and total MVPA).

7.4 Discussion

These findings extend the current literature by demonstrating that bouted MVPA did not predict cardiovascular fitness independent of the total volume of MVPA. Despite this, the amount of bouted physical activity may be important as children who engaged in at least one bout of MVPA $\geq$ 20 minutes ran 6 laps more, on average, than children who engaged in no bouts of MVPA $\geq$ 20 minutes. This finding complements previous research that reported significant associations between cardiovascular fitness and MVPA accumulated in 5 [126,200] or 10 [126] minute bouts. Further, these data support Canada's most recent physical activity guidelines for children where the recommendation that physical activity be accrued in bouts of at least 5-10 minutes was removed [268].

General physical activity is associated with cardiovascular fitness

Consistent with previous studies we observed a positive association between physical activity of varying intensity and cardiovascular fitness [126,191-195,198-201,203,204,207] and a negative association between sedentary time and cardiovascular fitness [126,201]. However, physical activity and sedentary time explained only a small portion of the variance in cardiovascular fitness. Morrow and Freedson [189] postulated that the association might be obscured by the subjective methods used to assess physical activity (e.g., self-reported physical activity by questionnaire). However, the weak association between physical activity or sedentary time and fitness persisted in recent studies that used objective measures to assess physical activity (e.g., accelerometry). This might also be explained by children's relatively high levels of cardiovascular fitness [189], their limited capacity to increase mitochondrial density [450], or insufficient stimulus to improve cardiovascular fitness due to the sporadic nature of children's physical activity [36,37].

We observed significant associations between children's cardiovascular fitness and activity of every intensity except light physical activity. This finding is in contrast to previous studies that reported no association between cardiovascular fitness and sedentary time [204,207] or moderate physical activity [203,207]. Furthermore, the strength of the association between physical activity and cardiovascular fitness varied between studies. These differences are likely due, at least in part, to variations in how cardiovascular fitness was measured and how physical activity outcomes were measured and processed. For example, cardiovascular fitness has been measured using treadmill endurance time [191], maximal aerobic power on a cycle ergometer [192-195] or treadmill [126,198-201], or using the 20 m shuttle run test [203,204,207]. Although MVPA, total physical activity (accelerometer counts/minute), sedentary time, light, moderate, and vigorous physical activity are commonly reported outcomes of objectively measured physical activity (by accelerometry), how these intensity levels are defined (i.e., accelerometer count thresholds) often varies considerably between studies. Other factors that commonly differ between studies are data collection (e.g., epoch) and processing (e.g., definitions of non-wear time) methods. Thus, it is not possible to compare results across studies.

Bouted MVPA is not an independent predictor of cardiovascular fitness

It is well established that MVPA is associated with a wide range of health benefits in children [268]. However, we and others [126,200,211] have now demonstrated that *bouted* MVPA is positively associated with cardiovascular fitness in children, after controlling for covariates such as sex [126,200], age, BMI z-score, and percent fat mass [126]. In this study we demonstrate for the first time that bouted MVPA did not explain significantly more variance in cardiovascular fitness than did total volume of MVPA, alone. This suggests that activity accrued in any pattern may provide a cardiovascular benefit for children.

In contrast, in American youth (n=2,500; aged 8-17 years) MVPA accumulated in bouts of at least 5 or 10 minutes predicted risk of overweight after adjusting for total MVPA [222]. This suggests that recommendations for physical activity may need to be outcome specific; that is, bouted MVPA might be recommended if healthy weight versus cardiovascular fitness is the intended benefit. This notion is supported by a recent study where microvascular function was associated with the frequency of light physical activity bouts ≥ 5 minutes whereas waist circumference was associated with the frequency, intensity, and duration of moderate physical activity bouts ≥ 5 minutes [211]. As data were not adjusted for the total volume of activity it is unclear whether bouted activity was an independent predictor of vascular health and/or waist circumference. As the minimum or optimal *volume* of activity required for health benefits varies by health outcome [32,268] it is also possible that the *pattern* of physical activity required for health benefits is health outcome specific.

It is unclear why bouted MVPA might influence weight status and cardiovascular fitness differently. Mark and Janssen [222] speculated that bouted MVPA might be associated with factors important to energy balance such as participation in sedentary behaviours. However, there is little evidence to support the postulate that participants who engage in a greater amount of bouted MVPA are less likely to engage in sedentary behaviours. The relation between *bouted* MVPA and sedentary time is unknown and, although seemingly counterintuitive, Jago et al. [321] reported that the most active children were also the most sedentary. A meta-analysis of 52 studies that found only a weak relation between physical activity and screen time also refutes this hypothesis [323].

Of interest, we observed that children who engaged in at least one bout of MVPA ≥ 20 minutes had greater cardiovascular fitness than children who accumulated all of their MVPA in shorter bouts. It is possible that longer bouts of MVPA contribute more to cardiovascular fitness than do shorter bouts. However, it is equally possible that children who were more fit were more likely to engage in bouts of MVPA that exceeded 20 minutes. As our data are cross-sectional, we are unable to determine causality.

Implications for children's physical activity guidelines

Previous versions of Canada's physical activity guidelines (introduced in 2002) for children and youth recommended that activity be accumulated in bouts of at least 5-10 minutes [276,277]. However, as there was no evidence to support this recommendation it was removed from the most recent (2010) guidelines [268]. Our results support this decision in that bouted MVPA did not predict children's cardiovascular fitness independent of total MVPA. However, our observation that children who accumulated at least one bout of MVPA ≥ 20 minutes were more fit than children who accumulated their MVPA in bouts < 20 minutes is important and begs future research to clarify the influence of bouted activity to cardiovascular fitness and other health outcomes.

Limitations

We acknowledge that this study has several limitations. First, it was cross-sectional thus we are unable to conclude that high physical activity levels promote high levels of cardiovascular fitness. Second, as optimal bout lengths to enhance children's health and fitness are not known we also do not know the biological significance of the bout lengths we evaluated in our study. Third, many children did not accumulate any MVPA in bouts of 10 – 20 minute or ≥ 20 minutes. Thus, we may have had insufficient power to detect an association between these more intense bouts of MVPA and cardiovascular fitness. We challenged this possibility by creating a dichotomous variable and the relation between the presence or absence of *any* MVPA in bouts ≥ 20 minutes and cardiovascular fitness emerged.

Conclusion

Bouted MVPA was not associated with cardiovascular fitness independent of total MVPA which suggests that specific activity patterns are not required to achieve cardiovascular fitness benefits in children. However, because children's activity is often accumulated sporadically it is important to better understand the significance of activity patterns on other aspects of health, including body weight. Further research that explores these relations is required to inform physical activity guidelines in future. Finally, as surprisingly little variance in cardiovascular fitness is explained by physical activity other factors that might explain this apparent paradox should be examined.

8 Is a novel school-based physical activity model (Action Schools! BC) an effective means to enhance cardiovascular fitness in children? A randomized controlled effectiveness trial [6]

SYNOPSIS: Increasing numbers of school-based physical activity interventions are available in the literature; however, these are predominantly studies of intervention efficacy. Few studies systematically disseminated the intervention and addressed intervention effectiveness. This chapter examines whether an intervention with demonstrated efficacy retains its ability to improve cardiovascular fitness after two years of province wide dissemination.

8.1 Introduction

Cardiovascular diseases are the leading cause of death worldwide [451]. In 2010, the estimated costs related to cardiovascular disease were $503.2 billion dollars in the United States alone [4]. In adults, those with high cardiovascular fitness are at a lower risk for cardiovascular disease compared to those who are less fit [33]. While youth rarely display clinical signs of cardiovascular disease (e.g., fatal or non-fatal cardiovascular events) cardiovascular fitness is also an important marker of health in young people [91] and cross-sectional studies demonstrated clustering of cardiovascular disease risk factors in youth with low cardiovascular fitness [97,99]. We have previously reported that 58% of children (aged 9-11 years) residing in Vancouver, Canada had at least one elevated risk factor for cardiovascular disease, while 9% had four or more elevated risk factors [11]. Longitudinal cohort studies provide strong evidence that high cardiovascular fitness in youth predicts cardiovascular health later in life [105]. Unfortunately youth today appear to be less fit than their predecessors [452,453] and may therefore be at increased risk of future cardiovascular disease given that cardiovascular fitness tracks across childhood [454] and adolescence [17].

Children spend nearly half of their waking hours at school [44] and schools are home to children from a wide range of socioeconomic and ethnic backgrounds [44,45]. Thus, schools provide an ideal context to assess childhood health, including health indicators such as low cardiovascular fitness. Physical activity interventions within schools have improved several aspects of youth health

[6] Original data from Chapter 8 are being used to prepare a manuscript (Nettlefold L, McKay HA, Naylor PJ, Warburton DE. The effectiveness of the dissemination of Action Schools! BC on cardiovascular fitness).

including physical activity duration and cardiovascular fitness [46]. However, this evidence is primarily from intervention *efficacy* trials (i.e., under well-controlled experimental conditions). Only a few physical activity intervention studies [373,374,455,456] have addressed *effectiveness* (i.e., as research is disseminated and translated into practice [47]), an essential next step to better understand health at a population level [48,419].

Action Schools! BC (AS! BC) is an active elementary school model delivered in the province of British Columbia, Canada. The AS! BC model was first evaluated in 2003-2004 as a controlled efficacy trial. The outcomes of the efficacy trial have been reported in detail elsewhere [357,358,381,389]. Briefly, children attending intervention schools had a 20% greater increase in cardiovascular fitness compared to children attending usual practice schools [357]. Further, we reported a positive effect of the model on physical activity [358] and bone health [381]. Of importance, there was no deleterious effect on academic performance [390], despite children at intervention schools having less curricular and more physical activity time than children at usual practice schools. These positive outcomes resulted in wide dissemination of the model across the province of British Columbia. Thus, we had the opportunity to undertake an effectiveness trial and evaluate the cardiovascular fitness response to the AS! BC intervention during two years of the province-wide dissemination. Our specific objectives were to evaluate short- (year one) and medium- (year two) term changes in cardiovascular fitness in boys and girls. We hypothesized that children attending intervention schools would increase their cardiovascular fitness significantly more than would children attending control schools.

8.2 Methods

The recruitment process is described in detail in Chapter 3. Children (n=1,319) attending 25 schools consented to participate in this component (cardiovascular fitness measurement) of a larger study (n=1,529 students; attending 30 schools).

The development and implementation of the AS! BC model is described in Chapter 3. Briefly, AS! BC is a flexible active whole school model that provides elementary schools with tools and support to create customized action plans aimed at increasing physical activity (to 150 minutes/week) across six Action Zones (School Environment, Scheduled Physical Education, Classroom Action, Family and Community, Extra-curricular, School Spirit; http://www.actionschoolsbc.ca). The model is not curriculum based and allows teachers and schools to choose areas to target for additional physical activity. The only prescriptive component of AS! BC was Classroom Action where teachers were asked to provide an additional 15 minutes of physical activity during class time each day for a total of 75 minutes/week [389].

We assessed anthropometry using standard methods, cardiovascular fitness using a multistage, 20 m shuttle run test [393], and physical activity using a questionnaire (PAQ-C). Detailed methods are provided in Chapter 3.

Statistical analysis

Statistical analyses were performed using Stata version 10.1 (StataCorp, College Station, Texas, USA). We compared baseline (T1) descriptive characteristics to determine differences (if any) between students attending schools that were and were not measured at the end of year 1 (T2) using unpaired t-tests. To assess between-group differences (intervention vs. control) in cardiovascular fitness we fit multivariable linear regression models with cardiovascular fitness (number of laps completed) at follow up (T2 or T4) as the dependent variable. We created separate models for girls and boys and report unstandardized coefficients for 1) crude models (only adjusted for cardiovascular fitness at the beginning of each year) and 2) models that also adjusted for covariates with known relationships to cardiovascular fitness (age, BMI, and physical activity at the beginning of each year). We assessed whether the effect was modified by baseline cardiovascular fitness, BMI, or out of school physical activity by introducing interaction terms into the model. We checked for influential data points using Cook's D statistics and tested assumptions of normality, linearity, and homoscedasticity using model residuals. Removal of influential data points did not change the overall message of the data; therefore, we include the complete data set here

To account for the clustered study design we report robust standard errors as calculated by Stata's vce (cluster) command. We analyzed all student data as per initial random assignment of the school. Importantly, the largest school in the study (n=163 students at baseline) chose not to remain in the control study arm after year one and adopted the AS! BC intervention at the start of year two. Thus, we also report this school as a crossover case study. For this school we compared the change in cardiovascular fitness during the first school year to the change in cardiovascular fitness during the second school year using a paired t-test. Results were considered statistically significant at $p<0.05$.

8.3 Results

Participants

The flow of participants through the study and reasons for exclusion are shown in Figure 8-1. To summarize, over the two-year study 1,319 children (640 intervention, 679 control) consented to participate in the cardiovascular fitness evaluation. We provide participant characteristics at baseline for children attending the 25 schools where we conducted cardiovascular fitness measures (Table 8-1).

Table 8-1. Participant characteristics at baseline (Fall 2005) for children attending the 25 schools where cardiovascular fitness was assessed.

	Girls		Boys	
	Control	Intervention	Control	Intervention
Age	9.9 (0.6) n=334	9.9 (0.6) n=337	10.0 (0.6) n=339	9.9 (0.6) n=296
Height (cm)	140.6 (7.5) n=310	140.2 (7.2) n=329	141.4 (7.3) n=313	140.5 (7.1) n=281
Weight (kg)	36.1 (8.5) n=312	36.2 (9.6) n=328	37.9 (10.3) n=313	38.0 (9.9) n=280
BMI (kg/m^2)	18.1 (3.1) n=310	18.2 (3.6) n=328	18.8 (3.8) n=313	19.0 (3.6) n=280
Physical activity summary score	3.0 (0.6) n=302	3.1 (0.6) n=282	3.2 (0.7) n=304	3.2 (0.7) n=241
Out of school physical activity	8.3 (2.8) n=311	8.5 (2.9) n=330	8.8 (3.1) n=313	9.0 (3.1) n=278
Cardiovascular fitness (laps)	21 (14, 31) n=290	19 (13, 28) n=318	27 (16, 40) n=302	21 (13, 33) n=277

Values are mean (SD) for all variables except cardiovascular fitness, which is presented as median (p25, p75); BMI, body mass index.

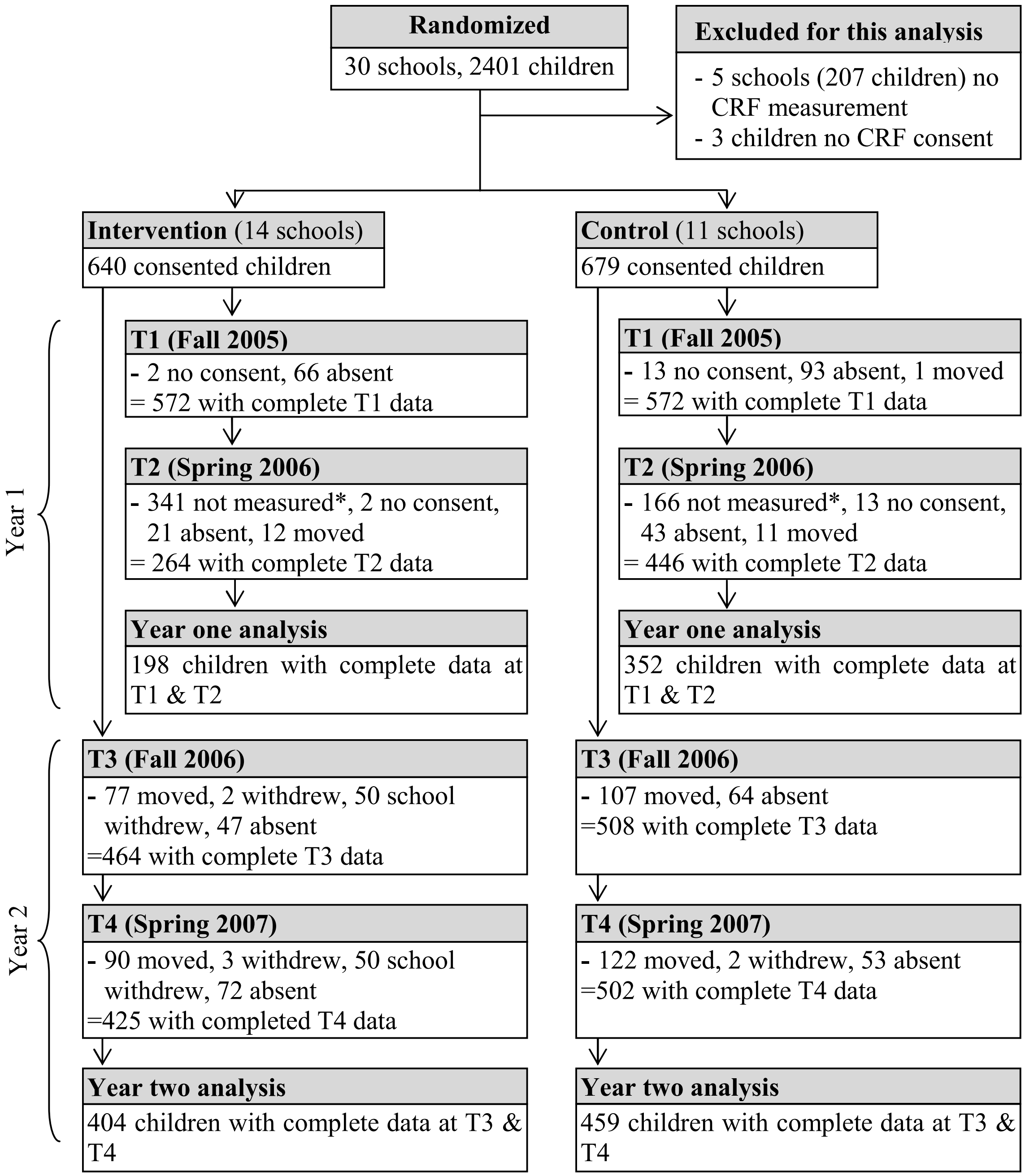

Figure 8-1. Flow of participants and reasons for exclusion from the study at each measurement time point.
'Complete data' means the child has cardiovascular fitness, age, body mass index, and physical activity data. 'Not measured' means that the children attended a school that was not measured in T2.

Short term (year one) changes in cardiovascular fitness

A month long, province-wide teachers strike (with subsequent student dismissal from school) during year one had resource implications and we were only able to assess 10 schools at T2 (Spring 2006). Thus, we evaluated year one change (T2-T1) based on data from these 10 schools. There were no differences in baseline physical activity (PAQ-C summary score, out of school physical activity score) among children attending schools that were measured at T2 and those attending schools that were not measured (data not shown). However, on average, children attending schools not measured at T2 had slightly higher BMI (+0.4, 95% CI 0.03-0.8 kg/m^2) and cardiovascular fitness (+1.5, 95% CI 0.01-3.0 laps) at baseline. The regression models with related coefficients are shown in Table 8-2.

