Advancing active living research in children: addressing active living measurement and evaluation while investigating the influence of diverse environmental exposures on physical activity and sedentary behaviour

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General Abstract

The increasing prevalence of high sedentary behaviour and low physical activity has paved the way for upstream population health policy interventions that focus on modifying built environment to facilitate a population-wide decrease in sedentary behaviour and increase in physical activity. As a result of this, an inter-disciplinary field of study is gaining prominence to understand the influence of built environment on sedentary behaviour and physical activity — Active living research. Even though there is a growing body of evidence that indicates the influence of built environment on physical activity; active living research is still considered an emerging field due to critical gaps in its conceptualization and implementation.

The purpose of this three study dissertation is to address some of these key gaps and lay the foundation for more rigorous active living research. With this dissertation being a quantitative component of an active living research initiative in Saskatoon, Saskatchewan, Canada, called Smart Cities Healthy Kids (www.smartcitieshealthykids.com), the primary gap addressed is the dearth of active living research among children. Moreover, the three independent studies that compose this dissertation build upon each other's evidence by developing evidence-based methods to address measurement and evaluation of active living evidence.

Study One

Although, physical activity and sedentary behaviour are increasingly measured with objective devices such as accelerometers, there still exists a possibility of inducing measurement bias due to the disproportionate amount of time these devices are worn (wear-time) by participants. This study specifically explores wear-time variation, both within and between

participants, and thereafter, examines the influence of systematic wear-time variation on the accumulation of physical activity and sedentary behaviour.

In doing so, this study proposes a data standardization methodology to minimize measurement bias due accelerometer wear-time variation.

Study Two

Increasingly, research indicates that **s**edentary behaviour is independently associated with a wide range of health outcomes; however, thus far, active living research has predominantly focused on only physical activity. Moreover, even though physical activity and sedentary behaviour are two distinct behaviours, their inter-dependent relationship needs to be studied in the same environment.

This study examines the influence of urban design, neighbourhood built and social environment, and household and individual factors (i.e., diverse environmental exposures) on objectively measured physical activity and sedentary behaviour in children aged 10-14 years. In doing this, this study combines its evidence with the World Health Organization physical activity guidelines to develop age-specific activity profiles. Generation of activity profiles enables a holistic picture of the influence of environment on the interplay between two distinct, yet related behaviours ─ physical activity and sedentary behaviour. The ultimate purpose of these activity profiles is to advance a consistent method to evaluate and compare active living evidence.

Study Three

To date, active living research has predominantly been conducted without taking variation in weather into account. Moreover, emerging evidence indicates that studying the influence of environment on physical activity and sedentary behaviour without considering weather variation, especially in the Canadian context, could generate results of low validity. Thus, this study aims to understand the influence of variation in weather on objectively measured physical activity and sedentary behaviour in children aged 10-14 years. More importantly, as weather is non-modifiable, the greater focus of this study is to understand how diverse environmental exposures, including urban design, moderate the influence of weather on physical activity and sedentary behaviour during the transition from spring to summer in Saskatoon, Saskatchewan, Canada.

General Conclusions

The three studies in the dissertation sequentially address key gaps in active living research. Study one proposes a methodology to minimize measurement bias and improve the analysis rigour of objective physical activity and sedentary behaviour data. Study two, taking diverse environmental exposures into consideration, investigates the inter-dependent nature of physical activity and sedentary behaviour, and proposes age-specific activity profiles that can be used to evaluate and compare active living evidence. Finally, study three reiterates the need to include weather variation in active living research by examining how environmental exposures moderate the influence of weather variation on physical activity and sedentary behaviour.

The factor that encompasses all three studies is the age group of the participants ─ 10 to 14 years. This age group reflects the transition from preadolescence to adolescence. Evidence indicates that physical activity and sedentary behaviour levels during adolescence track into adulthood, hence this dissertation aims to generate evidence that would advance active living interventions in this vital demographic. Specific to Saskatoon, preliminary evidence of this dissertation has aided the conceptualization of a Canadian Institutes of Health Research funded longitudinal study that will examine the influence of built environment on physical activity and sedentary behaviour in children aged 10-14 years in all four seasons of Saskatoon**.** Ultimately, in-depth evidence of this dissertation will also inform the implementation and analysis of the longitudinal study.

Abstract ─ Study One

Objective: Accelerometers are predominantly used to objectively measure the entire range of activity intensities ─ moderate to vigorous physical activity, light physical activity and sedentary behaviour. However, studies consistently report results without accounting for systematic accelerometer wear-time variation (within and between participants), thereby jeopardizing the validity of these results. This study describes the development of a standardization methodology to understand and minimize measurement bias due to wear-time variation.

Methods: Accelerometry is generally conducted over seven consecutive days, with participants' data being commonly considered 'valid' only if wear-time is at least 10 hours/day. However, even within 'valid' data, there could be systematic wear-time variation. To explore this variation, accelerometer data of Smart Cities, Healthy Kids study (www.smartcitieshealthykids.com) were analyzed descriptively and with repeated measures multivariate analysis of variance. Subsequently, a standardization method was developed, where case-specific observed wear-time was controlled to an analyst specified time period. Next, case-specific accelerometer data were interpolated to this controlled wear-time to produce standardized variables. To understand discrepancies owing to wear-time variation, all analyses were conducted pre- and post-standardization.

Results: Descriptive analyses revealed systematic wear-time variation, both between and within participants. Pre- and post-standardized descriptive analyses of moderate to vigorous physical activity, light physical activity and sedentary behaviour revealed a persistent and often significant trend of wear-time's influence on activity. Sedentary behaviour was consistently higher on weekdays before standardization; however, this trend was reversed post-standardization. Even though moderate to vigorous physical activity was significantly higher on weekdays both pre- and post-standardization, the magnitude of this difference decreased post-standardization. Multivariable analyses with standardized moderate to vigorous physical activity, light physical activity and sedentary behaviour as outcome variables yielded more stable results with narrower confidence intervals and smaller standard errors.

Conclusions: Standardization of accelerometer data is effective in not only minimizing measurement bias due to systematic wear-time variation, but also for providing a uniform platform to compare results within and between populations and studies.

Abstract ─ Study Two

Objective: Although physical activity and sedentary behaviour are separately quantifiable behaviours which are independently associated with a wide range of health outcomes, including obesity, there is a need to study them together due to their inter-dependent nature. This study aims to advance active living research by examining the influence of diverse environmental exposures, including urban design, on objectively measured physical activity and sedentary behaviour in children aged 10-14 years. In doing this, this study proposes a consistent method to evaluate and compare the impact of active living interventions on physical activity and sedentary behaviour i.e., active living evidence.

Methods: As part of the Smart Cities, Healthy Kids study (www.smartcitieshealthykids.com), Saskatoon's neighbourhood built environment was assessed by two replicable observation tools, in 2009: neighbourhood active living potential and Irvine-Minnesota Inventory. Neighbourhood socioeconomic variables were derived from 2006 Statistics Canada Census and 2010 G5 Census projections. In 2010, a questionnaire was administered to children to collect individual and household data, followed by accelerometry. Actical accelerometers were used to collect physical activity and sedentary behaviour data over seven consecutive days from 455 10-14 year old children. During accelerometer deployment, children's height and weight were measured with a portable stadiometer and weigh scale, respectively, to determine weight status using Centers for Disease Control and Prevention growth charts. Using accelerometer derived sedentary behaviour data and growth charts based weight status data, sensitivity analyses were conducted to generate daily thresholds for sedentary behaviour similar to age-specific physical activity thresholds that determine World Health Organization physical activity guidelines. Using the daily thresholds as cut-points, these activity profiles were defined: ***active/inactive*** and ***sedentary/non-sedentary***. Thereafter, with these activity profiles as outcome variables, and with neighbourhood, household and individual factors as predictors, multilevel logistic regression models were developed to understand the influence of urban design and environment on physical activity and sedentary behaviour.

Results: A complex set of factors including denser built environment, positive peer relationships and consistent parental support increased the likelihood of children being profiled as ***active***. The presence of these factors, however, did not decrease the likelihood of children being profiled as ***sedentary***.

Conclusions: Generation of activity profiles enabled a holistic picture of the influence of urban design and environment on the interplay between two distinct, yet related behaviours ─ physical

activity and sedentary behaviour. The ultimate purpose of these activity profiles is to advance a consistent method to evaluate and compare active living evidence.

Abstract ─ Study Three

Objective: To create active urban communities, emerging evidence suggests the need to study how diverse environmental exposures, including urban design, moderate the influence of variation in weather on physical activity and sedentary behaviour. Answering this call, this study has been conducted to understand how objectively measured physical activity and sedentary behaviour in children aged 10-14 years varies in an urban environment during the transition from spring to summer.

Methods: As part of Smart Cities, Healthy Kids study (www.smartcitieshealthykids.com), based on urban design, the city of Saskatoon was classified into grid-pattern, fractured grid-pattern and curvilinear neighbourhoods. Actical accelerometers were deployed between April and June 2010 (spring-summer) to collect activity (physical activity and sedentary behaviour) data over seven consecutive days from 455 10-14 year old children. Comprehensive weather data were obtained from Environment Canada. As evidence suggests the need to consider weather as a "whole" rather than controlling for individual weather variables in analyses, after extensive weather data exploration, localized weather patterns were simulated and integrated with cross-sectional accelerometry. After analyzing the urban design's moderation of localized weather's influence on physical activity and sedentary behaviour, multilevel multivariable analyses were conducted to understand the influence of diverse environmental exposures, including urban design and localized weather, on physical activity and sedentary behaviour.

Results: Urban design and environment played a significant role in influencing physical activity and sedentary behaviour even after taking a range of diverse environmental exposures, including localized weather into account.

Conclusions: Urban design can moderate the influence of variation in weather on physical activity and sedentary behaviour in children even during a single seasonal transition. However, before capturing this moderating effect, there is a need to incorporate weather as a "whole" by adopting novel methods to simulate and integrate localized weather with cross-sectional accelerometry. Ultimately, to confirm urban design's role in children's active living, there is a need to conduct longitudinal active living research to understand how urban design moderates the influence of seasonality throughout the year. Thus, this study will serve as a pilot to a Canadian Institutes of Health Research funded longitudinal investigation, where children's activity will be measured in all four seasons of Saskatoon.

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T.R.K

Dedication

I dedicate this work to my family, who not only endure my obsession with my work, but also support me in every possible way. They are the reason I strive and not give up. They are my strength, motivation and hope.

T.R.K

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List of Abbreviations

ALR	Active Living Research
ANOVA	Analysis of Variance
BMI	Body Mass Index
°C	Degree Celsius
CDC	Centers for Disease Control and Prevention
CIHR	Canadian Institutes of Health Research
CHMS	Canadian Health Measures Survey
GPS	Global Positioning System
HLM	Hierarchical Linear and Nonlinear Modeling software
kcal	Kilocalorie
kg	Kilogram
km/h	Kilometre per hour
LPA	Light Physical Activity
MANOVA	Multivariate Analysis of Variance
min	Minute
mm	millimetre
MVPA	Moderate to Vigorous Physical Activity
METS	Metabolic Equivalents
SASK	Seasonality and Active Saskatoon Kids
SBRN	Sedentary Behaviour Research Network
SCHK	Smart Cities Healthy Kids
SD	Standard Deviation

SED Sedentary Behaviour

SPSS Statistical Package for the Social Sciences

WHO World Health Organization

Chapter 1: Introduction and review of literature

1.1 Introduction

Various stakeholders in health, ranging from health care providers to researchers, agree that the increasing prevalence of obesity is troubling and needs to be stemmed.[1-8] The big question is how? As decades of interventions on individuals have not yielded expected results, a growing body of evidence suggests that focusing on contextual issues, such as environmental factors, may provide the answers to curb this pandemic.[9-17] To prevent obesity, a balance between energy consumption and energy expenditure is desired. However, this balance is proving increasingly difficult due to accumulating adverse environmental influences.

In addition to the increased consumption of nutrient-poor, energy-dense food products,[18] a major contributing factor to the growing prevalence of obesity has been the rapid mechanization in the 20th century resulting in decreasing accumulation of daily physical activity (PA) in populations.[19] For the purpose of this dissertation, PA is defined as any body movement produced by skeletal muscles that requires energy expenditure above 1.5 metabolic equivalents (METS).[20] Moreover, technologically enhanced communication practices and connectivity in the early 21st century have further contributed to this trend of decreasing PA. Thus, a focus on increasing PA in populations is not only timely, but also critical due to PA's established association with a wide range of chronic diseases, including obesity.[21,22]

One solution to facilitate PA in populations is to modify the environment to reengineer the way people move in their daily lives by changing the environment they are exposed to everyday.

In order to achieve this, it is important to study how a diverse range of environmental exposures (neighbourhoods, households, offices, schools, etc.) that overlap each other impact movement.

In answering this need, an inter-disciplinary field of study is gaining prominence to understand the influence of varied environmental exposures on PA ─ active living research (ALR). ALR's focus on broader environmental exposures to enable behavioural modification at the population level aligns with the ecological model of interventions where the emphasis is on multiple levels of exposures. Sallis et al[23] explore this perspective in their work titled "An Ecological Approach to Creating Active Living Communities", where the proposed model identifies potential environmental and policy influences on four domains of active living: recreation, transport, occupation, and household. In essence, to facilitate population-wide change in PA, Sallis et al[23] propose the application of ecological models to implement active living interventions targeting multiple levels of exposures operating through the four domains of active living.

The success of such an approach depends on the combination of concepts and methods from multiple disciplines.[23] This dissertation draws upon concepts and methods from varied disciplines such as epidemiology, kinesiology and health geography, hence the ecological model[23] provides an optimum medium to visualize the influence of varied environmental exposures at multiple levels on PA.

The ultimate aim of ALR is to generate evidence that would inform policy that enables the creation of active communities. Thus far, researchers conducting ALR have predominantly studied the influence of urban design and built environment on PA. Though there is a growing body of evidence[24-46] that details the many influences of urban design and environment on PA, there still are important knowledge gaps that need to be addressed to move ALR forward.

For instance, participants in most studies investigating the influence of urban design and environment on PA have been adults to date, and their behaviour may not necessarily be generalizable to children.[47] With the dearth of ALR in children as the primary premise, this dissertation will specifically focus on the age group of 10-14 years. This age cohort was chosen based on the theory that children between 10 and 14 years are at a crucial stage in their life course (transition from preadolescence to adolescence), hence behaviours adopted at this stage could solidify into adult life.[48] This theory is supported by the evidence that high levels of PA between the ages of 9 and 18 years is predictive of high levels of PA in adults.[49] More importantly, without involving children in ALR, crucial time is lost in terms of potential early interventions that could facilitate behaviour modification and pre-empt a wide range of chronic diseases, including obesity.

The dissertation is a part of an ALR initiative among children in Saskatoon, Saskatchewan, Canada, called Smart Cities Healthy Kids (SCHK). It consists of three independent, yet inter-connected studies that not only highlight and address key gaps in ALR, but also provide future directions. In pursuit of advancing ALR, the preliminary cross-sectional evidence generated by this dissertation has already aided the conceptualizing of a Canadian Institutes of Health Research (CIHR) funded longitudinal study that will examine the influence of urban design and environment on active living in children in all four seasons of Saskatoon ─ Seasonality and Active Saskatoon Kids (SASK).

1.2 Literature Review

This section describes the current state of evidence and provides a broader rationale for the dissertation. The dissertation is rooted in the rising prevalence of childhood obesity in Canada[7,8] and elsewhere,[18] and the fact that childhood obesity plays a part in triggering pathological processes which are associated with long term chronic disease morbidity.[50-53] Moreover, this research is driven by the established association of PA with a wide range of chronic diseases, including obesity,[21,22] and, the evidence that high levels of PA between the ages of 9 and 18 years is predictive of high levels of PA in adults.[49]

The decreasing accumulation of PA in populations has played a significant role in the alarming increase in obesity prevelance[7-9]. This phenomenon has compelled researchers to look for answers in the very environment we live in, and there is a large body of research examining the association of PA with human-modified places such as homes, schools, workplaces, parks, industrial areas, farms, roads and highways.[24-35] The crux of this new focus on urban design and environment is to test if polices that shape built environment can be used to reduce automobile travel and thereby increase active living.

1.2.1 ALR in Adults

To date, ALR has predominantly been conducted in adults and in general, evidence indicates that mixed land use, high density urban spaces with high safety, and improved access to PA for transportation and recreation, are positively associated with walking in adults.[25-27,34,35] Within the types of walking, distance to destinations appears to be more important for walking as a mode of transportation (active transport), while design appears to be more important for recreational walking.[26,33,34] Overall, according to a systematic review exploring the causality of built environment's influence on PA in adults,[54] built environment appears more likely to be associated with active transport than recreational walking.

Active transport on its own is being associated with increased accumulation of total daily PA[55] and as well as moderating weight gain due to sedentary behaviour (SED) such as television viewing.[56] However, a systematic review[57] exploring the association between active transport, physical activity and body weight in adults, revealed mixed results due to study heterogeneity. Similarly, in terms of associations between PA and other specific features of built environment, reviews of epidemiologic literature show mixed results with a call for more scientifically rigorous and generalizable studies with robust study designs.[37-39,54,58,59,60]

Nevertheless, over the past decade, researchers have begun placing additional emphasis on improved measures of both built environment and PA, and to ground research in theory and/or interventions.[23] Across the western world, ALR's incorporation of objective measures of PA has generated consistent evidence. In Canada, using objectively measured PA, researchers at Healthy Active Living and Obesity Research Group[36] found that adult PA accumulation differs between neighbourhoods of varying socioeconomic and recreation environments, with individuals living in high socioeconomic environment accumulating higher PA.

In United States, across three metropolitan areas (Seattle, Baltimore and Washington D.C), a latent profile analysis examining neighbourhood environment's influence on objectively measured PA[35] revealed that adults residing in high-walkable, recreationally dense neighbourhoods accumulated significantly higher PA. In Europe, a Swedish study[61] utilizing mixed-effects multilevel models, depicted that adults living in highly walkable neighborhoods were not only more likely to walk for transport and leisure, but were also more likely to accumulate higher PA.

1.2.2 ALR in Children and Adolescents

Indicative of previous trends in ALR, the evidence presented thus far in this literature review is specific to adults. Enumeration of this adult-specific evidence is necessary to trace the roots of ALR and set the stage for exploring literature more specific to this dissertation i.e., ALR in children and adolescents. Extrapolating from the 1989 United Nations 'Convention on the Rights of the Child',[62] for the purposes of this dissertation, children and adolescents have been defined as follows: children: 3-12 years and adolescents: 13-18 years.

Distinguishing between adult-centric and child and adolescent-centric ALR not only highlights age-specific evidence that is relevant to this dissertation, but also emphasizes the probability that adults' PA behaviour response to environmental influence may not necessarily be generalizable to children and adolescents.[47]

Child and adolescent-specific ALR evidence gathered before the previous decade indicates some consistent findings. Safety (especially for girls), perception of recreational environment, and opportunity for active transportation have been positively associated with PA. The most consistent finding associated with hindrance to PA was perceived lack of safety (from crime and/or traffic).[40-46,63-65] However, within the past decade, the publication of a range of systematic reviews of child and adolescent-specific ALR has revealed a complex and a much more nuanced influence of varied environmental exposures on PA in children and adolescents.[66-70]

Utilizing the ALR literature database, a systematic review that examined the influence of neighbourhood environment on children and adolescents[66] revealed that, in children, walkability and access/proximity to recreation facilities were positively associated with PA accumulation. Whereas, in adolescents, land-use mix and residential density were positively associated with PA.

A further exploration of literature beyond the influence of urban design on PA revealed two reviews[67,68] that highlighted the role of multilevel (home, school and individual level) environmental determinants on PA in children and adolescents. Van Der Horst et al[67] showed that, for both children and adolescents, self-efficacy and parental support were positively associated with PA. Specifically for adolescents, gender (male), parental education, goal orientation/motivation, physical education/school sports, and peer support were identified as additional factors that were positively associated with PA.

Similarly, Ferreira et al[68] in their semi-quantitative review found that both home and school environments could play a role in children's and adolescents' PA. For children, PA was positively associated with father's PA, time spent outdoors and school PA-related policies. For adolescents, support from significant others, mother's education level, family income, and non-vocational school attendance was positively associated with PA. Moreover, reiterating earlier evidence generated in child and youth-centric ALR, low crime incidence was a neighbourhood environment characteristic that was positively associated with higher PA in adolescents.

In combination, both reviews[67,68] portrayed evidence from more than 150 studies that explored environmental correlates of PA in children and adolescents. These reviews consistently depicted two environmental exposures directly relevant to ALR: home and schools. More specifically, even though these reviews show a multitude of significant environmental variables highlighting the heterogeneity of ALR methodology, they bring to the forefront the importance of parents' role in children's and adolescents' PA. Reiterating these findings, a systematic review of cross-sectional and longitudinal studies demonstrated the positive role of parental influence on PA in children and adolescents.[69]

However, the review determined that the results were mixed in terms of parental influence on adolescent PA. Ultimately, as the aim of active living interventions in early years is to facilitate positive behaviour changes that would improve PA accumulation and curb PA decline during the transition to adulthood, it is essential to uncover what environmental factors influence a change in PA in children and adolescents. A systematic review of prospective quantitative studies[70] investigating change in PA in children and adolescents aged 4–18 years showed that among 10–13 year olds, higher levels of previous PA and self-efficacy resulted in smaller declines in PA. Among 14–18 year olds, apart from self-efficacy, higher perceived behavioral support for PA were associated with smaller declines in PA.

In addition to the evidence outlined above, ALR[71,72] focusing on active transport to school indicates that child and adolescent active travel is positively associated with social interactions, facilities to assist active travel, urban design, shorter distance and safety.[71] Moreover, evidence also suggests that active transport in children and adolescents increases their overall PA and their likelihood to meet PA guidelines.[72]

Two systematic review of reviews[73,74]exploring the environmental correlates of PA in children and adolescents reiterate the evidence highlighted by the systematic reviews above[66-72] and bring to light several issues of relevance to child and adolescent-centric ALR, and in turn, to this dissertation itself. First, the subtle differences in the environmental influences on PA between children and adolescents lend credence to the theory mentioned in Section 1.1 ─ the transition from preadolescence to adolescence is a crucial stage in life course, where key environmental factors (for example, parental support and school environment) could be modified to facilitate an increase in long term PA.

Second, the reviews by Van Der Horst et al[67] and Ferreira et al[68] introduce school environment/policies as important environmental influences on child and adolescent PA. With children spending a considerable amount of their time during weekdays in schools, based on the Ecological Approach to Creating Active Living Communities,[23] schools could be considered one of the key domains to implement active living interventions.

Even though this dissertation is part of an ALR whose main focus is urban design and neighbourhood built environment, where schools are conceptually visualized as part of different neighbourhoods with distinct urban design, hence it was important to reiterate the role of schools as one of the important mediums for implementing active living interventions.

Finally, similar to the reviews conducted on ALR literature specific to adults, systematic reviews [66-70] on child and adolescent-specific ALR point towards more prospective studies using objective measures of PA and its potential environmental determinants. Moreover, although ALR so far has provided important initial direction, complex contextual mechanisms that influence PA still need to be unpacked, especially among children in transition from preadolescence to adolescence.

The limitation in ALR so far has been in the lack of standardized methods to measure PA and the use of non-generalizable methods to measure built environment. With respect to objective measurement of PA, accelerometers are increasingly being used in population studies.[36,75-78] The popularity of accelerometers is based on their documented superiority over self-reported measures.[79,80]

A growing reliance on accelerometers to study patterns of PA within and between populations makes the measurement and analysis protocol of accelerometer measures a key methodological issue. Thus, considerable research has been conducted to advance methodological expertise in accelerometry encompassing a wide range of categories including, assessment of reliability and validity of accelerometers, development of calibration protocols, and creation of data reduction methods.[81-86]

However, one aspect that has been consistently ignored in accelerometer-based PA measurement is the impact of systematic accelerometer wear-time variation on final estimates of PA. Typically, participants in ALR are asked to wear accelerometers for seven consecutive days, and there is a chance for systematic variation in daily wear-time, both within (on different days of accelerometer use) and between participants. The systemic variation occurs because participants often wear or remove accelerometers at their discretion, despite the instructions advising participants to wear the accelerometers from the time they wake up in the morning until the time they go to bed at night.

Therefore, in large population health studies, as variation in wear-time increases, the chance of measurement bias also increases because wear-time is directly related to the quantity of measured PA. To date, apart from exploring wear-time variation with inconclusive results[87-89] or statistically controlling for wear-time in multivariable analyses by including it as an independent variable,[90] most studies have not taken wear-time discrepancies and their impact on PA into account before performing final analyses.

1.2.3 Emergence of Sedentary Behaviour in Child and Adolescent-Centric ALR

However, despite these challenges, accelerometers provide the objective means to not only measure PA, but also segregate PA from SED. For the purpose of this dissertation, SED is defined as the lack of body movement during waking time that keeps energy expenditure below 1.5 METS.[91,92]

The distinction of PA from SED is critical due to the emergence of SED as an independent factor that influences a wide range of health outcomes in children, including obesity.[93] Moreover, with evidence now emerging that SED can track from childhood through adolescence into adulthood,[94] it is imperative to focus on curbing SED during the early years.

Researchers have now begun focusing exclusively on SED among children,[93-97]with some specifically investigating the influence of environmental exposures on children's SED.[98-104] In terms of capturing environmental exposures at multiple levels, almost identical to the ecological model proposed by Sallis et al,[23] an ecological model for SED proposed by Owen et al[105] again identifies four domains for intervention: leisure time, transport, occupation, and household. The only domain that differs from the PA-specific model is leisure time which replaces recreation. While both models[23,105] have primarily been proposed for adults, conceptually, they can be adopted for children and adolescents with very minor adaptations, such as replacing the occupation domain with schools. Similar to PA, conceptualizing an ecological model for SED is not only important to visualize the complexity of environmental influences, but also to comprehend the evidence accumulated thus far on the environmental influences on SED in children and adolescents.

Even though evidence accumulated to date on the environmental influences on SED in children and adolescents is limited, initial findings based on two systematic reviews[67,106] suggest a stronger role of home environment, with parental support and higher socioeconomic status being associated with lower SED. In terms of neighbourhood environment, higher perceived safety has been associated with lower SED.[106] In specifically exploring home physical environment's influence on SED, another systematic review[107] found that limiting television viewing, lower number of televisions per home, and absence of televisions in bedrooms were associated with lower SED in children, especially among girls.

Few studies[108] have looked at the relationship between active transport to school and leisure-related destinations with SED, and the results thus far are inconclusive. Likewise, although perceived safety has consistently been associated with lower SED,[107] there is a dearth of evidence in terms of urban design and built environment's relationship with SED in children and adolescents. Another limitation has been a pervasive inconsistency in measures used in capturing SED, ranging from overall screen time to television viewing to self-reported measures of overall SED.

Another evolving concept is the interplay between PA and SED, and how these two behaviours interact with each other within the wider context of varied environmental exposures. A recent meta-analysis by Pearson et al[109] explored the relationship between PA and SED in children and adolescents and concluded that even though SED is inversely associated with PA, these behaviours should not be considered as functional opposites. Thus, in developing active living interventions, it is imperative to understand the complex interplay of PA and SED in relationship with their shared environmental determinants, especially in children and adolescents, as both these behaviours could track into adulthood.[49,94]

In terms of environmental determinants of PA and SED in children and adolescents, it is apparent that there are some consistent overlaps. Home environment, especially higher socioeconomic status and positive parental support appear to be associated with higher levels of PA[66-70] and lower levels of SED.[67,106,107] Specific to urban design and built environment, perception of safety stands out as an important determinant for both PA[66] and SED.[106] However, based on the review of current literature, it is apparent that there is a lack of evidence on SED's association with urban design, schools and active transport. Therefore, it is vital that these gaps in knowledge in ALR are addressed.