Girls and boys attending intervention schools had higher cardiovascular fitness at follow up compared with children attending control schools (unclustered analysis $p<0.001$; data not shown). Girls attending intervention schools had a 37% greater increase in cardiovascular fitness than girls attending control schools (54% vs. 17%). Boys attending intervention schools had a 31% greater increase in cardiovascular fitness than boys attending control schools (48% vs. 17%). However, once we controlled for the clustered design, statistical significance at $p<0.05$ level did not persist (Table 8-2). There was evidence of an interaction between group and baseline cardiovascular fitness in boys across year one (B=-0.3, 95% CI -0.5 to -0.1; p=0.005) suggesting that the intervention was more beneficial for boys with lower baseline cardiovascular fitness than boys with higher baseline cardiovascular fitness.

Medium term (year two) changes in cardiovascular fitness

One intervention school withdrew after year one therefore year two changes (T4-T3) are based on data from 24 schools. We provide our multivariable model with related coefficients in Table 8-2. There was no difference for change in cardiovascular fitness between girls or boys attending intervention versus control schools across the second year of the trial.

Table 8-2. Unstandardized model coefficients (95% confidence interval) for the regression model that predicted cardiovascular fitness at the end of year 1 and year 2.

Model Coefficients	Girls		Boys	
	Year 1	Year 2	Year 1	Year 2
Crude Model	n=289	n=452	n=274	n=427
Constant (B_0)	8.2 (0.8, 15.5) *p*=0.03	9.0 (4.9, 13.1) *p*<0.001	12.2 (6.4, 18.0) *p*=0.001	9.9 (5.6, 14.2) *p*<0.001
Group (B_1)	6.8 (-1.6, 15.3) *p*=0.10	-2.1 (-6.8, 2.7) *p*=0.37	5.0 (-2.3, 12.2) *p*=0.16	-1.6 (-6.1, 2.9) *p*=0.48
CVF at start of year (B_3)	0.89 (0.6, 1.2) *p*<0.001	0.79 (0.7, 0.9) *p*<0.001	0.79 (0.6, 0.9) *p*<0.001	0.81 (0.7, 0.9) *p*<0.001
Adjusted Model	n=283	n=443	n=267	n=420
Constant (B_0)	3.2 (-34.1, 40.4) *p*=0.85	12.6 (-5.5, 30.6) *p*=0.16	24.5 (-19.9, 68.9) *p*=0.24	-3.2 (-30.6, 24.2) *p*=0.81
Group (B_1)	6.8 (-1.4, 15.0) *p*=0.093	-1.6 (-5.8, 2.7) *p*=0.46	4.7 (-1.9, 11.4) *p*=0.14	-1.6 (-5.9, 2.7) *p*=0.45
Covariates				
CVF (B_2)	0.82 (0.54, 1.1) *p*<0.001	0.72 (0.61, 0.85) *p*<0.001	0.67 (0.49, 0.86) *p*<0.001	0.75 (0.63, 0.86) *p*<0.001
Age (B_3)	2.2 (-0.8, 5.1) *p*=0.13	2.4 (0.1, 4.7) *p*=0.04	0.22 (-3.1, 3.6) *p*=0.89	2.4 (-0.009, 4.8) *p*=0.051
BMI (B_4)	-0.94 (-1.3, -0.56) *p*<0.001	-0.62 (-0.99, -0.24) *p*=0.003	-0.92 (-1.5, -0.31) *p*=0.008	-0.59 (-0.95, -0.23) *p*=0.002
PA (B_5)	0.24 (-0.27, 0.75) *p*=0.31	2.4 (0.60, 4.3) *p*=0.01	0.62 (0.08, 1.2) *p*=0.03	0.09 (-0.26, 0.45) *p*=0.60

The crude model fit was: CVF at follow up (T2 or T4) = B_0 + B_1Group + B_2Baseline CVF.
The model adjusted for potential confounders was: CVF at follow up (T2 or T4) = B_0 + B_1Group + B_2Baseline CVF + B_3Baseline age + B_4 Baseline BMI+ B_5Baseline PA. Results for 'Group' represent intervention schools relative to control schools. Baseline was either T1 (year 1 analysis) or T3 (year 2 analysis). CVF, cardiovascular fitness; BMI, body mass index; PA, out of school physical activity.

Crossover school

Of interest, we compared the change in cardiovascular fitness across year one (T2-T1) and year two (T4-T3) for students attending the school that crossed over from control to intervention in year two (Figure 8-2). Girls', but not boys', cardiovascular fitness increased significantly more (16% greater increase in girls; 4% greater increase in boys) in year two after the school adopted the AS! BC intervention.

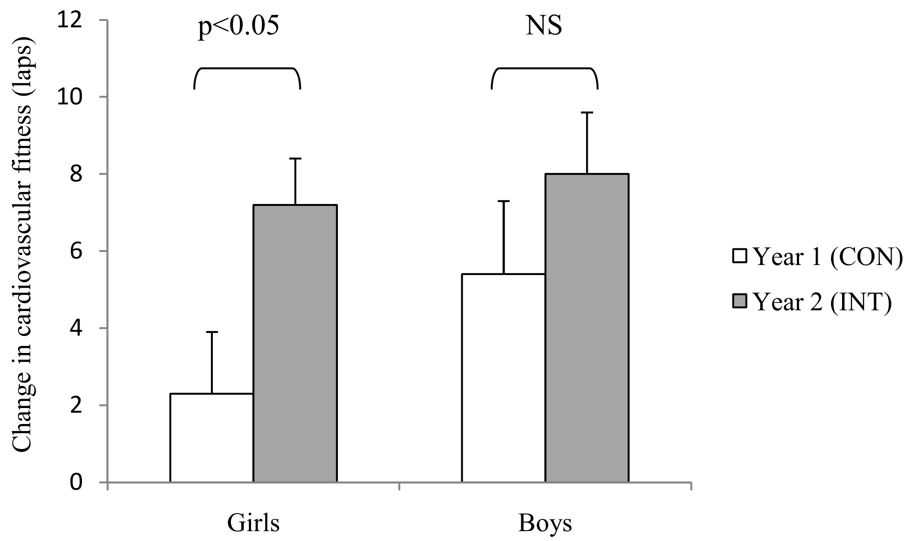

Figure 8-2. Change in cardiovascular fitness (additional laps completed) during each year of the evaluation for one school that adopted the AS! BC model after year one.
This graph illustrates the change in cardiovascular fitness for girls (n=51) and boys (n=43) attending a school that crossed over from the control arm to the intervention arm after year 1. Thus, year 1 represents the change in fitness before the school implemented Action Schools! BC whereas year 2 represents the change in fitness after the school implemented Action Schools! BC.

8.4 Discussion

Action Schools! BC is a flexible school-based physical activity intervention that assists elementary schools and teachers to create customized action plans to increase children's physical activity. We have previously reported that AS! BC is feasible [389] and capable of increasing cardiovascular fitness [357] within a targeted controlled setting over one school year. Here we extend our previous work by evaluating whether the intervention was effective after widespread provincial implementation and over a longer time interval (two years). Our findings demonstrate a greater increase in the cardiovascular fitness of girls (37% greater increase) and boys (31% greater increase) attending intervention compared with control schools during year one. The substantial difference for change between groups did not persist across the second year of the intervention.

The success of an earlier intervention trial we conducted in a targeted, controlled setting, was highlighted by a 20% greater increase ($p<0.05$) in cardiovascular fitness in children attending intervention schools compared to children attending control schools [357]. We compare this finding with the 37% greater increase in the cardiovascular fitness of girls, and the 31% greater increase for boys attending intervention schools, compared with girls and boys attending control schools during year one in the current study (unadjusted percent change). This corresponds to children completing approximately 30-60 seconds extra running time or 0.5-1.0 additional stages during the shuttle run. We also note that one control school, despite our instructions, adopted the AS! BC intervention during year two. After year two, this school demonstrated a significant increase in cardiovascular fitness in girls (+16% in year two vs. year one), but not in boys (+4% in year two vs. year one). This sex specific response in cardiovascular fitness following a school-based intervention is consistent with previous studies [359,360].

While the long-term implications and the clinical relevance of a 30-60 second greater improvement in childhood cardiovascular fitness are difficult to discern, evidence in adults suggests that even small improvements in cardiovascular fitness yield important health benefits [28]. For example, in adult men, a one-minute increase in treadmill test duration over approximately 5 years was associated with a 7.9% reduction in all-cause mortality and an 8.6% reduction in cardiovascular mortality [92]. Further, as cardiovascular fitness tracks through childhood [454] and adolescence [17] there is a potential for these small changes to influence adult health. Thus, we believe our results are physiologically and clinically relevant. We are also encouraged by the 37% and 31% greater increase in cardiovascular fitness after one year of intervention in light of data suggesting a secular decline in children's fitness of 0.43% per year from 1980-2000 [453]. The lack of statistical significance may represent a type II error as a result of the clustered study design with a wide variation in students per school across relatively small number of schools.

Previous school-based physical activity interventions were of mixed benefit for cardiorespiratory health. Specifically, improvements in cardiovascular fitness ranged from 6% to 97% (intervention vs. control) [354,356,359-363] whereas other interventions elicited no benefit [367,369,371]. Importantly, the magnitude of change (percent change or absolute values) we report after one year of intervention was similar to [356,360,363] or greater [354,361] than previous studies that demanded more substantial changes to the school day. The diversity in cardiovascular fitness response across studies may vary based on the intervention, the method used to assess cardiovascular fitness and the length of follow up. For example, cardiovascular fitness was assessed using the 20 m shuttle run

[354,357,360,362,363,369], a timed 1 mile walk/run [359,361], a timed 6 minute run [367], a timed 9 minute run [371] or a graded treadmill test with direct measures of gas exchange [356]. In general, investigations with shorter follow up times (1 school year) reported between group differences in cardiovascular fitness [354,356,357,360,361], whereas those with longer follow up times did not [367,369,371]. Our findings mimic this pattern with a clear trend towards larger changes during year one.

There were some notable differences at the teacher level between years that may help explain the findings. All teachers in year one attended an information session, volunteered to be part of the evaluation and attended training (intervention teachers only). In year two training was offered to all intervention teachers; however, attendance was not mandatory. Further, as children changed teachers each year it is possible that they moved to the classroom of a teacher who did not attend AS! BC training in year one. Therefore, teachers in year two may not have been as skilled or as committed to deliver the AS! BC intervention as year one teachers. Unfortunately, although we requested teachers keep a logbook, compliance was relatively low. These additional data (teacher compliance to logbooks and the volume of physical activity reported by teachers) are provided in Appendix R.

Strengths and limitations

Strengths of our study include the size and breadth of our cohort (~1,300 children across the province), the fact that we are re-evaluating the model for effectiveness after widespread dissemination, and the duration of follow up (2 years). However, we also acknowledge several limitations. First, due to a relatively small number of schools and large variability in the number of children per school, we were unable to apply multilevel modeling techniques to account for our clustered study design [457]. Thus, we applied a technique that essentially 'adjusts' the standard errors to account for the non-independence of individuals from the same cluster [458]. This may have limited our ability to detect significant intervention effects (type II error). Second, as a consequence of a province-wide teacher strike, resource limitations allowed us to measure only 10 of the 25 schools at T2, potentially reducing our power to detect change across year one. Third, it is possible that the intervention was of insufficient intensity and/or duration to provoke a larger change or that the intervention was not being delivered as planned. That said, the magnitude of the intervention effect was of similar or greater magnitude compared with previous studies. Although we requested teachers keep a logbook, compliance was relatively low and we were unable to obtain an accurate record of whether the model was implemented across all six action zones. Finally, although we observed what we accepted as clinically relevant changes in cardiovascular fitness over year one, the influence on long term (i.e., adult) health is unknown. Evidence suggests that childhood cardiovascular fitness is associated with cardiovascular health later in life [105]; but long-term studies after participation in a school-based physical activity intervention are lacking.

Conclusion

Our findings highlight the challenge of conducting school-based intervention trials that are clustered by nature. Our results also suggest a need for investing in teachers through ongoing refresher courses and renewed teacher training each year. Finally, future school-based studies might focus on novel strategies to enhance support for teachers to improve both their compliance to logging and their ability to offer more physical activity opportunities to their students.

9 Integrated discussion

The overall aim of this thesis was to evaluate the relation between physical activity, sedentary behaviour, and cardiovascular health in children. The aim of this final chapter is to highlight the unique elements of my thesis and to place the findings into the context of the wider body of literature. In the first section I provide an overview of the key findings of each chapter and highlight the contribution each makes to the current literature. Next, I discuss the findings as they relate to three general themes: 1) physical activity guidelines for children, 2) objective measures of physical activity and sedentary time in children, and 3) opportunities and challenges associated with school-based interventions. Within each of these sections, I highlight overall limitations of the thesis. I close the chapter with suggestions for future research and the summary and conclusions for Chapters 4-8.

9.1 Overview of findings and unique contributions

The association of accelerometer epoch length with the measurement and classification of children's activity intensity and pattern (Chapter 4)

> ***Key findings:*** *Epoch length (measurement interval) is associated with the measurement and classification of children's activity. The magnitude of the association is, in turn, associated with the intensity of activity (sedentary – vigorous) and the total volume of activity that children perform.*

Chapter 4 addressed a methodological question and aimed to evaluate the association of accelerometer epoch length with the measurement and classification of the intensity and patterns of children's physical activity and sedentary time. This is a key question given the sporadic nature of children's activity [36,37]. These findings add to the current body of knowledge by highlighting that data collection and processing decisions have a significant impact on how children's physical activity and sedentary time is represented when measured by accelerometry. Specifically, these data illustrate for the first time that the selection of epoch length has implications for how accumulated activity (i.e., bouts of sedentary time and MVPA) are measured. Further, these data demonstrate that the magnitude of the effect of epoch length was associated with the total volume of activity. These findings highlight the need for standardization of accelerometry methods for children so that results might be compared between research groups. Future research is required to evaluate whether physical activity measured using different epoch lengths is differentially associated with selected health outcomes.

The prevalence of sedentary behaviour, light physical activity, and MVPA during the school day in girls and boys (Chapter 5)

> ***Key findings:*** *Girls and boys differ in the nature of physical activity they undertake during the school day. Girls accrue less MVPA, are more sedentary and less likely to meet physical activity guidelines compared with boys. Both girls and boys are relatively inactive during scheduled physical education; fewer than 3% of children spent the recommended 50% of physical education class time engaged in MVPA.*

Chapter 5 described and compared the profile of physical activity and sedentary behaviour between girls and boys across a typical school day. It is important to have a clear picture of school day physical activity patterns because schools are viewed globally as an effective avenue to address concerns about children's physical *inactivity* and increased risk for non-communicable diseases [459]. These findings extend the current literature by examining different intensities of physical activity (sedentary time, light, and moderate to vigorous) across specific segments of an elementary school day (whole school day, classroom time, recess, lunch, and scheduled physical education). Generally, there was a difference between boys and girls in their physical activity levels at school. Specifically, boys accrued significantly more MVPA and were less sedentary than were girls. Further, a greater proportion of boys achieved recommended levels of physical activity across the school day and during recess and lunch breaks. Importantly, these findings highlight the need to devise effective school-based models of physical activity and to better understand how to motivate girls to increase their physical activity levels during school.

The cross-sectional association of physical activity and sedentary time with arterial compliance in young children (Chapter 6)

> ***Key findings:*** *Objectively measured physical activity, but not sedentary time, is associated with better cardiovascular health in children. Specifically, physical activity is associated with small artery compliance, but not large artery compliance in children.*

We know surprisingly little about *how* physical activity influences the cardiovascular health of children. Therefore, Chapter 6 evaluated the cross-sectional relation between physical activity, sedentary time, and arterial compliance in children. This study was the first to use an objective measure of physical activity and sedentary time (accelerometry) to examine the relation of specific elements of activity (i.e., activity intensity and bouts) with arterial compliance. These findings extend previous work from our laboratory that evaluated the relation between cardiovascular fitness, *self-reported* physical activity, and arterial compliance in children [177]. Generally, the benefits of physical activity on cardiovascular health were specific to small, but not large, artery compliance in children. MVPA accumulated in bouts was not significantly associated with small or large artery compliance. However, the strong trends towards a beneficial effect of short bouts (< 10 minutes) on small artery compliance suggest that the relatively small sample size may have been inadequate to evaluate this association. In future, studies with a larger sample size that follow children longitudinally would better establish the important relation between physical activity and arterial compliance in children and determine whether benefits persist as children grow and mature.

Physical activity and cardiovascular fitness in children: is bouted activity important? (Chapter 7)

> ***Key findings:*** *Physical activity, measured objectively, benefits cardiovascular fitness in children. Physical activity undertaken in bouts did not make an independent contribution to children's fitness beyond the contribution from the total amount of MVPA children performed.*

Chapter 7 delves further into better understanding how the unique nature of children's physical activity, which is often undertaken in short bouts, is related to cardiovascular fitness. Specifically, I addressed the cross-sectional association between accumulation patterns of MVPA (short and long bouts) with cardiovascular fitness in children. The unique finding of this study is that MVPA undertaken in bouts did not contribute independently to cardiovascular fitness when the total amount of MVPA was taken into account. Thus, children do not appear to require sustained bouts of MVPA to achieve cardiovascular fitness benefits. This is encouraging given that children's physical activity is typically sporadic and short in duration [36,37]. In future, studies with a larger sample size that follow children longitudinally would better establish the important relation between specific patterns of physical activity and the cardiovascular fitness of children and to determine whether benefits persist as children grow and mature.

Is a novel school-based physical activity model (AS! BC) an effective means to enhance cardiovascular fitness in children? A randomized controlled effectiveness trial (Chapter 8)

> ***Key Finding:*** *A whole school-based physical activity model may improve the cardiovascular fitness of children over the short term. However, ongoing training, resources, and support of teachers are likely key if benefits are to be enhanced or maintained.*

The literature supports that short-term physical activity interventions that target specific settings (e.g., classroom, physical education, and playground) can be an effective means to enhance children's physical activity and/or fitness [371,432,433,460]. However, there is a dearth of knowledge as to whether programs with established *efficacy* remain *effective* when implemented on a wide scale [354,365,461]. Therefore, Chapter 8 evaluated changes in cardiovascular fitness following two years of province-wide dissemination of a school-based physical activity model with demonstrated efficacy (Action Schools! BC) [357,358,381]. Unique features of this study are its length (2 years), relatively large breadth (province-wide), and contribution as a school-based physical activity intervention that first evaluated *efficacy* and then evaluated *effectiveness* as it was translated into school-based practice. There was a substantial benefit to the cardiovascular fitness of children attending intervention schools (31-37%) after one year. However, this was not statistically significant after controlling for school clusters. Further, the benefit did not persist into the second year. Given the escalating prevalence of childhood physical inactivity and obesity, it seems essential to undertake longer-term dissemination trials that evaluate in a real world setting whether or not school based physical activity models can effectively enhance children's cardiovascular fitness. A closer look at how to best support teacher's knowledge, training, and resources in order to enhance and sustain program implementation and subsequent health outcomes for children is sorely needed.

9.2 General discussion

9.2.1 How do the findings from this thesis relate to physical activity guidelines for children?

In Chapter 5 I reported that the majority of children were not meeting physical activity recommendations during three segments of the school day where one might anticipate that children would engage in physical activity: scheduled physical education, recess, and lunch. The volume of MVPA accrued during scheduled physical education was particularly low with fewer than 3% of girls and boys spending the recommended 50% [345] of class time engaged in MVPA. Although this outcome is disconcerting, these findings are not unique in reporting that very low amounts of MVPA are accrued by children during physical education [339,340,342], recess, and lunch breaks [343]. This finding also identifies an opportunity to target different school settings as a means to enhance children's fitness, and there are several examples where this has been done successfully [359,420]. Paradoxically, although physical activity across different school settings was low, most children were meeting the overall school-day physical activity recommendations of 30 minutes of MVPA/day [379] (Chapter 5). Further, children undertook 120 minutes/day of MVPA, on average which exceeded the standard recommendation for whole-day physical activity guidelines of ≥ 60 minutes/day [268-271,273,274,462]. These apparently discrepant findings may be explained through an examination of physical activity guidelines.

The evidence base that supported development of children's physical activity guidelines is comprised of data from both structured exercise interventions and observational studies. In general, exercise intervention studies demonstrated that 30-45 minutes of structured physical activity, 3-5 days/week, improved many health outcomes in children [279]. The recommended amount of physical activity was increased to 60 minutes/day to account for incidental activity that was not part of the initial investigation and to allow for inter-child variation [279]. Many of the observational studies evaluated during the development of Canada's most recent (2010) physical activity guidelines for youth assessed physical activity by self-report [268], which depends upon a child's ability to accurately recall their physical activity. Thus, both intervention and observational studies are more likely to capture predominantly *deliberate* physical activity and not *incidental* lifestyle activities.

If children's physical activity guidelines were based on studies that measured predominantly *deliberate* physical activity then the recommendation of 60 minutes of MVPA/ day may need to be reinterpreted as 60 minutes of MVPA/day *above* incidental, lifestyle activities. Given that accelerometers are designed to measure *all* activity, incidental or otherwise, it is possible that the 60 minute target is too low when measuring physical activity with accelerometers. Consequently, physical activity guidelines may need to be adjusted upwards in light of objective measures of physical activity that measure both incidental and deliberate physical activity. That said, accelerometers do not capture all sources of activity (e.g., swimming, cycling) and it is possible that the inability of accelerometers to measure swimming and cycling is offset by an 'over-measurement' of incidental activity. However, Andersen et al. [62] observed that cardiovascular risk factors clustered in children achieving 60 minutes of physical activity/day (measured using accelerometers) and suggested that physical activity guidelines may be too low. In addition, achieving MVPA guidelines may not be sufficient for health benefits if one is sedentary the rest of the day, as is common in adults [463]. Powell et al. [464] recently proposed that zero activity (i.e., entirely sedentary) be used as the baseline for building activity guidelines. This would remove the influence of an 'indefinite and shifting baseline' and allow for recommendations related to sedentary time and light physical activity.

Previous versions of Canada's physical activity guidelines for children [276] and youth [277] recommended a higher volume of activity than the current edition [268]. However the minimum volume of physical activity required for health benefits was unclear with the previous guidelines; the recommendations were for children and youth to increase their physical activity progressively over 5 months to 90 minutes *more* physical activity per day with a concomitant decrease in sedentary time. Although the total volume of physical activity recommended in the new guidelines appears lower, the language is much clearer and specifies that this must be *above* daily, incidental activity. The new guidelines emphasize aerobic activities of at least moderate intensity, with the acknowledgement that vigorous activities may provide greater health benefits. Although physical activity and cardiovascular fitness are considered independent risk factors for cardiovascular disease, cardiovascular fitness is more strongly related to cardiovascular disease risk factors in youth [465] and is more strongly related to mortality [466] and cardiovascular disease [25] in adults. Thus, the physical activity guidelines recommend activity that will promote cardiovascular fitness.

Methodological approaches used to assess physical activity may also influence how physical activity is represented. Among many factors, selecting an appropriate cut point or threshold is key. To illustrate, the high volume of MVPA reported in Chapters 6 and 7 reflects, in part, the cut points I applied to parse data into intensity categories. I chose to apply the cut points developed by Trost et al. [257], which are lower than those used by others (see Table 2-6 for a summary of other cut points currently applied in the literature). The decision to apply these cut points was made based on evidence from the literature and pragmatic reasons. For example, these cut points were developed in a laboratory-based study which included children of a similar age to those in this cohort [257]. Had I applied different cut points, the amount of physical activity and proportion of children who achieved physical activity guidelines would change [291]. In addition, the cut points of Trost et al. [257] align well with those developed for adults by Freedson [467]. Alignment of cut points between children and adults is important for longitudinal studies where a cohort is followed from childhood to young adulthood, as in an ongoing study in our laboratory.

In future, it may be important to include recommendations for children related to *total* sedentary time, as these are not yet available. Although evidence-based sedentary time guidelines for children were recently released, they are limited to screen time (≤ 2 hours/day) and a recommendation to minimize other sedentary time [42]. Given the absence of a recommended threshold for total sedentary time it is not possible to classify the children in my cohort as low, moderate or excessively sedentary, for example. To develop these guidelines and recommend "how sedentary is too sedentary", adequate data are needed to generate sex-specific dose response curves between objectively measured sedentary time and health outcomes. One challenge to achieving this is appropriately distinguishing between when children did not wear their accelerometers (non-wear time) and true sedentary time. Although an important concept, it is seldom discussed and evidence to support criteria for non-wear are seldom documented in the literature [396]. Through careful examination of my data, and as per the method of Esliger et al. [396], I accepted a maximum of 30 minutes of consecutive zeros as sedentary time and that longer intervals of zeroes likely represented that the monitor was not being worn.

Regardless of whether or not the children in this cohort are deemed sufficiently active and/or overly sedentary, the finding that girls were typically more sedentary and less active than boys would likely persist (Chapter 5). Further, even among these children who were, in general, meeting physical activity guidelines there was a relation between the volume of physical activity and/or sedentary time and indicators of cardiovascular health including arterial compliance (Chapter 6) and cardiovascular fitness (Chapter 7). Given the established age-related decline in physical activity [40,257], it seems inevitable that cardiovascular health will also decline with age. Thus it is imperative to monitor, promote and encourage physical activity among youth of all ages.

9.2.2 How important is it to assess physical activity and sedentary time using objective measures?

Without a doubt, subjective measures of physical activity and sedentary time, obtained through self-report, contributed to our understanding of the relation between activity and various health outcomes. It is however becoming increasingly clear that subjective measures of physical activity and sedentary time tell a different story than do objective measures. For example, objective measures of physical activity were more strongly associated with health outcomes than subjective measures [268]. The significant associations that I report between physical activity (assessed objectively with accelerometry) and arterial compliance, support this notion (Chapter 6). Curiously, a previous study from our group failed to detect a relation between physical activity (assessed by questionnaire) and arterial compliance in a cohort of a similar age and demographic [177]. Others have also reported an association between physical activity measured objectively and vascular health [87,438].

Objective measures of activity paint a detailed picture of one's activity patterns across a day or week, including information about sedentary time, light physical activity and bouted physical activity that are considered challenging, if not impossible, to measure using subjective instruments [464]. Different aspects of activity behaviours (sedentary time, light physical activity and bouted physical activity) are emerging as important independent indicators of health, beyond the traditional measure of MVPA. To illustrate, sedentary time was associated with cardiovascular mortality [23,24] and cardiovascular risk factors [224] in adults and with cardiovascular risk factors in children [410,411]. Light physical activity was associated with metabolic [378] and vascular [172] health in adults and as the largest contributor to energy expenditure [377,442] it plays a central role in maintaining healthy weight. Finally, bouts of sedentary time were associated with metabolic health in adults [326] and bouts of MVPA reduced the risk of excess weight in youth [222].

These findings support an association between light physical activity and vascular health (Chapter 6). The total amount of light physical activity explained more of the variability in small artery compliance than any other physical activity variable (after accounting for the influence of body surface area, BMI, and systolic blood pressure; Chapter 6). Given this positive relationship, it is encouraging that light physical activity was similar between girls and boys during most segments of the school day (Chapter 5) and over the entire wear interval (Chapters 6 and 7). These important findings would have gone undetected had physical activity been measured via questionnaire.

By measuring physical activity using accelerometry I was also able to evaluate whether short or long bouts of physical activity were important to children's vascular health (Chapter 6) and cardiovascular fitness (Chapter 7). This would not have been possible had a subjective measure of physical activity been used. Although bouted MVPA reduced the risk of overweight independent of total volume of MVPA in 2,500 youth measured as part of the National Health and Nutrition Examination Survey [222], these results in a much smaller cohort did not support an independent effect of bouted MVPA. Thus, larger sample sizes may be necessary to detect the independent relationship between bouted MVPA and indicators of health. Alternatively, bouted MVPA may promote only specific health outcomes such as healthy weight; this likelihood was discussed in Chapter 7.

Despite the many advantages of accelerometry, we have a long way to go. Future versions of accelerometry software will store data as a continuous variable so that epoch length will no longer be relevant (Russell Pate; personal communication). Currently, methodology varies substantially between studies given the many data collection and processing decisions made by individual researchers. Chapter 4 illustrated how the choice of epoch length might impact study outcome with respect to various activity variables. In addition, the choice of cut points [291] and criteria for non-wear time [427] significantly affect estimates of physical activity and sedentary time. To facilitate comparisons across studies, it is essential that the research community come together and reach consensus on standardized accelerometry methods to assess physical activity and sedentary time in children.

9.2.3 Challenges associated with school-based cohorts and interventions

There are many benefits associated with school-based intervention strategies as discussed in Chapters 5 and 8. Indeed, it is globally accepted that schools are an ideal avenue to positively influence children's physical activity and sedentary behaviours and subsequently, children's health [459]. However, schools must also be respected as places of learning and from a research design and implementation perspective schools present many challenges.

Curriculum

Schools have a primary duty to educate youth and as such, interventions to promote physical activity undertaken within the school setting must not detract or interfere with the established curriculum. In British Columbia, the Ministry of Education established a set of prescribed learning outcomes for each subject area. To illustrate, for physical education prescribed learning outcomes are categorized into three areas: 1) Active Living (includes knowledge and participation), 2) Movement Skills, and 3)

Safety, Fair Play, and Leadership [429]. Importantly, *participation* in physical activity is only one component of the required curriculum. This may explain why the proportion of physical education class spent engaged in MVPA was low in this cohort (Chapter 5).

The list of prescribed learning outcomes for physical education is long [429], yet there is only a limited time devoted to this subject in the overall school curriculum [337]. Thus, whole school approaches, where physical activity is encouraged through school culture and policy in addition to the physical education curriculum [44] are likely the best approach. Given the crucial role that teachers play in any school-based intervention, it is essential that teachers and school administrators be represented during program development and modification to ensure that the requirements are feasible within the constraints of the existing curriculum and other demands on teacher's time.

Study design

First, by nature schools present a nested design: children within classes, classes with schools, schools within districts, and even districts within regions. Therefore, cluster level randomization (i.e., randomization of schools as opposed to teachers or students) is ideal to minimize contamination that would occur if children allocated to intervention and control groups attended the same school [468].
However, depending on the variable of interest, observations *within* a cluster (students within schools) are likely to be more similar than observations *between* clusters (students from different schools). It is therefore essential to take clustering into consideration in the design, if possible and in the analysis of data. Failure to do so produces falsely narrow confidence intervals and can affect the conclusions drawn from the results of the study [457]. We did not account for clustering within the study design, *a priori*. Although I recognize this as a limitation, I accounted for clustering by using robust standard errors in my analyses (Chapter 8). This was deemed an appropriate method to account for clustering, given that the limited number of clusters and the large variability in cluster size did not allow for the use of mixed effect models [469]. However, it is possible that the robust standard errors were still too small, particularly for the year one analysis of cardiovascular fitness change (Chapter 8). As a consequence of the province wide teacher strike and ensuing resource limitations, only 10 schools were included for the year one analysis; approximately 30 clusters is recommended for accurate calculation of robust standard errors [469]. More schools (n=30) with fewer students in each would have increased the statistical efficiency of the trial [457]. However, this is often not feasible given that 1) school policy demands that all children who volunteer to participate in any school must be included, 2) schools are of substantially different sizes; 3) recruitment of a large number of schools

is often not feasible, and 4) costs prohibit measurement of the large numbers of schools required to account for clustering in the study design.

Second, as is true with any intervention, recruitment bias may influence study outcomes. Schools, teachers, and students all self-selected to participate in the intervention. Although volunteer schools were randomly allocated to intervention or control study arms, results from this thesis may not be applicable to the population of schools that did not volunteer to participate or to other regions outside of British Columbia, Canada. Further, although all students who attended intervention schools participated in the *intervention* as it was adopted as part of regular school process, only children who provided parental consent to participate in the *evaluation* were measured.

Third, to address my research questions I extracted a subset of children for whom cardiovascular health, physical activity, and sedentary time were measured objectively from a larger cohort (Action Schools! BC dissemination trial). Thus, I was unable to perform sample size calculations *a priori* for each research question and it is possible that the study was underpowered to address some of these research questions.

Finally, due to time and space constraints, several potential confounding variables were not assessed in this cohort. I was unable to assess physical maturity because it was not possible to ensure access to a private location in order for participants to complete the maturity questionnaire [470] we have used previously. A prediction equation to estimate age at peak height velocity (APHV; an indicator of maturity offset) is available [471]; however, the authors recommend using it only as a categorical variable (e.g., pre- or post-PHV) and Sherar et al. [472] note that it is most accurate around APHV (approximately age 12 in girls and age 14 in boys). Given that the average age of this sample was only 10 years, the prediction equation was deemed inappropriate [472]. Furthermore, unpublished data from our laboratory confirm that predicted APHV may be a poor predictor of measured APHV (via longitudinal data).

In addition to maturity, fundamental movement skills were not assessed. Fundamental movement skill competency is associated with increased physical activity and cardiovascular fitness [473]. Several studies observed gender differences; boys displayed greater mastery of object control skills [474-476] while girls demonstrated greater flexibility and balance [475] as well as greater [474] or similar [475,476] competency in locomotor skills. In theory, the randomized design should have eliminated between-group differences in maturity characteristics and fundamental movement skills, however, I was unable to confirm this or include these measures as a covariate in the analyses, had that been necessary.

Teacher compliance

Action Schools! BC was an intervention designed with generalist teachers in mind; all teachers at intervention schools in year one were trained at a one-day training session by the AS! BC Support Team and were provided with the resources and support they needed to deliver the intervention [389]. In year two we offered similar training and support to teachers who had research participants in their class; however, it was not mandatory for them to participate in training to remain in the study. This may explain why we were unable to detect an effect of the intervention on cardiovascular fitness at the end of the second year (Chapter 8). That is, we may have been assessing a failure in *delivery* of the intervention rather than the *effect* of the intervention [461]. It is crucial that, in future school-based intervention studies that; 1) all teachers are trained in a standardized way and that training be refreshed across a multiple year study, 2) researchers undertake a process evaluation to determine the barriers and facilitators to implementation and, 3) teachers complete activity logs so that dose and fidelity to the model can be tracked and evaluated (Appendix R).

Although we instructed teachers to maintain weekly activity (implementation) logs; compliance to this aspect of the study was low (Appendix R). Approximately 15% of teachers did not return *any* weekly physical activity logs. In addition, teachers provided activity logs for only 62% of school weeks, on average, over the two-year intervention. Thus, we were unable to use these logs to assess the quality or intensity of school day physical activity delivered. Therefore, as previously noted, it is possible that the intervention was not adequately delivered in year two. Future investigations should determine the barriers to teacher compliance (both delivering the intervention and completing activity logs) in dissemination trials and devise novel strategies to overcome them.

9.3 Future research

The limitations and gaps in the literature identified throughout the thesis and in the general discussion lay the groundwork for undertaking future trials. In this final section I highlight a few research areas, related questions, and important limitations that could be addressed to further enhance our understanding of the role of physical activity and sedentary behaviour in child health.

1) **To improve and standardize accelerometer methods:**
   a) What epoch length is most *accurate* to assess physical activity in children, adolescents, and adults?
   b) Is it appropriate to mathematically derive cut points for shorter epochs from thresholds developed using longer (i.e., 1 minute) epochs?
   c) What is the most appropriate interval to distinguish non-wear time from true sedentary behaviour? Is this interval age-dependent?
   d) Do different cut points yield different associations with health outcomes?

2) **To enhance our understanding of the importance of light physical activity and sedentary time:**
   a) Are light physical activity and sedentary time associated with indicators of childhood health such as body weight, fat mass and other risk factors for chronic disease?
   b) How should evidence-based guidelines for sedentary behaviours be developed and communicated to the general public?
   c) How sedentary is ‘too sedentary’?
   d) Are breaks in sedentary time related to children’s health as they are in adults?

3) **To enhance our understanding of the origin and implications of different physical activity levels between girls and boys:**
   a) How do the developmental patterns of motor performance, strength, and flexibility [477] influence physical activity levels of girls and boys during childhood?
   b) Do lower physical activity levels in girls versus boys contribute to the established [477] sex differences in motor performance, strength, and flexibility? Alternatively, do sex differences in motor performance, strength, and flexibility contribute the sex differences in physical activity levels?

4) **To increase the quantity and quality of longitudinal data sets:**

   a) Undertake a long-term longitudinal study of physical activity and sedentary time (objectively measured with accelerometers) to assess how behaviours change as children progress through adolescence into young adulthood. Ideally, these physical activity and sedentary time data would be linked to cardiovascular health and changes in the cardiovascular health of participants.
   b) Include measures of motor performance, strength, and flexibility in studies of children's physical activity behaviours.
   c) Conduct a school-based physical activity dissemination trial with a 2-3 year follow-up and include measures of biological maturity in the study protocol.
   d) Conduct a cluster randomized controlled trial using a study design that accounts for clustering *a priori*.

Addressing these areas will significantly increase our understanding of the relation between physical activity, sedentary behaviour, and childhood health. This in turn will contribute to the evolution of evidence-based physical activity and sedentary behaviour guidelines for children, and will facilitate the development of effective interventions targeting these behaviours with the ultimate goal of improving health not just in children, but across the lifespan.

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472. Sherar LB, Gyurcsik NC, Humbert ML, Dyck RF, Fowler-Kerry S, Baxter-Jones AD. Activity and barriers in girls (8-16 yr) based on grade and maturity status. Med.Sci.Sports Exerc. 2009; 41: 87-95.

473. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents: Review of associated health benefits. Sports Med. 2010; 40: 1019-1035.

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Appendices

Appendix A Glossary of key terms

Term	Definition
Accelerometer	A small device, typically worn at the waist, that measures the acceleration of the body. The acceleration data can then be translated into physical activity intensity. Most accelerometers use a piezoelectric sensor that generates a voltage proportional to the imposed acceleration. Accelerometer data are time stamped and therefore provide valuable information about the pattern of physical activity throughout the day. [7]
Activity	Encompassing the spectrum of movement from sedentary behaviour (very low MET value) up to vigorous physical activity (very high MET value).
Adolescent	Individuals approximately 13-18 years old.
Adult	Individuals approximately ≥ 18 years old
Arterial compliance	The change in arterial volume relative to the change in arterial pressure.
Atherosclerosis	A disease of the arteries in which fatty plaques develop on their inner walls, with eventual obstruction of blood flow. [8]
Aortic valve	A valve in the heart, lying between the left ventricle and the aorta. It is a semilunar valve that prevents blood returning to the ventricle from the aorta. [9]
Biological maturation	Progress towards the biologically mature state. Indicators of biological maturation include skeletal age, age at peak height velocity, secondary sex characteristics, and menarcheal status. [10]
BMI	Body Mass Index. Calculated as weight/height^2, where weight is measured in kg and height is measured in m.
Body composition	The relative amounts of different components in the body. Sports scientists often divide the body into two main components: fat-free mass (consisting of all the body tissue which is not fat) and fat mass (usually expressed as the percentage of the total body mass composed of fat). [11]
Bouted activity	Activity (physical activity or sedentary time) that is accumulated in extended periods of time. For example, when measuring moderate to vigorous physical activity using accelerometers, a 5 minute bout requires that every epoch for the 5 minute period is above the threshold for activity of that intensity. Longer bout lengths often allow for exceptions of several epochs below the threshold.