First, in terms of untangling the relationship between environment and SED, there is a need to study the combined influence of diverse environmental exposures (neighbourhood built and social environment, and household and individual factors) on SED. Second, even though screen time is considered a good indicator of SED, with exclusive SED guidelines being developed to limit screen time in children,[110,111] it is important to capture the entire range of SED using objective measures. Third, although PA and SED are separately quantifiable behaviours which are being independently associated with health outcomes,[21,22,93] it is imperative to study them together due to their inter-dependent nature. Finally, with the gaining momentum of ALR, there is a need to develop a consistent and generalizable method to evaluate and compare the impact of active living interventions on both PA and SED i.e., active living evidence.

In terms of generalizable methods, the measurement of built environment is another important aspect of ALR. Systematic reviews, both in adults[54,57,60,37-39] and children and adolescents[66-70] indicate heterogeneity in study designs and built environment measurement methods, resulting in mixed results. However, irrespective of these mixed results, evidence shows that across these age groups, some factors of built environment have had a consistent influence. For example, active transport has been influenced by urban design,[25-27,34-36,71,72] and built environment factors such as recreationally dense, high socioeconomic neighbourhoods were positively associated with PA.[35,36]

Nevertheless, there are some variations of influence. For instance, areas with high density and traffic, even though positively associated with PA in adults, [25-27,34,35] negatively influence children's PA.[66] However, the negative influence of urban density in children appears to taper off in adolescents, suggesting changes in perception of safety from crime and traffic with advancing age.[66] Perception of safety, although an important determinant of PA in adults, [25-27,34,35] appears to be a stronger determinant of both PA[40-46,73-75] and SED[106] in children and adolescents. This consistent finding is indicative of parents' influence on children's behaviour,[69] where parental perception of built environment features has a significant impact on children's PA.[112]

Conceptually, these findings are suggestive of the mutual relevance of established built environment factors in influencing behaviour in both adults and children. This slowly emerging consensus of significant built environment factors could be attributed to the increasingly generalizable tools of measuring built environment that have evolved over the past decade.[113] Nevertheless, as Sallis et al[113] conclude in their state of the science article 'measuring built environment for physical activity', further development of built environment measurement tools is needed to not only improve the quality of measures, but also to tailor these tools to different population age groups.

With respect to studying environmental associations with PA and SED, one concern that is frequently raised (particularly by lay audiences) is that variation in weather is often unaccounted for. Studies are now investigating this association both in adults and children and adolescents. In studies that have been conducted in temperate and continental climatic zones (Köppen-Geiger climate classification),[114] a fairly stable, and expected observation has been the higher levels of PA in warmer months for both adults and children and adolescents.[115-125] However, more in-depth and conditional questions are yet to be answered.

As highlighted in a systematic review by Tucker and Gilliland,[126] built environment studies that do not take weather variation into account exclude a vital determinant of PA and SED. This is especially true in Canada, where the majority of the population experiences a wide variation in seasonal temperatures and weather conditions.[114,127,128] Within Canada, the Prairie Provinces like Saskatchewan are known for extreme variations in weather.[127,128] Merchant et al[124] studied the variation of weather and its impact on leisure time PA among Canadian adults, and found the relationship between seasonality and PA was stronger in Saskatchewan than other Canadian provinces.

Specific to adolescents, Bélanger et al[129] conducted a longitudinal study of seasonal variation in PA among Canadian adolescents over a five-year period. The results depicted that temperature and rainfall had the most significant impact on PA. In a Norwegian study,[120] PA was measured objectively in spring, fall, and winter of the same calendar year in children aged 9 years and adolescents aged 15 years. Results showed a strong seasonal association with PA in 9 year old children, but not in 15 year old adolescents. Similar findings were observed in the European

Youth Heart Study,[121] where significant seasonal variation in PA was observed in 8-10 year old children, but not in 14-16 year old adolescents.

Despite the increasing focus on the influence of weather, there is still a paucity of studies regarding weather variation in ALR. First, most of these studies have predominantly focused exclusively on PA and have not taken SED into consideration. Second, as the earth's weather conditions are interrelated and dynamic in nature,[130] it essential to recognize the complexity of localized weather patterns and to avoid traditional dependence on individual variables such as temperature and precipitation.

Still, evidence clearly indicates that studies so far have relied exclusively on isolated weather variables' influence on PA and SED.[115-125] Finally, and more importantly, as weather is non-modifiable, the real focus should be on understanding how built and social environmental exposures moderate the influence of variation in weather on PA and SED. For example, it is known that PA in children varies with socioeconomic influences at both household and neighbourhood levels,[131-134] and it would be interesting to observe how these socioeconomic influences moderate the relationship between weather and PA.

In summary, in advancing ALR, there are crucial knowledge gaps that could be classified into three categories: 1) methodology, 2) outcomes and 3) determinants. Methodologically, apart from measurement bias due to systematic accelerometer wear-time variation, non-objective measurement of SED, non-generalizable methods to measure built environment and lack of evidence-based methods to evaluate and compare active living evidence standout as the primary issues. For outcomes, the dearth of studies examining the combined patterns of the inter-related behaviours of PA and SED is the main issue. Finally, for determinants, inadequate evidence of the influence of diverse environmental exposures including weather variation on PA and SED is the primary problem.

1.3 Statement of the Problem

Accelerometers have played a vital role in not only advancing the objective measurement of PA, but also enabling objective segregation of PA from SED. In fact, the emergence of SED as an independent factor has coincided with the growth of accelerometer usage in ALR. Although, accelerometers have revolutionized the way active living is measured, the objectivity of accelerometry is at risk if systematic accelerometer wear-time variation is not addressed.

That is, a measurement method whose primary purpose is to reduce subjectivity could itself induce measurement bias if a standardized method is not adopted to control for wear-time irregularities. In this dissertation, study one explores systematic wear-time variation and captures its impact on final estimates of PA and SED. Thereafter, a data standardization methodology is proposed to control for wear-time variation and produce standardized outcome variables of ALR ─ PA and SED.

In ALR, the need for adoption of appropriate methods goes beyond the measurement of PA and SED. As this research is being conducted across the world in cities and towns of different sizes and types of urban design,[24-47] it would be difficult to compare results across studies and populations without the measurement of built environment using generalizable methods. The generalizability of ALR depends not only on the ability to compare determinants (built environment), but also outcomes i.e., PA and SED. The lack of evidence-based methods to capture the impact of active living interventions on PA and SED hinders the evaluation of ALR. Moreover, in studying the impact of built environment, it is important not to ignore other diverse environmental exposures such as neighbourhood social environment, household environment and individual factors.

Study two in this dissertation depicts the usage of generalizable built environment measures, and also captures neighbourhood social environment, household, and individual factors in studying the impact of diverse environmental exposures on objectively measured PA and SED in children aged 10-14 years (as participants in this research are in transition from childhood [through preadolescence] to adolescence, to avoid confusion, from here on they will called as children). In doing this, the second study proposes a method to evaluate and compare the impact of active living interventions on PA and SED.

Finally, in pursuit of generating evidence to inform policy to create active living communities, it is essential to understand how urban design and environment moderates the influence of weather variation on PA and SED. However, a pervasive problem that encompasses all ALR is the exclusion of variation in weather as a variable.[126] Moreover, studies that have looked into the influence of weather have not only excluded built environment in their analyses, but also predominantly concentrated on the influence of isolated individual weather variables (temperature, precipitation, etc.) on PA.[115-125] Absent from these investigations was the recognition of the complexity of localized weather patterns[130] and the importance of including SED.

Study three provides evidence for the need to include weather in conducting ALR. The study captures the influence of weather on objectively measured PA and SED in children aged 10-14 years during the transition from summer to spring in Saskatoon, Saskatchewan, Canada. Furthermore, it shows how urban design and environment can moderate the impact of weather variation on PA and SED. In doing this, study three replicates the methods used in study two to capture the influence of diverse environmental exposures, including weather during the transition from spring to summer.

In capturing the influence of weather, study three proposes a method to simulate and integrate localized weather patterns with cross-sectional accelerometry instead of using isolated individual weather variables in analyses.

The overall aim of the dissertation is to address key gaps in ALR and lay the foundation for more rigorous research. The primary gap that is addressed by the dissertation is the dearth of ALR in children. All three studies in the dissertation are based on the same data from an existing ALR initiative in children in Saskatoon. The three studies, while independent in their aims and hypotheses, are inter-connected as they build upon each other's evidence by using the same data.

1.3.1 Aims, Hypotheses of Study 1

Hypothesizing that systematic accelerometer wear-time variation is inevitable in accelerometry, and that this systematic wear-time variation impacts final estimates of both PA and SED, this study aims to develop a standardization methodology to understand and minimize the influence of wear-time variation on PA and SED. The eventual purpose of this study is to generate standardized outcome variables of ALR i.e., PA and SED.

1.3.2 Aims, Hypotheses of Study 2

Based on the hypothesis that urban design impacts PA and SED, this study aims to examine the influence of diverse environmental exposures (neighbourhood built and social environment, and household and individual factors) on objectively measured PA and SED in children aged 10-14 years. Moreover, this study will take the hierarchical nature of the data (level 2: neighbourhoods; level 1: individuals) into consideration to develop a method to evaluate and compare the impact of active living interventions on PA and SED.

1.3.3 Aims, Hypotheses of Study 3

This study is based on the hypothesis that variation in weather influences PA and SED, and that this influence can be moderated by urban design. Based on this hypothesis, this study aims to investigate not only the influence of weather on objectively measured PA and SED in children aged 10-14 years, but also how this influence is moderated by urban design and environment during the transition from summer to spring in Saskatoon. The purpose of this study is to generate evidence that emphasizes the importance of taking weather into account in ALR. In achieving its purpose, this study aims to develop a method to simulate and integrate localized weather patterns with cross-sectional accelerometry.

Chapter 2: Smart Cities Healthy Kids ─ Methodology and Methods

2.1 Introduction

As part of the SCHK initiative, all three studies in the dissertation are primarily based on a common set of methods. However, due to the independent aims and hypotheses of the three studies, each study in this dissertation utilizes and enumerates individualized methods in their respective chapters. This chapter will describe methods common to all three studies and set up the stage for individual studies.

2.2 Urban Design of Saskatoon

Currently, Saskatoon's metropolitan area population of 260,600[135] is spread across 65 residential neighbourhoods. However, during the conceptualization and implementation of SCHK, Saskatoon had 60 neighbourhoods. Neighbourhoods in this study are defined as 'natural' geospatial entities established by the municipal planning and approved by the city council. Saskatoon is a city of well-defined neighbourhoods where the city plans and designs neighbourhoods, locates services and amenities, enables elementary schools, and encourages neighbourhood associations to form.

The residential neighbourhoods of Saskatoon gradually developed since its incorporation as a city in early 1900s.[136] This gradual development, reflecting the predominant urban planning approaches of the day has resulted in distinct urban design (Figure 2.1), providing an optimum setting to study the impact of urban design and built environment of neighbourhoods on health. The neighbourhoods designed prior to 1930 follow a traditional ***grid-patterned*** street design, typified by higher density, mixed-use neighbourhoods connected by straight, intersecting streets and back alleys (Figure 2.1-Planning Era 1).

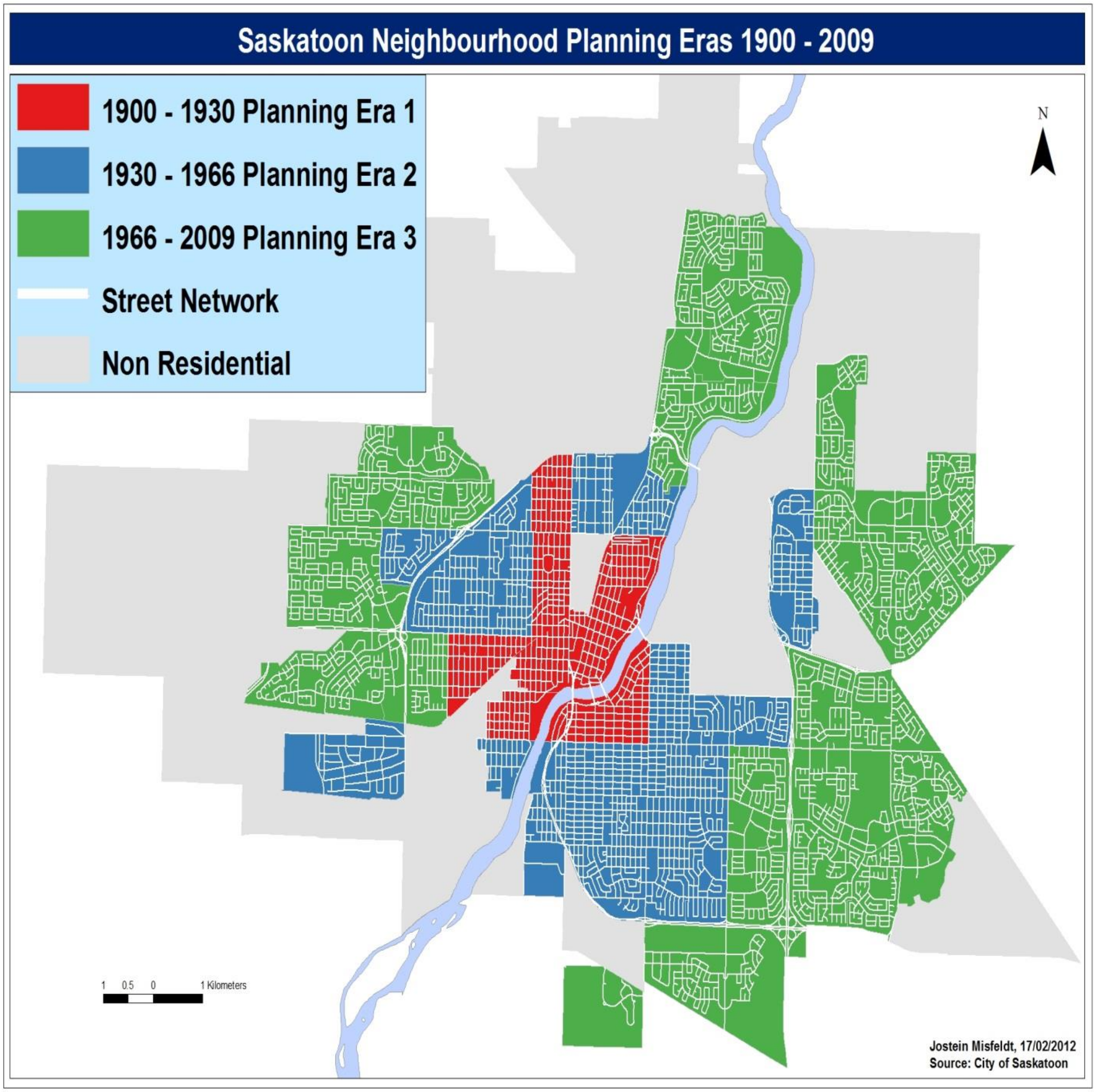


Figure 2.1 Neighbourhood planning eras of Saskatoon depicting varied urban design

The semi-suburban neighbourhoods built between 1931 and 1966 follow a ***fractured-grid pattern.*** They are predominantly residential, with lower density and become progressively car-oriented as the distance from the urban centre increases (Figure 2.1-Planning Era 2). Finally, the suburban neighbourhoods built after 1967 follow ***curvilinear*** street patterns, characterized by low-density, almost exclusively residential and highly car-oriented configurations (Figure 2.1-Planning Era 3).

Working with the City of Saskatoon's Neighbourhood Planning Department, the SCHK research team has validated the three types of neighbourhoods belonging to the three different planning eras (Figure 2.1). With the city of Saskatoon as a 'case in point', SCHK set out to explore if specific municipal policies and strategies employed in planning neighbourhoods drive the structures set in built environment; and if built environment in turn, constrains or facilitates children's activity. For the purpose of this dissertation, activity is defined as all physical activity and sedentary behaviours during waking time.

2.3 Built Environment Measures

In 2009, specific built environment characteristics of all 60 residential neighbourhoods in Saskatoon were measured. Most built environment studies appear to have selected their measuring tools without pre-specified theoretical constructs. For SCHK, a specific construct to select built environment measurement tools was utilized ─ the degree to which neighbourhood environment supports and encourages PA and discourages SED. Another criterion for selection was previously validated tools which generate generalizable results.

Based on these criteria, two replicable tools called the neighbourhood active living potential (Appendix A)[137,138] and the Irvine-Minnesota inventory (Appendix B)[139,140] were used to measure specific aspects of built environment. Neighbourhood active living potential is an 18 item tool that was validated by the SCHK team[141] by adding a new dimension called universal accessibility (which measures disabled individuals' access to built environment) to existing dimensions of safety, density of destinations and activity friendliness. Although names differ from study to study, these dimensions are similar to urban design and quality measures used in many of the other built environment studies.[142,143] In implementing this tool, pairs of observers independently rated neighbourhoods' built environment by travelling a predetermined route created by random selection and connection of block segments to determine a walking route. The inter-observer reliability for neighbourhood active living potential was above 80%.[141]

Similarly, two observers were employed to administer the Irvine Minnesota Inventory (inter-observer reliability of above 70%),[139] to measure built environment of neighbourhoods in five dimensions: diversity of destinations, pedestrian access, attractiveness, safety from traffic and safety from crime. In both built environment tools, safety is measured as the observers' perceived safety of the neighbourhoods.

2.4 Census-based Measures

Neighbourhood level socioeconomic variables were derived from 2006 Statistics Canada Census data[144] and 2010 G5[145] Census projections. These variables were used to account for neighbourhood social environment.

2.5 Neighbourhood Selection and Recruitment

Before proceeding to recruitment, ethics approval from the University of Saskatchewan's Research Ethics Board and from both Catholic and public school boards of Saskatoon was obtained (Appendix C). In 2010, a multi-stage clustered sampling method was employed to recruit children from a sampling frame that consisted of all 60 residential neighbourhoods in Saskatoon.

First, neighbourhoods representing all three neighbourhood types of Saskatoon (Figure 2.1) were identified. Second, 40 schools located in these neighbourhoods were selected to recruit 1610 children aged 10-14 years (i.e., participants). The total sample was representative of all 60 neighbourhoods, and the children belonging to the school clusters were representative of the neighbourhoods in which the schools were located. This assumption is based on the fact that children in Saskatoon predominantly attend schools within their neighbourhoods. Of the 1610 children from whom self-reported activity data were collected, 455 children agreed to participate in accelerometry.

2.6 Individual and household data

In 2010, after obtaining informed consent from parents/guardians of the children (Appendix D) and prior to deploying accelerometers, a custom built questionnaire (Appendix E) was administered to children to capture their perception of a range of factors (household, parental, peer and neighbourhood) that influence PA and SED. The items of this questionnaire were scored using Likert scaling.

2.7 Accelerometry

Actical accelerometers (Mini Mitter Co., Inc., Bend, OR, USA) were deployed through schools from April to June in 2010. Children were visited at their respective schools and were asked to wear the devices on their right hip using an elastic belt, every day for 7 consecutive days. They were advised to remove the accelerometers during night time sleep and during any water-based activities. Children were asked to return the accelerometers at the end of the 7 day cycle. To improve compliance, they were offered a drop-in pass for a civic leisure centre upon return of their accelerometers. Those who wore accelerometers on all 7 days were entered in a draw to win a Wii videogame system and a Wii Fit program.

The devices began measuring data at 00:00 on the day following device deployment (i.e., almost a full day after the device was deployed) to minimize the potential for subject reactivity within the first day of wearing the accelerometer. Accelerometers measure movement in time stamped activity counts which are sequentially aggregated to a predetermined period of time to delineate intensities of activity that occur throughout the day.

For example, accelerometers were preprogrammed to measure movement in 15 second epochs in order to capture the sporadic nature of children's activity.[146] The raw data thus obtained were analyzed using KineSoft version 3.3.63 (KineSoft, Loughborough, UK), a custom software which reaggregates activity counts to one minute to produce a series of activity intensities that represent the complete range of daily waking activity: moderate to vigorous physical activity (MVPA), light physical activity (LPA), and of course SED. MVPA and LPA are the two categories of PA, and when accumulated, together they depict the total PA.Activity intensities were derived using cut-points (SED: <100 counts/minute; LPA: 100 to <1500 counts/minute; MVPA: ≥1500 counts/minute) based on evolving evidence.[147-150] **Table 2.1** enumerates these cut-points with appropriate examples.[151]

Table 2.1 Classification of accelerometer cut-points delineating activity intensities

Intensity	Active Energy Expenditure (kcal. kg-1.min-1)	Activity Example	Accelerometer Count Range (counts per min)
MVPA	≥ 0.04	walking at speeds of ≥3.2km/h	≥ 1500
LPA	0.01 to <0.04	walking at speeds of <3.2km/h	100 to <1500
SED	<0.01	sitting, screen time	<100

MVPA: moderate to vigorous physical activity; LPA: light physical activity; SED: sedentary behaviour; kcal: kilo calorie; kg: kilogram; min: minute; km/h: kilometre per hour. Note: Adapted from "Physical activity of Canadian children and youth: Accelerometer results from the 2007 to 2009 Canadian Health Measures Survey," by R. C. Colley., et al, 2011, *Health Reports* 22(1), 15-23

Moreover, the accelerometers and cut-points used in SCHK are the same as those used in the 2007-2009 Canadian Health Measures Survey (CHMS),[151] whose accelerometry results depicted activity patterns in a nationally representative sample of children in Canada. Furthermore, using the accelerometer sample of the 2007-2009 CHMS, operational definitions and data reduction techniques were developed by Colley et al.[85] These definitions and techniques were adopted to generate valid data for this dissertation. Generation of valid data is essential to avoid including days when the participants did not wear the device, or wore the device for a period which is deemed insufficient to interpret levels of activity.[85, 151,152]

A valid day was defined as a day of accelerometry with 10 or more hours of wear-time.[153] Daily wear-time was estimated by subtracting non-wear-time from 24 hours of that particular day. It was determined that non-wear-time would be a period of at least 60 consecutive minutes of zero counts, including up to 2 minutes of counts between 0 and 100.[85] The final sample consisted of data from children with at least four valid days including at least one valid weekend day, i.e., the valid sample. **Table 2.2** compares the total accelerometry sample (455 participants) with the valid sample (331 participants) across the major demographics and the urban design of Saskatoon. **Table 2.2** also clearly depicts one of the challenges of obtaining objective PA and SED data in ALR ─ compliance (e.g. smaller sample of 14 year old children).

2.8 Weight Status

At the time of accelerometer deployment, a portable stadiometer and weigh scale were used to measure height and weight. After calculating body mass index [(BMI = weight [kg]/height [m]2), weight status (healthy, overweight or obese) was determined by Centers for Disease Control and Prevention (CDC) growth charts.[154]

Table 2.2 Distribution of total vs valid accelerometry sample across urban design

Demographic Category	All Neighbourhoods		Grid		Fractured Grid		Curvilinear	
	Total (%)†	Valid (%; %)††	Total (%)	Valid (%; %)	Total (%)	Valid (%; %)	Total (%)	Valid (%; %)
Total	455 (100.00)	**331** (72.00; **100.00**)	127 (27.91)	**95** (20.87; **28.70**)	146 (32.08)	**100** (21.97; **30.20**)	182 (40.00)	**136** (28.89; **41.10**)
Boys	219 (48.00)	**166** (36.48; **50.20**)	59 (12.96)	**45** (9.89; **13.60**)	72 (15.82)	**53** (11.64; **16.00**)	88 (19.34)	**68** (14.94; **20.50**)
Girls	236 (52.00)	**165** (36.26; **49.80**)	68 (14.94)	**50** (10.98; **15.10**)	74 (16.26)	**47** (10.32; **14.20**)	94 (20.65)	**68** (14.94; **20.50**)
Age 10	91 (20.00)	**70** (15.38; **21.10**)	22 (4.83)	**16** (3.51; **4.80**)	35 (7.69)	**25** (5.49; **7.60**)	34 (7.47)	**29** (6.37; **8.80**)
Age 11	122 (26.81)	**91** (20; **27.50**)	42 (9.23)	**32** (7.03; **9.70**)	33 (7.25)	**22** (4.83; **6.60**)	47 (10.32)	**37** (8.13; **11.20**)
Age 12	113 (24.83)	**85** (18.68; **25.70**)	33 (7.25)	**27** (5.93; **8.20**)	36 (7.91)	**26** (5.71; **7.90**)	44 (9.67)	**32** (7.03; **9.70**)
Age 13	95 (21.20)	**64** (14.06; **19.30**)	19 (4.20)	**13** (2.85; **3.90**)	34 (7.6)	**23** (5.05; **6.90**)	42 (9.40)	**28** (6.15; **8.50**)
Age 14	34 (7.40)	**21** (4.61; **6.30**)	11 (2.40)	**7** (1.53; **2.10**)	8 (1.70)	**4** (0.87; **1.20**)	15 (3.30)	**10** (2.19; **3.00**)
Aboriginal	101 (22.19)	**65** (14.28; **19.60**)	41 (9.01)	**28** (6.15; **8.50**)	37 (8.13)	**21** (4.61; **6.30**)	23 (5.05)	**16** (3.51; **4.80**)
Non-Aboriginal	354 (77.80)	**266** (58.46; **80.40**)	86 (18.90)	**67** (14.72; **20.20**)	109 (23.95)	**79** (17.36; **23.90**)	159 (34.94)	**120** (26.37; **36.30**)

†percentage within the total sample; ††percentage within the total sample followed by percentage within the valid sample; all valid data are in bold font

2.9 Outcome Variables

Current PA guidelines for children aged 5-11 years and youth aged 12-17 years recommend at least 60 minutes of MVPA every day.[155] However, on any given day, individuals can accumulate this recommended quantity of MVPA, and still remain sedentary for most of the day.[151] As a result, as aforementioned in the literature review (Section 1.2), SED has gained increased research attention,[93-97] and evidence is fast accumulating linking SED with a range of long-term health outcomes irrespective of PA accumulation.[93] Still, it is not just MVPA and SED that constitute the full spectrum of daily activity; LPA (e.g. household chores) is an essential part of daily activity as well. The Canadian Society for Exercise Physiology recommends taking a 'whole day' approach to healthy, active living[156] by achieving or exceeding recommended MVPA every day, and at the same time minimizing SED and maximizing LPA. Therefore, MVPA, LPA and SED are visualized as the outcome variables in this dissertation, with the exception of study two, in which these variables are used as determinants as well as predictors to understand the interplay between them.