[7] Chen KY, Bassett DR. The technology of accelerometry-based activity monitors: Current and future. Med Sci Sports Exerc 2005; 37(11):S490-S500.
[8] "Atherosclerosis" Concise Medical Dictionary. Oxford University Press, 2010. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[9] "Aortic valve" Concise Medical Dictionary. Oxford University Press, 2010. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[10] Baxter-Jones ADG, Eisenmann JC, Sherar LB. Controlling for maturation in pediatric exercise science. Pediatr Exerc Sci 2005; 17:18-30.
[11] "Body composition" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.

Term	Definition
Capacitive arterial compliance (C_1)	Relationship between decline in pressure and decline in volume in the arterial tree during the exponential component of diastolic pressure decay of the arterial waveform (said to reflect large artery compliance). [12]
Cardiac output	The volume of blood ejected with each contraction multiplied by the heart rate. [13]
Cardiovascular disease	Any disease of the heart and blood vessels. [14]
Cardiovascular fitness	The ability to transport and utilize oxygen during prolonged strenuous physical activity. It reflects the overall transporting efficiency of the lungs, heart, circulation, and active muscles, and the ability of the muscles to use the oxygen supplied. [15]
Child	Individuals approximately 6-12 years old.
Clustered risk	The presence of multiple risk factors for a disease within an individual.
Collagen	Protein substance that is the main constituent of bones, tendons, cartilage, connective tissue and skin. It is made up of inelastic fibres that form a mesh. [16]
Coronary heart disease	A disease of the heart that involves narrowing of the coronary arteries. This may cause a blockage of an artery and a heart attack. [17]
Development	Refers to the acquisition of behavioral competence (includes cognitive, social, emotional development etc.). [18]
Diastole	The portion of the cardiac cycle that includes relaxation and filling of the ventricles. [19]
Diastolic blood pressure	Lowest pressure in the aorta occurring immediately prior to ventricular contraction and ejection of blood. [20]
Dicrotic notch	Brief pressure fluctuation visible on an arterial waveform that results from closure of the aortic valve. The dicrotic notch signifies the end of systole and the beginning of diastole.

[12] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler Thromb Vasc Biol 2003; 23(4):554-566.
[13] Klabunde RE. Cardiovascular Physiology Concepts. 2005. Lippincott Williams & Wilkins: USA p 5
[14] "Cardiovascular disease" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. University of British Columbia. 8 March 2011.
[15] Tremblay MS, Shephard RJ, Brawley LR. Research that informs Canada's physical activity guides: an introduction (Appendix A). Appl Physiol Nutr Metab 2007; 32 (Suppl 2E):S1-S8.
[16] "Collagen" World Encyclopedia. Philip's, 2008. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[17] "Coronary heart disease" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. University of British Columbia. 8 March 2011.
[18] Baxter-Jones ADG, Eisenmann JC, Sherar LB. Controlling for maturation in pediatric exercise science. 2005. 17:18-30.
[19] Klabunde 2005, p 63.
[20] Klabunde 2005, p 95.

Term	Definition
Dissemination	The set of planned, systematic efforts designed to make a program or innovation more widely available. [21]
Distensibility	The relative change in vessel diameter (or area) for a given change in pressure. [22]
Effectiveness	The extent to which a specific intervention, procedure, regimen, or service produces a beneficial result under *typical* conditions. [23]
Efficacy	The extent to which a specific intervention, procedure, regimen, or service produces a beneficial result under *ideal* conditions. [24]
Elastic modulus	The pressure change required for (theoretical) 100% stretch from resting diameter (inverse of distensibility). [25]
Elastin	A rubber-like glycoprotein that is the main component of the elastic fibers found in tendons, ligaments, and the walls of bronchi and arteries. [26]
Epoch	The measurement interval over which accelerometer counts are summed.
Exercise	Planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness. [27]
Frankfort plane	A line used in anthropometry, which passes from the highest point of the ear canal through to the lowest point of the eye socket. [28]
Growth	Refers to a change in size, either of the entire individual (e.g., become taller and heavier) or of various parts (e.g., heart, lungs). [29]
Hypertension	Elevated arterial blood pressure above the normal range expected in a particular age group. [30]

[21] Owen N, Glanz K, Sallis JF, Kelder SH. Evidence-based approaches to dissemination and diffusion of physical activity interventions. Am J Prev Med 2006; 31(4S):S35-S44.
[22] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler.Thromb.Vasc.Biol. 2003; 23(4):554-566.
[23] Last JM. A dictionary of epidemiology (4th edition). 2001. Oxford University Press: New York, NY.
[24] Last 2001.
[25] Oliver 2003.
[26] "Elastin" A Dictionary of Genetics. Robert C. King, William D. Stansfield and Pamela K. Mulligan. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[27] Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. Public Health Reports 1985;100 (2):126-131.
[28] “Frankfort plane” www.merriam-webster.com/medical.
[29] Baxter-Jones ADG, Eisenmann JC, Sherar LB. Controlling for maturation in pediatric exercise science. 2005. 17:18-30.
[30] "Hypertension" Concise Medical Dictionary. Oxford University Press, 2010. Oxford Reference Online. Oxford University Press. University of British Columbia. 4 February 2011.

Term	Definition
Implementation	Refers to what a program consists of when it is delivered in a particular setting. This includes aspects of fidelity, dosage, quality, participant responsiveness, program differentiation, monitoring of any comparison conditions, program reach, and adaptation. [31]
Incidence	The number of instances of illness commencing, or of persons falling ill, during a given period in a specified population. [32]
Intervention study	A comparison of the outcome between two or more groups of patients that are deliberately subjected to different regimes to test a hypothesis, usually of treatment (in a clinical trial). Wherever possible those entering the trial should be allocated to their respective groups randomly, and one group (controls) should have no active treatment (randomized controlled trial). [33]
LPA	Light physical activity. Defined here as activity requiring approximately 1.5-2.9 METs.
Maximal aerobic power	The maximum amount of oxygen that can be transported and used during performance of a large muscle task. Also known as maximal oxygen intake and maximal oxygen consumption. [34]
MAP	Mean arterial pressure. The average arterial blood pressure during a complete cardiac cycle. It can be approximated as diastolic pressure + 1/3 (systolic pressure-diastolic pressure). [35]
MET	Metabolic equivalent. A measure of energy output equal to the basal metabolic rate of a resting subject (assumed to equal an oxygen consumption of 3.5 mL/kg/min or 1 kcal/kg/hour). Physical activity intensity is often expressed in multiples of METs. [36]
MPA	Moderate physical activity. Defined here as activity requiring approximately 3-5.9 METs.
MVPA	Moderate to vigorous physical activity. Defined here as activity requiring ≥ 3 METs.

[31] Durlak JA, DuPre EP. Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. Am J Community Psychol 2008; 41:327-350.
[32] Last JM. 2001. A dictionary of epidemiology (4th edition). Oxford University Press: New York, NY.
[33] "Intervention study" Concise Medical Dictionary. Oxford University Press, 2010. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[34] Tremblay MS, Shephard RJ, Brawley LR. 2007. Research that informs Canada's physical activity guides: an introduction (Appendix A). Appl Physiol Nutr Metab 2007 32 (Suppl 2E):S1-S8.
[35] "Mean arterial pressure" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[36] Tremblay 2007.

Term	Definition
Obesity	The presence of excessive body fat (adipose tissue) in relation to lean body mass. The distribution and amount of body fat and the extent of adiposity are both clinically relevant, but precise measurement can be difficult. Measures of weight relative to height and a body mass index (BMI) > 30 are used to define clinical obesity. [37]
Objective (measure of activity)	Physical activity or sedentary time that is measured using an accelerometer, pedometer, or doubly labelled water (for example) is considered objectively measured because it doesn't depend on a participant to accurately remember and honestly report their activities. Thus, there is less potential for recall and/or reporting bias than with subjective measures.
Oscillatory arterial compliance (C_2)	Relationship between oscillating pressure change and oscillating volume change around the exponential pressure decay during diastole (said to reflect small artery compliance) [38]
Oxidative metabolism	A metabolic process that uses oxygen to produce energy for cellular work. [39]
Pedometer	Pedometers are spring-loaded devices most often worn at the hip. The spring-loaded mechanism allows pedometers to count the total number of steps taken during the wear period.
Physical activity	Any bodily movement produced by skeletal muscles that results in energy expenditure.[40]
Physical activity patterns	For the purposes of this thesis, I use this term to describe the manner in which activity is accrued. That is, whether activity is accumulated sporadically or in longer more prolonged bouts.
Physical education	An academic course included in the curriculum and offered within the normal school timetable. [41]
Physically active (person)	Meeting established guidelines for physical activity (usually reflected in achieving a threshold number of minutes of moderate to vigorous physical activity/day). [42]
Physical inactivity	The absence of physical activity; usually reflected as the amount or proportion of time not engaged in physical activity of some predetermined intensity.[43]

[37] "Obesity" A Dictionary of Public Health. Ed. John M. Last, Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[38] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler.Thromb.Vasc.Biol. 2003;23(4):554-566.
[39] "Aerobic metabolism" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[40] Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. Public Health Reports 1985; 100 (2):126-131.
[41] Trudeau F, Shephard RJ. Contribution of school programmes to physical activity levels and attitudes in children and adults. Sports Med 2005; 35(2): 89-105.
[42] Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab 2010; 35:725-740.
[43] Tremblay 2010.

Term	Definition
Predictive Validity	The extent to which a test or measure predicts selected outcomes at some later point in time. [44]
Prevalence	The number of events (e.g., instances of cardiovascular disease) in a given population at a designated time. [45]
Pulse pressure	The difference between systolic and diastolic blood pressures. [46]
Pulse wave velocity	The speed with which the pulse wave travels along a length of artery. [47]
Recall bias	A systematic error that is caused by differing degrees of accuracy in remembering past events, including previous medical history. This bias often arises when people's past history includes events that they have forgotten or not mentioned because they consider them irrelevant, embarrassing, or shameful. [48]
Receiver operating characteristic curve	A graphic means for assessing the ability of a screening test to discriminate between healthy and diseased persons. [49] It has been applied in studies of physical activity to discriminate between sedentary time and physically active time.
Reliability	The degree to which results obtained by a measurement or procedure can be replicated. [50]
Risk factor	Risk factors are statistically related to the risk of disease or clinical event but do not necessarily identify the disease itself. [51] Risk factors can be modifiable (e.g., physical activity level) or non-modifiable (e.g., age, sex). If the relation between a risk factor and the disease remains after taking a second risk factor into consideration, the two risk factors are said to be independent risk factors for the disease.
Risk marker	Risk markers are biologically related to the disease. The conventional view is that a surrogate, to be a reliable substitute for a morbid event end point, must track with the frequency of the end point both as an epidemiologic marker and as a therapeutic responder. [52]
Screen time	Time spent in screen-based sedentary behaviours such as time spent watching television, using a computer, or playing video games.

[44] Ruiz JR, Castro-Pinero J, Artero EG, Ortega FB, Sjostrom M, Suni J, Castillo MJ. Predictive validity of health-related fitness in youth: A systematic review. Br J Sports Med 2009; doi:10.1136/bjsm.2008.056499.
[45] Last JM. A dictionary of epidemiology (4th edition). 2001. Oxford University Press: New York, NY.
[46] Klabunde RE. Cardiovascular Physiology Concepts. 2005. Lippincott Williams & Wilkins: USA p 95.
[47] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler.Thromb.Vasc.Biol. 2003; 23(4):554-566.
[48] "Recall bias" A Dictionary of Public Health. Ed. John M. Last, Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[49] Last 2001.
[50] Last 2001.
[51] Cohn JN. Introduction to surrogate markers. Circulation 2004; 109 (Suppl IV): IV20-IV21.
[52] Cohn 2004.

Term	Definition
Sedentary	A distinct class of behaviours (e.g., sitting, watching TV, driving) characterized by little physical movement and low energy expenditure (≤ 1.5 METs). [53]
Stiffness index	The ratio of the natural logarithm of systolic/diastolic blood pressure to the relative change in diameter. [54]
Stroke volume	The volume of blood ejected with each contraction of the ventricles. [55]
Subjective (measure of activity)	Physical activity or sedentary time that is measured through a questionnaire or an interview is considered subjective because it depends on a participant to accurately remember and honestly report their activities. Thus, there is potential for recall and/or reporting bias.
Supine	The body position of an individual lying on their back.
Sympathetic tone	State of partial vasoconstriction of blood vessels maintained by impulses from the sympathetic nervous system. [56]
Systemic vascular resistance	The resistance to blood flow within the vasculature. Systemic vascular resistance is determined by the size of blood vessels, the arrangement of the vascular network, and the viscosity of the blood. [57]
Systole	The portion of the cardiac cycle that includes contraction of the ventricles and ejection of blood into the arterial system. [58]
Systolic blood pressure	Peak pressure in the aorta occurring after ventricular contraction. [59]
Tempo (of activity)	Refers to the pattern of activity accumulation. That is, whether activity is accumulated in short or long periods. See also *bouted activity*.
Total activity	Activity (physical activity or sedentary time) that is accumulated in any pattern. That is, every epoch that meets or exceeds the intensity threshold is counted towards the total regardless of the intensity of surrounding epochs.
Tracking	The process of maintaining rank within a cohort during a longitudinal study.
Triglyceride	A lipid or neutral fat consisting of glycerol combined with three fatty-acid molecules. Triglycerides are synthesized from the products of digestion of dietary fat: they are the form in which digested fat is transported in the bloodstream. [60]

[53] Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab 2010; 35: 725-740.
[54] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler.Thromb.Vasc.Biol. 2003; 23(4):554-566.
[55] Klabunde RE. Cardiovascular Physiology Concepts. 2005. Lippincott Williams & Wilkins: USA p 5.
[56] "Sympathetic tone" The Oxford Dictionary of Sports Science & Medicine. Oxford University Press, 2007. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.
[57] Klabunde 2005, p 4.
[58] Klabunde 2005, p 63.
[59] Klabunde 2005, p 94.
[60] "Triglyceride" Concise Medical Dictionary. Oxford University Press, 2010. Oxford Reference Online. Oxford University Press. University of British Columbia. 8 March 2011.

Term	Definition
Validity	The degree to which a measurement measures what it purports to measure.[61]
Variance	A measure of the variation shown by a set of observations, defined by the sum of the squares of deviation from the mean, divided by the number of degrees of freedom in the set of observations. [62]
Vasodilatory capacity	The ability of blood vessels to increase their diameter.
VPA	Vigorous physical activity. Defined here as activity requiring ≥ 6 METs.
Young's modulus	Elastic modulus per unit area (accounts for wall thickness). [63]
Youth	Individuals ≤ 18 years old.

[61] Last JM. A dictionary of epidemiology (4th edition). 2001. Oxford University Press: New York, NY.
[62] Last JM. A dictionary of epidemiology (4th edition). 2001. Oxford University Press: New York, NY.
[63] Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. Arterioscler.Thromb.Vasc.Biol. 2003; 23(4):554-566.

Appendix B Reviews that examined the effect of school-based physical activity interventions on weight status

First Author	Primary outcome variable(s)	Results/conclusion
Harris 2009 [64]	BMI Searched articles up to September 2008 with a minimum duration of 6 months.	No effect on: - BMI: mean difference -0.05 kg/m^2 (-0.19 to 0.10)
Gonzalez-Suarez 2009 [65]	BMI, percentage of body fat, waist girth, triceps skinfold, waist to hip ratio Searched articles between 1995-2007	Positive effect on: - Prevalence of overweight/obesity: odds ratio = 0.74 (0.60 to 0.92) - Waist girth: mean difference = -1.56 (-2.53 to -0.60) - Percent body fat: mean difference = -1.51 (-2.47 to -0.56) - Triceps skinfold: mean difference = 0.10 (0.03 to 0.16) No effect on: - BMI: mean difference = -0.62 (-1.39 to 0.14) - Waist to hip ratio: mean difference = -0.01 (-0.03 to 0.00)
Brown 2009 [66]	Childhood obesity Searched articles between January and September 2006 with a minimum duration of 12 weeks	PA only interventions had a positive effect on: - BMI: in 5/15 studies (2 studies only showed effects in girls) PA only had no effect on: - BMI: 10/15 studies (5 studies were in adolescent females) Combined PA and dietary interventions had a positive effect on: - BMI: in 9/20 studies (2 studies only showed effects in boys, 2 studies only showed effects in girls) Overall, results are inconsistent and short term.

[64] Harris KC, Kuramoto LK, Schulzer M, Retallack JE. Effect of school-based physical activity interventions on body mass index in children: a meta-analysis. CMAJ 2009 Mar 31;180(7):719-726.

[65] Gonzalez-Suarez C, Worley A, Grimmer-Somers K, Dones V. School-based interventions on childhood obesity: a meta-analysis. Am.J.Prev.Med. 2009 Nov;37(5):418-427.

[66] Brown T, Summerbell C. Systematic review of school-based interventions that focus on changing dietary intake and physical activity levels to prevent childhood obesity: an update to the obesity guidance produced by the National Institute for Health and Clinical Excellence. Obes.Rev. 2009 Jan;10(1):110-141.

First Author	Primary outcome variable(s)	Results/conclusion
Shaya 2008 [67]	Obesity Searched articles between June 1986 and June 2006	Positive effect in: - 13/15 of the intervention studies that focused exclusively on PA
Kropski 2008 [68]	Overweight/obesity Searched articles between January 1990 and December 2005 with a minimum duration of 6 months	PA intervention - 1/2 studies (girls only) showed a beneficial effect Combined PA and dietary interventions - Insufficient evidence to draw conclusions on the effectiveness of these interventions.

[67] Shaya FT, Flores D, Gbarayor CM, Wang J. School-based obesity interventions: a literature review. J.Sch.Health 2008 Apr;78(4):189-196.
[68] Kropski JA, Keckley PH, Jensen GL. School-based obesity prevention programs: an evidence-based review. Obesity (Silver Spring) 2008 May;16(5):1009-1018.

Appendix C Action Schools! BC advisory committee membership [69]

Name	Title	Constituency Represented
Marion Lay	President and CEO	2010 Legacies Now
Andrew Hazlewood	Assistant Deputy Minister	BC Ministry of Health
Laurie Woodland	Acting Executive Director, Healthy Living/Chronic Disease Prevention	BC Ministry of Health
Bobbi Plecas	Lead Director, Initiatives Department	BC Ministry of Education
Heather Hoult	Director, Health Promoting Schools	BC Ministry of Education
Lori Zehr	Manager, Physical Activity/Chronic Disease Prevention/Healthy Living	BC Ministry of Health
Lee Southern	Executive Director	BC School Trustees Association
Tom Hierck	President	Principals & Vice Principals Association of BC
Shirley Wilson	External Committee Volunteer	BC Confederation of Parent Advisory Councils
Don Hutchinson	Middle School Teacher	Montgomery Middle School
Jane Hunter	Principal	RJ Tait Elementary School
Lorraine Greaves	Executive Director	BC Centre of Excellence for Women's Health
Sharon White	Policy Analyst/Sport Consultant	Ministry of Tourism, Sports and the Arts
Michelle Kilborn	Teacher & President	Physical Education BC
Dr. Ron Wilson	Physician	BCMA – Athletics & Recreation Committee
Heather McKay	Principal Investigator	University of British Columbia, Faculty of Medicine
PJ Naylor	Associate Director of Research (Evaluation)	University of Victoria
Bryna Kopelow	Program Consultant, Manager, AS! BC	JW Sporta
Jennifer Fenton	Program Consultant, AS! BC	JW Sporta

[69] Table reprinted with permission from: H. M. Macdonald. Effectiveness of a school-based physical activity intervention for increasing bone strength in children: Action Schools! BC. University of British Columbia; 2006.

Name	Title	Constituency Represented
Patti Hunter	Director, Physical Activity and Healthy Living	2010 Legacies Now
Bruce Dewar	Executive Vice President	2010 Legacies Now
Janice Macdonald	Regional Executive Director	Dieticians of Canada, BC Region
Douglas McCall	Executive Director	Joint Consortium for School Health
Kathy Cassels	DASH/Breakfast for Learning Coordinator	The Directorate of Agencies for School Health
Marion Taylor	Consultant	2010 Legacies Now
Karen Strange		Healthy Eating Team, AS! BC
Meghan Day	Graduate Student, Dietician	Healthy Eating Team, AS! BC
Jane MacCarthy	Senior Communications and Media Relations Manager	2010 Legacies Now

Appendix D School health inventory questionnaire

Action Schools! BC

School Health Inventory

Complete every 2 years

When completed, please send this form to Action Schools! BC: fax 604.737.6043 email info@actionschoolsbc.ca

School/SD#: ______________________________

Completed by: ______________________________

Date of Inventory: ______________________________

The School Health Inventory (SHI) is one of six inventories designed to assist school Action Teams to assess their school environment and identify areas to determine the gaps where action is needed. Schools can then create goals to incorporate into their School Action Plan.

1. School Health Policies and School Environment

1.1 Representative committee for school health programs

Does the school have a representative* committee that meets at least twice a year and oversees school health policies and programs concerning physical activity, healthy eating, and tobacco prevention and cessation?

☐ Yes, there is a representative committee that meets at least twice a year and oversees school health policies and programs.

☐ There is a committee, but it is not representative; **or** it does not address physical activity, healthy eating, and tobacco prevention and cessation policies and programs; or it meets less than twice a year.

☐ There is no committee for school health programs, but there are plans to establish one.

☐ There is no committee for school health programs, and there are no plans to establish one.

** Representative means it includes relevant members of the school community, such as students, school staff (e.g. teachers, administrators, food services and custodial staff), families, community practitioners (e.g. recreation programmers, public health nurses, counselors), and community volunteers (e.g. coaches).*

1.2 Written health policies

a) Does the school or district have written school health policies that commit the school to the following? (check all that apply)

☐ Providing a broad range of competitive and noncompetitive physical activities that help students develop the skills needed to participate in lifetime physical activity.

Step 2

Step 2

☐ Providing foods that are low in fat, sodium, and added sugars wherever food is available inside the school (in the case of schools with cafeterias, this would also apply to food being served in the cafeteria).

☐ Providing a 100% tobacco-free environment 24 hours a day.

b) Does the school have written policies about helmet and safety equipment for cyclists and those commuting to school with 'small wheel vehicles' (e.g. rollerblades, skateboards, scooters)?

☐ Yes, the school has both helmet and safety equipment policies.

☐ The school has policies about helmet and safety equipment for only one of the above.

☐ There are no written policies about helmet or safety equipment, but there are plans to develop them in the future.

☐ No, there are no written policies about helmet or safety equipment, and there are no plans to develop them in the future.

1.3 Recess

Are students provided with at least 20 minutes of recess* during each school day, and do teachers or recess monitors encourage students to be active?

☐ Yes, students are provided with at least 20 minutes of recess each day, and are encouraged to be active.

☐ Recess is provided for at least 20 minutes each day, but neither teachers nor recess monitors encourage students to be active.

☐ Recess is provided each day, but for less that 20 minutes; **or** it is provided on some days, but not on all days.

☐ Recess is not provided on any day.

** Recess is an opportunity for unstructured physical activity, and should complement rather than substitute for physical education.*

1.4 Adequate physical activity facilities

Are physical activity facilities adequate in the following ways? (check all that apply)

☐ Both indoor and outdoor facilities are available for physical education, classroom physical activity, and extracurricular physical activity programs.

☐ Physical education classes do not have to be cancelled due to weather extremes (rain, high or low temperatures, etc.).

☐ In physical education classes, all students can be physically active without overcrowding or safety risks.

☐ For extracurricular activities, all interested students can sign-up and participate without overcrowding or safety risks.

1.5 Access to physical activity facilities outside school hours

Can all students use the school's indoor and outdoor physical activity facilities outside school hours*?

- ☐ Yes, students can use the school's indoor and outdoor physical activity facilities outside school hours.
- ☐ Indoor or outdoor facilities are available, but not both.
- ☐ Indoor or outdoor facilities are available, but the hours of availability are limited.
- ☐ No, students can not use the school's indoor and outdoor physical activity facilities outside school hours.

* *Outside school hours means before and after school, evenings, weekends, and school vacations.*

1.6 Access to facilities and programs that promote safe, active transportation to and from school

Does the school have the following facilities and programs that promote safe, active transportation to and from school? (check all that apply)

- ☐ A 'car-free zone' to provide safe walking areas.
- ☐ Adequate* facilities available to lock bicycles and small wheel vehicles like skateboards and scooters.
- ☐ A 'walk-to school' program involving teachers and families.
- ☐ Programs promoting the use of helmets and safety gear for those who use active transportation to school (bicycles and small wheel vehicles).

* *Adequate means that most of the time (80% +) there are spaces available for students to lock up active transportation equipment.*

1.7 Fund-raising efforts promote physical activity

Do school fund-raising efforts promote physical activity (e.g. fun runs, family walks, programs like Jump Rope for Heart)?

- ☐ Yes, all of the school's fund-raising efforts promote physical activity in some form.
- ☐ Some of the school's fund-raising efforts promote physical activity in some form.
- ☐ The school's fund-raising efforts do not involve or promote physical activity, but there are plans to change in the future.
- ☐ The school's fund-raising efforts do not involve or promote physical activity, and there are no plans to change in the future.

Step 2

Step 2

1.8 Fund-raising efforts support healthy eating

Do school fund-raising efforts support healthy eating through the sale of non-food items or healthy foods* instead of foods that are of minimal and low nutritive value**?

- ☐ Yes, fund-raising efforts support healthy eating through the sale of non-food items or foods low in sodium, and added sugars.
- ☐ Fund-raising efforts rarely support health eating.
- ☐ Fund-raising efforts typically include the sale of foods high in fat, sodium and added sugars, but there are plans to change this practice.
- ☐ Fund-raising efforts typically include the sale of foods high in fat, sodium and added sugars, and there are no plans to change this practice.

* *Healthy foods are low in fat, sodium, and added sugars (for example, fruits, vegetables pretzels, air-popped popcorn).*

** *Foods of minimal nutritional value include carbonated soft drinks, chewing gum and certain candies. Foods of low nutritive value provide most calories in the form of fat and/or sugars but contain few vitamin or minerals. Examples include candy, fried chips and juice drinks.*

1.9 Access to healthy foods

Does the school promote the sale and distribution of healthy foods* and discourage the sale and distribution of foods of minimal and low nutritive value** throughout the school grounds until after the end of the last lunch period?

- ☐ Yes, the school promotes the sale and distribution of healthy foods and discourages the sale and distribution of foods of minimal and low nutritive value.
- ☐ The school prohibits the sale and distribution of foods of minimal nutritional value and other foods of low nutritive value throughout the school grounds, but only during meal service hours.
- ☐ No, but there are plans to do so.
- ☐ No, and there are no plans to do so.

1.10 Staff orientation to school health policies

Are staff oriented to (verbal and/or written orientation) and given copies of the policies on physical activity, healthy eating, and tobacco prevention and cessation that relate to their job responsibilities?

- ☐ Yes, staff are oriented to and given policies about these topics as they relate to their job responsibilities.
- ☐ Staff are oriented to or given copies of the above policies, but not both.
- ☐ No, but there are plans to do so.
- ☐ No, and there are no plans to do so.

1.11 Communication of school health policies

Does the school communicate its policies on physical activity, healthy eating, and tobacco prevention and cessation to students, staff, families and visitors in each of the following ways? (check all that apply)

☐ 'Tobacco-free school' signs
☐ Student handbook
☐ Staff handbook
☐ Family handbook and/or newsletters
☐ Staff orientation and meetings
☐ Student orientation
☐ Announcements at school events
☐ Community meetings
☐ Contracts with outside vendors and organizations that rent school facilities
☐ Other methods? ____________________
☐ School policy is not communicated to students, staff, families or visitors

2. Physical Education and other Physical Activity Programs

2.1 150 minutes of physical education per week (IRP guidelines)

Do all intermediate grade students receive scheduled physical education* for at least 150 minutes per week throughout the school year, spread over at least three days?

☐ Yes, intermediate grade students receive 150 minutes of physical education per week spread over at least three days each week throughout the school year.
☐ Students receive 90-149 minutes of physical education over at least three days each week throughout the school year.
☐ Students receive 90+ minutes of physical education on one or two days each week throughout the school year.
☐ Students receive fewer than 90 minutes of physical education per week.

* *Physical education refers to scheduled instruction-based physical education classes.*

2.2 Equitable distribution of gym time

Do all intermediate grade classes receive equal amounts of gym time?

☐ Yes, all intermediate grade classes receive equal amounts of gym time.
☐ No, all intermediate grade classes do not receive equal amounts of gym time.

Step 2

2.3 Student preparation for physical education (adequate time in clean, safe changing facilities)

Do students have adequate time in clean, safe changing facilities to change before and after physical education class?

☐ Yes, students have adequate time to change, and the changing facilities are clean and safe.
☐ Students have only one of the above.
☐ Students do not change for physical education.

2.4 Assessment of satisfaction with physical education

Is information collected from students about their satisfaction/enjoyment and participation in physical education?

☐ Yes, information about student satisfaction/enjoyment and participation is collected several times each year.
☐ Information is collected annually.
☐ Information is collected less than annually.
☐ No, information about student satisfaction/enjoyment and participation in physical education is not collected.

2.5 Promotion of community-based physical activity

Does the physical education program use promotional methods to promote student participation in a variety of community-based physical activity*?

Promotional methods (check all that apply):

☐ Class discussions
☐ Bulletin boards
☐ Public address announcements
☐ Take-home flyers
☐ Homework assignments
☐ Newsletter articles
☐ Other: ____________________
☐ The program does not promote participation in community-based physical activity.

* *Examples of community based physical activity include clubs, teams, recreational classes, special events, and use of playgrounds, parks, bike paths, etc.*

3. School Health Services

Does your school have health service positions/budgets?

☐ Our school does have health service positions/budgets.
☐ Our school health service positions/budgets have been cut.
☐ Our school does not have health service positions/budgets.

3.1 Physical activity promotion

Does the school nurse* or other health service practitioner** promote physical activity to students and their families through the following methods? (check all that apply)

☐ Distribution of educational materials
☐ Individual advice
☐ Small group discussions
☐ Presentations
☐ Other_______________
☐ Our school does not have a school nurse or other health service practitioner.

* *School nurse means a licensed nurse employed by the school or district.*
** *Other health service practitioner refers to a health professional who provides service to the school on either a contracted or a volunteer basis.*

3.2 Healthy eating promotion

Does the school nurse or other health service practitioner promote healthy eating to students and their families through the following methods? (check all that apply)

☐ Distribution of educational materials
☐ Individual advice
☐ Small group discussions
☐ Presentations
☐ Other:_______________
☐ Our school does not have a school nurse or other health service practitioner.

Step 2

Step 2

4. Health Promotion for Staff

4.1 Staff physical activity/fitness programs

Does the school or district offer* staff members physical activity/fitness programs** that are accessible and free or low-cost?

☐ Yes, the school or district offers staff members physical activity or fitness programs that are accessible and free or low-cost.
☐ The school or district offers accessible physical activity/fitness programs, but the programs are not low-cost.
☐ The school or district offers physical activity/fitness programs, but the programs are not low-cost and not accessible.
☐ The school or district does not offer physical activity/fitness programs.

* *Offer means that the school or district has a special arrangement for staff to participate in physical activity/fitness programs either on-site or off-site through a community program.*
** *Physical activity/fitness programs include classes, workshops, facilities and special events.*

4.2 Staff healthy eating programs

Does the school or district offer* staff members healthy eating programs that are accessible and free or low-cost?

☐ Yes, the school or district offers staff members healthy eating programs that are accessible and free or low-cost.
☐ The school or district offers accessible healthy eating programs, but the programs are not low-cost.
☐ The school or district offers healthy eating programs, but the programs are not low-cost and not accessible.
☐ The school or district does not offer healthy eating programs.

* *Offer means that the school or district has a special arrangement for staff to participate in physical activity/fitness programs either on-site or off-site through a community program.*

4.3 Staff participation in health promotion programs

Does the school or district promote and encourage staff participation in health promotion programs? (check all that apply)

Participation promotion methods: (check all that apply)
☐ Information at orientation for new staff
☐ Information included with pay cheque
☐ Flyers posted on school walls

☐ Letters mailed directly to staff
☐ Announcements at staff meeting
☐ Articles in school/staff newsletter
☐ Incentive/reward programs
☐ Public recognition
☐ Other methods: ____________________________
☐ The school or district does not promote or encourage staff participation in health promotion programs.

4.4 Staff access to facilities that promote physical activity

Does the school have bike racks, changing facilities and shower facilities for staff who choose to actively commute to work or exercise at the school during breaks?

☐ The school has all of the above facilities.
☐ The school has two of the above facilities.
☐ The school has one of the above facilities.
☐ There are no facilities available to the staff.

5. Family and Community Involvement

5.1 Family education

Does the school provide families with opportunities to learn about physical activity, healthy eating, and tobacco prevention and cessation, through educational materials* sent home and involvement in school-sponsored activities**?

☐ Yes, the school provides families with opportunities to learn about physical activity, healthy eating, and tobacco prevention and cessation through educational materials sent home and involvement in school-sponsored activities.
☐ The school provides many opportunities to learn about only two of the three topics.
☐ The school provides few opportunities; or provides many opportunities to learn about only one of the three topics.
☐ The school does not provide families with opportunities to learn about physical activity, healthy eating, or tobacco prevention and cessation.

** Examples of educational materials include brochures, newsletter articles, introductions to curricula, and homework assignments that require family participation.*
*** Examples of school-sponsored activities include parent/teacher meetings, health fairs, food tastings, international meals, field days, walkathons, and fun runs.*

Step 2

5.2 Student and family involvement in planning meals
Note: Only for those schools with breakfast/hot lunch programs

Are students and families involved* in planning school meals?

☐ Yes, students and parents are involved with planning school meals.
☐ Students or parents are involved, but not both.
☐ Neither are involved, but there are plans to involve one or both groups.
☐ Neither are involved, and there are no plans to involve them.

** Examples of being involved include giving menu and recipe suggestions, identifying food preferences, and participating in taste-testing activities.*

5.3 Family and community involvement in programs

Do families and community members help plan and implement school physical activity and/or healthy eating programs?

Examples of family and community involvement: (check all that apply)

☐ Volunteering to help in the classroom, cafeteria, or with special events.
☐ Serving on a school planning committee for physical activity or healthy eating programs.
☐ Designing or conducting a needs assessment or program evaluation.
☐ Other ____________________________
☐ Family and community members do not help plan and implement school physical activity and/or healthy eating programs.

5.4 Community access to school facilities

Do community practitioners have access to indoor and outdoor school facilities* outside school hours** to participate in or conduct health promotion programs***?

☐ Yes, community practitioners have access to school facilities.
☐ Yes, but the hours of access are somewhat limited.
☐ Yes, but the hours of access are quite limited; or there is access to indoor or outdoor facilities but not both.
☐ Community practitioners do not have access to either indoor or outdoor school facilities.

** Examples of school facilities include classrooms, gymnasiums, and outdoor areas.*
*** Outside school hours means before and after school, in the evening, on weekends, and during school vacations.*
**** Examples of health promotion programs include physical activity, healthy eating and/or tobacco prevention and cessation programs.*

Appendix E School action plan

Action Schools! BC

School Action Plan

School Year: ________

Complete this form to develop your School and or Classroom Action Plans. Use the Action Schools! BC Planning Guide or contact the Action Schools! BC Support Team to assist you.
Phone 604.738.2468 or 1.800.565.7727 or
email info@actionschoolsbc.ca

School/SD#: ______________________ Plan: ☐ School ☐ Teacher

Completed by: ______________________

Grade/Div: ______________________ Date Completed: ______________________

When completed, please send this form to Action Schools! BC: fax at 604.737.6043 or email info@actionschoolsbc.ca

Goal Statements *(see Guide)*	**Actions** *(see Guide)*	**Date(s) or Timing for Action**
Action Zone: School Environment – e.g. policies, professional development, facilities/equipment		
Action Zone: Scheduled Physical Education – Gr 4-7 (150 min/wk) – Active Living, Movement, Personal & Social Responsibility		PE schedule (e.g. 2x40min/wk):
Achieve curriculum outcomes		
Action Zone: Classroom Action – e.g. 15x5, health, nutrition		
Provide _____ min/day of physical activity (in addition to scheduled PE)	Action Schools! BC Action 15x5	All year, September–June
Action Zone: Family & Community – e.g. active field trips, guest demonstrations, family nights		
Action Zone: Extra-Curricular – e.g. clubs, intramurals, team sports		
Action Zone: School Spirit – e.g. school wide events, sports days		

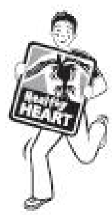
Appendix F Contents of the classroom action bin

Action Schools! BC

Classroom Action

GRADES 4 TO 7

– take an Action Schools! BC action break –

HEALTH TARGET	RESOURCES PROVIDED	EQUIPMENT PROVIDED
	**BOUNCE-AT-THE-BELL** • Bounce-at-the-Bell Poster (F) **SKIPPING ROPE** • Jump2bFit Manual/CD/DVD (F) • Active Playgrounds (F)	36 Skip Ropes 8′ (2.4m)
	**CLASSROOM WORKOUTS & DANCE** • 6 Fit Kids' Workouts DVD • 65 Energy Blasts DVD **CHAIR AEROBICS** • Jump2bFit CD • Ever Active…Everywhere **PLAYGROUND GAMES** • Great Gator Games (F) • Active Playgrounds (F) **TAG** • You're It! Tag, Tag…and More Tag (F) **PLAYGROUND CIRCUITS** • Action Schools! BC Playground Circuit (provided at workshop and posted on www.actionschoolsbc.ca)	Sidewalk Chalk 3 Playground Balls 7" (17.8cm)
	**STRETCHING** • Action Schools! BC Head-to-Toe Stretch Poster (F) • Get Strong 101 DVD **STRENGTHENING** • *Classroom Action Resource* – Grip Strengthening – Exercising with Bands • Get Strong 101 DVD	36 Hand Grippers 15 Exercise Bands (Red)
	**ACTION BREAKS** • 65 Energy Blasts DVD **BRAIN ENERGIZERS** • *Classroom Action Resource* – Brain Energizers and Brain Focusers	
SUPPLEMENTARY RESOURCES	• *Action Pages!* • Action Schools! BC Sporting Spirit Poster (F) • p.s.a.p. – Teaching the Basics Manual "Coupon" • Heart Smart Brochure • Wheelchair Sports Teaching Resource • Road Safety for Kids & Parents! • Hero in You Poster	

(F) Available in French – Request a French Package
www.actionschoolsbc.ca

www.actionschoolsbc.ca

Appendix G Invitation letter and consent form for school administrators

Action Schools! BC
Investigators:
Patti-Jean Naylor PhD, Heather McKay PhD
Contact Number: [redacted]

Information to Administrators:

We are pleased to welcome you and your school to participate in the Action Schools! BC (AS!BC) Research Study during the 2005-2006 school year. The ultimate goal of AS! BC is to “make healthy choices the easy choices” to enhance the health and well-being of all children. The pilot phase of the program in the lower mainland was a great success and we hope that you will be able to participate in the ongoing efforts to evaluate this model in schools across BC. Your participation will be instrumental in helping us determine if AS! BC is a feasible and effective means to providing physical activity and healthy eating opportunities in the schools and whether there are also benefits for the schools involved in the implementation of it.