Table 2.3 Hierarchical classification of derived predictors

Heirarchy	Type	Examples of Derived Variables	Source
Neighbourhood Level Variables[2,3]	Urban Design	Grid-pattern Fractured Grid-Pattern Curvilinear	Urban Planning
	Built Environment	Diversity of Destinations Safety from Traffic Safety from Crime Attractiveness Pedestrian Access Density of Destinations Safety Universal Accesibility Activity Friendliness	Observation Tools: Neighbourhood Active Living Potential and Irvivine Minesotta Inventory
	NeighbourhoodSocial Environment†	Dwelling Value Dwellings per Acre Household Income Socioeconomic Deprivation Index	Statistic Canada Census 2005 G5 2010 Census Projections
Individual Level Variables	Household, Parental, Peer, and Neighbourhood Factors and Personal Attributes†[2,3]	Family support in terms of transportation to places with physical activity access Peer Support to walk or Bike Parental support for physical activity Household Socioeconomic Status Parents' Education	Smart Cities Healthy Kids Custom Built Questionnaire
	Demographics[1,2,3]	Sex Aborignal status Age	
	Activity Measures[2]	LPA SED Weartime in Hours	Accelerometry
	Localized Weather[3]	Warm-Wet-Cold Cold-Dry-Calm Cold-Dry-Windy Cold-Wet-Calm Hours of Illimination	Environment Canada

[1] Predictors used in study one; [2] Predictors used in study two; [3] Predictors used in study three; LPA: light physical activity; SED: sedentary behaviour

2.10 Predictors

Using data from all the measures mentioned in the above sections, an extensive set of variables were derived for this dissertation. Taking into account the hierarchical nature of data distribution, these variables were segregated into two levels: neighbourhood level variables (Level 2) and individual level variables (Level 1). **Table 2.3** not only depicts the set of variables which were identified as predictors in this dissertation, but it also identifies study specific predictors. Apart from these the predictors derived from the measures mentioned in the above sections, **table 2.3** also includes simulated localized weather variables which have been described in detail in chapter 5(Sections 5.3.1 and 5.3.2).

2.11 Statistical Analyses

All analyses in the dissertation were conducted using the valid sample and statistical significance for all analyses was set at $p<0.05$. Statistical Package for the Social Sciences (SPSS 21) was used to conduct all analyses except multilevel modeling, which was conducted using Hierarchical Linear and Nonlinear Modeling software (HLM 7). It is important to note that even though the assumptions of linearity and normality are satisfied by multilevel models fitted in this dissertation, the assumption of independence of observations is violated due to the nested nature of the data ─ children are nested within the neighbourhoods they reside in i.e., the observations of a group of children within the same neighbourhood are not independent of each other.

Chapter 3: Study One

Title: Towards Uniform Accelerometry Analysis: A Standardization Methodology to Minimize Measurement Bias Due to Systematic Accelerometer Wear-Time Variation

This study has been published as an original research article in a peer-reviewed journal.[157] Overall, apart from a few changes to the language and layout that were required to fit the graduate thesis format, this study is presented in its original published form. The introduction section below may reiterate some aspects that were already discussed in the review of literature (Section 1.2).

3.1 Introduction

Different types of accelerometers are increasingly being used in interdisciplinary research to objectively measure activity patterns in populations.[36,75-78] The popularity of accelerometers is based on their documented superiority over self-reported measures[79,80] and their ability to provide a detailed picture of frequency and duration of activity intensities ─ MVPA, LPA and SED.[158] A growing reliance on accelerometers to study patterns of activity within and between populations makes the measurement and analysis protocol of accelerometer measures a key methodological issue.

In ALR, accelerometers are typically used to collect data during waking hours from participants over a period of 7 consecutive days ─ 5 weekdays and 2 weekend days.[36,159] Widely accepted data reduction standards[85] deem that participants are required to wear accelerometers (wear-time) for at least 10 hours on a given day to capture the entire range of activity, and such a day is termed a valid day. Analyses are conducted using data from only the valid days,[151,159] however, even within this valid data, there is a chance for systematic variation in daily wear-time, both within (on different days of accelerometer use) and between participants.

The systemic variation occurs because even though participants are asked to wear accelerometers from the time they wake up in the morning until the time they go to bed at night, every participant wears or removes the accelerometer at her/his discretion, thus potentially introducing a random or non-random bias to activity measurement.

A random (but highly imprecise) bias would result if accelerometers are removed during waking hours (non-wear-time) by participants without regard to the type of activity that subsequently goes unmeasured. A non-random bias would result if accelerometers are removed during waking hours by participants consistently before engaging in a certain type of activity, in other words, activity measured is consistently different from the real activity engaged by participants. Furthermore, in large population health studies, as variation in wear-time increases, the chance of final estimates of activity being distorted increases as wear-time is directly related to the amount of activity measured.

Specific to non-wear-time, Tudor-Locke et al,[87] using accelerometer data from the 2005-2006 National Health and Nutritional Examination Survey, concluded that non-wear-time appears to distort population estimates of all accelerometer measured activity, especially estimates of SED. However, distinct from non-wear-time, the purpose of this particular study is to explicitly address the impact of systematic variation of wear-time on estimates of activity. To our knowledge, apart from statistically controlling for wear-time in multivariable analyses by including it as an independent variable,[90] most studies so far have not taken into account wear-time discrepancies and their impact, before performing final analyses.

Two studies that have explored wear-time variation arrived at inconclusive results.[88,89] For example, Catellier and colleagues[88] utilized sophisticated imputation methods in tackling wear-time irregularities with an assumption that the data (activity) were missing at random, or completely missing at random. However, at the same time, the authors acknowledged that there is no objective way of determining whether the data are missing at random, completely missing at random, or not missing at random.

To preserve the expected objectivity of accelerometry and to avoid complicated statistical techniques that rely on many assumptions, a method of standardization of measured activity controlling for wear-time is essential. This would not only minimize measurement bias due to systematic wear-time variation, but would also create a uniform platform to compare estimates of activity obtained from all types of accelerometers, both within and between populations.

3.2 Methods

Excluding the methods to determine standardized data, all other relevant methods for this study have already been discussed in Chapter 2.

3.2.1 Statistical analyses

All analyses were conducted using the valid sample. First, using valid days' data from the complete valid sample (N=331 participants with 4 or more valid days), between participant wear-time variation was examined. Next, to assess systematic wear-time variation within participants over the entire 7 day accelerometry period, repeated measures multivariate analysis of variance (MANOVA) and pairwise comparisons between each day of accelerometry were conducted using a sub-sample from the complete valid sample. All participants in this sub-sample (N=130) had valid data on all 7 days of accelerometry.

Finally, valid days' data from the complete valid sample was analyzed to understand discrepancies in final results owing to wear-time variation. In this final round, all analyses (descriptive and multivariable) were conducted twice: first with the pre-standardized outcome variables, and then the same analyses were repeated using standardized outcome variables. The outcome variables in all final analyses were mean MVPA, LPA ad SED, either pre-standardized or post-standardized.

3.2.2 Standardization

Within the valid sample, for each participant, case specific sum of 'valid days' ($\sum$VD) was multiplied by an analyst defined time period (10 hours in this study) to determine case specific controlled wear-time (wt_{CON}).

$$\mathrm{wt}_{CON} = \sum \mathrm{VD} \times 10 \text{ hours} \qquad (3.1)$$

Subsequently, the observed or unstandardized total valid activity intensities in minutes (Act_{USTD}) i.e., SED, LPA or MVPA of each participant were interpolated to this case specific controlled wear-time to calculate case specific standardized total valid activity intensities in minutes (Act_{STD}).

$$\mathrm{Act}_{STD} = \frac{(\sum \mathrm{VD} \times 10) \times \mathrm{Act}_{USTD}}{\mathrm{wt}_{UCON}} \text{ minutes} \qquad (3.2)$$

Where, wt_{UCON} is the observed or uncontrolled valid wear-time.

Finally, the standardized total valid activity intensities of each participant were divided by case specific sum of 'valid days' to derive case specific standardized *mean* activity intensities in minutes (Mean $\mathrm{Act}_{\mathrm{STD}}$) i.e., ─ standardized mean MVPA, LPA or SED.

$$\text{Mean Act}_{STD} = \frac{(\sum \text{VD} \times 10) \times \text{Act}_{USTD}}{\frac{\text{wt}_{UCON}}{\sum \text{VD}}} \text{ minutes} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

A standardization scenario: Assume that a participant has 4 valid days, and during these 4 valid days, assume that this participant accumulated 48 hours of wear-time (uncontrolled wear-time). Suppose during these 48 hours of total wear-time, this participant accumulated total valid MVPA of 400 minutes (unstandardized MVPA), then the standardized mean MVPA will be calculated using this procedure. First, the 4 valid days will be multiplied by 10 hours to calculate the controlled wear-time of 40 hours (equation 3.1). Next, the 400 minutes of total unstandardized MVPA will be multiplied by 40 hours of controlled wear-time and this amount will be divided by 48 hours of uncontrolled wear-time to arrive at total standardized MVPA of 333.33 minutes (equation 3.2).

Finally, this total standardized MVPA will be divided by the 4 valid days to calculate the standardized mean MVPA of 83.33 minutes for this participant (equation 3.3). This standardization procedure will be conducted for each participant in the study to calculate the standardized mean SED, LPA and MVPA of all participants.

3.3 Results

Figure 3.1 descriptively outlines the variation in mean daily wear-time between participants across the total valid sample. After exploring variation of wear-time between participants, repeated measures MANOVA using both the univariate and multivariable approaches showed significant change in wear-time during the 7-day period of accelerometry. The within-subject effect tested with the Greenhouse-Geisser adjustment[160] yielded highly significant estimates (F_{GG}

$_{(5.27, 679.8)}$ = 35.63, $p < 0.001$) and 21% of the wear-time variation was explained by the 7 day period of accelerometry i.e., time effect.

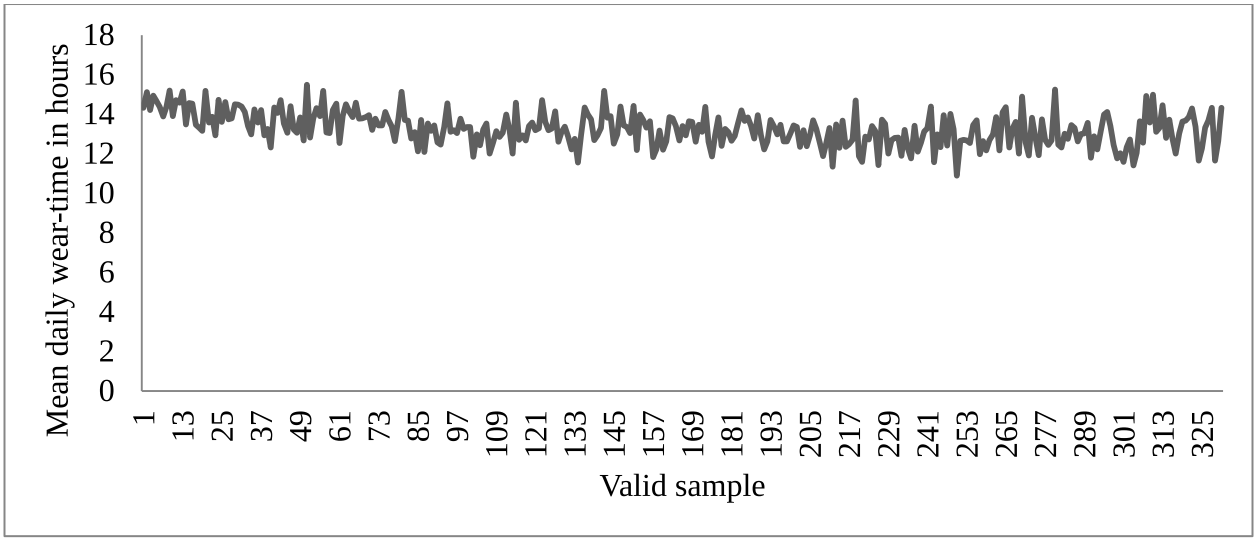


Figure 3.1 Descriptive picture of mean daily wear-time differences between all participants in the valid sample

This variation of wear-time within participants was further explored by pairwise comparisons between each day of the week (Table 3.1). This showed the systematic nature of wear-time variation over one week of accelerometry. Among the weekdays, participants consistently accumulated lower wear-time on Mondays and higher wear-time on Fridays in comparison with all other weekdays. Another consistent finding was the accumulation of lower wear-time on weekend days in comparison with all other days of the week.

After observing the systematic variation in wear-time, the pattern of higher wear-time during weekdays was further explored. **Figure 3.2** depicts a highly consistent and statistically significant pattern of higher wear-time during weekdays in comparison with weekend days across all age groups as tested by paired t-tests ─ [$t_{(330)} = 11.74$, p <0.001]; 10 years [$t_{(69)} = 3.82$, p <0.001]; 11 years [$t_{(90)} = 6.90$, p <0.001]; 12 years [$t_{(84)} = 6.35$, p <0.001]; 13 years[$t_{(63)} = 4.76$, p <0.001]; 14 years [$t_{(20)} = 4.38$, p <0.001].This information provided the rationale for testing measurement of activity accumulation pre- and post-standardization between weekdays and weekend days using paired t-tests.

Table 3.1 Pairwise comparisons depicting wear-time differences in minutes between each day of accelerometry

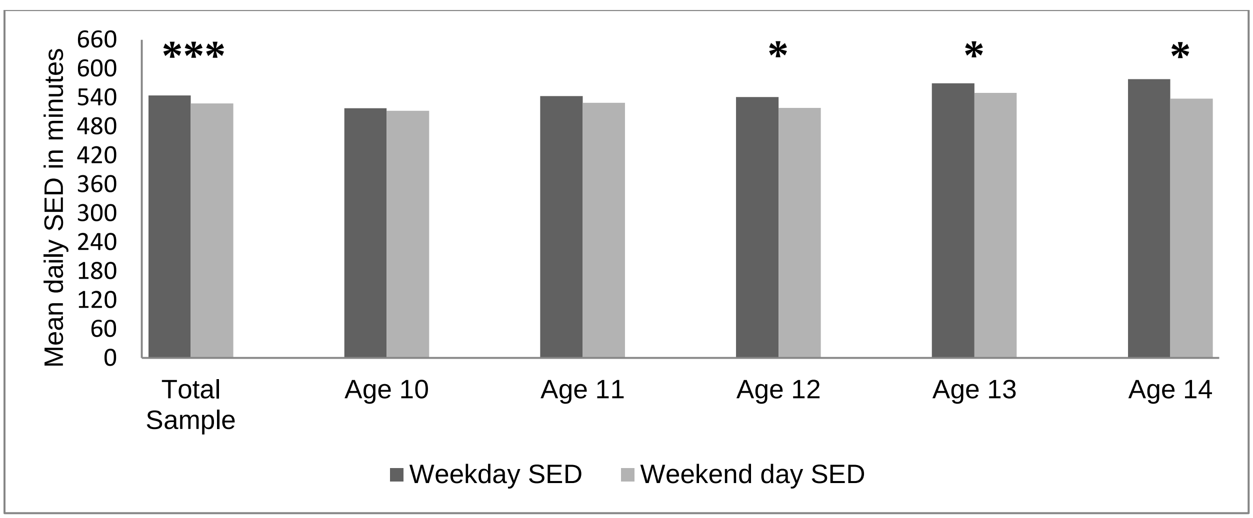
Mean Differences†	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday	**0.00**						
Tuesday	22.22*	**0.00**					
Wednesday	23.30*	1.175	**0.00**				
Thursday	27.60*	5.479	4.303	**0.00**			
Friday	70.28**	48.16**	46.99**	42.68**	**0.00**		
Saturday	14.16	-7.962	-9.137	-13.44	-56.12**	**0.00**	
Sunday	-59.12**	-81.12**	-82.41**	-86.72**	-129.4*	-73.28**	**0.00**

† Each value presented in the table is a result of subtraction of wear-time between 2 days of accelerometry (wear-time on days in columns subtracted from wear-time on days in rows); ***p*<0.001; **p*<0.01

***p<0.001

Figure 3.2 Paired t-tests showing differences between mean daily wear-time on weekdays and weekend days

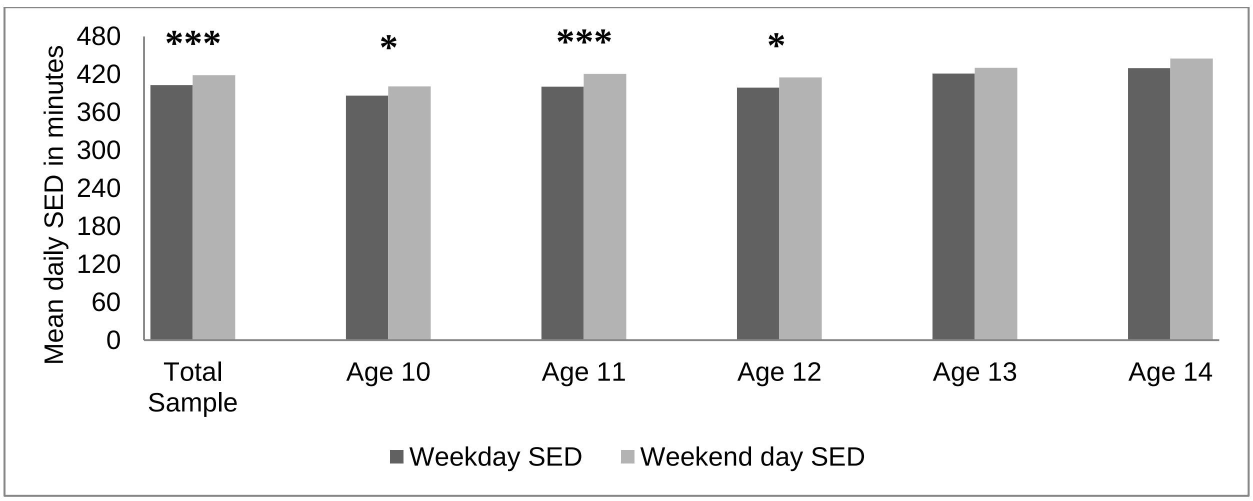
Figure 3.3 shows the comparison of pre-standardized mean SED during weekdays and weekend days. Consistent with the pattern depicted in **Figure 3.2**, weekdays have higher values than weekend days across all age groups, with statistically significant differences observed in the total sample [$t_{(330)} = 3.41$, $p < 0.001$] and in the age groups of 12 years [$t_{(84)} = 2.16$, $p < 0.05$], 13 years [$t_{(63)} = 2.0$, $p < 0.05$] and 14 years [$t_{(20)} = 2.12$, p <0.05].



***p<0.001; *p<0.05

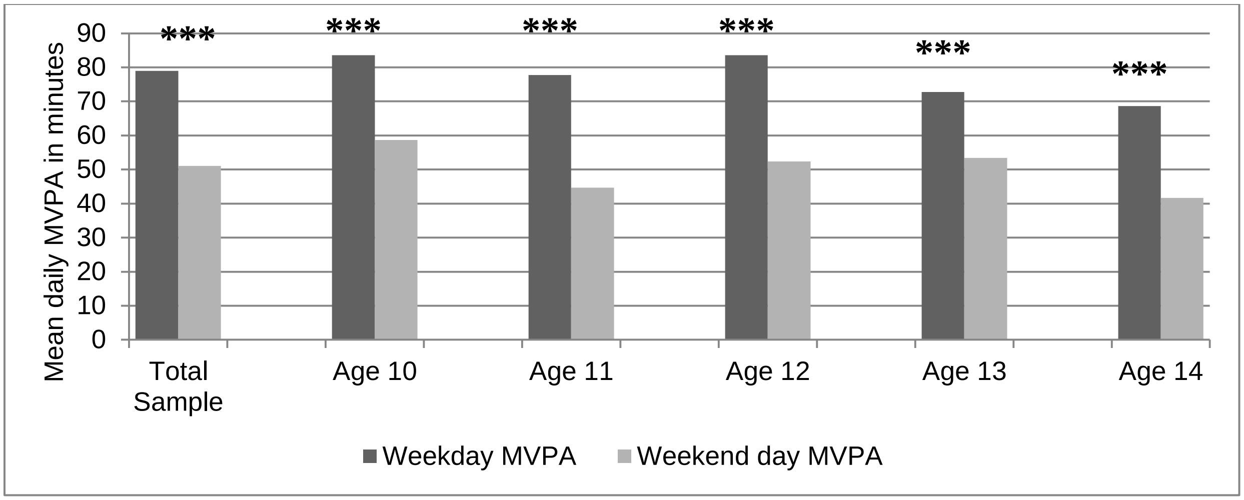
Figure 3.3 Paired t-tests showing differences between mean daily pre-standardized SED on weekdays and weekend days

When the same analysis was repeated post-standardization (Figure 3.4), an opposite pattern was observed ─ higher values of SED were observed on weekend days across all age groups, with statistically significant differences observed in the total sample [$t_{(330)}$ = 5.68, p<0.001] and in the age groups of 10 years [$t_{(69)}$ = 2.28, p <0.05], 11 years [$t_{(90)}$ = 3.78, p<0.001] and 12 years [$t_{(84)}$ = 3.08, p <0.05]. **Figures 3.5** and **3.6** depict the pre- and post-standardized mean MVPA during weekdays and weekend days. Weekday values of MVPA were significantly higher compared to weekend values across all age groups ─ [$t_{(330)}$ = 16, p <0.001]; 10 years [$t_{(69)}$ = 6.64, p <0.001]; 11 years [$t_{(90)}$ = 10.36, p <0.001]; 12 years [$t_{(84)}$ = 9.63, p <0.001]; 13 years[$t_{(63)}$ = 4.29, p <0.001]; 14 years [$t_{(20)}$ = 5.0, p <0.001].



***p<0.001; *p<0.05

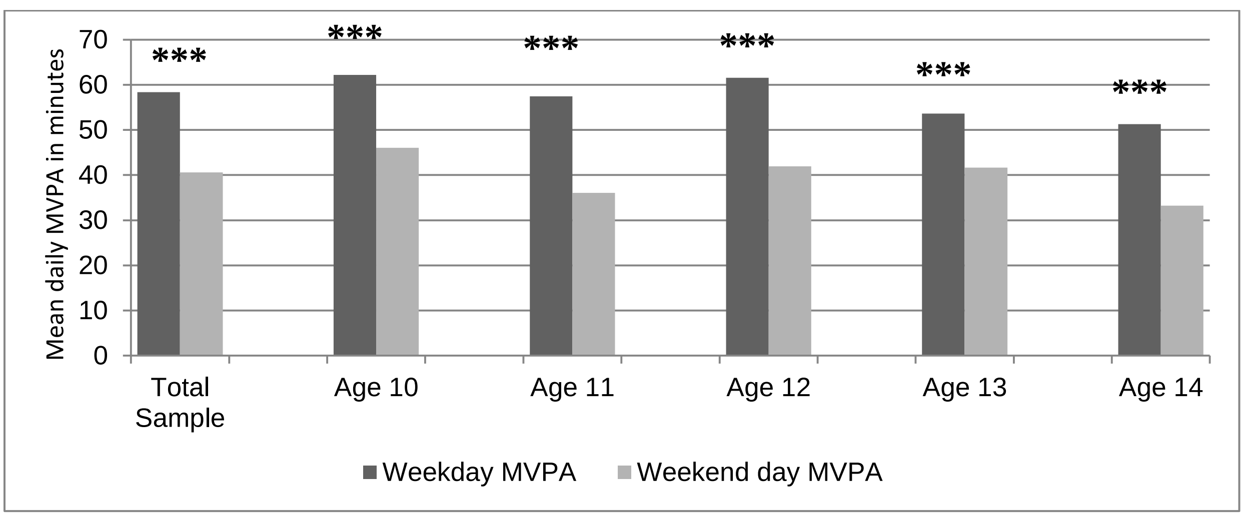
Figure 3.4 Paired t-tests showing differences between mean daily post-standardized SED on weekdays and weekend days



***$p<0.001$

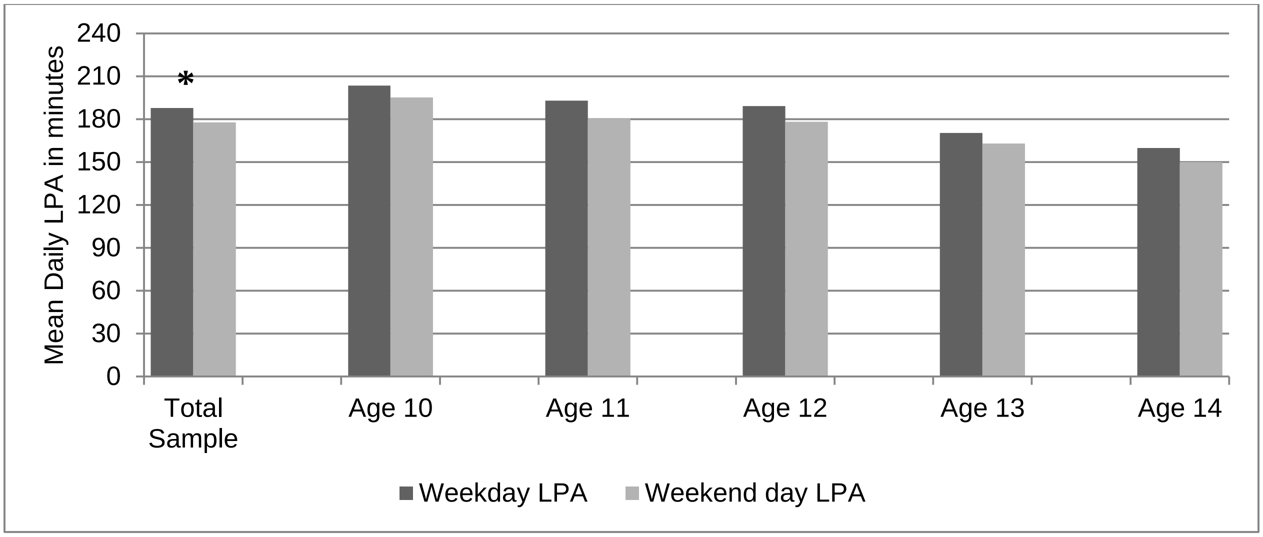
Figure 3.5 Paired t-tests showing differences between mean daily pre-standardized MVPA on weekdays and weekend days

However, unlike the post-standardized SED pattern, weekday MVPA remained significantly higher across all age groups even after standardizing the data ─ total sample [$t_{(330)} = 5.69$, $p < 0.001$]; 10 years [$t_{(69)} = 5.43$, $p < 0.001$]; 11 years [$t_{(90)} = 8.39$, $p < 0.001$]; 12 years [$t_{(84)} = 7.95$]; 13 years[$t_{(63)} = 3.65$, $p < 0.001$]; 14 years [$t_{(20)} = 3.8$, $p < 0.001$].



***$p<0.001$

Figure 3.6 Paired t-tests showing differences between mean daily post-standardized MVPA on weekdays and weekend days



*$p<0.05$

Figure 3.7 Paired t-tests showing differences between mean daily pre-standardized LPA on weekdays and weekend days

Figures 3.7 and **3.8** portray the pre and post-standardized mean LPA during weekdays and weekend days. Similar to the pattern observed with SED, when wear-time standardization was applied for the LPA outcome (Figure 3.8), weekend LPA was consistently greater than weekday LPA for the total sample and for each of the age groups, although the differences were small and not statistically significant.

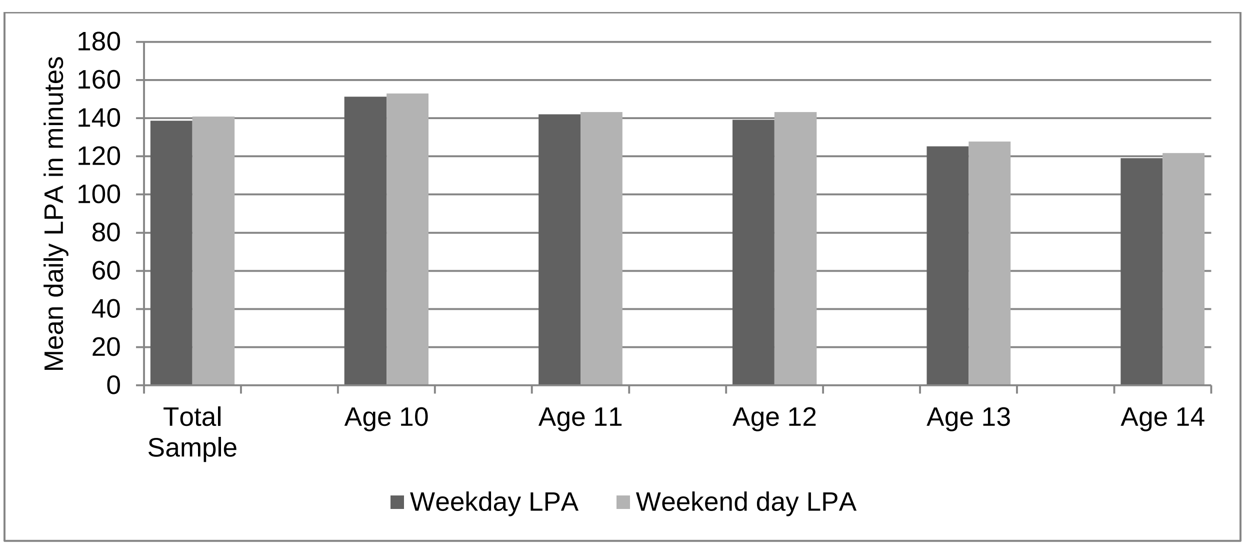


Figure 3.8 Paired t-tests showing differences between mean daily post-standardized LPA on weekdays and weekend days

After descriptive analyses, with MVPA, LPA ad SED as the outcome variables, bivariate analyses were conducted to identify significant demographic factors ─ age, sex, ethnicity (data not shown). Thereafter, these significant independent factors were used to conduct multivariable analyses ─ first with pre-standardized outcome variables (Table 3.2), and then with post-standardized outcome variables (Table 3.3). For all pre-standardized analyses, to statistically adjust for wear-time bias, mean daily wear-time was used as a covariate in the models. Even after controlling for wear-time in pre-standardized models, the results obtained in the post-standardized models were superior ─ for all outcomes and for each independent variable included in the models, the results depicted narrower confidence intervals, smaller standard errors, and sometimes higher beta coefficients, particularly for SED outcome variable (Table 3.3).

Table 3.2 Multivariable linear regression models for accelerometer outcomes before data standardization

Outcome variable: sedentary behaviour					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* - value	Lower Bound	Upper Bound
Gender	6.137	0.082	0.086	-1.504	22.64
Age	2.550	0.233	0.000	7.590	17.62
Aboriginal	7.665	0.112	0.017	3.230	33.39
Wear time	3.605	0.466	0.000	28.33	42.52
Outcome variable: Light physical activity					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* -value	Lower Bound	Upper Bound
Gender	-0.056	-1.141	0.255	-11.90	3.163
Age	-0.318	-6.496	0.000	-13.52	-7.234
Aboriginal	-0.151	-3.028	0.003	-24.37	-5.174
Wear time	0.316	6.338	0.000	0.530	1.007
Outcome variable: Moderate to vigorous physical activity					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* -value	Lower Bound	Upper Bound
Gender	-0.132	-2.438	0.015	-15.15	-1.619
Age	-0.091	-1.694	0.091	-5.233	0.390
Aboriginal	-0.106	-1.980	0.049	-16.96	-0.055
Wear time	0.133	2.451	0.015	0.978	8.928

C.I: confidence interval. Note: Values that differ from post-standardized models are in bold font.

Table 3.3 Multivariable linear regression models for accelerometer outcomes after data standardization

Outcome variable: sedentary behaviour					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* -value	Lower Bound	Upper Bound
Gender	4.591	0.102	0.053	-0.120	17.95
Age	1.922	0.264	0.000	5.885	13.45
Aboriginal	5.777	0.122	0.020	2.088	24.82
Wear-time has been controlled by standardization of sedentary behaviour					
Outcome variable: Light physical activity					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* -value	Lower Bound	Upper Bound
Gender	-0.049	-0.958	0.339	-8.031	2.769
Age	-0.349	-6.787	0.000	-10.06	-5.538
Aboriginal	-0.106	-2.059	0.040	-13.91	-0.316
Wear-time has been controlled by standardization of light physical activity					
Outcome variable: Moderate to vigorous physical activity					
				95.0% C.I	
Covariates	Std. Error	Estimate	*p* -value	Lower Bound	Upper Bound
Gender	-0.133	-2.456	0.015	-11.31	-1.249
Age	-0.095	-1.745	0.082	-3.975	0.238
Aboriginal	-0.107	-1.970	0.050	-12.67	-0.008
Wear-time has been controlled by standardization of moderate to vigorous physical activity					

C.I: confidence interval. Note: Values that differ from pre-standardized models are in bold font

3.4 Discussion

The purpose of this study is to develop a standardization methodology to understand and minimize the influence of wear-time variation on activity measurement. To our knowledge, studies to date, typically do not report the exploration of wear-time variation, and/or the influence of this variation on analyses and conclusions. In this study, a number of analyses were conducted to determine that wear-time could vary between participants (Figure 3.1) and within participants (Table 3.1).

Furthermore, a characteristic wear-time variation pattern over the entire 7 day accelerometry period was observed (Table 3.1). On weekdays, starting with low wear-time on Monday, there was a gradual increase as the week progressed, with wear-time peaking on Friday. However, a notable drop was observed over the weekend, with participants accumulating lower wear-time on Saturday and Sunday.

It would be interesting to see if similar patterns exist in other accelerometry data sets or in future studies conducting accelerometry. More importantly, it is essential to explore wear-time variation in detail to identify unique patterns so that these patterns are taken into account in final analyses. For example, in this study, the significant differences between weekday and weekend day wear-time (Table 3.1 and Figure 3.2) determined the type of descriptive analyses that were conducted for accelerometer outcomes before and after standardization.

These descriptive analyses compared pre- and post-standardized weekday and weekend measurement of MVPA, LPA ad SED. Weekday MVPA was significantly higher than weekend MVPA across all age groups, both before and after standardization of data (Figures 3.5; 3.6), confirming prevailing evidence that children are more active on weekdays.[161-163] However, after standardization, the magnitude of the weekday vs. weekend MVPA difference reduced considerably.

In their assessment of impact of non-wear-time on accelerometer outputs, Tudor-Locke et al[87] speculated that not wearing accelerometers during waking hours affects SED more adversely than other intensities. Their speculation is confirmed in this study by the evidence generated in the pre- and post-standardized descriptive analyses of SED. Wear-time, which was significantly lower during the weekend days (Table 3.1 and Figure 3.2), was obviously a result of participants removing their accelerometers for longer periods during weekend waking hours. As expected from previous reported observations,[87] accelerometer removal resulted in lower 'non-standardized' estimates of SED on weekends (Figure 3.3). However, after data were standardized by controlling for wear-time variation, weekend SED estimates turned out to be higher than weekday estimates (Figure 3.3). This finding is important as it means that not accounting for systematic wear-time variation across weekdays and weekend days could lead to opposite conclusions.

As shown in this study, wear-time variation should be expected when conducting accelerometry over a period of 7 days in population health studies, both within and between participants. However, it is difficult to expect or speculate the magnitude of wear-time's impact on the estimation of activity intensities which could vary between different groupings or even settings (weekday vs. weekend, boys vs. girls, etc.).

Data standardization becomes especially useful in this context, as it enables evidence to be generated to confirm wear-time's influence on estimation of activity intensities, as well as to understand the magnitude of this influence. In doing this, data standardization reduces the measurement bias due to wear-time variation and creates a uniform platform to not only derive activity intensities, but also to compare them across different groups.

Beyond descriptive analyses, standardization of accelerometer data could aid in building robust multivariable models. Studies so far have accounted for wear-time in multivariable analyses by including wear-time as an independent variable.[90] This commonly used method was tested by comparing multivariable analyses conducted with all three activity intensities as outcome variables, both before and after data standardization (Tables 3.2 and 3.3). For all three outcome variables (mean MVPA, LPA ad SED), post-standardized multivariable analyses yielded more stable results. However, the narrower standard errors and confidence intervals, and higher beta coefficients could be a result of constricting the daily data to 10 hours and further exploration of post-standardized models is necessary to reiterate their robustness.

With the ever increasing focus on active living, dependency on accelerometers or similar objective activity recorders will inevitably increase. To curtail inaccurate conclusions due to wear-time induced measurement bias, there is a need to generate evidence that is based on uniform data analysis, and, standardization methodology presented in this study is a step in that direction. However, this methodology needs to be adopted with caution because the analyst defined time period used to determine the controlled wear-time (equation 3.1: wt_{CON}) will have an impact on the estimates of accelerometer outcomes.

The criteria to determine controlled wear-time should depend on the research question. In this study, the primary goal of data standardization was to understand and minimize the impact of wear-time variation on different activity intensities. This was achieved by comparing these intensities before and after data standardization. In principle, to execute such a comparison, the controlled wear-time could be determined by using any analyst defined time period (8, 10, 12 hours etc…). However, since the criteria to qualify a day of accelerometry as a valid day was a minimum wear-time of 10 hours/day, this time period was deemed to be most pragmatic to determine controlled wear-time.

3.5 Conclusion

Accelerometry is undoubtedly a vast improvement over self-reported measures of PA and SED; however, it is important to realize that wear-time plays a critical role in determining activity measurement in accelerometry. This study's findings indicate that if substantiated observations are to be made within populations, and valid comparisons are to be made between populations, there is a need to not only explore wear-time variation in detail, but also to minimize the measurement bias caused by this variation.

3.6 Acknowledgements

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Chapter 4: Study Two

Title: Developing Evidence-based Methods to Evaluate Active Living: Capturing the Influence of Diverse Environmental Exposures on Objectively Measured Physical Activity and Sedentary Behaviour in Children

Having addressed the wear-time discrepancies in accelerometry in study one, study two will utilize the accelerometer data to investigate the influence of diverse environmental exposures on physical activity and sedentary behaviour in children. This study will be submitted as an original research article to a peer-reviewed journal. Its original version has been slightly modified to meet the requirements of the graduate thesis format. Also, the introduction section below may reiterate some aspects that were already discussed in the review of literature (Section 1.2).

4.1 Introduction

The rapid mechanization in the 20th century[19] and technologically enhanced communication practices in the early 21st century have contributed to decreasing levels of PA in populations. Among the different types of interventions that are being implemented to counter this trend, population health active living interventions focused on modifying built environment through urban planning policy have gained momentum in recent times.[24-46] In general, evidence generated by ALR point towards mixed land use, high density urban spaces and high degree of safety as important facilitators of healthy, active living. [25-27,34,35] However, reviews of epidemiological literature have shown mixed results, emphasizing the importance of adopting generalizable methods in conducting ALR. [37-39] Moreover, to date, participants in most studies investigating the influence of urban design and environment on PA have been adults, and their behaviour may not necessarily be generalizable to that of children's behaviour.[47]

Studies that have explored the association between urban environment and children's PA report some consistent findings. Evidence indicates that safety (both social and traffic-related), positive perception of recreational environment, and opportunity for active transportation promote PA in children. However, the most consistent finding has been the detrimental effect of perceived lack of safety (from either crime or traffic) on PA. [41-46,54-56] Although these patterns have provided important initial direction, complex contextual mechanisms that influence PA still need to be untied, especially in children. The limitation so far has been in the use of non-generalizable methods to measure built environment. More importantly, the emergence of SED as an independent factor that influences a wide range of health outcomes[93] makes it imperative to include SED in ALR. Despite the fact that SED is increasingly being studied in children,[93-97] with some investigations specifically focusing on the influence of environmental exposures on children's SED,[98-94] essential gaps in knowledge are still prevalent.

First, in terms of untangling the relationship between environment and SED, there is a need to study the combined influence of diverse environmental exposures (neighbourhood built and social environment, and household factors) on SED. Second, even though screen time is considered a good indicator of SED, with exclusive SED guidelines being developed to limit screen time in children,[110,111] it is important to capture the entire range of SED using objective measures. Third, although PA and SED are separately quantifiable behaviours which have been independently associated with health outcomes,[21,22,93] it is imperative to study them in relation to each other due to their inter-dependent nature. Finally, with the gaining momentum of ALR, there is a need to develop a consistent and generalizable method to evaluate and compare the impact of active living interventions on both PA and SED.

With the dearth of ALR in children as the primary motivation, this study will specifically focus on the age group of 10-14 years based on the premise that these children are at a crucial stage in their life course (transition from preadolescence to adolescence) and behaviours embedded at this stage could solidify into adult life.[47] This is supported by the evidence that high levels of PA between the ages of 9 and 18 years is predictive of high levels of PA in adults.[49] Furthermore, ALR in children will facilitate active living interventions that would focus on early behaviour modification and pre-empt a wide range of chronic diseases, including obesity.

Therefore, this cross-sectional study will examine the influence of urban design and environment on the inter-dependent patterns of objectively measured PA and SED in children aged 10-14 years by taking into account diverse environmental exposures ─ the neighbourhood built environment and socioeconomic factors, family characteristics and the household environment. In doing so, this study will introduce a consistent and generalizable method to evaluate and compare the impact of active living interventions on both PA and SED.

4.2 Methods

Excluding the methods to define activity profiles, all other relevant methods for this study have already been discussed in Chapter 2. Only valid accelerometer data (section 2.7) have been used in analyses reported in this study.

4.2.1 Activity Profile Definitions

Researchers in the Sedentary Behaviour Research Network (SBRN) emphasize that authors should use the term 'inactive' to describe those who are not meeting age-specific PA guidelines.[92] Taking cue from these recommendations, and by using age-specific daily PA threshold proposed by World Health Organization (WHO),[164] children were defined as ***active*** if they accumulated 60 minutes or more mean MVPA/valid day, and as ***inactive*** if they accumulated less than 60 minutes of mean MVPA/valid day.

SBRN also recommends that SED should be defined as any behaviour characterized by an energy expenditure ≤1.5 METs incurred while in a sitting or reclining posture.[92] This criteria used to define SED is technically an 'intensity cut-point' that is used to segregate SED from any other form of PA (the same cut-point was used in this study). As there are currently no SED guidelines akin to PA guidelines that recommend limiting daily SED purely on a quantitative basis, (except minimizing screen time),[111] the definition of 'sedentary' profile is still open for discussion.

To advance this discussion and to define 'sedentary' profile for the purpose of this research, an evidence-based method was adopted to determine a daily cut-point for SED minutes. In the nationally representative accelerometry sample of the CHMS, children accumulated more than 480 minutes (8.6 hours) sedentary time, on average, in a day.[151] In SCHK, children accumulated 540.28 minutes sedentary time, on average, in a day. Taking these population specific observations into account, a series of mean SED/day cut-points with multiples of 60 (300, 360, 420, 480, 540, 600, 660) were used to conduct sensitivity analyses (Table 4.1.1) with weight status (overweight or obese vs. healthy weight status) derived from CDC growth charts[154] as the criterion variable.

Accumulations of less than 480 and 540 mean minutes of SED/day were protective against overweight or obese status (odds ratio [OR] =0.42; 95% confidence interval [CI] =0.18-0.97 and OR=0.51; CI=0.30-0.88). Out of the two statistically significant SED cut-points, 480 minutes/day was chosen due to its stronger relationship with the criterion variable compared to 540 minutes/day. Using 480 minutes/day as the primary predictor of overweight or obese weight status, multivariable logistic regression analysis was conducted (Table 4.1.2). Covariates included bivariately significant demographic and socioeconomic variables (Table 2.3).

Table 4.1 Analyses to determine daily SED cut-point for defining 'sedentary/non-sedentary' Profiles

Table 4.1.1 Sensitivity analysis testing daily SED cut-points protective of overweight and/or obese status

SED cut-points	OR	CI
SED minutes/day (<360 vs. ≥360)	0.000	0.000-0.000
SED minutes/day (<420 vs. ≥420)	0.213	0.270-1.667
SED minutes/day (<480 vs. ≥480)*	0.428	0.188-0.975
SED minutes/day (<540 vs. ≥540)*	0.515	0.301-0.882
SED minutes/day (<600 vs. ≥600)	0.542	0.292-1.006
SED minutes/day (<660 vs. ≥660)	0.503	0.117-2.157

Table 4.1.2 Multivariable logistic regression depicting the selected SED cut-point's association with overweight and/or obese status

Variables	OR	CI
SED minutes/day (<480 vs. >480)*	0.424	0.182-0.989
Boys vs. Girls	1.092	0.658-1.815
Age 11 vs. Age 10	0.877	0.430-1.789
Age 12 vs. Age 10	1.217	0.576-2.570
Age 13 vs. Age 10	1.571	0.691-3.571
Age 14 vs. Age 10	0.711	0.246-2.050
Mother's Education (University degree vs. all other)**	0.521	0.311-0.870

SED: sedentary behaviour; *$p<0.05$; **$p<0.01$; wear-time was controlled for in both sensitivity analyses and the multivariable logistic regression analysis.

Again, children who accumulated less than 480 minutes of mean SED/day were 58% less likely to be overweight or obese (OR=0.42; CI=0.18-0.98). Accelerometer wear-time was controlled for in all sensitivity analyses (Table 4.1.1) and in the multivariate logistic regression analysis (Table 4.1.2). Based on this evidence, children were defined as ***sedentary*** if they accumulated 480 minutes or more mean SED/valid day, and ***non-sedentary*** if they accumulated less than 480 minutes of mean SED/valid day.

Finally, as mentioned in section 2.9, apart from MVPA and SED, LPA is an essential part of daily behaviour, and researchers are now recommending a 'whole day'[156] approach to healthy, active living by achieving or exceeding recommended MVPA minutes, minimizing SED and maximizing LPA. The relationship between MVPA, LPA and SED is complex, and as there is a need to understand this complex relationship to devise and implement active living interventions, the interplay between these intensities of activity has been explored in this study.

4.2.2 Statistical Analyses

First, the total sample was divided into four groups (***active/inactive and sedentary/non-sedentary***) and descriptively analysed to depict group differences between children residing in different types of neighbourhoods (Table 4.2). Next, differences in activity between weekdays and weekend days were descriptively analyzed (Figures 4.1 and 4.2). Finally, two fixed effects multilevel logistic regression models were fitted in HLM7 by Bernoulli distribution of the outcome variables ─ dichotomized MVPA (at 60 minutes/day) and SED (at 480 minutes/day). Before fitting these models, utilizing neighbourhood level and individual level variables (Table 2.3), separate bivariate analyses were conducted to identify significant predictors at both levels. Only bivariately significant predictors were used in the multilevel logistic regression models (Tables 4.3 and 4.4).

In both tables 4.3 and 4.4, model 1 depicts the influence of neighbourhood level variables and model 2 is the final model depicting the influence of both neighbourhood and individual level variables. Only significant results from the final model are presented here.

4.3 Results

4.3.1 Descriptive results

Descriptive analysis by urban design (Table 4.2) showed no significant between-group differences; however there were some clear patterns. Whether children were profiled as ***active*** or ***inactive***, most children were predominately ***sedentary***. That is, even if children accumulated 60 or more minutes of mean MVPA/day, they still accumulated 8 or more hours of mean SED/day. Further, MVPA and SED were segregated between weekdays and weekend days to descriptively analyse their patterns because children's lifestyle patterns differ between weekdays and weekends and they are likely exposed to different environments as well during weekdays and weekend days.

Figures 4.1 and **4.2** depict these patterns across all age groups in both boys and girls. Children were consistently ***active*** during weekdays and ***inactive*** during weekend days, with boys being more ***active*** than girls across all age groups during weekdays (Figure 4.1). However, children were consistently ***sedentary*** during both weekdays and weekend days across all age groups of boys and girls (Figure 4.2). Based on these observations, boys and girls of all age groups could be characterized as ***active*** and ***sedentary*** on weekdays, and ***inactive*** and ***sedentary*** on weekend days.

Table 4.2 Descriptive depiction of activity profiles by Saskatoon's urban design

Variables	Total	Grid	Fractured-Grid	Curvilinear
Number of Sampled schools	30.00	6.00	10.00	14.00
Age in decimal years (mean)	11.60	11.60	11.50	11.63
(SD; min,max)	(1.10; 10.00, 14.00)	(1.10; 10.00, 14.00)	(1.20; 10.00, 14.00)	(1.20; 10.00, 14.00)
Body mass index (mean)	19.90	19.80	20.30	19.70
(SD; min,max)	(4.00; 13.40, 35.90)	(4.20; 14.00, 35.90)	(4.20; 13.40, 34.30)	(3.70; 14.20, 33.80)
Daily accelerometer wear-time in minutes (mean)	796.30	794.00	797.00	797.30
(SD; min,max)	(51.10; 653.30, 930.20)	(53.10; 680.80, 930.20)	(53.30; 653.30, 915.00)	(48.10; 684.50, 910.60)
Daily MVPA in minutes (mean)	71.20	72.80	67.30	73.10
(SD; min,max)	(31.80; 8.00, 234.50)	(33.70; 8.00, 178.10)	(32.90; 13.30, 234.50)	(29.40; 16.60, 182.00)
Daily SED in minutes (mean)	540.20	537.80	546.60	537.30
(SD; min,max)	(64.80; 317.40, 691.30)	(68.90; 317.40, 682.60)	(70.50; 344.00, 691.30)	(57.00; 379.70, 663.40)
Daily LPA in minutes (mean)	184.70	183.30	183.00	187.00
(SD; min,max)	(38.90; 92.50, 311.60)	(39.10; 104.40, 282.50)	(40.90; 92.50, 311.60)	(37.40; 98.00, 294.60)
Percentage Active and Non-Sedentary children	15.40	5.10	4.50	5.70
Percentage of Active and Sedentary children	43.20	11.80	11.80	19.60
Percentage of Inactive and Non-Sedentary children	1.20	0.00	0.90	0.30
Percentage of Inactive and Sedentary children	40.20	11.80	13.00	15.40

SD: standard deviation; min: minimum; max: maximum; MVPA: moderate to vigorous physical activity; SED: sedentary behaviour; LPA: light physical activity; Active and Non-Sedentary: ≥60 minutes of daily MVPA + <480 minutes of daily SED; Active and Sedentary : ≥60 minutes of daily MVPA + ≥480 minutes of daily SED ; Inactive and Non-Sedentary: <60 minutes of daily MVPA + <480 minutes of daily SED; Inactive and Sedentary: <60 minutes of daily MVPA + ≥480 minutes of daily SED

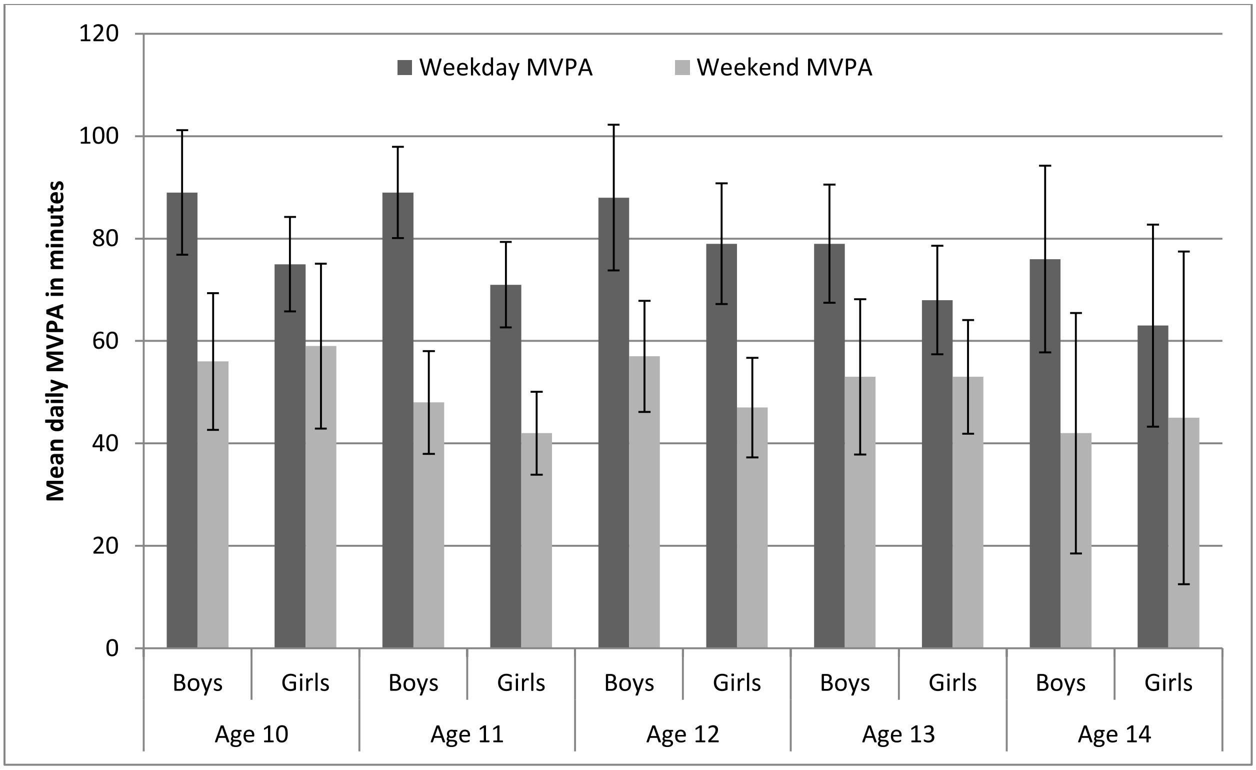

Figure 4.1 Mean daily moderate to vigorous physical activity on weekdays and weekend days

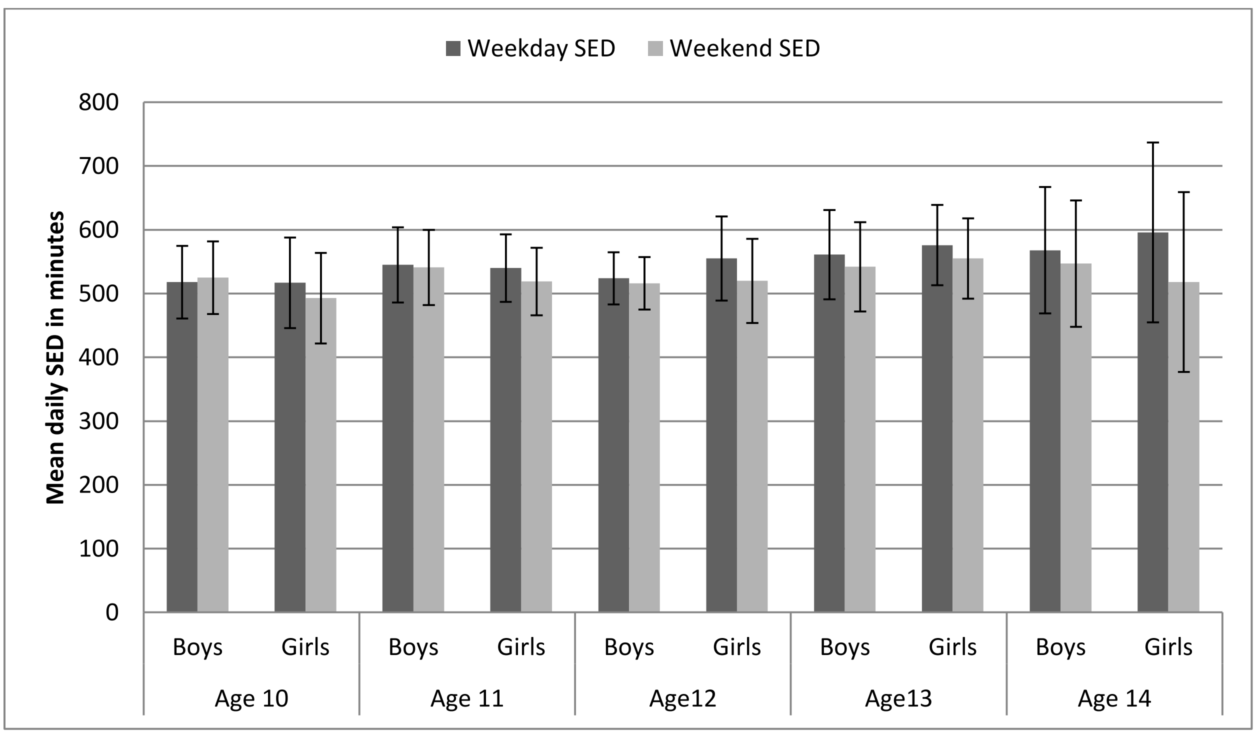

Figure 4.2 Mean daily sedentary behaviour on weekdays and weekend days

Table 4.3 Multilevel logistic regression model predicting ***active*** profile (mean daily MVPA ≥60 minutes)

	Null Model		Model 1		Model 2	
Variables	OR	CI	OR	CI	OR	CI
Intercept	1.44	1.10-1.90	2.50	1.56-4.00	0.06	0.00-42.31
Planning Era 2 vs. Era 1			0.63	0.40-1.00	0.40	0.16-0.97
Planning Era 3 vs. Era 1			0.71	0.42-1.20	0.69	0.24-1.96
Diversity of destinations-High vs Low			0.52	0.33-0.84	0.64	0.26-1.59
Boys vs. Girls					2.04**	1.15-3.61
Frequent family transport vs. Infrequent family transport					2.34**	1.18-4.67
Frequent active transport with peers vs. Infrequent active transport with peers					1.90**	1.10-3.29
Sedentary throughout the week vs. Non-Sedentary					0.15*	0.06-0.37
Active on weekends vs. Inactive					17.24*	6.20-47.97
LPA					2.08**	1.15-3.61
Age 11 vs. Age 10					0.79	0.30-5.89
Age 12 vs. Age 10					0.77	0.31-10.89
Age 13 vs. Age 10					0.44*	0.02-0.71
Age 14 vs. Age 10					0.27*	0.08-0.90
Wear-time					1.30	0.81-2.08

OR: odds ratio; CI: confidence interval; MVPA: moderate to vigorous physical activity; LPA: light physical activity; *p<0.05; **p<0.01;***p<0.001; frequent family transport and frequent active transport with peers: ≥3times/week; infrequent family transport and infrequent active transport with peers: <3times/week; excluding LPA and wear-time, all other variables are categorical.