The evaluation procedures will take place from September 2005 through to June 2006. During this interval, we will ask you to complete one semi-structured telephone interview. At this time we would ask that you please consider your participation in the Action Schools! BC Research Study. We invite you to read, complete and sign the attached consent form. An Action Schools! BC Research Assistant will collect this form from you.

We are excited to be working with the Administrators involved in Action Schools! BC. Your involvement is appreciated. If you have any questions please contact Josie McKay at [redacted], Dr. Heather McKay at [redacted] or Dr. PJ Naylor at [redacted].

Sincerely,

Dr. PJ Naylor
[redacted]

Sincerely,

Dr. Heather McKay
[redacted]

Action Schools! BC Consent Form For Administrators

Procedures:

- Semi-structured telephone interview (1 / year)

I understand that the above procedure is a component of the process evaluation for the Action Schools! BC Research Study and will focus on the context for, and implementation of, Action Schools! BC. I understand that I will be asked about my thoughts and experiences regarding the context for, and implementation of Action Schools! BC in a telephone interview that will last 30 minutes to 45 minutes.

I understand the information I provide will be confidential and that my anonymity will be maintained by using code numbers to identify the information obtained in the interview. I understand that notes will be taken and the interview will be audio-taped and will be transcribed for further analysis. Only the researchers will have access to the audio-tape, transcript and consent form. I understand that the information I provide will be combined with other participants' data and at no time will individual names be used.

I know that all written notes that the researchers might take will be shredded after the researchers have put the information on to computer disk. I know that a summary of the interview results may be sent to me for review upon my request, and that I may change information that I feel identifies myself or my organization. I am also aware that tapes will be erased immediately after the interview has been transcribed. All information will be securely stored in a locked cabinet at the University of British Columbia or University of Victoria.

I understand my participation is completely voluntary and I may provide comments or withdraw at any time without penalty to myself or my organization. I may also obtain a copy of this consent form to keep upon my request.

Possible Harms:
None

Benefits:

I understand that if I choose to participate in the Action Schools! BC Research Study, I will learn more about how physical activity and healthy eating can contribute to improved health. I understand that the researchers hope that through this program, my school will achieve the many benefits that accompany a healthy lifestyle and that I will receive a summary of the findings at the end of the study.

Rights and Welfare of the Individual:

I understand that I have the right to refuse participation in this Research Study. It is understood that I am free to withdraw from any or all parts of the program at any time without penalty. I understand that my identity will remain confidential as all individual records and results will be analyzed and referred to by number code only. Files are kept in the Vancouver General Hospital, Bone Health Research Lab and the University of Victoria, School of PE in a locked cabinet and accessible only to those directly involved in the study (namely, the Action Schools! BC Research Study Team) will have access to my records and results. I understand that my data or my school will not be referred to by name in any program reports or research papers. I understand that the results of this study may be shared with others both in written and oral format to audiences such as the BC Principals and Vice Principals Association, BC Council of Parent Advisory Councils, Canadian Association for Public Health, BC Healthy Living Alliance, the Chronic Disease Prevention Alliance of Canada, the BC Ministries of Health and Education and the Provincial Advisory Group of Action Schools! BC.

I understand that I may ask questions at any time. I understand that I will have the opportunity to discuss the results with the research team when they have come available. Should I have any concerns about this program or wish further information I can contact Josie McKay, [redacted], Dr. PJ Naylor, [redacted], or Dr. Heather McKay, [redacted]. If I have any concerns about my rights or treatment as a research subject, I may contact the Associate Vice-President of Research at the University of Victoria at [redacted].

Compensation for Injury:

Signing this consent form in no way limits my legal rights against the sponsors, investigators or anyone else.

(Continued on other side)

I agree to participate in the following components of the Action Schools! BC Research Study.

Please check (✓) one.

___ I agree to participate in the AS! BC Research Study and to participate if asked in a telephone interview about the AS! BC model

___ I do not agree to participate in the AS! BC Research Study and to participate if asked in a telephone interview about the AS! BC model

I understand that at any time during the AS! BC Research Study I will be free to withdraw without jeopardizing any medical management, employment or educational opportunities. I understand the contents of all three pages of this form, the proposed procedures and possible risks. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this program.

Name (please print) ________________________________

Signature ________________________________

Date ________________________________

Principal Investigators

Dr. P.J. Naylor,
[redacted]

Dr. Heather McKay,
[redacted]

Appendix H Invitation letter and consent form for teachers

Action Schools! BC
Investigators:
PJ Naylor PhD, Heather McKay PhD
Contact Number: [redacted]

Information to Teachers:

We are pleased to invite you and your school to participate in Action Schools! BC (AS! BC) Research Study during the 2005-2006 school year. The ultimate goal of the AS! BC program is to "make healthy choices the easy choices" to enhance the health and well-being of all children. The pilot phase of the program in the lower mainland was a great success and we hope that you will be able to participate in the ongoing efforts to evaluate this model in schools across BC. Your participation will be instrumental in helping us determine if AS! BC is a feasible and effective means to provide physical activity and healthy eating opportunities in the schools and whether there are also benefits for the adults involved in the implementation of it.

The research study will take place between September 2005 and June 2006. During this interval we will ask you to complete weekly logs of your classroom activities. You may also be asked to complete a Health Behaviour and Community Connections questionnaire twice during the year and / or participate in one semi-structured telephone interview. At this time we would ask that you please consider your participation in the AS! BC Research Study. We invite you to read, complete and sign the attached consent form. An AS! BC Research Assistant will collect this form from you.

We are excited to be working with the teachers and students involved in Action Schools! BC. Your involvement is appreciated. If you have any questions please contact Josie McKay at [redacted], Dr. PJ Naylor at [redacted] or Dr. Heather McKay at [redacted].

Sincerely,

Dr. PJ Naylor
[redacted]

Sincerely,

Dr. Heather McKay
[redacted]

Action Schools! BC Consent Form for Teachers

Procedures:

- Weekly Action Logs either 1) submitted to your regional facilitator, 2) entered on the web data entry form or 3) sent by mail to the AS! BC research team
- Semi-structured telephone interview (1 / year)
- Health Behaviour and Community Connections Survey (2/year)

I understand that the above procedures are components of the process evaluation for the Action Schools! BC Research Study and focus on the context for, and implementation of, Action Schools! BC. I understand that I will be asked about my thoughts and experiences regarding the context for, and implementation of Action Schools! BC in a telephone interview that will last 30 minutes to 45 minutes. I understand that I will be asked, as a secondary component of the evaluation, to complete a Health Behaviour and Community Connections Survey that will take 30 minutes at the outset of the project and again at the end of the year. I also know that my weekly classroom logs will be included as part of the evaluation.

I understand the information I provide will be confidential and that anonymity will be maintained by using code numbers to identify the information obtained in the interview. I understand that notes will be taken and the interview may be audio-taped and will be transcribed for further analysis. Only the researchers will have access to the tapes, transcripts and consent forms. I understand that the information I provide will be combined with other participants' data and at no time will individual names be used.

I know that all written notes that the researchers might take will be shredded after the researchers have put the information onto computer disk. I know that a summary of the interview results may be sent to me for review upon my request, and that I may change information that I feel identifies myself or my organization. I am also aware that tapes will be erased immediately after the interview has been transcribed. All information will be securely stored in a locked file cabinet at the University of British Columbia or University of Victoria.

I understand my participation is completely voluntary and I may provide comments or withdraw at any time without penalty to myself or my organization. I may also obtain a copy of this consent form to keep upon my request.

Possible Harms:
None

Benefits:
I understand that if I choose to participate in the Action Schools! BC Research Study, I will learn more about how physical activity and healthy eating can contribute to improved health. I understand that the researchers hope that through this program, my school will achieve the many benefits that accompany a healthy lifestyle and that I will receive a summary of the findings at the end of the study.

Rights and Welfare of the Individual:

I understand that I have the right to refuse participation in this research study. It is understood that I am free to withdraw from any or all parts of the program at any time without penalty. I understand that my identity will remain confidential as all individual records and results will be analyzed and referred to by number code only. Files are kept at the Vancouver General Hospital, Bone Health Research Lab and the University of Victoria, School of PE in a locked cabinet and only those directly involved in the study (namely, the Action Schools! BC Research Study Team) will have access to my records and results. I understand that my data or my school will not be referred to by name in any program reports or research papers. I understand that the results of this study may be shared with others both in written and oral format to audiences such as the BC Principals and Vice Principals Association, BC Council of Parent Advisory Councils, Canadian Association for Public Health, BC Healthy Living Alliance, the Chronic Disease Prevention Alliance of Canada, the BC Ministries of Health and Education and the Provincial Advisory Group of Action Schools! BC.

I understand that I may ask questions at any time. I understand that I will have the opportunity to discuss the results with the research team when they have become available. Should I have any concerns about this program or wish further information I can contact Josie McKay, [redacted], Dr. P.J. Naylor, [redacted] or Dr. Heather McKay, [redacted]. If I have any concerns about my rights or treatment as a research subject, I may contact the Director, Office of Research Services at the University of British Columbia at [redacted].

Compensation for Injury:

Signing this consent form in no way limits my legal rights against the sponsors, investigators or anyone else.

(Continued on other side)

I agree to participate in the following components of the Action Schools! BC Research Study.

Please check (✓) one.

___I agree to have my classroom logs included in the AS! BC Research Study and to participate if asked in a telephone interview about the AS! BC program.

___ I do not agree to participate in the AS! BC Research Study and to participate if asked in a telephone interview about the AS! BC program.

Please check (✓) the secondary component below if you wish to participate in this part of the study.

___ I agree to participate in the Health Behaviour and Community Connections survey component of the AS! BC Research Study.

___ I do not agree to participate in the Health Behaviour and Community Connections survey component of the AS! BC Research Study.

I understand that at any time during the AS! BC Research Study I will be free to withdraw without jeopardizing any medical management, employment or educational opportunities. I understand the contents of all three pages of this form, the proposed procedures and possible risks. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this program.

Name (please print) ____

Signature ____

Date ____

Principal Investigators:

Dr. P.J. Naylor, Assistant Professor,
[redacted]

Dr. Heather McKay, Professor,
[redacted]

Appendix I Invitation letter and consent form for families

Principal Investigators

Heather McKay PhD, [redacted] and Patti-Jean Naylor PhD, [redacted]

Co-investigators
Joan Wharf-Higgins PhD, Ryan Rhodes PhD,
Stephen Manske PhD, Darren Warburton PhD, Shannon Bredin PhD

Research Coordinators
Sharon Storoschuk and Connie Waterman [redacted]

Information for Families:

We are pleased to invite you and your child to be a part of the Action Schools! BC (AS! BC) Research Study. Your child's school has agreed to be a part of the AS! BC Research Study and we now invite you and your child to read the following information on this exciting initiative!

The Action Schools! BC Program

The goal of AS! BC is to "make healthy choices the easy choices" to improve the health and well-being of all children. The program was developed in response to the reality that many Canadian children are physically inactive and as a result are at a greater risk of developing chronic diseases such as heart disease, obesity, Type II diabetes and osteoporosis. AS! BC helps schools to provide more physical activity to students and encourage healthy lifestyles. The success of this program was recently tested in schools in the Lower Mainland. As a result of participating in more physical activity, students had improvements in heart and bone health. You can learn more about AS! BC and the results of the research study on our website at www.actionschoolsbc.ca. We are now offering the AS! BC Program to schools across the province and with funding from the Canadian Institutes of Health Research we are conducting a second research study to see if the program will be successful in different areas of BC.

The Action Schools! BC Research Study

We will be conducting a 3-year study to determine if the AS! BC Program can positively change physical activity and eating behaviours, self-esteem and heart health in students across BC. To see if such changes occur as a result of the program, it is important for us to compare the AS! BC Program with regular school routines of physical activity. For this reason, schools who chose to participate in the AS! BC Research Study will be randomly assigned to one of two groups; intervention or usual practice.

The intervention schools will receive the AS! BC Program and the usual practice schools will continue with their regular program of physical activity. Students from all schools will be invited to participate in the research study. Therefore, if your child's school is a usual practice school (not doing the AS! BC Program) we would still like to ask them to participate in the research study. At the end of the study period the AS! BC Program will be offered to all schools.

During the first year of the research study, there will be three measurement sessions between September 2005 and June 2006 (Fall, Winter and Spring). Each session will require your child to be absent from class for a minimum of 70 minutes. Detailed information about all measurements that will occur during these sessions is provided in the attached consent form.

In addition, your child may be asked to wear an accelerometer three times during the school year. Accelerometers are 'motion sensors' that work using the same technology as the motion sensor lights for houses and carports. The purpose of the motion sensor is to get an idea of your child's physical activity patterns. The accelerometer is small and lightweight and is worn on a belt around the waist. If your child is selected for the accelerometer study, we will ask you and your child to complete a short transportation survey. This survey will require about 10 minutes to complete and we will only ask you to complete it once.

At this time we would ask that you please consider you and your child's participation in the AS! BC Research Study. We invite you to read, complete and sign the attached consent form and Health History Questionnaire. Once you have completed the forms, please place them in the attached envelope, seal it and return the envelope to your child's teacher. A research assistant will arrange to pick them up. Please note that should you and your child choose not to participate in the research study, your child will still be able to participate in AS! BC.

We are excited to expand AS! BC to schools throughout the province and we look forward to working with the students, parents and teachers in your region. You and your child's participation will be important in helping us determine if AS! BC is an effective means to provide physical activity and encourage healthy living in schools. If you have any questions please contact Sharon Storoschuk or Connie Waterman (Research Coordinators) at [redacted], Dr. Heather McKay (Principal Investigator) at [redacted] or Dr. PJ Naylor (Principal Investigator) at [redacted].

Sincerely,

Dr. Heather McKay,
[redacted]

Action Schools! BC Consent Form for Families

Please read the following with your child, and if you and your child would like to participate please sign the attached form and return the signed form to your child's teacher. You may keep the other pages for your records.

Procedures. Your child's participation in the Action Schools! BC (AS! BC) Research Study will involve three in-school testing sessions in the Fall, Winter and Spring of the next three school years. All children will participate in the Anthropometry and Questionnaire components and a smaller random sample of students will participate in the Cardiovascular Health and Musculoskeletal Fitness and Accelerometer components.

Anthropometry: Measures of height, weight and calf and waist circumference will be taken. Total Time - 10 minutes: Fall and Spring.

Questionnaires: Your child will be assisted in the completion of questionnaires that will assess their physical activity, nutrition, self-esteem and attitudes and perceptions about physical activity. A trained research assistant will discuss the importance of these assessments with the children. Total Time – 1 hour: Fall, Winter and Spring.

Cardiovascular Health and Musculoskeletal Fitness: We will evaluate aerobic fitness using a shuttle run in which students repeatedly run 20 meter laps in time with a clearly audible "beep" until they become tired and choose to stop. Musculoskeletal fitness (i.e., muscle strength and power) will be assessed using a hand held dynamometer. A research assistant will provide clear instructions for each procedure to the students. Resting blood pressure and heart rate will be recorded before all fitness procedures. A smaller group of students (25%) will be recruited for this portion of the study. Total Time - 45 minutes: Fall and Spring.

Accelerometers: We will monitor children's physical activity with accelerometers. Children will wear the accelerometer (on a belt around their waist) from the time they get up until the time they go to bed (approximately 12 hours) for 5 consecutive days. A research assistant will provide clear instructions for how to wear the accelerometer. A small group of students (25%) who participate in the cardiovascular component (item 3 above) will be recruited for this portion of the study. Total time – 45 minutes in the Fall for a session on accelerometer instructions. Accelerometers will be worn for 5 days in the Fall, Winter and Spring. We will also ask the participating parents and the child to complete a short transportation survey. Transportation survey – 10 minutes: Fall.

Health History Questionnaire:
If you and your child agree to participate in the AS! BC Research Study, you will be asked to complete the attached Health History Questionnaire to determine if there are any health reasons to exclude your child from the research study and to identify any conditions or medications that may affect study outcomes.

Possible Harms:
None.

Benefits:
If you and your child choose to participate in the AS! BC Research Study, you and your child will learn more about how physical activity and healthy eating can contribute to improved health. At the end of the study you and your child will receive a summary of the results indicating the general findings of the study and your child's personal performance. It is our hope that through this program, your child will achieve the many health benefits that accompany an active lifestyle.

Rights and Welfare of the Individual:

You have the right to refuse your child's participation in this research study. It is understood that you are free to withdraw your child from any or all parts of the study at any time without penalty. If you and your child choose not to participate in the study this will not prevent them from participating in AS! BC. If your child's teacher chooses to stop participating in AS! BC we would like to still involve your child in the research study.

Confidentiality:

Your child's identity will remain confidential as all individual records and results will be analyzed and referred to by number code only. Files are kept in locked cabinets at the Vancouver General Hospital – Research Pavilion, Centre for Clinical Epidemiology and Evaluation. Only those directly involved in the study (namely, the AS! BC Research Team) will have access to your child's records and results. Your child will not be referred to by name in any program reports or research papers. Your child's results will remain confidential and they will not be discussed with anyone outside the research team.