4.3.2 Active Profile (Table 4.3)

The following children were more likely to be ***active*** throughout the week: Boys (OR=2.04; CI=1.15-3.61); children who received frequent (>3 times/week) family transportation to a place with physical activity access (OR=2.34; CI=1.18-4.67); children who frequently (>3times/week) walked or biked with their peers (OR=1.90; CI=1.10=3.29); children who were ***active*** during the weekend days (OR=17.24; CI=6.20=47.97); and finally, children who accumulated higher LPA throughout the week (OR=2.08; CI=1.15-3.61).

The following children were less likely to be ***active*** throughout the week: children residing in fractured grid-pattern neighbourhoods (planning era 2) in comparison with children residing in older grid-pattern neighbourhoods (planning era 1; OR=0.40; CI=0.16-0.97); children who were sedentary throughout the week (OR=0.15; CI=0.06-0.37) and children aged 13 (OR=0.44; CI=0.21-0.90) and 14 (OR=0.27; CI=0.08-0.90) years in comparison with children aged 10 years.

4.3.3 Sedentary Profile (Table 4.4)

The following children were less likely to be ***sedentary*** throughout the week: Aboriginal children (OR=0.32; CI=0.14-0.75); children who were ***active*** on weekend days (OR=0.18; CI=0.07-0.46), and children who accumulated higher LPA throughout the week (OR=0.50; CI=0.27-0.95).

The following children were more likely to be ***sedentary*** throughout the week: children who were ***sedentary*** during weekend days (OR=10.84; CI=4.14-28.35), children who wore the accelerometers for longer number hours each day (OR=3.98; CI=2.46-6.44); and finally, children aged 11 (OR=2.59; CI=1.08-6.20), 12 (OR=3.64; CI=1.34-9.85), and 13 (OR=9.26; CI=2.29-37.32) years in comparison with children aged 10 years.

Table 4.4 Multilevel logistic regression model predicting ***sedentary*** profile (mean daily SED ≥480 minutes)

	Null Model		Model 1		Model 2	
Variables	OR	CI	OR	CI	OR	CI
Intercept	3.02	2.25-4.04	2.98	2.09-4.25	0.00	0.00-0.00
Planning Era 2 vs. Era 1			0.79	0.40-1.56	0.95	0.34-2.64
Planning Era 3 vs. Era 1			1.23	0.66-2.27	1.38	0.48-3.94
Boys vs. Girls					0.60	0.31-1.18
Aboriginal vs. Non-aboriginal					0.32**	0.14-0.75
Sedentary on weekends vs. Non-Sedentary					10.84*	4.14-28.35
Active on weekends vs. Inactive					0.18*	0.07-0.46
LPA					0.50*	0.27-0.95
Age 11 vs. Age 10					2.59**	1.08-6.20
Age 12 vs. Age 10					3.64**	1.34-9.85
Age 13 vs. Age 10					9.26*	2.29-37.32
Age 14 vs. Age 10					4.26	0.70-25.90
Wear-time					3.98***	2.46-6.44

OR: odds ratio; CI: confidence interval; SED: sedentary behaviour; LPA: light physical activity; *p<0.05; **p<0.01;***p<0.001; excluding wear-time and LPA all other variables are categorical.

4.4 Discussion

The purpose of this study is to understand the influence of diverse environmental exposures on the inter-dependent nature of PA and SED. In doing so, this study aims to introduce a consistent and generalizable method to evaluate active living evidence i.e., PA and SED. Thus, at the very outset, age-appropriate activity profiles were defined by combining existing and evolving evidence on PA and SED (Table 4.1).

These activity profiles serve as examples of a consistent and generalizable method to evaluate and compare active living evidence. In fact, both descriptive and multivariable analyses in this study were conducted by taking activity profiles into consideration. Descriptive analysis showed that across all neighbourhoods, children were predominantly ***sedentary*** irrespective their ***active/inactive*** profile (Table 4.2). The relationship between ***active/inactive*** and ***sedentary/nonsedentary*** profiles was further investigated by comparing weekday and weekend activity. Boys and girls in all age groups were ***active*** during weekdays and ***inactive*** during weekend days (Figure 4.1); however, boys and girls in all age groups were ***sedentary*** during both weekdays and weekend days (Figure 4.2).

The results of descriptive analyses not only establish the consistent pattern of children's ***sedentary*** profile, but they also corroborate existing evidence that children are more ***active*** on weekdays.[134-136] The PA difference between weekdays and weekend days, which could be the result of both, differential environmental exposure between weekdays (school days) and weekend days, and greater influence of home physical and social environment during the weekends, requires further exploration.

The importance of home environment is emphasized in a recent review examining the influence of the home physical environment on the PA and SED in children aged 8–14 years.[165] The review highlights the positive association of media equipment at home with SED and the negative association of PA equipment at home with SED. The review also underscores the evidence that social environment, especially parental influence is critical in increasing PA.

Reiterating the factors highlighted in the review,[165] the model profiling ***active/inactive*** children (Table 4.3) in this study found that social environment played an important role in determining children's activity profiles. Children who received frequent (>3time/week) transport from their families to a place with PA access, and children who frequently (>3times/week) walked or biked with their peers were more likely to be ***active***. Parental and peer support is obvious in these observations, however, this support is influenced by more complex mechanisms.

Parental support towards children's access to PA could be related to vehicle ownership which in turn is determined by socioeconomic status of the family. The fact that parents need to drive children to places with PA access throws light on wider environmental determinants like the distance of recreational facilities from home and the perception of safety in terms of not letting children travel alone. Perceptions of safety in combination with peer relationships also come into play if children have to walk or bike together. This finding reiterates established evidence that safety plays a vital role in children active living. [41-46,63-65]

In terms of varied environmental exposure and greater influence of home physical and social environment, weekends could have a differential influence on all intensities of activity, and in turn, the activity intensities accumulated during the weekend could influence overall activity. For this reason, weekend intensities were included as independent variables in the final analyses. It was interesting to observe that weekend days' activity played a role in both ***active/inactive*** and ***sedentary/nonsedentary*** profiles. Children who were ***active*** during the weekend days were more likely to be ***active*** and less likely to be ***sedentary*** throughout the week. Moreover, children who were ***sedentary*** during the weekend days were more likely to be ***sedentary*** throughout the week. These observations emphasize the importance of developing active living interventions specifically for weekends.

The unambiguous focus on MVPA and SED in determining activity profiles is apparent in our study, however, the finding that LPA was associated in determining both ***active/inactive*** and ***sedentary/nonsedentary*** profiles brings to light the concept of 'whole day' active living.[156] Children who accumulated higher LPA throughout the week were more likely to be ***active*** and less likely to be ***sedentary*** throughout the week. Furthermore, children who were ***sedentary*** throughout the week were less likely to be ***active.*** These findings echo the inter-dependent relationship between MVPA, LPA and SED, and future population health ALR interventions should focus not only on increasing daily MVPA, but also on interrupting daily SED to increase daily LPA.

Overall, older children were less likely to be ***active*** and more likely to be ***sedentary***, and boys were more likely to be ***active***. Both these findings are consistent with existing evidence.[151,165] Moreover, as PA is known to track into adulthood,[49] it is imperative that interventions to facilitate behaviour modification should not only be initiated at an early age, but considering the strong evidence of lower PA in girls, future active living research should focus on sex/gender specific interventions.

Finally, at the neighbourhood level, children living in fractured grid pattern neighbourhoods (planning era 2) were less likely to be ***active*** than children living in grid pattern neighbourhoods (planning era 1) . This finding validates the results of multivariate analysis of covariance of the same data published by Esliger et al in 2012.[159] An explanation of this finding is that the older grid pattern neighbourhoods with their mixed land use are denser and more walkable in comparison with the fractured grid pattern neighbourhoods which are predominantly residential and more car-oriented. Thus, this observation is consistent with existing ALR evidence which points towards the positive association of PA with mixed land use, high density urban spaces with high safety, and improved access to active transportation. [25-27,34,35]

4.4.1 Strengths and Limitations

The strengths and limitations of this study could be classified into the categories of methods and statistical analysis. In terms of methods, even though accelerometry allows objective segregation of PA and SED, there are some obvious limitations. As accelerometers are not water resistant they are not used to capture water based activities. Moreover, waist mounted accelerometers do not record activities that fail to alter the axis of the device (i.e., cycling).

More importantly, the inability of accelerometers to obtain social and spatial context related to activity accumulation poses difficulty in establishing accurate associations. For example, in this study, although associations between activity accumulation and neighbourhood design/ social environment have been established, these findings do not objectively elaborate ***how*** activity is accumulated within diverse social contexts or ***where*** (neighbourhood, indoor/outdoor, playground, recreational facility etc…) activity is accumulated.

To develop appropriate interventions, it is important to understand the immediate social and spatial context within which the activity occurs. Studies are now emerging which utilize ecological momentary assessments[166] and global positioning systems[167-169] to understand the complex social and spatial associations of activity accumulation. These advances when combined with accelerometry would provide the methodological depth to tease out the complex pathways that determine activity accumulation.

Apart from the need for advanced objective measures, studies investigating the influence of environment on PA and SED need to take variation in weather into account,[126] especially in a geographic location such as Saskatoon which experiences a wide variation in seasonal weather patterns.[100] The data for this study were collected between April 28 and June 11 in 2010, and historically, this period in the calendar year experiences a seasonal transition which could very well influence activity accumulation. However, capturing the variation in weather is a complex endeavour which requires a holistic methodology to account for the inter-related nature of weather variables that act in concert to influence human behaviour.[130] Such an analysis necessitates an exclusive investigation focusing on how urban design and environment moderates the influence of weather variation, which was beyond the scope of this study.

In terms of statistical analyses, to our knowledge the relationship between different intensities of activity has not been explored in-depth, and the incorporation of this analytical strategy paves the way for understanding how these intensities influence each other. However, there are certain limitations in statistical analyses. First, sensitivity analyses conducted to generate the daily SED threshold for defining ***sedentary/nonsedentary*** profiles were based on cross-sectional data representative of children aged 10-14 years in Saskatoon.

More importantly, the 60 minute interval cut-points used in sensitivity analyses were based on a decision rule of convenience to introduce a uniform and generalizable method to categorize SED accumulation. Thus, the activity profiles created in this study should be interpreted with caution and should be validated with rigorous sensitivity analyses using longitudinal data sets representative of different populations. Nevertheless, this study introduces a method that could be adapted with emerging evidence (i.e., PA and SED guidelines), and future activity profiles could be very well be classified into more than two categories i.e., multiple gradations of activity based on PA and SED accumulation.

4.5 Conclusion

Universally, as multi-disciplinary ALR interventions gain further momentum, the need for consistent evaluation outcomes will become more apparent. Utilizing globally accepted guidelines in generating activity profiles would not only be evidence-based, but also be specific to different age groups. However, as guidelines evolve over time, it is pragmatic to develop a method that could be adapted with changes in evidence.

In working towards this goal, this study combined WHO PA guidelines with evidence from Canadian ALR to develop age-specific activity profiles. Moreover, in creating these activity profiles, a holistic picture of the influence of urban environment on the interplay between two distinct, yet related behaviours (PA and SED) was depicted. Activity profiles generated here are a step towards facilitating consistent and well-defined active living evaluation outcomes that can be used to both, quantify the impact of interventions, and create a uniform platform to compare results across interventions.

4.6 Acknowledgements

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Chapter 5: Study Three

Title: Integrating Localized Weather Patterns with Cross-Sectional Accelerometry to Capture Weather Variation's Influence on Children's Physical Activity and Sedentary Behaviour in an Urban Environment

5.1 Introduction

As mentioned in Section 4.4.1, in examining the influence of diverse environmental exposures on PA and SED, variation in weather needs to be factored in. However, such an investigation requires an exclusive focus on weather variation, and was beyond the scope of study two. Study three takes weather variation into account, and builds on the evidence generated in study two to capture urban design's moderation of weather variation on objectively measured PA and SED in children. This study will be submitted as an original research article to a peer-reviewed journal. Its original version has been slightly modified to meet the requirements of the graduate thesis format. The introduction section below may reiterate some aspects that were already discussed in the literature review (Section 1.2). Also, as a common set of variables were used in the analyses of studies two and three, there will be a minor overlap between the discussion sections (Sections 4.4 and 5.5) of both studies.

5.2 Literature Review

ALR is gaining global recognition as it has the potential to address health inequities by informing upstream policy interventions for creating active urban communities.[170] With the goal of delineating pathways that facilitate active living, a large body of research has evolved that investigates the influence of human-modified places such as homes, schools, workplaces, parks, industrial areas, farms, roads and highways.[24-34] However, to date, participants in most studies investigating the influence of built environment on PA have been adults, and their behaviour may not be generalizable to that of children's behaviour.[47]

In ALR, one factor that has consistently been underexplored is how built and social environmental factors moderate the influence of variation in weather on PA. The evidence generated by such an exclusion of variation in weather has the potential to lead to unsubstantiated conclusions, as weather is a perennial factor that encompasses all other environmental exposures. This gap in ALR evidence was highlighted by a systematic review of studies investigating the influence of weather on PA.[126] The review indicates that ALR conducted without factoring in weather variation excludes a vital determinant that could have a significant impact on PA.

The significance of weather's influence on PA is especially important in temperate and continental climatic zones (Köppen-Geiger climate classification)[114] due to a wide variation in seasonal weather in these regions. Studies that have explored weather's influence on PA in populations inhabiting these regions report a fairly stable and expected observation of higher PA levels in warmer months, among all age groups.[115-125] Research on the influence of weather on children and adolescent PA provides further insight into the complexities of seasonal variations in PA (for the purposes of this study, children and adolescents have been defined as follows: children: 3-12 years and adolescents: 13-18 years[62]).

Evidence from a five-year longitudinal study of seasonal adolescent PA showed that higher temperatures increased PA, and higher rainfall reduced PA.[129] In another study, PA measured using accelerometers across seasons in a cohort of 9 and 15 year old individuals found a significant seasonal association with PA for only young children (9 years).[120] Similar findings were observed in the European Youth Heart Study,[121] where significant seasonal variation in PA was observed in 8-10 year old children, but not in 14-16 year old adolescents.

In Canada, the majority of the population experiences a wide variation in seasonal temperatures and weather conditions.[114,127,128] Within Canada, prairie provinces like Saskatchewan (where this study was conducted) are known for particularly extreme variations in weather.[127,128] This variation of Canadian weather and its impact on leisure time PA in Canadian adults was studied by Merchant et al,[124] who observed that the relationship between seasonality and PA was indeed stronger in Saskatchewan.

Despite the increasing accumulation of evidence on the influence of weather on PA, there are several key knowledge gaps. First, most studies thus far have exclusively focused on weather's influence on PA without taking into account the wider range of environmental exposures.[115-125] Second, weather as a natural phenomenon is a complex, energy-driven process whose predictability is dependent on the interrelatedness and dynamics of specific characteristics such as temperature, atmospheric pressure, and precipitation.[130] The weather patterns experienced on a day-to-day basis evolve from the movement of air masses with fairly well known origins and trajectories, as well as relatively predictable temperature and precipitation regimes.[130]

In spite of this intricacy, to date, research has been mostly focused on the influence of individual components of weather (e.g. temperature and precipitation) on PA, instead of understanding how the interrelatedness of these weather components impacts PA.[115-125] Third, as weather is non-modifiable, research emphasis should be on understanding the moderation of weather's influence on PA by built and social environmental factors. For example, it is known that PA in children varies with socioeconomic influences at both household and neighbourhood levels,[131-134] and it would be valuable to estimate how socioeconomic conditions moderate the relationship between weather and PA.

Finally, the emergence of SED as an independent factor that influences a wide range of health outcomes[93] has added a new dimension to ALR. While SED is increasingly being studied in children,[93-97] with some investigations specifically focusing on the influence of environmental exposures on children's SED,[98-104] there is a lack of research focused on how environmental exposures moderate the influence of weather on both PA and SED.

This study hypothesizes that variation in weather influences PA and SED, and this influence can be moderated by urban design. Based on this hypothesis, this study aims to investigate not only the influence of weather on objectively measured PA and SED in children aged 10-14 years, but also how this influence is moderated by urban design and features of the built environment during the transition from summer to spring in Saskatoon, Canada. In achieving this aim, this study focuses on integrating localized weather patterns with cross-sectional accelerometry.

5.3 Methods

All relevant methods for this study have been discussed in chapter 2, with the exception of the methods used to simulate and integrate localized weather patterns with cross-sectional accelerometry. Only valid (Section 2.7) and standardized accelerometer data (Section 3.2.2) have been used in all the analyses.

5.3.1 Simulation of Localized Weather Patterns: Rationale

The new spatial synoptic classification[171] categorizes each day at a particular geographic location into one of six weather types (dry moderate, dry polar, dry tropical, moist moderate, moist polar, moist tropical), or into a transitional weather type which characterizes a day transitioning from one of the six categories into another. The synoptic methodology[171] recognizes the complexity of localized weather patterns and supersedes the traditional dependence on individual weather variables. Studies that have used synoptic methods have largely focused on the relationship between air pollution and human mortality,[172-175] and similar approaches could be used to advance ALR.

Taking inspiration from synoptic classification, a methodology to simulate localized weather patterns has been adopted in this study. The weather that was experienced in Saskatoon during the period when accelerometry was conducted (April 28 to June 11, 2010) was explored to create specific categories of weather by combining key weather variables. The fundamental rationale behind this methodology is that weather as we experience it is determined by a combination of many weather variables (e.g. temperature, precipitation), and as human beings, we are influenced by the collective effect of these weather variables.

Conceptually, it is imperative to simulate weather patterns by combining weather variables because the impact of weather cannot be measured by observing the influence of individual weather variables. Even though statistically it is possible to isolate weather variables and determine their influence on health outcomes, in reality, weather variables do not occur in isolation. Moreover, findings obtained by studying the influence of individual weather variables could not only mask the real picture, but also lead to incorrect conclusions.

For instance, when considered independently, individual weather variables such as temperature and precipitation could depict a disparate influence on human behaviour. However, conceptually, we would respond differently on a day where these two elements interact to create a distinct weather pattern. For example, two weather patterns/categories can be created for two different days by combining hypothetical values of these elements: warm and wet day (e.g. temperature of 25 degrees Celsius (°C) and precipitation of 20 millimetres [mm]) and warm and dry day (e.g. temperature of 25 °C and precipitation of 0 mm).

Even though these two weather categories portray the same temperature value, they could have a different influence on behaviours like PA and SED due to the distinct interaction of temperature and precipitation.

5.3.2 Integration of Localized Weather with Cross-Sectional Accelerometry: Methodology

Accelerometer data were obtained in 25 sequential one week cycles between April 28 and June 11, 2010 (45 day transition period from spring to summer: Figure 5.1). Each one week cycle of accelerometry was conducted on a different cohort of children within the total sample, with each cohort consisting of a different set of children. To match the accelerometry period, detailed weather data for the days between April 28 and June 11, 2010, were obtained from Environment Canada.[176,177] Based on previous evidence,[115-130,171-175] extensive exploration of the weather data was conducted to identify daily values of key weather variables corresponding to the accelerometry period: maximum temperature, precipitation, speed of maximum wind gust and hours of illumination.

Descriptive analyses were conducted to understand the distribution (i.e., mean, median, standard deviation [SD]) of daily values of the selected weather variables during the 45 days of accelerometry in question (Table 5.1). Thereafter, the daily values of each of these weather variables were aggregated to their corresponding one week cycle of accelerometry to calculate their mean weekly values. Aggregating weather variables to their respective cycles of accelerometry aligns with the focus of this inquiry whose interest is to understand the overall influence of weather that was experienced during accelerometry. This approach of capturing weather also complements the capture of PA and SED, which themselves are aggregated to one week to understand activity accumulation over a period of time. Furthermore, a decision rule was applied where 1 SD of the distribution of daily weather values during the 45 days of accelerometry as the cut-point, mean weekly values of the subsequent weather variables were categorized as follows: maximum temperature: ≥ 1SD = Warm; < 1SD = Cold; precipitation: ≥ 1SD = Wet; < 1SD = Dry; speed of maximum wind gust: ≥ 1SD = Windy; < 1SD = Calm.

Table 5.1 Distribution of selected weather variables over the period of accelerometry

	Maximum temperature (°C)	Precipitation (mm)	Speed of maximum wind gust (km/h)	Hours of illumination
Definition	The highest temperature in °C observed at a location for a specified time interval	Any and all forms of water, liquid or solid that falls from clouds and reaches the ground	The speed in km/h of the maximum wind gust during the day	Duration of daylight hours from sunrise to sunset, plus the duration of morning and evening twilight
Mean	15.80	4.30	46.44	17.32
Standard deviation	6.25	7.96	12.27	0.69
Range	23.00	38.60	45.00	2.26
Minimum	6.00	0.00	31.00	16.03
Maximum	29.00	38.60	76.00	18.29
Cut-point to simulate localized weather	22.05	12.26	58.71	N/A

°C: degree Celsius; mm: millimetre; km/h: kilometre per hour; Note: The cut-points shown here are 1 SD of the distribution of daily weather values during the 45 days of accelerometry

Finally, based on these categories, one of the following four localized weather patterns was assigned to each week of accelerometry (weekly weather): Warm-Wet-Calm, Cold-Dry-Calm, Cold-Dry-Windy and Cold-Wet-Calm (Table 5.2). Although, mathematically, the possible combination of weather patterns is higher than four, it is important to highlight that the classification of localized weather is based on actual weather recorded during the accelerometry. As the range (2.26) and SD (0.69) of hours of illumination during the 45 days of accelerometry was negligible, mean (weekly) hours of illumination was excluded from this classification and was instead included as an independent variable in multivariable analyses.

Table 5.2 Distribution of the valid accelerometry sample across simulated weather patterns and urban design

	Total (%)	Grid (%)	Fracture Grid	Curvilinear (%)
Cold-Dry-Calm	110 (33.20)	19 (5.70)	40 (12.10)	51 (15.40)
Cold-Dry-Windy	24 (7.30)	14 (4.20)	10 (3.00)	0 (0.00)
Cold-Wet-Calm	144 (43.50)	56 (16.90)	30 (9.10)	58 (17.50)
Warm-Wet-Calm	53 (16.00)	6 (1.80)	20 (6.00)	27 (8.20)

%: percentage within the total sample

5.3.3 Adverse Weather

Similar to the decision rules applied to create localized weather patterns, adverse weather was categorized utilizing a more extreme cut-point (i.e., 2 SD). Using 2 SD of the distribution of daily weather values during the 45 days of accelerometry as the cut-point, daily values of the subsequent weather variables were categorized as follows: minimum daily temperature ≥2SD:

Cold day; maximum daily temperature ≥ 2SD: Hot day; daily precipitation and daily speed of maximum wind gust ≥ 2SD: Rainy and Windy day.

5.3.4 Statistical Analyses

First, for each cohort of accelerometry (25 in total), outcome variables of this study (MVPA and SED) were aggregated to their corresponding one week cycle of accelerometry to calculate mean cohort MVPA and SED. Thereafter, analysis of variance (ANOVA) was conducted to assess group differences in mean MVPA and SED between the four types of localized weather patterns (Warm-Wet-Calm, Cold-Dry-Calm, Cold-Dry-Windy and Cold-Wet-Calm), and to compare group differences in mean MVPA and SED between the three neighbourhood types of Saskatoon (Figure 2.1) segregated by the four types of localized weather patterns.

Next, for each adverse weather day type (Cold, Hot, and Rainy and Windy), MVPA and SED minutes were identified and aggregated to calculate the mean values for each participant. Similarly, for non-adverse weather days, MVPA and SED minutes were aggregated to calculate mean MVPA and SED for each participant. Subsequently, MVPA and SED differences between adverse and non-adverse weather days were analysed in three stages. First, paired t-tests were used to assess differences in MVPA and SED between adverse and non-adverse days were conducted. Second, paired t-tests were reemployed to assess differences in MVPA and SED between adverse and non-adverse days within the same types of neighbourhoods. Finally, ANOVA was conducted to test group differences in MVPA and SED on adverse days between the three neighbourhood types of Saskatoon.

Finally, similar to the models introduced in section 4.2.2, two fixed effects multilevel logistic regression models were fitted in HLM7 by Bernoulli distribution of the outcome variables ─ dichotomized MVPA (at 60 minutes/day) and SED (at 480 minutes/day). All the variables included in the multilevel models were bivariately significant. In both multilevel models (Tables 5.9 and 5.10), model 1 depicts the influence of localized weather patterns (with Warm-Wet-Calm category as the reference) and as well as the influence of other individual level variables. The SED multilevel model also includes a continuous variable of mean hours of illumination specific to each week of accelerometry. Mean hours of illumination was not fitted in the MVPA multilevel model as its influence on MVPA was insignificant in bivariate analyses. For both outcomes, model 2 is the final model depicting the influence of both neighbourhood and individual level variables. Only significant results from the final model are presented here.

5.4 Results

Figure 5.1 depicts the seasonal transition from spring to summer in Saskatoon in the year 2010, during which accelerometry was conducted. This seasonal transition shows the fluctuation of maximum, mean and minimum temperature across the period of accelerometry.