Please be assured that you and your child may ask questions at any time and we welcome your comments and suggestions. We will be glad to discuss your child's results when they become available. Should you have any concerns about this program or wish further information please contact Sharon Storoschuk or Connie Waterman (Research Coordinators), [redacted], Dr. Heather McKay (Principal Investigator) [redacted] or Dr. PJ Naylor (Principal Investigator) at [redacted]. If you have any concerns about your child's rights or treatment as a research subject, you may contact the Director, Office of Research Services at the University of British Columbia at [redacted].

Compensation for Injury:

Signing this consent form in no way limits your legal rights against the sponsors, investigators or anyone else.

Consent Form – September 2005

Please fill out both sides of this form and return it to your child's teacher in the envelope provided.
Please keep the other pages for your records.

<u>Parent's Consent Statement</u>:

I/We ____ the
(*Please print the name of one or both parents/guardians*)

parents/guardians of ____have received and read all
(*Please print child's first and last name*)

6 pages of the information letter and consent form and understand the purpose and procedures of the Action Schools! BC Research Study as described.

<u>Please check (✓) one.</u>

___I agree to have my child participate in the 3-year Action Schools! BC Research Study (anthropometry, questionnaires) with the understanding that my child may or may not be randomly selected to participate in the cardiovascular health and musculoskeletal fitness and <u>accelerometer</u> portions of the study.

___ I do not agree to have my child participate in Action Schools! BC Research Study.

I understand that at any time during the 3-year Action Schools! BC Research Study we will be free to withdraw without jeopardizing any medical management, employment or educational opportunities. I understand the contents of all six pages of this form and the proposed procedures. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this program.

_________________________ _________________________
Signature of Parent or Guardian Date

____
Printed name of the Parent or Guardian signing above

(Continued on other side)

Child's Statement:

I have talked with my parents/guardians about the Action Schools! BC Program and Research Study and I understand what I will be asked to do. I understand that if I want to I can stop being in the research study at any time and I will still be able to participate in activities at my school. I have had the chance to ask questions and have received satisfactory answers to all of my questions.

__________________________ __________________________

Signature of Child Date

____

Printed name of child

__________________________ __________________________

School Name Grade and Division

Appendix J Health history questionnaire

Action Schools! BC

Health History Questionnaire - Fall 2005

Please take the time to answer the following questions about your child's health. This questionnaire is voluntary and you are free to leave any questions unanswered. Please be assured that all information will remain strictly confidential and will only be available to the researchers. If you have any questions regarding the contents of this questionnaire, please contact Josie McKay [redacted] or Dr. Heather McKay [redacted] at the University of British Columbia. You can also email any questions to [redacted] Please return this questionnaire to your child's teacher along with the consent form if you and your child choose to participate. Thank you for your participation in the Evaluation Component of Action Schools! BC.

PARENT(S) REGARDING YOU:

1.0 Where were you born?

Mother: ______________________ Father: ______________________

1.1 Where were **your parents** born?

Maternal Mother: ______________________ Maternal Father: ______________________

Paternal Mother: ______________________ Paternal Father: ______________________

1.2 How long have you lived in North America? Years: __________ Months: __________

1.3 Where did your family live before moving to North America? ______________________

1.4 How would you classify your family ethnically? (i.e., Caucasian-Canadian, Japanese-Canadian, etc.)

____

1.5 If you wish to have your child's results sent home at the end of the study, please provide us with the following contact information.

Mailing Address:

____

Phone Number ______________ **Email** ______________

REGARDING YOUR CHILD:

Child's name: ______________________ Age: ________ Birth Date (d/m/y) ______________

Child's birth weight ______________ (grams or lbs/ozs)

2.0 **Nutrition History:**

2.1 Who prepares your child's meals (i.e. mother, father, grandmother, nanny)? ______________

2.2 Does your child drink milk every day?

_____YES: **if yes:**

How many cups per day? ________

Has your child always drank milk every day (after being weaned from breast or bottle)?
yes ________ no ________

if no, at what age did she/he start drinking milk every day? ________ years old.

_____NO: **if no:**

Has your child ever drank one or more cups of milk per day (after being weaned from breast or bottle)?

______ yes: at what age did she/he stop drinking milk every day? ________ years old.

How many cups did he/she drink until that age? ________ cups per day

______ no : (never drank milk on a daily basis after being weaned)

2.3 Is your child on a special diet? ________ Yes ________ No

If yes: ________ vegetarian

________ low sodium

________ low cholesterol

________ other

Please specify: ______________________

3.0 Medical History and Status:

3.1 Has your child ever been treated for any of the following conditions?

	Yes	No
food allergies	O	O
hypothyroidism	O	O
other allergies	O	O
hyperthyroidism	O	O
asthma	O	O

other conditions (please list)____

3.2 Is your child currently taking any medications? ________ Yes ________ No

If **yes**, what medication(s) is your child taking? ____________________________

What are these medication(s) for? ____________________________

3.3 Has your family doctor ever said that your child has a heart condition and that he/she should only do physical activity recommended by a doctor? _______Yes _______No

3.4 Does your child complain of chest pain when they are doing physical activity? _______Yes _______No

3.5 In the past month, has your child complained of chest pain when they were not doing any physical activity? _______Yes _______No

3.6 Does your child have a bone or joint problem that could be made worse by a change in their physical activity? _______Yes _______No

3.7 Does your child lose their balance because of dizziness or do they ever lose consciousness? _______Yes _______No

3.8 Do you know of any other reason why your child should not participate in physical activity? _______Yes _______No

4.0 Bone History:

4.1 Has your child ever been hospitalized, confined to bed or had a limb immobilized (i.e., arm in a cast)?
________ Yes ________ No

If yes: list condition, approximate date and time involved
(Example: wrist fracture summer, 1990 10 weeks)

Reason	**Date**	**Time Involved**

4.2 Is there a history of wrist, hip, or spine fractures in your family? ________ Yes _______ No

If yes: indicate who was affected

______ mother
______ maternal grandmother
______ maternal grandfather
______ father
______ paternal grandmother
______ paternal grandfather

4.3 Is there a history of osteoporosis in your family? _______ Yes _______ No

If yes: indicate who was affected

______ mother
______ maternal grandmother
______ maternal grandfather
______ father
______ paternal grandmother
______ paternal grandfather

4.4 Is there a history of any other bone disease in your family?
________ Yes ________ No

If yes: please indicate the family member(s) affected

1. ____________________________
2. ____________________________

What is the name of the condition(s) affecting this family member?

1. ____________________________
2. ____________________________

5.0 Physical Activity:

5.1 How would you rate the physical activity level of your child?
Physical activity is defined as vigorous activity that makes them sweat and/or breathe hard.

________ Inactive
________ Sometimes active
________ Moderately active
________ Often active
________ Very active

THANK YOU FOR YOUR PARTICIPATION

Appendix K Physical activity questionnaire for children (PAQ-C)

Action Schools! BC
Physical Activity Questionnaire – Fall 2005

ID: ______________
Checked by: ___________

We would like to know about the physical activity you have done in the last 7 days. This includes sports or dance that make you sweat or make your legs feel tired, or games that make you huff and puff, like tag, skipping, running, and climbing.

Remember:

A. There are no right or wrong answers – this is not a test.

B. Please answer all questions as honestly and accurately as you can – this is very important.

---

1. PHYSICAL ACTIVITY IN YOUR **SPARE TIME (this <u>does not</u> include P.E classes).**
Have you done any of the following activities in the **past 7 days**? If yes, how many times and for how long?
(Remember, **recess is 15 minutes long, and lunch is usually ½ an hour** (30 minutes)).

Tick only one circle per row	No	1-2	3-4	5-6	7 or more times	time per session
Skipping	O	O	O	O	O	________
Four Square	O	O	O	O	O	________
Creative Playground	O	O	O	O	O	________
Tag	O	O	O	O	O	________
Walking for exercise	O	O	O	O	O	________
Bicycling	O	O	O	O	O	________
Jogging or running	O	O	O	O	O	________
Swimming	O	O	O	O	O	________
Baseball, softball	O	O	O	O	O	________
Dance	O	O	O	O	O	________
Football	O	O	O	O	O	________
Badminton	O	O	O	O	O	________
Skateboarding/Scooter	O	O	O	O	O	________
Soccer	O	O	O	O	O	________
Street Hockey	O	O	O	O	O	________
Volleyball	O	O	O	O	O	________
Floor Hockey	O	O	O	O	O	________
Basketball	O	O	O	O	O	________
Ice skating	O	O	O	O	O	________
Cross-country skiing	O	O	O	O	O	________
Ice hockey/ringette	O	O	O	O	O	________
Martial Arts	O	O	O	O	O	________
Gymnastics	O	O	O	O	O	________
Rollerblading	O	O	O	O	O	________
Skiing/Snowboarding	O	O	O	O	O	________
Other: __________	O	O	O	O	O	________

2. In the last 7 days, during your **PHYSICAL EDUCATION (PE) CLASSES**, how often were you very active (playing hard, running, jumping and throwing)? Check only one.

O I don't do PE
O Hardly ever
O Sometimes
O Quite often
O Always

3. In the last 7 days, what did you do most of the time at **RECESS?** Check only one.

O Sat down (talking, reading, doing school work)
O Stood around or walked around.
O Ran or played a little bit.
O Ran around and played quite a bit.
O Ran and played hard most of the time.

4. In the last 7 days, what did you normally do **AT LUNCH** (besides eating lunch)? Check only one.

O Sat down (talking, reading, doing school work)
O Stood around or walked around.
O Ran or played a little bit.
O Ran around and played quite a bit.
O Ran and played hard most of the time.

5. In the last 7 days, on how many days **RIGHT AFTER SCHOOL**, did you do sports, dance, or play games in which you were very active? Check only one.

O None.
O 1 time last week.
O 2 or 3 times.
O 4 times last week.
O 5 times last week.

6. In the last 7 days, on how many **EVENINGS** did you do sports, dance, or play games in which you were very active? Check only one.

O None.
O 1 time last week.
O 2 - 3 times.
O 4 - 5 times last week.
O 6 - 7 times last week.

7. How many times did you do sports, dance, or play games in which you were very active **LAST WEEKEND?** Check only one.

O None.
O 1 time.
O 2 - 3 times.
O 4 - 5 times.
O 6 or more times.

8. Which **ONE** of the following five statements describes you best for the last 7 days? Read all 5 before deciding on the one answer that describes you.

O All or most of my free time was spent doing things that involved **little physical effort** (e.g. watching TV, homework, playing computer games, Nintendo).

O **I sometimes (1-2 times last week) did physical things** in my free time (e.g. played sports went running, swimming, bike riding, did aerobics).

O **I often (3-4 times last week) did physical things** in my free time.

O **I quite often (5-6 times last week) did physical things** in my free time.

O **I very often (7 or more times last week) did physical things** in my free time.

9. How many hours per day did you watch television or play video games (PlayStation, X-Box) or computer games last week? (each show is usually a half hour or 30 minutes). Check only one.

O I watched/played less than 1 hour or have no TV (or no video/computer games).
O I watched/played more than 1 hour but less than 2.
O I watched/played more than 2 hours but less than 3.
O I watched/played more than 3 hours but less than 4.
O I watched/played more than 4 hours.

10. Were you sick last week, or did anything prevent you from doing your normal physical activities?

O Yes
O No

If yes, what prevented you?____

11. Mark how often you did physical activity (like playing sports, games, doing dance or any other physical activity) for each day last week (this includes P.E., lunch, recess, after school, evenings, spare time, etc). **Circle the days that you had P.E. during the last week.**

	None	Little Bit	Medium	Often	Very Often
Monday	O	O	O	O	O
Tuesday	O	O	O	O	O
Wednesday	O	O	O	O	O
Thursday	O	O	O	O	O
Friday	O	O	O	O	O
Saturday	O	O	O	O	O
Sunday	O	O	O	O	O

12. Do you participate in **organized sport** (soccer, dance, karate etc.) outside of school?

O Yes
O No

13. Do you participate in other **organized activities** (music lessons, Chinese school tutoring, girl guides, boy scouts) outside of school?

O Yes
O No

14. If you do participate in organized sport or other activities, how many nights during the week do you do these sports and/or activities? (If you have swimming lessons on 2 nights of the week, check the circle beside "2" and write swimming lessons on the line. You can have more than one activity on a line).

SPORTS		**OTHER ACTIVITIES**	
O 1	__________	O 1	__________
O 2	__________	O 2	__________
O 3	__________	O 3	__________
O 4	__________	O 4	__________
O 5	__________	O 5	__________
O 6	__________	O 6	__________
O 7	__________	O 7	__________

For questions 15, 16, 17 and 18: Outside of required school physical education classes did you do this activity during the last 7 days (on what days? And how long?)?

Circle the best answer

Activity	**No I didn't do this**	**Yes I did this**	**Circle the days that you did this last week**	**On average, how many minutes did you do this activity each day? (one TV show is usually 30 minutes)**
15. Sport and Dance				
a) Baseball / Softball	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
b) Basketball	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
c) Marching band / drill team	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
d) Dance (ballet, jazz, modern, tap)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes

e) Dance (social, recreational)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
f) Football	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
g) Golf	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
h) Gymnastics, tumbling, trampoline	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
i) Hockey (field, ice or roller)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
j) Martial arts (karate, judo or boxing)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
k) Racquet Sports: badminton, tennis, squash, racquetball	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
l) Skating: ice, roller, in-line, skateboarding	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
m) Skiing: downhill, cross-country, water	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
n) Soccer	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
o) Volleyball	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
p) Wrestling (competitive / sport)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
q) Other: (specify)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
16. Exercise	**No I didn't do this**	**Yes I did this**	**When?**	**How Long?**
a) Aerobics / aerobic dancing/ bench aerobics	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
b) Calisthenics: push-ups, sit-ups, jumping jacks	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
c) Running, jogging, jumping rope	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
d) Swimming lengths	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
e) Walking for exercise	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
f) Weight lifting / weight training	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
g) Exercise machine: cycle, treadmill, rower, climber	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
h) Other: (specify)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
17. General Physical Activities	**No I didn't do this**	**Yes I did this**	**When?**	**How Long?**
a) Bicycling	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
b) Hiking	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes

c) Walking for transportation	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
d) Water play: in pool, lake or ocean	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
e) Outdoor chores: mowing, raking, gardening	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
f) Indoor chores: mopping, sweeping, vacuuming,	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
g) Other: (specify)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
18. Education and Entertainment	**No I didn't do this**	**Yes I did this**	**When?**	**How Long?**
a) Computer/Internet	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
b) Video games	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
c) Homework, studying	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
d) Reading (not for school)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
e) Sitting and talking with friends (not on phone), listening to music	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
f) Talking on phone	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
g) Television or video viewing	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
h) Other: (specify)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes
i) Other: (specify)	0	1	Mon Tues Wed Thurs Fri Sat Sun	minutes

IN SCHOOL BUT NOT IN PHYSICAL EDUCATION (PE)

19. Mark an "X" in the box for each day last week that you did some type of physical activity during school but **not in PE or recess**

Monday	Tuesday	Wednesday	Thursday	Friday

20. Mark an "X" in the box by each day last week that you did some type of physical activity during school that **wasn't in PE or recess** AND that was hard enough to make you breathe harder, sweat or get tired.

Monday	Tuesday	Wednesday	Thursday	Friday

21. Tick all of the activities you did **during school** in the last 7 days but **not in PE or at recess**

Not in PE or Recess – ***Tick all that apply.***

a) ____ Aerobics/ chair aerobics / energy blast
b) ____ Jumping jacks, bounce at the bell, gator jumps
c) ____ Running, jogging
d) ____ Walking
e) ____ Jumping rope / skipping
f) ____ Walking for exercise
g) ____ Stretching
h) ____ Strength exercises - Stretchy bands and grippers
i) ____ Push-ups, sit-ups
j) ____ Playground circuit
k) ____ Other ____________________

22. Tick all of the activities you did **during recess** in the last 7 days

In Recess – ***Tick all that apply.***

a) ____ Aerobics/ chair aerobics / energy blast
b) ____ Jumping jacks, bounce at the bell, gator jumps
c) ____ Running, jogging
d) ____ Walking
e) ____ Jumping rope / skipping
f) ____ Walking for exercise
g) ____ Stretching
h) ____ Strength exercises - Stretchy bands and grippers
i) ____ Push-ups, sit-ups
j) ____ Playground circuit
k) ____ Other ____________________

23. Think about what 'other'/education and entertainment activities you did yesterday.

Activity	No I didn't do this yesterday	Yes I did this yesterday	How many minutes did you do this activity? (one TV show is usually 30 minutes)
a) Computer/Internet	0	1	minutes
b) Video games	0	1	minutes
c) Homework, studying	0	1	minutes
d) Reading (not for school)	0	1	minutes
e) Sitting and talking with friends (not on phone), listening to music	0	1	minutes
f) Talking on phone	0	1	minutes
g) Television or video viewing	0	1	minutes
h) Other: (what?)	0	1	minutes
i) Other: (what?)	0	1	minutes

THANK YOU!

Appendix L   Weekly physical activity log for teachers

Action Schools! BC Weekly Activity Log "How To"

Chart Description

School – the school name.

SD# – the school district number. If you are an Independent School please indicate with "Ind" and your city/town.

Teacher – the teacher name.

Grade – a two-digit grade or the letter k.

Division – a two-digit number.

Week of – the date of the Monday of the week being reported.

Frequency – this is the number of times in a given day the activity occurred.

Duration* – this is the duration in minutes of the activity for one occurence.

For Bounce-at-the-Bell,* this is the # of jumps for one occurence.

Comments – a place to put additional comments, e.g. an activity that worked really well, specifics of new or unique activities, reasons for low activity rates.

Scheduled PE:

Provide a brief description of the activities conducted during your physical education period. For example: Fitness circuit, Tag Games, Skipping and indicate how long you spent on each of these in the "DUR" column.

Classroom Action:

Check off the activities conducted each day of the week held within the classroom or in an alternative space (not during your scheduled physical education) and then record the number of times in a given day the activity occurred in the "FREQ" column and the amount of time this activity took in the "DUR" column.