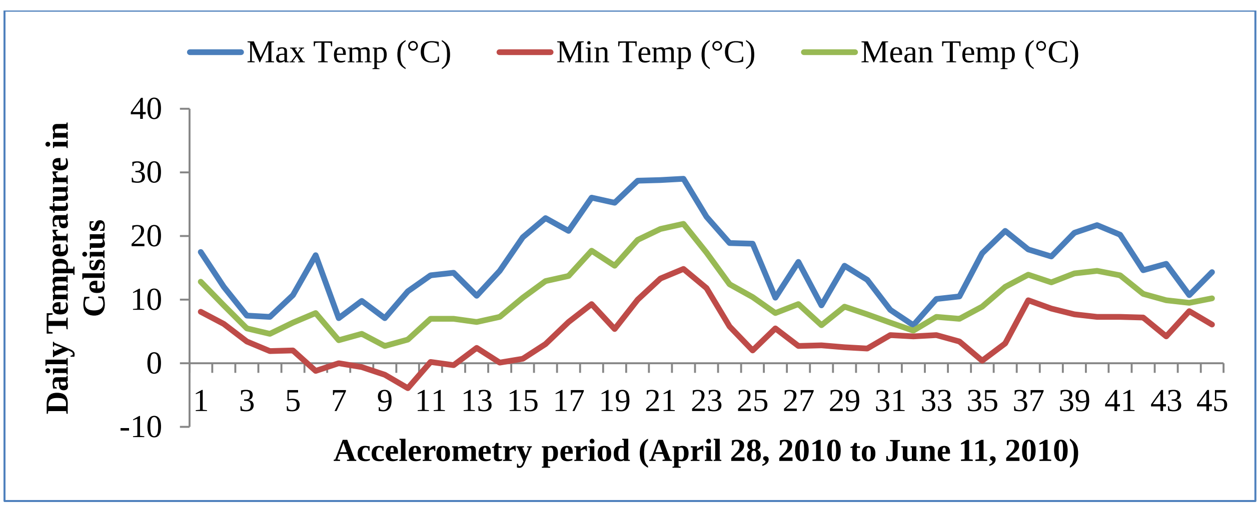

Figure 5.1 Seasonal transition from spring to summer matched with the period of accelerometry

Within this period of accelerometry, between the four types of localized weather patterns, the group differences in mean MVPA and SED point towards a pattern: Warm-Wet-Calm weather was associated with significantly lower SED and higher MVPA, whereas Cold-Dry-Windy weather was associated with significantly higher SED and lower MVPA (Table 5.3). Differences in MVPA and SED accumulation were also observed between adverse and non-adverse days. In comparison with non-adverse weather days, children accumulated significantly higher MVPA on Hot days and lower MVPA on Cold days and Rainy and Windy days (Table 5.4.1). In comparison with non-adverse weather days, children accumulated significantly higher SED on Rainy and Windy days (Table 5.4.2).

Table 5.3 ANOVA testing Group differences in MVPA and SED on different types of localized weather Patterns

Table 5.3.1 Group differences in MVPA on different types of simulated localized weather

	Cold-Dry-Calm	Cold-Dry-Windy	Cold-Wet-Calm	Warm-Wet-Calm
Cold-Dry-Calm	0.00	10.63***	-0.77	-6.4
Cold-Dry-Windy	-10.63	0.00	-11.4	-17.11
Cold-Wet-Calm	0.77	11.40***	0.00	-5.7
Warm-Wet-Calm	6.48***	17.11***	5.70***	0.00

Table 5.3.2 Group differences in SED on different types of simulated localized weather

	Cold-Dry-Calm	Cold-Dry-Windy	Cold-Wet-Calm	Warm-Wet-Calm
Cold-Dry-Calm	0.00	-9.96	2.69	11.06***
Cold-Dry-Windy	9.96**	0.00	12.66***	21.03***
Cold-Wet-Calm	-2.69	-12.66	0.00	8.36**
Warm-Wet-Calm	-11.06	-21.03	-8.36	0.00

Note: Each value presented in the tables is a result of subtraction of group MVPA and SED between 2 types of localized weather patterns (values in rows subtracted from values in columns); ***$p<0.001$; **$p<0.01$

Table 5.4 Paired Samples T-test testing differences in MVPA and SED accumulation on adverse vs. non-adverse days

Table 5.4.1 Paired samples T-test testing differences in MVPA accumulation on adverse vs non-adverse days		**Table 5.4.2** Paired samples T-test testing differences in SED accumulation on adverse vs non-adverse days	
	Non-adverse day		Non-adverse day
Hot day	13.65***	Hot day	0.45
Cold day	-6.57	Cold day	-2.53
Rainy and Windy day	-19.56	Rainy and Windy day	20.51*

Note: Non-adverse day values have been subtracted from adverse day values; ***p<0.001; **p<0.01; *p<0.05; MVPA: moderate to vigorous physical activity; SED: sedentary behaviour

5.4.1 Moderation of Localized Weather Patterns by Urban Design

This section describes how urban design of Saskatoon (meaning grid, fractured-grid, and curvilinear types of neighbourhoods) moderates the influence of variation in weather on MVPA and SED. Among the different types of neighbourhoods experiencing similar weather patterns, a recurring observation was that children residing in fractured grid-pattern neighbourhoods accumulated significantly lower MVPA (Table 5.5) and higher SED (Table 5.6).

Table 5.5 ANOVA testing group differences in MVPA between different types of neighbourhoods stratified by localized weather patterns

MVPA accumulation during Warm-Wet-Calm weather				MVPA accumulation during during Cold-Dry-Windy weather			
	Grid	Fractured Grid	Curvilnear		Grid	Fractured Grid	Curvilnear
Grid	0.00	3.67	−5.46	Grid	0.00	0.00	N/A
Fractured Grid	−3.67	0.00	**−9.13*** **	Fractured Grid	0.00	0.00	N/A
Curvilinear	5.46	**9.13*** **	0.00	Curvilinear	N/A	N/A	0.00
MVPA accumulation during during Cold-Dry-Calm weather				**MVPA accumulation during during Cold-Wet-Calm weather**			
	Grid	Fractured Grid	Curvilnear		Grid	Fractured Grid	Curvilnear
Grid	0.00	3.07	−4.41*	Grid	0.00	**6.31*** **	3.78*
Fractured Grid	−3.07	0.00	**−7.49*** **	Fractured Grid	**−6.31*** **	0.00	−2.52
Curvilinear	4.41*	**7.49*** **	0.00	Curvilinear	−3.78***	2.52	0.00

Note: Each value presented in the table is a result of subtraction of group MVPA between 2 types of urban design (values in rows subtracted from values in columns) ; ***p<0.001; **p<0.01; fractured grid's detrimental effect has been highlighted in bold; ANOVA: analysis of variance; MVPA: moderate to vigorous physical activity

Table 5.6 ANOVA testing group differences in SED between different types of neighbourhoods stratified by localized weather patterns

SED accumulation during Warm-Wet-Calm weather				SED accumulation during Cold-Dry-Windy weather			
	Grid	Fractured Grid	Curvilnear		Grid	Fractured Grid	Curvilnear
Grid	0.00	**−13.70***	6.31	Grid	0.00	0.00	N/A
Fractured Grid	**13.70***	0.00	**20.01*** **	Fractured Grid	0.00	0.00	N/A
Curvilinear	−6.31	**−20.01*** **	0.00	Curvilinear	N/A	N/A	0.00
SED accumulation during Cold-Dry-Calm weather				**SED accumulation during Cold-Wet-Calm weather**			
	Grid	Fractured Grid	Curvilnear		Grid	Fractured Grid	Curvilnear
Grid	0.00	−7.24	4.29	Grid	0.00	**−9.19*** *	−4.09
Fractured Grid	7.24	0.00	**11.53*** **	Fractured Grid	**9.19*** **	0.00	5.10
Curvilinear	−4.29	**−11.53*** **	0.00	Curvilinear	4.09	−5.10	0.00

Note: Each value presented in the table is a result of subtraction of group SED between 2 types of urban design (values in rows subtracted from values in columns); ***p<0.001; **p<0.01; *p<0.05 fractured grid's detrimental effect has been highlighted in bold; ANOVA: analysis of variance; SED: sedentary behaviour

Urban design also influenced significant differences in MVPA and SED accumulation between adverse and non-adverse days. Within the same neighbourhoods, on Hot days, significantly higher MVPA (Table 5.7.1) and lower SED (Table 5.7.2) were observed in children belonging to grid-pattern and curvilinear neighbourhoods (Table 5.7.1). Finally, in delineating group differences in MVPA and SED on adverse days between different types of neighbourhoods, it was observed that on Hot days, children residing in fractured grid neighbourhoods accumulated significantly lower MVPA (Table 5.8.1) and higher SED (Table 5.8.2) in comparison with children in grid-pattern and curvilinear neighbourhoods.

Table 5.7 Paired samples T-test testing differences in MVPA and SED accumulation on adverse vs. non-adverse days between children residing within the same types of neighbourhoods

Table 5.7.1 Paired samples T-test testing differences in MVPA accumulation on adverse vs. non-adverse days between children residing within the same types of neighbourhoods

Grid		Fractured Grid		Curvilinear	
	Non-adverse day		Non-adverse day		Non-adverse day
Hot day	17.53**	Hot day	0.83	Hot day	17.69***
Rainy and Windy day	-31.47	Rainy and Windy day	N/A	Rainy and Windy day	-8.1

Table 5.7.2 Paired samples T-test testing differences in SED accumulation on adverse vs. non-adverse days between children residing within the same types of neighbourhoods

Grid		Fractured Grid		Curvilinear	
	Non-adverse day		Non-adverse day		Non-adverse day
Hot day	-18.19	Hot day	9.53	Hot day	−24.22**
Rainy and Windy day	41.06**	Rainy and Windy day	N/A	Rainy and Windy day	0.75

Note: Non-adverse day values have been subtracted from adverse day values; ***p<0.001; **p<0.01; *p<0.05; MVPA: moderate to vigorous physical activity; SED: sedentary behaviour

Table 5.8 ANOVA testing group differences in MVPA and SED between different types of neighbourhoods on Hot days

Table 5.8.1 ANOVA testing group differences in MVPA between different types of neighbourhoods on Hot days			
	Grid	Fractured Grid	Curvilnear
Grid	0.00	**25.7***	4.73
Fractured Grid	**-25.7**	0.00	**-20.96**
Curvilinear	-4.73	**20.96***	0.00

Table 5.8.2 ANOVA testing group differences in SED between different types of neighbourhoods on Hot days			
	Grid	Fractured Grid	Curvilnear
Grid	0.00	**-34.58**	10.76
Fractured Grid	**34.58***	0.00	**45.34****
Curvilinear	-10.76	**-45.34**	0.00

Note: Values in rows subtracted from values in columns; **p<0.01; *p<0.05; ANOVA: analysis of variance; MVPA: moderate to vigorous physical activity; SED: sedentary behaviour

5.4.3 Multilevel Multivariable Models

The final multilevel multivariable models depict the influence of localized weather patterns and urban design on MVPA (Table 5.9) and SED (Table 5.10) by taking into account individual level demographic factors and neighbourhood level built environment variables. Even though both models exhibit some similarities, there are distinct differences in the factors that influence MVPA and SED.

Localized weather did play a significant role in influencing both MVPA and SED accumulation. In comparison with Warm-Wet-Calm weather, children who experienced Cold-Wet-Calm weather were less likely to accumulate higher MVPA (OR=0.44; CI=0.01-0.92), and children who experienced Cold-Dry-Calm weather were more likely to accumulate higher SED (OR=39.50; CI=2.21-70.83). However, one common factor for both models, which reiterates the findings in descriptive analyses, was that children who experienced Cold-Dry-Windy weather were less likely to accumulate higher MVPA (OR= 0.78; CI= 0.01-0.83) and more likely to accumulate higher SED (OR=42.45; CI=1.66-108.25). Finally, a variable associated specifically with SED accumulation was the hours of illumination. As the mean hours of illumination experienced by children increased, the odds of accumulating SED decreased (OR=0.81; CI=0.68-0.98).

Table 5.9 Multilevel logistic regression model predicting the influence of localized weather patterns and urban design on MVPA (mean daily MVPA dichotomized at 60 minutes)

	Null Model		Model 1		Model 2	
Variables	OR	CI	OR	CI	OR	CI
Intercept	1.72	1.34-2.12	1.13	0.61-2.87	0.26	0.00-16.72
Cold-Dry-Windy vs. Warm-Wet-Calm*			0.58*	0.21-0.84	0.78*	0.01-0.83
Cold-Dry-Calm vs. Warm-Wet-Calm			0.67	0.23-12.74	0.54	0.24-16.35
Cold-Wet-Calm vs. Warm-Wet-Calm			0.32*	0.16-0.78	0.44*	0.01-0.92
Boys vs. Girls			1.42*	1.27-4.28	2.06**	1.27-3.33
Age 11 vs. Age 10			0.63	0.28-9.42	0.82	0.41-7.63
Age 12 vs. Age 10			0.81	0.49-9.75	0.86	0.43-9.32
Age 13 vs. Age 10			0.42	0.56-19.42	0.67	0.32-22.42
Age 14 vs. Age 10			0.50	0.03-44.77	0.53	0.12-36.67
Fractured Grid vs. Grid					0.45**	0.22-0.93
Curvilinear vs. Grid					0.59	0.11-2.73
Diversity of destinations-High vs Low					2.09**	1.14-3.83

OR: odds ratio; CI: confidence interval; MVPA: moderate to vigorous physical activity; *p<0.05; **p<0.01;***p<0.001

Table 5.10 Multilevel logistic regression model predicting the influence of localized weather patterns and urban design on SED (mean daily SED dichotomized at 480 minutes)

	Null Model		Model 1		Model 2	
Variables	OR	CI	OR	CI	OR	CI
Intercept	2.16	1.45-3.10	1.26	0.72-3.23	0.14	0.00-0.89
Mean Hours of Illumination			0.72**	0.29-0.82	0.81**	0.68-0.96
Cold-Dry-Windy vs. Warm-Wet-Calm			37.82*	2.38-104.67	42.50*	1.66-108.25
Cold-Dry-Calm vs. Warm-Wet-Calm			34.63*	4.58-73.85	39.50*	2.21-70.83
Cold-Wet-Calm vs. Warm-Wet-Calm			2.41	1.41-16.59	3.41	0.86-13.48
Boys vs. Girls			0.96	0.52-2.54	0.98	0.53-1.80
Age 11 vs. Age 10			2.39	0.40-6.42	1.82	0.83-4.01
Age 12 vs. Age 10			2.27	0.38-3.72	1.68	0.77-3.67
Age 13 vs. Age 10			3.11*	1.12-28.30	7.75*	2.14-28.01
Age 14 vs. Age 10			6.20	0.23-60.02	7.75	0.95-62.80
Fractured Grid vs. Grid					0.77	0.34-1.74
Curvilinear vs. Grid					1.32	0.61-2.88

OR: odds ratio; CI: confidence interval; MVPA: moderate to vigorous physical activity; *p<0.05; **p<0.01;***p<0.001

In terms of the urban design of Saskatoon, children residing in fractured grid-pattern neighbourhoods were less likely to accumulate higher (>60 minutes) MVPA (OR=0.45; CI=0.22-0.93) in comparison with children living in grid-pattern neighbourhoods. However, this influence of urban design was not significant in the SED model. Similarly, higher diversity of destinations within a neighbourhood was significant in increasing the likelihood of higher MVPA accumulation (OR=2.09; CI=1.14-3.83), whereas this factor did not feature in the final SED model. With respect to age and sex, boys were more likely to accumulate higher MVPA (OR=2.06; CI=1.27-3.33), and children aged 13 years were more likely to accumulate higher (>480 minutes) SED (OR=7.75; CI=2.14-28.01).

5.5 Discussion

In examining how urban design moderates the influence of variation in weather on PA and SED in children, this study aimed to generate evidence that emphasizes the importance of taking weather into account in ALR. This study also proposed methods to simulate and integrate localized weather patterns with cross-sectional accelerometry.

Although simulating localized weather patterns has been effectively utilized in other areas of health research,[172-175] similar approaches have been absent in ALR, where, most research has focused on studying the influence of individual weather variables.[115-125] To address this gap, localized weather patterns were simulated by applying decision rules specific to the period of time during which accelerometry was conducted i.e., transition from spring to summer. To our knowledge, such simulation and integration of localized weather with cross-sectional accelerometry has not been utilized previously. The purpose of simulating localized weather is to understand how a range of weather conditions, acting in concert during a seasonal transition, influence MVPA and SED accumulation in children.

Initial results suggested Warm-Wet-Calm weather was associated with both higher MVPA and lower SED. On the other hand, Cold-Dry-Windy weather was consistently associated with lower MVPA and higher SED. It is apparent that exposure to higher daily temperatures played a role in higher MVPA and lower SED accumulation. This observation corroborates the established evidence[119-124] that overall, in temperate climatic zones, a rise in temperature facilitates higher PA.

However, the patterns observed here go beyond understanding the influence of individual weather variables. For instance, even though existing evidence also points towards precipitation being detrimental to PA accumulation,[125,129] Warm-Wet-Calm weather, which factored in precipitation, facilitated accumulation of MVPA. Moreover, in both Warm-Wet-Calm and Cold-Dry-Windy weather patterns, the common factor was the speed of maximum wind gust, which strongly impacted accumulation of both MVPA and SED. These observations not only underline the complexity of weather, but also the need to account for the interrelatedness and dynamics of specific characteristics such as temperature, atmospheric pressure and precipitation.[130]

More importantly, as weather is non-modifiable, the real focus should be on how built environmental factors moderate the influence of variation in weather on PA and SED. However, epidemiological investigations of active living to date have either concentrated exclusively on weather or built environment. In addressing this gap in this study, all four types of localized weather patterns simulated for the period between April 28 and June 11, 2010 were taken into account when exploring MVPA and SED differences in children living in the three types of neighbourhoods in Saskatoon.

When MVPA and SED accumulation was compared between children who experienced the same type of localized weather patterns, a clear pattern emerged. Children residing in fractured grid-pattern neighbourhoods consistently accumulated less MVPA and more SED in comparison with children in grid-pattern and curvilinear neighbourhoods of Saskatoon. An identical pattern was observed on Hot days (one of the types of simulated adverse weather days), during which MVPA was significantly lower and SED was significantly higher in children residing in fractured grid-pattern neighbourhoods. This recurring pattern of lower MVPA and higher SED among children residing in particular type of neighbourhoods is indicative of how urban design moderates the influence of weather.

Irrespective of type of neighbourhood, children in general accumulated higher MVPA on Hot days. This observation might seem to defy a logical expectation that an adverse weather day would discourage any type of PA. However, it must be noted that Hot weather days were simulated by applying a decision rule (>2SD) to the distribution of daily maximum temperature within the 45 days of accelerometry. This resulted in 28.3 °C as the cut-point to determine Hot weather days, and all three Hot weather days fell in the month of May (May 17-19, 2010).[176] The designated cut-point for Hot weather days is however considerably lower than the daily extreme maximum temperature of 37.2 °C for the month of May according to the Canadian Climate Normals from 1981-2010.[178] This reiterates the fact that accounting for weather needs to be directed by decision-rules and common sense, resulting in different observations from year to year for the same geographic location.

As depicted in this study, the inevitable fluctuation in weather necessitates the case by case simulation of localized weather. Higher MVPA accumulation on Hot weather days supports current evidence that in temperate climatic zones, a rise in temperature facilitates PA at moderate to vigorous levels.[119-124] Similarly, lower MVPA and higher SED on Rainy and Windy days adds to evidence that precipitation and wind could be detrimental to PA accumulation.[125,129]

Multilevel multivariable analyses conducted to understand the influence of localized weather patterns and urban design on MVPA and SED yielded results that emphasized the complexity of factors influencing children's active living. In terms of the urban design of Saskatoon, children residing in fractured grid-pattern neighbourhoods were less likely to accumulate higher MVPA in comparison with children residing in grid-pattern neighbourhoods. This observation validates previous evidence generated by two independent studies utilizing the same data ─ first, a multivariate analysis published by Esliger et al in 2012,[159] and second, a multilevel modeling of diverse environmental exposures, presented in this thesis (Chapter 4: study two). In these two studies, weather was not taken into account, and the fact that urban design had a significant influence on MVPA accumulation even after accounting for localized weather suggests that is has a strong influence on PA in children aged 10-14 years.

Complementing the influence of urban design, the built environment of Saskatoon also played a part in children's active living. Diversity of destinations, a built environment factor measured by Irvine Minnesota Inventory (Appendix B), increased the likelihood of children accumulating higher MVPA. This independent influence of urban design and built environment on children's MVPA can be attributed to the fact that the older grid-pattern neighbourhoods with their mixed land use are denser, have more diversity of destinations, and therefore are more walkable in comparison with the fractured grid-pattern neighbourhoods which are predominantly residential and more car-oriented.

Even though current evidence indicates that recreationally dense, high socioeconomic status neighbourhoods facilitate PA across all age groups,[35,36] some factors such as high density and traffic negatively influence children's PA.[66] However, the negative influence of urban density in children appears to taper off in adolescents, suggesting changes in perception of safety from crime and traffic with advancing age.[66] This changing perception of urban environment as children transition into adolescence is corroborated by this study's finding that children in denser urban spaces with better access to active transportation were more active.

At the individual level, 13 year old children were more likely to accumulate higher SED in comparison with 10 year old children, and boys were more likely to accumulate higher MVPA. Both these findings are again consistent with existing evidence.[151,165] In terms of localized weather patterns, Cold-Dry-Windy weather increased the likelihood of higher SED accumulation, and decreased the likelihood of higher MVPA accumulation. Another weather factor that specifically influenced SED was the hours of illumination. As the number of hours of illumination experienced by the children increased, the likelihood of children accumulating SED decreased, an observation that complements existing evidence that longer daylight days could influence higher PA in children.[179]

Thus, after taking diverse environmental exposures at the neighbourhood and individual level into account, localized weather did influence active living. However, as weather is non-modifiable, the focus falls on understanding the moderating power of urban design and environment to mitigate, or exacerbate, the influence of weather variation on active living. Although evidence from this study does indicate moderation of weather variation by urban design during the transition from spring to summer, these findings need to be confirmed with longitudinal ALR conducted in all four seasons of Saskatoon. Moreover, as PA and SED patterns are known to track into adulthood,[49,94] it is imperative that ALR to facilitate behaviour modification should not only be initiated at an early age, but considering the strong evidence of lower PA in girls, future ALR should focus on sex/gender specific interventions.

5.5.1 Strengths and Limitations

The primary strength of this study is the simulation and integration localized weather patterns with cross-sectional accelerometry, which allowed the investigation of the influence of variation in weather on MVPA and SED during a single seasonal transition. Additionally, to date, as ALR is not conducted by taking both built environment and variation in weather into account, this study provides the evidence to include variation in weather in future ALR. The approach taken in this study to capture weather is based on novel methods that use decision rules to simulate weather patterns. Even though this approach is conceptually solid, future studies could use alternative methods to build on the evidence generated here. For example, instead of using decision rules to create weather patterns, individual weather variables could be used to create interaction terms that could represent distinct weather patterns. Irrespective of the approach taken, the findings of this study emphasize the importance of accounting for weather's interrelated nature.

Moreover, there are some limitations that need to be addressed in future investigations. Even though objective activity data is obtained through accelerometers, the lack of social and spatial context related to activity accumulation poses difficulty in establishing accurate understanding. For example, in this study, even though associations between activity accumulation and urban design have been established, these findings do not objectively elaborate *how* activity is accumulated within different environmental contexts or *where* (neighbourhood, indoor/outdoor, playground, recreational facility, etc.) activity is accumulated.

To develop appropriate interventions, it is important to understand the immediate social and spatial context within which the activity occurs. Studies are now emerging which utilize ecological momentary assessments[166] and global positioning systems[167-169] to understand the complex social and spatial associations of activity accumulation. These advances, when combined with accelerometry, would provide the methodological depth to tease out the complex pathways that determine activity accumulation.

5.6 Conclusion

As shown in this study, urban design can moderate the influence of variation in weather on both MVPA and SED in children even during a single seasonal transition. Moreover, this study further illustrates that in order to comprehensively measure weather variation, there is a need to incorporate the interrelatedness of weather variables in analyses. This incorporation could be enabled by adopting methods to simulate and integrate localized weather with cross-sectional accelerometry. Ultimately, to confirm urban design's role in children's active living, there is a need to conduct longitudinal ALR to understand how urban design moderates the influence of seasonality throughout the year.

5.7 Acknowledgements

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Chapter 6: General Discussion

In addressing the causality of obesity, the Foresight report[180] identifies several cross-cutting themes that reiterate the complexity of this condition. Of the themes identified to provide a foundation for developing interdisciplinary and intersectoral interventions, this dissertation addresses the critical role played by diverse urban environmental factors in influencing PA. This focus on environmental exposures' influence on PA is part of an interdisciplinary field of study called ALR that is gaining prominence worldwide to inform policy and address inequities perpetuated by the lack of access to healthy, active living.[170]

The complex causality of obesity is further complicated by its early onset and the growing prevalence of this debilitating pandemic.[181,182] As highlighted in the literature review (Section 1.2), this dissertation aims to address the dearth of ALR in children. More specifically, children in transition from preadolescence to adolescence formed the focus of this work because evidence suggests that behaviour embedded at this stage can solidify into adulthood.[48] However, the real benefits of ALR evidently extend beyond the prevention of obesity because of PA's established association with a wide range of chronic diseases.[21,22] The necessity of studying the influence of environment on PA seems apparent, but what is not as readily appreciated is the fact that even after achieving the recommended levels of PA,[155] children, and in fact adults, can be highly sedentary. This phenomenon was depicted in Chapter 4 of this dissertation (Table 4.2; Figures 4.1 and 4.2). Moreover, given that SED is independently associated with long term health outcomes,[93] it is imperative to study SED when conducting ALR. Thus, this dissertation investigates the influence of diverse environmental exposures on both PA and SED.

The ability to objectively measure and segregate PA and SED, plus their established superiority over self-reported measures,[79,80] makes accelerometers a key a methodological component in ALR. Also, with their increasing usage, accelerometer measurement and analysis protocol are crucial to the validity of ALR. Even though considerable research has been conducted to advance methodological expertise in accelerometry, differential compliance of participants wearing these devices raises important questions ─ are substantiated observations being made within populations, and valid comparisons being made between populations? If the conclusions of studies are being based on accelerometry analyses where wear-time irregularities are not being addressed, then the answer is probably no.

Study one in this dissertation explores the impact of accelerometer wear-time variation, both within and between participants. In doing so, it proposes a data standardization methodology to minimize measurement bias due to systematic accelerometer wear-time variation. However, to advance ALR, reliable measurement should extend beyond the measurement of SED and PA. Study two utilizes generalizable and replicable methods to measure urban environment before examining the influence of diverse environmental exposures on the interplay between PA and SED ─ with PA and SED being two separately quantifiable, yet inter-connected behaviours, it is necessary to understand how they influence each other. In doing this, study two proposes a consistent method to evaluate and compare the impact of active living interventions on PA and SED (active living evidence).

In studying the influence of urban environment on PA and SED, one factor that has predominantly been ignored is weather. In Canada, and especially in the prairie provinces like Saskatchewan where there is a wide variation in seasonal temperatures and weather conditions,[127,128] it is vital to study how urban environment moderates the influence of variation in weather on PA and SED. Furthermore, as the earth's weather conditions are interrelated and dynamic in nature,[130] it is essential to recognize the complexity of localized weather patterns and to avoid traditional dependence on individual variables such as temperature and precipitation.