Other Action Zones:

Provide a list of any other activities that your class participated in from any of the six Action Zones:

School Environment	Family & Community
Physical Education	Extra-Curricular
Classroom Action	School Spirit

Step 4

Action Schools! BC

Weekly Activity Log

fax to 604-737-6043

School/SD#: ____________________

Teacher: ____________________

Grade: __________ Division: ____________________

Week of: ____________________

MONDAY	FREQ	DUR	TUESDAY	FREQ	DUR	WEDNESDAY	FREQ	DUR	THURSDAY	FREQ	DUR	FRIDAY	FREQ	DUR
Scheduled PE:			**Scheduled PE:**			**Scheduled PE:**			**Scheduled PE:**			**Scheduled PE:**		
Classroom Action:			**Classroom Action:**			**Classroom Action:**			**Classroom Action:**			**Classroom Action:**		
☐ Bounce at the Bell			☐ Bounce at the Bell			☐ Bounce at the Bell			☐ Bounce at the Bell			☐ Bounce at the Bell		
☐ Classroom Workout			☐ Classroom Workout			☐ Classroom Workout			☐ Classroom Workout			☐ Classroom Workout		
☐ Energy Blasts			☐ Energy Blasts			☐ Energy Blasts			☐ Energy Blasts			☐ Energy Blasts		
☐ Grippers			☐ Grippers			☐ Grippers			☐ Grippers			☐ Grippers		
☐ Exercise Bands			☐ Exercise Bands			☐ Exercise Bands			☐ Exercise Bands			☐ Exercise Bands		
☐ Chair Aerobics			☐ Chair Aerobics			☐ Chair Aerobics			☐ Chair Aerobics			☐ Chair Aerobics		
☐ Head-to-Toe Stretch			☐ Head-to-Toe Stretch			☐ Head-to-Toe Stretch			☐ Head-to-Toe Stretch			☐ Head-to-Toe Stretch		
☐ Skipping			☐ Skipping			☐ Skipping			☐ Skipping			☐ Skipping		
☐ Playground Circuit			☐ Playground Circuit			☐ Playground Circuit			☐ Playground Circuit			☐ Playground Circuit		
☐ Timed Running			☐ Timed Running			☐ Timed Running			☐ Timed Running			☐ Timed Running		
☐ Tag			☐ Tag			☐ Tag			☐ Tag			☐ Tag		
☐ Playground Games			☐ Playground Games			☐ Playground Games			☐ Playground Games			☐ Playground Games		
☐ Nutrition			☐ Nutrition			☐ Nutrition			☐ Nutrition			☐ Nutrition		
☐ Health			☐ Health			☐ Health			☐ Health			☐ Health		
Other Action Zones:			**Other Action Zones:**			**Other Action Zones:**			**Other Action Zones:**			**Other Action Zones:**		

Appendix M Log sheet used to record accelerometer on and off times

ACTION SCHOOLS! BC 7-DAY ACTIVITY LOG – Fall 2006

Name: ________________________________ School:________________________________ Grade :__________ Division: __________

Directions:

1) Please have your child wear the motion sensor under their clothing.

2) The motion sensor should be fitted snugly on the waist with the sensor positioned in the front above the hip. The belt should feel comfortable but not floppy.

3) The motion sensor should be worn for 12 hours (8 AM – 8 PM) and should only be removed during that period if the child is going swimming, having a bath or a shower. It is not waterproof.

4) Please note the time when the motion sensor is first put on the child and when it is taken off daily on the log on the reverse side of this form as well as anything that affected your child's movement patterns on any given day.

5) The motion sensor is like a smart 'pedometer' but it is very valuable. Please have your child put on the motion sensor on Tuesday morning to take it into school and an Action Schools! BC researcher will collect them from the classroom.

Thank you very much for your help!

Monitor:_______	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday
Dates							
On Time AM							
Off Time PM							
Did weather change your routine?	No	No	No	No	No	No	No
	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did illness change your routine?	No	No	No	No	No	No	No
	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was motion sensor removed during wear time?	No	No	No	No	No	No	No
	Yes	Yes	Yes	Yes	Yes	Yes	Yes
If yes, what time?	___:____ to ___:____	___:____to ___:____	___:____ to ___:____	___:____ to ___:____	___:____ to ___:____	___:____ to ___:____	___:____ to ___:____
Why was the monitor removed?							
Any problems? Please explain.							

Appendix N Comparison of the physical activity levels of children with 3 or 4 days of valid accelerometry data

Previous research that measured physical activity using accelerometry found that children with fewer valid (i.e., 3 days of at least 10 wear hours) days had higher physical activity levels than children with a greater number of valid days (i.e., 4 days of at least 10 wear hours)[70]. To evaluate whether this was a concern in our cohort and determine whether the number of valid days should be included as a covariate in my analyses, I compared the wear time and physical activity levels of children in our cohort with 3 valid days to the wear time and physical activity levels of children with 4 valid days. I used an unpaired t-test for normally distributed variables and a Wilcoxon-Mann-Whitney test for skewed data. The level of significance was set *a priori* at $p<0.05$.

At baseline, 382 participants had valid accelerometry data (i.e., at least 10 hours/day on at least 3 days). This included 176 children (46%; 89 boys, 87 girls) with 3 valid days and 206 children (54%; 93 boys, 113 girls) with 4 valid days. The mean (standard deviation) or median (25^{th}, 75^{th} percentile) values for accelerometer wear time and physical activity variables are available in Table A- 1. There were no differences in any physical activity variable between 3 and 4 day accelerometry data files. Therefore, the number of valid days was not included in any of the analyses.

[70] Dencker M, Thorsson O, Karlsson MK, Linden C, Svensson J, Wollmer P, Andersen LB. Daily physical activity and its relation to aerobic fitness in children aged 8-11 years. Eur.J.Appl.Physiol. 2006 Mar:96(5):587-592

Table A- 1. Mean (SD) or median (p25, p75) physical activity levels among children with 3 or 4 valid days of physical activity data (measured via accelerometry).

	3 valid days (n=176)	4 valid days (n=206)	Mean (95% CI) or median difference
General physical activity			
Accelerometer wear time (hours/day)	13.1 (1.0)	13.1 (0.9)	0.03 (-0.16, 0.23)
Total physical activity (cpm)	484.6 (140.3)	468.2 (149.2)	16.4 (-12.9, 45.7)
MVPA (min/day)	127.6 (38.1)	121.9 (37.3)	5.7 (-1.8, 13.1)
Sedentary time (min/day)	537.1 (65.6)	543.8 (65.7)	-6.7 (-20, 6.5)
Light physical activity (min/day)	121.8 (23.6)	118.8 (20.3)	3.1 (-1.4, 7.5)
Moderate physical activity (min/day)	107.3 (29.2)	103.1 (28.6)	4.2 (-1.6, 10.0)
Vigorous physical activity (min/day)	17.5 (11.3, 27.0)	16.6 (10.0, 24.8)	0.9 [a]
MVPA accumulated in bouts			
0-5 min	105.7 (27.4)	101.7 (26.8)	4.0 (-1.4, 9.5)
5-10 min	10.3 (4.3, 16.5)	9.1 (4.9, 13.0)	1.2 [a]
10-20 min	3.8 (0.0, 9.7)	5.8 (0.0, 11.6)	-2.0 [a]
≥20 min	0.0 (0.0, 0.0)	0.0 (0.0, 5.2)	0.0 [a]

Difference calculated as 3 day – 4 day data. CI, confidence interval, cpm, accelerometer counts/minute.

[a] *confidence intervals not calculated for non-parametric comparisons*

Appendix O Additional data for chapter 6

Table A- 2. Unstandardized multivariable model coefficients (95% confidence interval) and adjusted r^2 for the hierarchical linear regression to determine the independent effect of bouted MVPA on small artery compliance.

	Constant (B_0)	BSA (B_1)	SBP (B_2)	BMI (B_3)	MVPA (B_4)	Bouted MVPA (B_5)	Model fit ($r^2_{adjusted}$)
Base model	1.9 (-3.1, 6.9) (p=0.45)	9.5 (5.9, 13.0) (p<0.001)	-0.07 (-0.11, -0.03) (p=0.002)	-0.05 (-0.25, 0.15) (p=0.62)	0.01 (0.0001, 0.02) (p=0.047)	----	0.371
Base model + MVPA (0-5 minute bouts)	2.3 (-2.9, 7.4) (p=0.39)	9.3 (5.8, 12.9) (p<0.001)	-0.07 (-0.11, -0.03) (p=0.001)	-0.05 (-0.25, 0.16) (p=0.65)	0.02 (-0.01, 0.04) (p=0.24)	-0.01 (-0.04, 0.02) (p=0.57)	0.373
Base model + MVPA (5-10 minute bouts)	2.0 (-3.1, 7.0) (p=0.44)	9.4 (5.8, 12.9) (p<0.001)	-0.07 (-0.11, -0.03) (p=0.002)	-0.05 (-0.25, 0.16) (p=0.66)	0.01 (-0.01, 0.02) (p=0.27)	0.01 (-0.05, 0.07) (p=0.72)	0.372
Base model + MVPA (10-20 minute bouts)	2.3 (-2.9, 7.4) (p=0.39)	9.4 (5.8, 12.9) (p<0.001)	-0.07 (-0.12, -0.03) (p=0.001)	-0.05 (-0.25, 0.15) (p=0.64)	0.01 (-0.003, 0.02) (p=0.15)	0.01 (-0.04, 0.07) (p=0.57)	0.373
Base model + MVPA (≥ 20 minute bouts)	1.9 (-3.2, 7.0) (p=0.46)	9.4 (5.9, 13.0) (p<0.001)	-0.07 (-0.11, -0.03) (p=0.002)	-0.05 (-0.25, 0.15) (p=0.62)	0.01 (0.0002, 0.02) (p=0.056)	-0.002 (-0.9, 0.9) (p=0.99)	0.371

The base model was: Small artery compliance = $B_0 + B_1BSA + B_2BMI + B_3SBP + B_4$ MPVA(total). The model used to test the independent contribution of bouted MVPA was: Small artery compliance = $B_0 + B_1BSA + B_2BMI + B_3SBP + B_4$ MPVA(total) + B_5[Bouted MVPA], where bouted MVPA was the volume of MVPA (minutes/day) accumulated in bouts of 0-5 minutes, 5-10 minutes, 10-20 minutes or ≥ 20 minutes. BSA, body surface area; BMI, body mass index; SBP, systolic blood pressure; MVPA, moderate to vigorous physical activity.

Appendix P   Sample size required to detect significant associations for chapter 6

Results for three physical activity variables approached significance ($0.05<p<0.1$) suggesting that the study may have been underpowered to detect these associations. I used the Stata command 'powerreg' to calculate the sample size required to achieve statistical significance (alpha=0.05, power=0.8) using the r^2 values observed in the current study (n=102).

Total physical activity (average counts/minute)

The r^2 of the base model (BSA, BMI and systolic blood pressure) was 0.345 and the r^2 of the full model (base model + total physical activity) was 0.367. To reach statistical significance the required sample size is n=228 participants.

Bouted MVPA (0-5 minute bouts, minutes/day)

The r^2 of the base model (BSA, BMI and systolic blood pressure) was 0.345 and the r^2 of the full model (base model + 0-5 minute bouts of MVPA) was 0.364. To reach statistical significance the required sample size is n=264 participants.

Bouted MVPA (5-10 minute bouts, minutes/day)

The r^2 of the base model (BSA, BMI and systolic blood pressure) was 0.345 and the r^2 of the full model (base model + 5-10 minute bouts of MVPA) was 0.364. To reach statistical significance the required sample size is n=264 participants.

Appendix Q Additional data for chapter 7

Table A- 3. Spearman rank correlation coefficients between cardiovascular fitness (number of laps) and physical activity variables.

	Boys (n=173)	**Girls (n=193)**	**Combined (n=366)**
MVPA (min/day)			
Total MVPA	0.19 (p=0.01)	0.15 (p=0.03)	0.20 (p<0.001)
Bouted MVPA (0-5 min)	0.12 (p=0.11)	0.15 (p=0.04)	0.15 (p=0.005)
Bouted MVPA (5-10 min)	0.14 (p=0.07)	0.06 (p=0.42)	0.13 (p=0.01)
Bouted MVPA (10-20 min)	0.25 (p=0.001)	0.13 (p=0.08)	0.21 (p<0.001)
Bouted MVPA (≥20 min)	0.29 (p<0.001)	0.07 (p=0.33)	p=0.24 (p<0.001)
Total physical activity (cpm)	0.26 (p<0.001)	0.18 (p=0.01)	0.25 (p<0.001)
Sedentary time (min/day)	-0.20 (p=0.008)	-0.11 (p=0.12)	-0.17 (p=0.001)
Light physical activity (min/day)	0.04 (p=0.61)	0.09 (p=0.22)	0.06 (p=0.29)
Moderate physical activity (min/day)	0.16 (p=0.04)	0.14 (p=0.06)	0.17 (p<0.001)
Vigorous physical activity (min/day)	0.25 (p<0.001)	0.17 (p=0.02)	0.24 (p<0.001)

MVPA, moderate to vigorous physical activity; cpm, accelerometer counts per minute.

Table A- 4. Unstandardized multivariable model coefficients (95% confidence interval) and adjusted r^2 for the hierarchical linear regression to determine the independent effect of bouted MVPA on cardiovascular fitness (controlled for age, BMI, sex, and total MVPA)

	Constant (B_0)	Age (B_1)	BMI (B_2)	Sex (B_3)	MVPA (total) (B_4)	MVPA (bouted) (B_5)	Model fit ($r^2_{adjusted}$)
Base model	-1.7 (-28.9, 25.4) (p=0.90)	4.2 (1.7, 6.7) (p=0.001)	-1.3 (-1.7, -0.89) (p<0.001)	-4.3 (-7.1, -1.5) (p=0.002)	0.09 (0.05, 0.13) (p<0.001)	----	0.169
Base model + MVPA (0-5 min bouts)	0.64 (-26.7, 28.0) (p=0.96)	4.1 (1.6, 6.6) (p=0.001)	-1.3 (-1.7, 0.9) (p<0.001)	-3.8 (-6.6, -0.9) (p=0.009)	0.14 (0.06, 0.22) (p=0.001)	-0.08 (-0.19, 0.03) (p=0.17)	0.171
Base model + MVPA (5-10 min bouts)	-2.2 (-29.6, 25.2) (p=0.87)	4.2 (1.8, 6.7) (p=0.001)	-1.3 (-1.7, -0.89) (p<0.001)	-4.3 (-7.1, -1.6) (p=0.002)	0.10 (0.04, 0.15) (p<0.001)	-0.03 (-0.29, 0.22) (p=0.79)	0.167
Base model + MVPA (10-20 min bouts)	0.74 (-26.5, 28.0) (p=0.96)	4.0 (1.6, 6.5) (p=0.001)	-1.3 (-1.7, 0.87) (p<0.001)	-3.8 (-6.6, -1.0) (p=0.008)	0.07 (0.03, 0.12) (p=0.001)	0.17 (-0.04, 0.37) (p=0.12)	0.172
Base model + MVPA (≥ 20 min bouts)	-1.6 (-28.7, 25.6) (p=0.91)	4.2 (1.8, 6.7) (p=0.001)	-1.3 (-1.7, 0.87) (p<0.001)	-3.9 (-6.7, -1.1) (p=0.007)	0.08 (0.04, 0.12) (p<0.001)	0.13 (-0.08, 0.34) (p=0.21)	0.170

The base model was: Cardiovascular fitness = $B_0 + B_1Age + B_2BMI + B_3[Sex] + B_4\ MVPA(total)$. The model used to test the independent contribution of bouted MVPA was: Cardiovascular fitness = $B_0 + B_1Age + B_2BMI + B_3[Sex] + B_4\ MVPA(total) + B_5[Bouted\ MVPA]$, where age, BMI, total MVPA, and bouted MVPA were continuous variables; sex was 0 (boys) or 1 (girls); Bouted MVPA was the volume of MVPA (minutes/day) accumulated in bouts of 0-5 minutes, 5-10 minutes, 10-20 minutes or ≥ 20 minutes). BMI, body mass index; MVPA, moderate to vigorous physical activity.

Appendix R Additional data for chapter 8

Teacher compliance to logbooks

Teachers at intervention and control schools kept weekly physical activity logs (Appendix L). In year one there were 110 teachers; 79% returned at least one physical activity log (81% of usual practice teachers, 77% of intervention teachers). In year two there were 120 teachers; 91% returned at least one physical activity log (92% of usual practice teachers, 90% of intervention teachers). The group of intervention teachers during year two includes 15 teachers at one school that crossed over from usual practice to intervention after the first year. On average, teachers returned 15 weekly logs (range 0 – 30; 58%) during year one and 21 weekly logs (range 0 – 43; 66%) during year two.

Differences in reported physical activity between year one and year two

To evaluate whether the volume of physical activity reported by intervention and control teachers differed from year one to year two, separate linear regression models were fit for teachers at intervention and control schools. The model was: PA reported = $B_0 + B_1$[Year], where year was either year 1 or year 2. Robust standard errors were calculated to account for clustering of teachers within schools. There was no difference in the volume of physical activity reported by either intervention ($p=0.42$) or control teachers ($p=0.35$) from year one to year two (Figure A- 1).

Differences in reported physical activity between intervention and control teachers

To evaluate whether the volume of physical activity reported by teachers at intervention schools differed from the volume of activity reported by teachers at control schools, separate linear regression models were fit for year one and year two. The model was: PA reported = $B_0 + B_1$[Group], where group was either 0 (control) or 1 (intervention). Robust standard errors were calculated to account for clustering of teachers within schools. Figure A- 1 illustrates the average volume of physical activity (minutes/day) that teachers reported delivering across each year of the intervention. After adjusting for clustering within schools, intervention teachers reported delivering more physical activity than teachers at usual practice schools during year one (+7.3 min/day, 95% CI 2.3, 12.2). The difference in reported physical activity during year two between teachers at intervention and control schools was significant in the unclustered analysis ($p=0.006$); however, this became non-significant after adjusting for clustering (+4.3 min/day, 95% CI -0.1, 8.6; $p=0.053$).

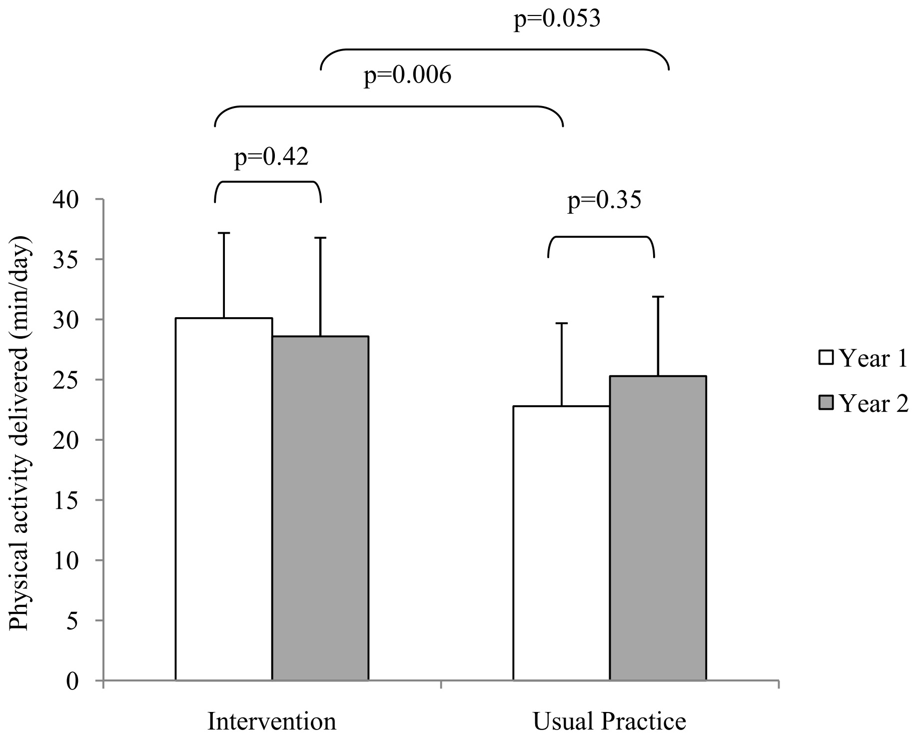


Figure A- 1. Comparison of the volume of physical activity reported by teachers at intervention and control schools across year one and year two of the study.
The difference (+7.3 minutes/day during year one; +4.3 minutes/day during year two) between intervention and control schools was adjusted for clustering of teachers within schools.