Study three first introduces the simulation and integration of localized weather patterns with cross-sectional accelerometry during the transition from spring to summer in Saskatoon. The main focus of this study is to examine how the urban design of Saskatoon moderates the influence of weather variation on PA and SED and contributes to generating much needed evidence on the role of weather variation in ALR.

All three studies, although independent in their aims and hypotheses, ultimately aim to advance ALR. In fact, as mentioned in the introduction (Section 1.1), this dissertation is an essential part of an ALR initiative in Saskatoon ─ SCHK. With the city of Saskatoon as a 'case in point', SCHK set out to explore if specific municipal policies and strategies employed in planning neighbourhoods drive the structures set in built environment; and if built environment in turn, constrains or facilitates children's activity.

Moreover, the preliminary evidence generated by this dissertation has aided the conceptualization of a longitudinal investigation on PA and SED in children in all four seasons in Saskatoon. More importantly, the in-depth evidence of this dissertation will inform the implementation and analysis of the SASK. Ultimately, the relevance of this ALR will extend beyond Saskatoon to other urban jurisdictions where local urban planning policy makers and researchers work together to tackle childhood obesity.

The sections below summarize the main findings of all three studies in the dissertation, and specify the implication of evidence generated by each study.

6.1 Standardization of Accelerometer Data

With study one addressing measurement of PA and SED before studies two and three could investigate the influence of urban design and environment on PA and SED, the analyses of study one focused on exploring discrepancies in accelerometer wear-time. This approach revealed systematic wear-time variation, both within and between participants. The systematic wear-time variation translated into a direct impact on the measurement of all activity intensities (MVPA, LPA and SED), as depicted by weekday and weekend day differences between the same activity intensities, before and after accelerometer data standardization.

It is difficult to speculate the magnitude of wear-time's impact on the estimation of activity intensities as they could vary between different groups or even settings (e.g. weekday vs. weekend, boys vs. girls). This is where data standardization plays a role to confirm wear-time's influence on estimation of activity intensities, as well as for understanding the magnitude of this influence. Data standardization reduces measurement bias due to wear-time variation and creates a uniform platform to not only derive activity intensities, but also to compare them across different groups.

Beyond descriptive analyses, standardization of accelerometer data could aid in building robust multivariable models. This was demonstrated in the multivariable analyses of study one, where usage of standardized activity intensities as outcome variables yielded more stable results in comparison with unstandardized activity intensities.

Study one also depicted that when accelerometer data analyses are conducted using current methods and recommendations,[87,146-151] wear-time variation is highly likely. Thus, before conducting analyses using accelerometer data, it would be prudent to explore the presence of systematic accelerometer wear-time variation, both within and between participants.

The ultimate decision to use standardized data should depend on the research questions and hypotheses of a study. For example, in study two, standardized data were not used in final descriptive and multilevel multivariable analyses. This is because the primary purpose of study two was to understand the influence of urban design and environment on PA and SED, and in this process, to develop evidence-based activity profiles which could be used to compare active living evidence.

The first step in the development of these activity profiles depended on utilizing the cut-point of 60 minutes of daily MVPA (global PA guidelines threshold)[164] to categorize children as ***active*** or ***inactive*** (Section 4.2.1). To enable this categorization, it was essential to use "unstandardized/absolute" values of daily MVPA accumulation because we know from study one that daily values of all intensities of activity were attenuated post-standardization (Figures 3.4, 3.6 and 3.8). Thus, absolute values of SED were applied in developing ***sedentary*** and ***nonsedentary*** profiles.

Irrespective of the aims and hypotheses of a study using accelerometer data, as mentioned at the beginning of this section, as a rule, wear-time variation needs to be explored and understood before final analyses are conducted. In this dissertation, wear-time variation was explored in-depth in study one before conducting studies two and three. In terms of study three, as the hypotheses did not deem the usage of absolute values of SED and PA as imperative, all analyses were conducted using standardized data.

Universally, with PA and SED becoming critical public health issues,[1] the measurement protocol of these behaviours requires renewed focus at all stages of research i.e., design, implementation and analysis. This dissertation is part of a mixed-methods ALR initiative in Saskatoon which is employing strategies at all stages of research to improve measurement of objective PA and SED data. At the design and implementation stages, the main focus is on improving compliance with accelerometer usage by participants as low compliance could lead to reduced sample sizes. The foundation to achieving this goal lies in designing meticulous deployment of accelerometers throughout schools. Efficient deployment is often dependent on strong relationships between researchers, schools and communities, and establishment of these relationships relies on the continuity of effective messaging and knowledge translation. At the implementation stage, follow-up measures such as the use of email reminders to the parents/guardians to ensure accelerometer usage on all seven days of accelerometry are proving to be an effective method to improve compliance.

Even with improved design and implementation, measurement bias due to systematic accelerometer wear-time variation[157] cannot be ruled out in large population health interventions. To increase the scientific rigour of active living measurement, studies are now moving towards 24-hour accelerometer usage by developing algorithms that could objectively segregate sleep time from PA and SED.[183] Such an approach would ensure uniform collection of accelerometer data, and if combined with effective design and implementation, could play a significant role in reducing systematic wear-time variation. Nevertheless, even with effective design and implementation of 24-hour accelerometry, the expectation of complete compliance is impractical. Thus, ultimately, the exploration of accelerometer data at the analysis stage and the utilization of standardization of accelerometer data when needed (i.e., if the study hypothesis requires standardization) would ensure a uniform platform to derive activity intensities.[157]

6.2 Capturing Diverse Environmental Exposures in Child-Centric ALR

The ecological perspective[23,105] that drives this research provides the theoretical framework to test the influence of varied environmental determinants on PA and SED in children. By including urban design, neighbourhood built and social environment, and household and individual factors, studies two and three in this dissertation investigate how different environmental factors at multiple levels of influence affect PA and SED.

Urban design, as hypothesized, played a significant role in determining PA in both studies two and three (after factoring in weather), with children residing in fractured grid-pattern neighbourhoods being less likely to be ***active*** in comparison with children residing in grid-pattern neighbourhoods. This finding not only validates the results of multivariate analysis of the same data published by Esliger et al in 2012,[159] but also reiterates existing evidence that mixed land use and high density urban spaces with improved access to active transportation[25-27,34,35] are positively associated with PA. This is because the older grid-pattern neighbourhoods in Saskatoon with their mixed land use are denser and more walkable in comparison with the fractured grid pattern neighbourhoods, which are predominantly residential and more car-oriented.

However, as measured by the two built environmental assessment tools ─ neighbourhood active living potential (Appendix A) and Irvine-Minnesota inventory (Appendix B), older grid-pattern neighbourhoods in Saskatoon, even though denser and more walkable, were perceived to be less safe in terms of both traffic and crime. The observation that neighbourhoods perceived to have lower safety being associated with higher PA contradicts the most consistent existing evidence that perceived lack of safety (from both traffic and crime) is associated with low PA in children.[40-46,63-65]

Still, the reality is much more nuanced and brings to light the complexity of ALR. As depicted in the Section 1.2, a comprehensive review of literature of child and adolescent-centric ALR[66-72,73] indicates differential impact of environmental exposures on PA between children and adolescents. With this dissertation focusing on children in transition from preadolescence to adolescence, the findings which contradict existing evidence could be symptomatic of changing behavioural response in children during this crucial stage in lifecourse.

This evolving variation of response to environmental exposures during the transition from preadolescence to adolescence was further reiterated by the finding that diversity of destinations (as measured by built environment tools) was associated with higher accumulation of MVPA in study three. This is because diversity of destinations was higher in older grid-pattern neighbourhoods which are perceived to be less safe in comparison to fractured and curvilinear pattern neighbourhoods.

Beyond urban design and built environment, within the past decade, child and adolescent-specific ALR has revealed the significant influence of homes, schools and the transportation between homes and schools in influencing PA.[66-72] At home, positive parental influence in terms of support towards accumulating PA has emerged as a major factor that determines children's overall PA.[69] Similarly, active transport facilitated by positive social interactions, facilities to assist active travel, urban design, shorter distance and safety,[71] appears to increase the probability of achieving recommended PA guidelines. This emerging evidence has been reiterated in study two, where parental support in providing transport to places with PA access, and active transport facilitated by peer relationships increased the likelihood of children being ***active.***

One finding that has been consistently reported, but not well explored is low PA among children on weekends.[161,162] In study two, weekend activity was investigated with results showing that children accumulated higher ***sedentary*** time during weekends irrespective of being ***active*** or ***inactive***. Moreover, multilevel multivariable analyses showed that children who were ***active*** during the weekend days were more likely to be ***active*** and less likely to be ***sedentary*** throughout the week. These observations, when viewed in context of the important role played by home environment (especially parental support), reveal that active living interventions in children should extend beyond urban planning policy.

The observation that children were predominantly ***sedentary*** irrespective of their PA accumulation highlights a factor that has been relatively under-investigated with objective measures in ALR. Current evidence suggests that there are some consistent overlaps in the environmental influence of PA and SED in children, with home environment, especially socioeconomic status and positive parental support, appearing to be positively associated with PA[66-70] and negatively associated with SED.[61,106,107] Specific to urban design and built environment, perception of safety stands out as an important determinant for both PA[66] and SED.[106] In this dissertation, apart from increasing age and weekend activity, the only factor that was common to both PA and SED accumulation was the variation in weather. To obtain consensus of evidence on the environmental influences of SED, current findings point towards increasing the rigour of ALR by utilizing objective measurement of SED.

In terms of improving methods of measurement, built environment measurement has seen considerable advancement in the past decade, with increasingly generalizable tools being developed across the world.[113] The ALR initiative in Saskatoon which encompasses this dissertation utilized two such generalizable tools to measure built environment characteristics of Saskatoon's neighbourhoods. Even though these measurement tools were not developed specifically for children, factors (i.e., urban density) measured by these tools which are normally associated negatively with children's PA[63-66] were, however, positively associated with PA in this study. Thus, it appears that built environment measures developed for adults could be adapted to conduct child-centric ALR, especially in adolescents who are transitioning into adulthood.

Nevertheless, development of the next generation of built environment measurement tools should not only be specific to the populations under investigation, but should also focus on mixed-methods to capture both objective measures and subjective perceptions.[113] Although objective measures provide the necessary rigour to built environment measurement, they exclude the critical perceptions of participants that determine the response to built environment. Mixed-methods ALR could be the answer to obtain a comprehensive picture of the interaction between built environment and populations

6.3 Evaluating Activity Accumulation: Inter-dependence of PA and SED

The purpose of developing activity profiles in study two is to propose an evidence-based method to evaluate and compare active living evidence. However, the rationale for creating this method is much deeper. The emergence of SED as an independent entity that could determine long term health outcomes[93] has provided an additional dimension to ALR. Moreover, PA and

SED's association and how these two behaviours interact with each other within the wider context of varied environmental exposures is an evolving concept that warrants rigorous examination.

The activity profiles developed in study two by utilizing cut-points of MVPA and SED enable the descriptive depiction and comparison of activity patterns across different groups and sub-populations. For instance, as mentioned in the previous section, the fact that children were ***sedentary*** during weekends irrespective of being ***active*** or ***inactive*** indicates that these behaviours have a more complex relationship. This observation is consistent with a recent meta-analysis[109] investigating the association between PA and SED in children and adolescents which concluded that even though SED is inversely associated with PA, these behaviours should not be considered as functional opposites.

Thus, although PA and SED are intrinsically connected behaviours, conceptually, they are in essence two separate behaviours that could be influenced differently by varied environmental determinants as depicted in this dissertation. This concept has informed the development of two separate models (tables 4.3 and 4.4) in study two, where activity profiles that inform MVPA and SED accumulation were used as the outcome variables. Within these models, apart from including diverse environmental variables, different intensities of PA, and SED were included to understand the nuanced influence of these intensities on activity profiles i.e., MVPA and SED accumulation.

This approach is substantiated by the 'whole day'[156] approach to healthy, active living, where apart from MVPA and SED, LPA is considered an essential part of daily activity and individuals should not only try and achieve the recommended levels of MVPA, but also minimize SED and maximize LPA. The multilevel models in study two explored the relationship between MVPA, LPA and SED to depict that higher daily LPA increased the likelihood of children being

active and ***non-sedentary*** i.e., higher likelihood of accumulating more MVPA and less SED. In the realm of ALR, this relationship between the different intensities of activity needs further testing to tailor appropriate interventions.

In developing active living interventions, it is essential to envision evaluation frameworks which rely on evidence-based methods to evaluate and compare the impact of interventions. However, the magnitude of this complexity is further amplified by the dearth of gold standards for measurement and evaluation of activity in ALR. Thus, the activity profiles developed in study two are intended to contribute towards evolving frameworks of active living evaluation such as the 2014 Report Card on Physical Activity for Children and Youth.[156] The report card is an exhaustive collation of active living indicators and their grades in Canada and fourteen other countries. Hierarchically, the indicators include governmental and non-governmental strategies and investments; environmental factors like schools and built environment; and behaviours that contribute to overall PA such as active transportation. In evaluating the impact of these indicators on PA and SED it would be ideal to establish quantifiable dose-response relationships. The activity profiles proposed in this dissertation are an example of quantifying activity which could be utilized to test the response to the relevant indicators.

6.4 Integrating Localized Weather with Cross-Sectional Accelerometry

The need to factor in weather variation in ALR is emphasized in study three, with the results showing that urban design moderates the influence of variation in weather on PA and SED in children. In study three, taking inspiration from synoptic classification,[171] a methodology was developed where weather that was experienced during the period when accelerometry was conducted (April 28 to June 11, 2010) was explored to create specific categories of weather patterns by combining key weather variables.

The synoptic classification has been utilized in other areas of health research,[172-175] where studies exploring the relationship between active living and weather[115-125] have predominantly relied on the analysis of the influence of individual weather variables. This dependence on individual variables such as temperature and precipitation ignores the inter-related nature of weather conditions.[130] The ultimate result is the generation of evidence that fails to factor in actual weather conditions experienced at the study location when the data are collected (Section 5.3.1).

Even though the synoptic classification was not applied in study three, the methodology adopted follows the same rationale. Exploring the data obtained from Environment Canada[176,177] during the period accelerometry was conducted, key weather variables were combined to generate integrated weather categories. With all analyses in study three being conducted utilizing these weather categories as variables, this dissertation sets a precedent of holistically integrating weather in ALR. In fact, study three is serving as a pilot to a CIHR-funded longitudinal study that will examine the influence of urban design and environment on active living in children in all four seasons of Saskatoon.

Although the development of integrated weather categories might seem logical, what is not as apparent is the complexity of integrating accelerometry with localized weather. For logistical reasons, accelerometers in large population health studies are deployed in sequential weeks in cohorts of participants within the total sample.

In fact, this sequential weekly deployment of accelerometers has resulted in the capture of PA and SED data from April to June in 2010 in participants of SCHK. Thus the implementation of accelerometry over a period of time has enabled the weather variation to be captured in this cross-sectional study. This method of integrating accelerometry with localized weather could not only be employed by future cross-sectional studies, but a vast amount of existing cross-sectional accelerometer data could be analyzed by factoring in weather.

6.5 Multilevel Modeling and Statistical Limitations

In terms of multivariable analyses, research that involves urban environment (i.e., neighbourhoods) obligates one to visualize data hierarchically, both for conceptual and statistical rigour.[185-188] Conceptually, to avoid an atomistic fallacy, and statistically, to generate robust estimates,[187] children in studies two and three were visualized to be nested in their respective neighbourhoods of residence and multilevel logistic regression models were fitted to accommodate predictors at both neighbourhood and individual levels (Table 2.3). All models were fitted in HLM7 by Bernoulli distribution of MVPA and SED to depict fixed effects.

In conceptualizing methods to capture the influence of environmental exposures distributed into multiple hierarchies, there is a risk of utilizing advanced statistical techniques that are disconnected from the theory and hypotheses that drive the very research which enables these statistical techniques.[187] The hypotheses of studies two and three concentrate on capturing urban design and environment's influence on PA and SED, and in turn, introduce a number of methods to advance ALR. The focus on urban environment is driven by the neighbourhood built environment of Saskatoon, which is categorized into three types of urban design (Figure 2.1). Thus, even though data were aggregated to correspond with children's neighbourhoods of residence for statistical rigour, the hypotheses of studies two and three are based on the broad division of these neighbourhoods into three types. Consequently, in multilevel models of studies two and three, the urban design of Saskatoon was used as a categorical variable to understand its influence on PA and SED. Therefore, the conceptual background of studies two and three fostered the development of fixed effects models which ensured statistical rigour, but excluded the determination of variation in PA and SED at both hierarchical levels (neighbourhood and individual) of multilevel models.

Apart from conceptual mechanisms driving multilevel analyses, the sample size restricted multilevel modeling to fixed effects due to lack of convergence in models. For instance, PA, SED and weather data were accumulated to their respective weeks of accelerometry and not modeled as daily observations nested within individuals (e.g. random effects). Still, even though this might be construed as limiting the statistical depth of the data available on individual days, the focus of ALR is not activity accumulated on a single day, but understanding activity patterns over a period of time. Similarly, in terms of understanding weather variation's influence on PA and SED, the focus is not on individual weather days, but on how weather variation over a period of time influences PA and SED.

Finally, lack of convergence also prevented building more complex models by introducing within and between hierarchical level interaction variables. Nevertheless, the multilevel models utilized in this dissertation do capture the influence of a diverse set of environmental variables to highlight a statistically rigorous analytical method to conduct ALR.

Chapter 7: Future Directions and Conclusions

In working towards understanding the complex pathways through which environmental exposures influence PA and SED in all age groups, utilizing technology driven novel methods to measure and evaluate ALR has the potential to drive future research. While associations between activity accumulation and urban environment have been established [25-27,34,35] and corroborated by the findings in this dissertation, there is still a lack of clarity in two areas: ***how*** activity is accumulated within different environmental and social contexts, and ***where*** specifically (neighbourhood, indoor/outdoor, playground, recreational facility etc…) activity is accumulated. Without understanding the immediate environmental, social and spatial contexts within which PA and SED occur, active living interventions will miss their mark in effecting behaviour change.

Recently studies have been emerging which utilize ecological momentary assessments[166] to understand the multifaceted environmental and social associations of activity accumulation. Ecological momentary assessments enable research participants to report behaviours of interest such as PA and SED recurrently at specific points or periods that are relevant to the research questions. Although technological advances in methods might generally be associated with increased objectivity, ecological momentary assessments deployed through smart phones can obtain critical subjective assessments as well. Such assessments could complement accelerometry by gathering time stamped contextual information from study participants. For example, when combined with accelerometry, ecological momentary assessments could derive what type of activity was responsible for different intensities of PA and SED.

Furthermore, these assessments could also aid in connecting the type, intensity and frequency of activity with important environmental and social contexts such as parental and peer support. Thus, technological advances have the potential to increase the scientific rigour, and as well as enable mixed-methods ALR.

Similarly, linking accelerometry with global positioning systems[167-169] could provide objective time stamped spatial context to the accumulation of PA and SED. Currently, participants' activity is predominantly associated with a specific spatial category (i.e., neighbourhoods, homes, etc.) based on the research questions. For example, in this dissertation, children's activity was associated with the type of neighbourhoods in which they resided and this association does not confirm if the activity was accumulated within their neighbourhoods or elsewhere. Global positioning systems equipped accelerometry would supersede such existing methods by providing an objective insight into ***where*** participants accumulate activity.

Ecological momentary assessments and global positioning systems can transform the implementation of active living interventions by closing critical gaps in evidence. However, both these methods could be construed as intrusive, especially among children, and large sets of digital data[189,190] obtained through such measures could pose new challenges in terms of protecting participant confidentiality. Thus, it is imperative to develop a framework of ethics to enable appropriate and transparent use of technologically advanced methods in ALR.

Beyond providing subjective context to PA and SED, ecological momentary assessments can also facilitate mixed-methods capture of built environment.[191,192] That is, currently used observational survey audits (Appendix A and B) and objective, global information system-enabled built environment measures[113] could be combined with subjective, ecological assessments of participants' perception of their built environment. The use of ecological momentary assessments could be of particular importance in child and adolescent-centric ALR where children's changing perception of environment could not only be effectively captured, but also be compared with parental perception.

Finally, the Foresight report[180] report points towards a system sciences approach[196-198] in advancing ALR, where policy interventions are not only multi-faceted, but also inter-disciplinary and inter-sectoral. However, this endeavour is complicated by the fact that policy interventions can yield unpredictable results, and in an ideal world, a simulation of the results of policy interventions before implementation could provide a never before achieved foresight.

This ability to pre-inform policy could be enabled by computational modeling,[196-198] where dynamic policy-based hypotheses could be operationalized before policy implementation to delineate the implications of specific interventions. However, operationalizing such computational models requires inordinately large sets of data. Fortunately, specific to ALR, this need for large data could be addressed by one promising solution ─ the global growth of smart phones.[199] Smartphones have a built-in set of diverse sensors such as accelerometers that can be repurposed[168-169] to collect rich longitudinal behavioural and outcome "big data". The innovative approach of using smartphone based sensor data to conduct system sciences-based ALR could inform a wide range of population health interventions targeting health inequities.

In conclusion, this dissertation makes a valuable contribution to the existing literature, and indicates the importance of ALR extending beyond cross-sectional examinations. In particular, this can be accomplished by conceptualizing longitudinal investigations that take into account overlapping environmental exposures, including the cyclical variation in weather throughout the year. Ultimately, such advancement in study design, aided by technology driven novel mixed-methods, could not only confirm existing associations, but also establish causality in ALR.

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APPENDIX A

Neighbourhood Active Living Potential

Built Environment Measurement Tool I

Neighbourhood **A**ctive **L**iving **P**otential

Neighbourhood: ________________________________

Observer: ________________________________

Time In: ________________ Time Out: ________________

1. Number of Destinations

1	2	3	4	5	6
None	Few	Some	Adequate	Many	Very Many

Notes: ____

____

2. Variety of Destinations

1	2	3	4	5	6
Homogenous	Mostly Homogenous	Somewhat Homogenous	Somewhat Mixed	Mixed	Highly Mixed

Notes: ____

____

3. Inclusive of Pedestrians

1	2	3	4	5	6
Highly not Inclusive	Mostly not Inclusive	Somewhat not Inclusive	Somewhat Inclusive	Mostly Inclusive	Highly Inclusive

Notes: ____

____

4. Exclusive of Pedestrians

1	2	3	4	5	6
Highly not exclusive	Mostly not exclusive	Somewhat not exclusive	Somewhat exclusive	Mostly exclusive	Highly exclusive

Notes: ____

____

5. Social Dynamic – Likelihood of Interaction

1	2	3	4	5	6
Highly not likely	Mostly not likely	Somewhat not likely	Somewhat Likely	Mostly Likely	Highly Likely

Notes: ____

____

6. Street Network Addresses Pedestrian Needs

1	2	3	4	5	6
Highly not addressed	Mostly not addressed	Somewhat not addressed	Somewhat Addressed	Mostly Addressed	Highly Addressed

Notes: ____

____

7. Street Network Limits Pedestrians

1	2	3	4	5	6
Highly not limited	Mostly not limited	Somewhat not limited	Somewhat limited	Mostly limited	Highly Limited

Notes: ____

____

8. Street Network Addresses Cyclist's Needs

1	2	3	4	5	6
Highly not addressed	Mostly not addressed	Somewhat not addressed	Somewhat Addressed	Mostly Addressed	Highly Addressed

Notes: ____

____

9. Street Network Limits Cyclists

1	2	3	4	5	6
Highly not limited	Mostly not limited	Somewhat not limited	Somewhat limited	Mostly limited	Highly Limited

Notes: ____

____

10. Transportation System Connections

1	2	3	4	5	6
Highly not connected	Mostly not connected	Somewhat not connected	Somewhat Connected	Mostly Connected	Highly Connected

Notes: ____

____

11. Environmental Stimulus

1	2	3	4	5	6
Highly not Stimulating	Mostly not Stimulating	Somewhat not Stimulating	Somewhat Stimulating	Mostly Stimulating	Highly Stimulating

Notes: ____

____

12. Stimulus Impact - Overwhelming

1	2	3	4	5	6
Highly not Overwhelming	Mostly not Overwhelming	Somewhat not Overwhelming	Somewhat Overwhelming	Mostly Overwhelming	Highly Overwhelming

Notes: ____

____

13. Visual Interest

1	2	3	4	5	6
Highly not Interesting	Mostly not Interesting	Somewhat not Interesting	Somewhat Interesting	Mostly Interesting	Highly Interesting

Notes: ____

____

14. Effort to Walk Around

1	2	3	4	5	6
Highly not Difficult	Mostly not Difficult	Somewhat not Difficult	Somewhat Difficult	Mostly Difficult	Highly Difficult

Notes: ______________________________

____

15. Effort to Bicycle Around

1	2	3	4	5	6
Highly not Difficult	Mostly not Difficult	Somewhat not Difficult	Somewhat Difficult	Mostly Difficult	Highly Difficult

Notes: ______________________________

____

16. Options for Action in Case of Physical Danger

1	2	3	4	5	6
None	Few	Some	Adequate	Many	Very Many

Notes: ______________________________

____

17. Perception of Safety from Crime

1	2	3	4	5	6
Highly not Threatening	Mostly not Threatening	Somewhat not Threatening	Somewhat Threatening	Mostly Threatening	Highly Threatening

Notes: ______________________________

____

18. Threat of Traffic to Pedestrians

1	2	3	4	5	6
Highly not Threatening	Mostly not Threatening	Somewhat not Threatening	Somewhat Threatening	Mostly Threatening	Highly Threatening

Notes: ______________________________

____

19. Threat of Traffic to Cyclists

1	2	3	4	5	6
Highly not Threatening	Mostly not Threatening	Somewhat not Threatening	Somewhat Threatening	Mostly Threatening	Highly Threatening

Notes: ______________________________

____

20. Accessibility of path/sidewalk/ walking surface for people with disabilities

1	2	3	4	5	6
Not at all Accessible	Mostly not Accessible	Somewhat not Accessible	Somewhat Accessible	Mostly Accessible	Completely Accessible

Notes: ______________________________

21. Are the crossing signals and other signs adapted for people with disabilities

1	2	3	4	5	6
Not at all Adapted	Mostly not Adapted	Somewhat not Adapted	Somewhat Adapted	Mostly Adapted	Completely Adapted

Notes: ____________________

22. Are the surroundings adapted for people with disabilities

1	2	3	4	5	6
Not at all Adapted	Mostly not Adapted	Somewhat not Adapted	Somewhat Adapted	Mostly Adapted	Completely Adapted

Notes: ____________________

APPENDIX B

Irvine Minnesota Inventory

Built Environment Measurement Tool II

Segment # (insert at top of column)															
	Date														
	Time in														
	Observer														
	Neighbourhood														
	Weather	Clear =7; Mainly Sunny =6; Mainly Cloudy =5; Overcast =4; Light Rain =3; Showers =2;													
	Wind	Calm = 1; Light wind = 2; Strong wind = 3													
	If this segment is adjoining other segments, indentify which ones.														
Take pictures at the beginning of the segment															
Answer questions 1 - 6 based on this end of the segment															
1a	What street/avenue/etc. is this segment?														
1b	What is the cross street at the beginning of the segment?														
Street Crossing															
2a	Consider the places at this end of the segment that are intended for pedestrians to cross the street. Are these places marked for pedestrian crossing? If no skip to 2e.	all =2; some=1; none = 0; cul de sac = 8													
2b	What type of marking do the crosswalks have?														
	Pedestrian crossing sign	yes = 1; no = 0; NA = 8													
	White painted lines	yes = 1; no = 0; NA = 8													
	Zebra striping	yes = 1; no = 0; NA = 8													
	Raised Crosswalk	yes = 1; no = 0; NA = 8													
	Different road surface or paving (i.e. tiles,colored concrete, etc.)	yes = 1; no = 0; NA = 8													
	Illuminated overhead sign	yes = 1; no = 0; NA = 8													
	Curb bulb out	yes = 1; no = 0; NA = 8													
	Other - describe	yes = 1; no = 0; NA = 8													
2c	What is the condition of these crossings?	good = 3; fair = 2; poor = 1; none = 0													
2d	Is the sidewalk connected to the crosswalk?	all =2; some=1; none = 0; N/A = 8													
2e	Is the sidewalk connected to the road?	all =2; some=1; none = 0; N/A = 8													
3a	Are there curb cuts at all places where crossing is expected to occur?	all =2; some=1; none = 0													
3b	Are curb cuts graded for visual impairments?	all =2; some=1; none = 0; N/A = 8													
3c	In the absence of curb cuts are there nearby alleys/ driveways that could be used instead?	yes = 1; no = 0; NA = 8													
3d	What is the condition of the curb cuts?	good = 3; fair = 2; poor = 1; NA = 8													

3e	Are the curb cuts connected to the crosswalks?	all =2; some=1; none = 0; N/A = 8													
Segment # (insert at top of column)															
4a	Is this an uncontrolled intersection? If yes skip to 4c.	yes = 1; no = 0													
4b	Indicate if the following traffic/pedestrian signals/systems are present and/or functional. Mark all that apply.														
	Traffic signal	present and functional = 2; present = 1; absent = 0													
	Stop sign	present and functional = 2; present = 1; absent = 0													
	Yield sign	present and functional = 2; present = 1; absent = 0													
	Pedestrian activated signal	present and functional = 2; present = 1; absent = 0													
	Pedestrian underpass/overpass/bridge	present and functional = 2; present = 1; absent = 0													
	Number countdown	present and functional = 2; present = 1; absent = 0													
	Audio assisted signals for visual impairments	present and functional = 2; present = 1; absent = 0													
	Flashing hand	present and functional = 2; present = 1; absent = 0													
4c	How many vehicle lanes are there for cars? (including lanes intended for driving and turning).	Six or more= 6; five= 5; four = 4; three = 3; two = 2; one = 1; NA (no lanes for car travel) = 8													
5	For an individual who is on this segment how safe (traffic wise) do you think it is to cross the street from this segment?	very safe = 2; moderately safe = 1; unsafe = 0; cul de sac = 8													
6	For an individual who is on this segment how convenient (traffic wise) do you think it is to cross the street from this segment?	very convenient = 2; moderately convenient = 1; inconvenient = 0; cul de sac = 8													
Neighbourhood Identification															
7	Does the segment have banners that identify the neighbourhood?	yes = 1; no = 0													
8a	Is this segment a . . .	one way = 1; two way = 2													
8b	Is this a pedestrianized street?	yes = 1; no = 0													
9a	Is there a pedestrian refuge?	yes = 1; no = 0													
9b	Is the pedestrian refuge accessible?	yes = 1; no = 0; NA = 8													
Views															
10	If there a significant open view rate its attractiveness.	attractive = 3; neutral = 2; unattractive = 1; NA (no views) = 8													
Take a picture of the open view.															
11	What types of dwellings are present on this segment? Mark all that apply. If no dwellings skip to 12.														

	Single Family Detatched (1 unit)	yes = 1; no = 0; NA = 8													
Segment # (insert at top of column)															
	Single Family Duplex (2 units)	yes = 1; no = 0; NA = 8													
	Townhouse/condo/apartment (3+ Units)	yes = 1; no = 0; NA = 8													
	Mobile/manufactured Home	yes = 1; no = 0; NA = 8													
	Other - describe	yes = 1; no = 0; NA = 8													
12	How many buildings on this segment have front decks or balconies?	some/a lot = 2; few = 1; none = 0													
13a	How many buildings have garage doors facing the street?	some/a lot = 2; few = 1; none = 0													
13b	Are garages dominating the streetscape?	yes = 1; no = 0; NA = 8													
14	Mark off all types of public space on this area and rate their attractiveness. If none skip to 15.	yes = 1; no = 0													
	Plaza or square	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
	Playground	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
	Landscaped open space	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
	Playing fields	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
	Community garden/allotment	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
	Other - describe	attractive = 3; neutral = 2; unattractive = 1; NA = 8													
15a	Are there greenbelts/trails/paths other than sidewalks connected to the segment? If no paths skip to 16.	yes = 1; no =0													
15b	Please indicate if the path/trail is . . .														
	Unsealed	yes = 1; no =0													
	Sealed	yes=1; no = 0													
	Elephant	yes = 1; no =0													
	Other - describe	yes=1; no = 0													
16	Are any of the following other elements present? Mark all that apply. If no skip to 17.	yes = 1; no = 0													
	Abandoned building/house/lot	yes=1; no = 0													
	Undeveloped land	yes = 1; no = 0													
	Agricultural land/farming	yes=1; no = 0													

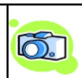
	Renovation/construction	yes = 1; no = 0													
	Railway Tracks	yes=1; no = 0													
	Utility Substation	yes = 1; no = 0													
Segment # (insert at top of column)															
	Transformer Box	yes = 1; no = 0													
	Other - describe	yes=1; no = 0													
17	Are there nature features present on this segment? If no skip to 18a.	yes = 1; no = 0													
	Open Field (not playing field)	yes=1; no = 0													
	Lake/Pond	yes = 1; no = 0													
	Fountain/Reflecting Pool	yes=1; no = 0													
	Stream/River/Canal/Creek	yes = 1; no = 0													
	Forest/Woods	yes=1; no = 0													
	Other - describe	yes = 1; no = 0													
18a	Is this segment exclusively residential?	yes=1; no = 0													
18b	Are there schools? Mark all that apply. If no skip to 18c.	yes=1; no = 0													
	Elem/Middle/Junior High	yes = 1; no = 0													
	High School/ Collegiate	yes=1; no = 0													
	University/College/Institute	yes = 1; no = 0													
	Daycare/Childcare	yes=1; no = 0													
	Other - describe	yes = 1; no = 0													
18c	Are there recreational/leisure/fitness facilities? Mark all that apply. If no skip to 18d.	yes=1; no= 0													
	Gym/Fitness Center (incl yoga)	yes = 1; no = 0													
	Indoor Arena	yes=1; no= 0													
	Indoor Community Pool	yes = 1; no = 0													
	Golf course	yes=1; no= 0													
	Outdoor Community Pool	yes = 1; no = 0													

	Outdoor Hockey Arena	yes=1; no= 0													
	Other - describe	yes = 1; no = 0													
18d	Are there public/civic buildings present? Mark all that apply. If no skip to 18e.	yes=1; no= 0													
Segment # (insert at top of column)															
	Community Centre/ Civic Centre	yes = 1; no = 0													
	Library	yes=1; no= 0													
	Museum	yes = 1; no = 0													
	Auditorium/Concert Hall	yes=1; no= 0													
	Theater	yes = 1; no = 0													
	Post Office	yes=1; no= 0													
	Police Station	yes = 1; no = 0													
	Courthouse	yes=1; no= 0													
	Community Service Organizations	yes=1; no= 0													
	Firehall	yes = 1; no = 0													
	Other - describe	yes=1; no= 0													
18e	Are there any institutional uses? Mark all that apply. If no skip to 18f.	yes = 1; no = 0													
	Religious Institution	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Healthcare/Medical Clinic including dental or vision.	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Other	Six or more= 3; three to five= 2; one to two= 1; zero=0													
18f	Are there any commercial uses? Mark all that apply. If no skip to 18g.	yes=1; no= 0													
	Retail Stores	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Bank/Financial Service	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Hotel	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Car Dealership	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Gas/Service station	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Pharmacy	Six or more= 3; three to five= 2; one to two= 1; zero=0													

	Home Business	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Other	Six or more= 3; three to five= 2; one to two= 1; zero=0													
18g	Office	Six or more= 3; three to five= 2; one to two= 1; zero=0													
18h	Services	Six or more= 3; three to five= 2; one to two= 1; zero=0													
18i	Are there any industrial/manufacturing elements? If no skip to 19a.	yes = 1; no = 0													
Segment # (insert at top of column)															
	Light(paint, fabric)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Med/Heavy industrial (chemicals, oil)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
19a	Determine whether any of these distinctive retail types are present (focusing on the form of the building).														
	Big Box Shops (includes super stores or warehouse stores)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Shopping Mall	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Stripmall/Row of shops	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Drive thru	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Vertical mixed use	Six or more= 3; three to five= 2; one to two= 1; zero=0													
19b	How many of these land uses are present on this segment?														
	Bars/Night Clubs	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Adult Uses	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Cheque Cashing Stores	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Pawn Shops	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Liquor Stores	Six or more= 3; three to five= 2; one to two= 1; zero=0													
19c	How many of the following gathering places are on this segment?														
	Bookstores	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Art or Craft Galleries	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Movie Theatre	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Games Room	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Other - describe	Six or more= 3; three to five=													

20a	Are there food outlets/stores on this segment? If no then skip to 21.	yes = 1; no = 0													
20b	Are any of the following restaurant types are present? If none skip to 20c.	yes = 1; no = 0													
	Type 1 (i.e., limited menu/preparation/fast food, McDonald's, KFC, Orange Julius)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Type 2 (i.e., restaurants, Kelsey's, BP's)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Type 3 (i.e., banquet facilities, hotels, buffets)	Six or more= 3; three to five= 2; one to two= 1; zero=0													
20c	How many ethnic restaurants are present?	Six or more= 3; three to five= 2; one to two= 1; zero=0													
Segment # (insert at top of column)															
20d	How many of the following specialty shop types are present? If none skip to 20e.	yes = 1; no = 0													
	Coffee Shop	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Bakery	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Butcher	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Deli	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Farmers' market	Six or more= 3; three to five= 2; one to two= 1; zero=0													
20e	Are any of the following types of stores are present? If none skip to 20f.	yes = 1; no = 0													
	Convienence Store	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Grocery Store	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Ethnic Grocery Store	Six or more= 3; three to five= 2; one to two= 1; zero=0													
	Other - describe	Six or more= 3; three to five= 2; one to two= 1; zero=0													
20f	Are there outdoor dining areas on this segment? (e.g. outdoor tables at coffee shops or plazas, cafés, etc.)	yes = 1; no = 0													
20g	How many street vendors or stalls are on this segment?	some/a lot = 2; few = 1; none = 0													
Transportation															
21a	Is there a public transportation hub or bus transit mall on this segment?	yes = 1; no = 0													
21b	How many bus stops are on this segment? If none skip to 22a.	Three of more = 3; two = 2; one=1; none = 0													
21c	How many bus routes service this segment?	Six or more= 3; three to five= 2; one to two= 1; zero=0													
21d	At the bus stop, is there a . . .														
	Bench	yes = 1; no = 0; NA = 8													

	Shelter	yes = 1; no = 0; NA = 8													
	Route Map	yes = 1; no = 0; NA = 8													
Bicycle Lanes															
22a	Are there bicycle lanes on the segment? If no skip to 23a.	yes = 1; no = 0													
22b	How are the bicycle lanes demarcated? Mark all that apply.														
	Paint	yes = 1; no = 0; NA = 8													
	Signage	yes = 1; no = 0; NA = 8													
	Other - describe	yes = 1; no = 0; NA = 8													
22c	What is the quality of the demarcation?	good = 3; fair = 2; poor = 1; NA = 8													
Segment # (insert at top of column)															
22d	Is the bike lane maintained?	yes = 1; no = 0; NA = 8													
23a	Are there bike parking facilities available on this segment?	yes = 1; no = 0													
23b	How many bikes can be parked at these facilities?	1-5 = 1; 6-15 = 2; 16+ = 3; NA = 8													
23c	How many bikes are currently parked on this segment?	0 =0; 1-5 = 1; 6-15 = 2; 16+ = 3													
23d	How safe do you feel it is for a bike to ride on this segment?	very safe = 2; pretty safe = 1; unsafe = 0;													
24	Is there a snow route on this segment?	yes = 1; no = 0													
Barriers															
25a	Are any barriers found on this segment? If no skip to 26a.	yes = 1; no = 0													
25b	Heavy traffic	no barrier = 0; can be overcome = 1; can be somewhat overcome = 2; cannot be overcome = 3													
25c	Freeway	no barrier = 0; can be overcome = 1; can be somewhat overcome = 2; cannot be overcome = 3													
25d	Railway	no barrier = 0; can be overcome = 1; can be somewhat overcome = 2; cannot be overcome = 3													
25e	Road Construction	no barrier = 0; can be overcome = 1; can be somewhat overcome = 2; cannot be overcome = 3													
25f	Other - describe	no barrier = 0; can be overcome = 1; can be somewhat overcome = 2; cannot be overcome = 3													

	Take a picture of the barrier														
Sidewalks															
26a	How many sides of the street have sidewalks?	two = 2; one = 1; none = 0													
26b	Is the sidewalk complete on one or both sides?	both = 2; one = 1; neither = 0													
26c	What is the condition or maintenance of the sidewalk?	good = 3; fair = 2; poor = 1; NA = 8													
26d	At any point along the segment do driveways, alley ways or parking lot entrances affect the quality of the sidewalks?	yes = 1; no = 0; NA =8													
26e	Is this segment universally accessible on one or both sides?	both = 2; one = 1; neither = 0													
26f	Please indicate if any of the following buffers are present.														
	Parked cars	yes = 1; no = 0													
	Grass	yes = 1; no = 0													
	Trees	yes = 1; no = 0													
Segment # (insert at top of column)															
	Landscaped buffer strip	yes = 1; no = 0													
	Paving, Bricks and/or concrete, gravel	yes = 1; no = 0													
	Other buffer - describe	yes = 1; no = 0													
Mid Block Crossing															
27a	Is there a marked mid block crossing for pedestrians? If no skip to 28.	yes = 1; no = 0													
27b	What type of marking does this crosswalk have?														
	White painted lines	yes = 1; no = 0; NA = 8													
	Zebra striping	yes = 1; no = 0; NA = 8													
	Different road surface or paving (i.e. tiles,colored concrete, etc.)	yes = 1; no = 0; NA = 8													
	Signage	yes = 1; no = 0; NA = 8													
	Overhead illuminated sign	yes = 1; no = 0; NA = 8													
	Pedestrian crossing sign	yes = 1; no = 0; NA = 8													
	Other - describe	yes = 1; no = 0; NA = 8													
Steepness															
28	How steep or hilly is this segment? Mark all that apply.	steep slope = 2; moderate slope = 1; flat or gentle slope = 0													
Sidewalk Amenities															
29a	Are there benches (not a bus stop), chairs and/or ledges for sitting on this segment?	yes = 1; no = 0													

			1	2	3	4	5	6	7	8	9	10	11	12	13
29b	Are there public pay phones on this segment?	yes = 1; no = 0													
29c	Are there newspaper boxes on this segment?	yes = 1; no = 0													
29d	Are there mailboxes on this segment?	yes = 1; no = 0													
29e	Is there an ATM on this segment?	yes = 1; no = 0													
29f	Are there public garbage cans/recycling receptacles on this segment?	yes = 1; no = 0													
29g	Are there obvious public restrooms on this segment that are clearly open to the public?	yes = 1; no = 0													
29h	Indicate if any of these sidewalk obstructions are present. Mark all that apply. If no skip to 30a.	yes = 1; no = 0													
	Poles or signs	yes = 1; no = 0													
	Parked cars	yes = 1; no = 0													
	Greenery	yes = 1; no = 0													
	Garbage cans	yes = 1; no = 0													
	Construction/rennovation	yes = 1; no = 0													
	Street lights	yes = 1; no = 0													
	Other - describe	yes = 1; no = 0													
Street Trees															
30a	How many street trees are on this segment? (Only include trees that are on the public right of way).	some/a lot = 2; few = 1; none = 0													
Segment # (insert at top of column)															
30b	Is the sidewalk shaded by trees?	completely = 2; partially = 1; no shade = 0													
Buildings															
31a	How many storeys are most buildings on the segment?	5 or more = 3; 3-4 = 2; 1-2 = 1; heights vary, no predominant height = 0; NA = 8													
31b	Are the facades adapted to human scale?	some/a lot = 2; few = 1; none = 0													
31c	How much of this segment has blank walls or buildings with blank walls (include fences)?	some/a lot = 2; few = 1; none = 0													
32	Does at least 50% of the segment have buildings?	yes = 1; no = 0													
Parking															
33	Are there parking facilities, including parking lots, visible on this segment (do not include parking structures that are completely underground)?	yes = 1; no = 0													
34	Is there an overpass/underpass connected to this segment?	yes = 1; no = 0													
Traffic features															
35a	Is there a posted speed limit on this segment? Only include those on the segment itself.	yes = 1; no = 0													
35b	What is the posted speed?	less than 20 = 1; 20-40 = 2; more than 40 = 3; more than one speed limit posted = 4; NA = 8													
36	Are there measures on this segment that could slow down traffic? Mark all that apply. If no skip to 37a.	yes = 1; no = 0													
	School Zone sign/ playground ahead sign	yes = 1; no = 0													
	Speed bump/hump/dip	yes = 1; no = 0													

	Raised Crosswalk	yes = 1; no = 0													
	Roundabout	yes = 1; no = 0													
	Curb bulb/extensions	yes = 1; no = 0													
37a	Is there a cul-de-sac or permanent street closing on this segment?	yes = 1; no = 0													
37b	Is there a pedestrian access point or cut through point that allows pedestrians to go from one segment to another (even though vehicular traffic may not be able to)?	yes = 1; no = 0													
37c	Is there an alley?	yes = 1; no = 0													
37d	Do any of the alley or parking lot entrances pose a danger to pedestrians?	yes = 1; no = 0; NA= 8													
Other features of the segment															
38	Is there public art that is visible on this segment?	yes = 1; no = 0													
39	Are there billboards or large signs present on this segment?	yes = 1; no = 0													
Olfactory/Aural Character															
40a	Is the predominant smell unpleasant?	yes = 1; no = 0													
40b	Do you hear any of the following overwhelming sounds? If no skip to 41.														
	Planes	constant = 3; intermittent = 2; minimal = 1; none= 0													
	Trains	constant = 3; intermittent = 2; minimal = 1; none = 0													
	Automobiles	constant = 3; intermittent = 2; minimal = 1; none = 0													
Segment # (insert at top of column)															
	Sirens	constant = 3; intermittent = 2; minimal = 1; none = 0													
	Industrial	constant = 3; intermittent = 2; minimal = 1; none = 0													
Safety															
41	How many buildings on this segment have windows with bars? (proportion)	some/a lot = 2; few = 1; none = 0													
42	Are there poorly maintained buildings on this segment?	yes = 1; no = 0													
43a	How much graffiti is apparent on this segment?	some/a lot = 2; few = 1; none = 0													
43b	Are there gang signs or markers present?	yes = 1; no = 0													
Take a representative picture of the graffiti															
44a	How much litter is apparent on this segment?	some/a lot = 2; few = 1; none = 0													
44b	Are there needles or drug paraphernalia present?	yes = 1; no = 0													
45	Are there dumpsters visible on this segment?	some/a lot = 2; few = 1; none = 0													

46	Is there visible electrical wiring overhead on the segment?	yes = 1; no = 0													
Lighting															
47	Is there outdoor lighting on the segment? (Include lighting that is intended to light public paths and public spaces)	yes = 1; no = 0													
48	Please indicate if the lighting is . . .														
	Human scale	yes = 1; no = 0; NA = 8													
	Vehicle scale	yes = 1; no = 0; NA = 8													
People															
49	Are there any lurking places present on this segment?	yes = 1; no = 0													
50	How safe do you feel from crime on this segment?	very safe = 2; pretty safe = 1; unsafe = 0;													
51	Are there opportunities for passive surveillance?	some/a lot = 2; few = 1; none = 0													
Dogs															
52a	Are there any loose/unsupervised/barking dogs on this segment that seem menacing?	yes = 1; no = 0													
52b	Are there "Beware of Dog" signs present?	some/a lot = 2; few = 1; none = 0													
	Take a picture of the intersection at this end of the segment														
53	What is the cross street at the end of the segment?														
Answer questions 54-59 based on this end of the segment															
Street Crossing															
54a	Consider the places at this intersection that are intended for pedestrians to cross the street. Are these places marked for pedestrian crossing? If no skip to 54e. If cul de sac skip to 57.	all =2; some=1; none = 0; cul de sac = 8													
54b	What type of marking do the crosswalks have?														
	Pedestrian crossing sign	yes = 1; no = 0; NA = 8													
	White painted lines	yes = 1; no = 0; NA = 8													
	Zebra striping	yes = 1; no = 0; NA = 8													
	Raised Crosswalk	yes = 1; no = 0; NA = 8													
Segment # (insert at top of column)															
	Different road surface or paving (i.e. tiles,colored concrete, etc.)	yes = 1; no = 0; NA = 8													
	Illuminated overhead sign	yes = 1; no = 0; NA = 8													
	Curb bulb out	yes = 1; no = 0; NA = 8													
	Other - describe	yes = 1; no = 0; NA = 8													
54c	What is the condition of these crossings?	good = 3; fair = 2; poor = 1; none = 0													
54d	Is the sidewalk connected to the crosswalk?	all =2; some=1; none = 0; N/A = 8													
54e	Is the sidewalk connected to the road?	all =2; some=1; none = 0; N/A = 8													
55a	Are there curb cuts at all places where crossing is expected to	all =2; some=1; none = 0; N/A													

55b	Are curb cuts graded for visual impairments?	all =2; some=1; none = 0; N/A = 8													
55c	In the absence of curb cuts are there nearby alleys/driveways that could be used instead?	yes = 1; no = 0; NA = 8													
55d	What is the condition of the curb cuts?	good = 3; fair = 2; poor = 1; NA = 8													
55e	Are the curb cuts connected to the crosswalks?	all =2; some=1; none = 0; NA = 8													
56a	Is this an uncontrolled intersection? If yes skip to 56c.	yes = 1; no = 0													
56b	Indicate if the following traffic/pedestrian signals/systems are present and/or functional. Mark all that apply.														
	Traffic signal	present and functional = 2; present = 1; absent = 0													
	Stop sign	present and functional = 2; present = 1; absent = 0													
	Yield sign	present and functional = 2; present = 1; absent = 0													
	Pedestrian activated signal	present and functional = 2; present = 1; absent = 0													
	Pedestrian underpass/overpass/bridge	present and functional = 2; present = 1; absent = 0													
	Number countdown	present and functional = 2; present = 1; absent = 0													
	Audio assisted signals for visual impairments	present and functional = 2; present = 1; absent = 0													
	Flashing hand	present and functional = 2; present = 1; absent = 0													
56c	How many vehicle lanes are there for cars? (including turning lanes)	six or more = 6; five = 5; four = 4; three = 3; two = 2; one = 1; NA (no lanes for car travel) = 8													
57	For an individual who is on this segment how safe (traffic wise) do you think it is to cross the street from this segment?	very safe = 2; moderately safe = 1; unsafe = 0; cul de sac = 8													
58	For an individual who is on this segment how convenient (traffic wise) do you think it is to cross the street from this segment?	very convenient = 2; moderately convenient = 1; inconvenient = 0; cul de sac = 8													
	Time out														

APPENDIX C

Research Ethics Approval Documents

UNIVERSITY OF SASKATCH EWAN

Behavioural Research Ethics Board (Beh-REB)

Certificate of Re-Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	Beh #
Nazeem Muhajarine	Community Health and Epidemiology	09-211

INSTITUTION (S) WHERE RESEARCH WillBE CARRIED OUT

University of
Saskatchewan Saskatoon
SK

SUB-INVESTIGA TOR(S)

Bill Holden, Karen Chad. Cordel l Neudorf, Adam Baxter-Jones, Scott Be!L Kathryn Green, Lauren Sherar, Dale Charlie Clark, Pau l Han ley, Linda Manin. Kelley Moore. Sara Kirk, Tracey R idalls, Jostein Misfeldt, Ross Minett, Kristjana Loptson

SPONSORING AGENCIES

CANADIAN I NSTITUTES OF HEALTH RESEARCH (Cll-IR)

TITLE

Working Upstream: Effecti ng Health Children Through Neighbourhood Design

RE-APPROVED ON	EXPIRY DATE
21-Sep-2010	21-Oct-201 I

Full Board Meeting

Delegated Review _

CERTIFICATION

The University of Saskatchewan Behavioural Research Ethics Board has reviewed the above-named research project The proposal was found to be acceptable on eth ical grounds. The princi pal investigator has the responsi bil ity for any other ad m in istrati ve or regu latory approvals that may pertain to th is research project. and for ensuring that the authorized research is carried out accord ing to the conditions outl ined in the original protocol subm itted for ethics review. Th is Certificate of Approval is val id for the above time period provided there is no change i n experimental protocol or consent process or d ocuments.

Any sign ificant changes to your proposed method, or your consent and recruitment proced ures shou ld be reponed to the Chair for Research Ethics Board consideration i n ad vance of its implementation.

ONGOING REVIEW REQUIREMENTS

In order to receive annual renewaL a status report must be subm itted to the REB Chair for Board consideration with in one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the followi ng website for further instructions: http:;iwww. usask. calresearch/eth icsreview/

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University. 1607 110 Gymnasium Place
Saskatoon. SK S7N 4J8
Phune (306) %6-2975 Fax (306) 966-2069

UNIVERSITY OF SASKATCHEWAN

Behavioural Research Ethics

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	BEH#
Nazeem Muhajarine	Community Health and Epidemiology	14-187

INSTITUTION(S) WHERE RESEARCH WILL BE CONDUCTED
University of Saskatchewan

STUDENT RESEARCHER(S)
Tarun Katapally

FUNDER(S)
UNIVERSITY OF SASKATCHEWAN COLLEGE OF MEDICINE

TITLE
Advancing Active Living Research in Children: Addressing Active Living Measurement and Evaluation while Investigating the Influence of Diverse Environmental Exposures on Physical Activity and Sedentary Behaviour

ORIGINAL REVIEW DATE	APPROVAL ON	APPROVAL OF:	EXPIRY DATE
02-Jun-2014	02-Jun-2014	Application for Behavioural research Ethics Review Secondary analysis of de-identified data from BEH 09-211	01-Jun-2015

Full Board Meeting O

Delegated Review

CERTIFICATION
The University of Saskatchewan Behavioural Research Ethics Board has reviewed the above-named research project. The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to the conditions outlined in the original protocol submitted for ethics review. This Certificate of Approval is valid for the above time period provided there is no change in experimental protocol or consent process or documents.

Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

ONGOING REVIEW REQUIREMENTS
In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current date each the remains open, and upon study completion. Please refer to the following website for further instructions: http://www.usask.ca/research/ethics_review/

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University, 1602-110 Gymnasium Place
Saskatoon SK S7N 4J8
Telephone: (306) 966-2975 Fax: (306) 966-2069

APPENDIX D

Consent forms

Dear Parents and Guardians,

We are conducting a three year research project entitled *Smart Cities, Healthy Kids* (www.smartcitieshealthykids.ca). Up to this point our research has been focused on learning about the neighbourhoods in Saskatoon by observing them. For example, we have been visiting neighbourhoods around the city, and looking at what kinds of opportunities there are for children to be active in them. We have also looked at neighbourhood safety, traffic safety, and places that children might want to walk to, like schools, parks or stores.

This next phase of the research project has two parts. The first part involves your child completing two questionnaires. The first questionnaire will ask your child to tell us what fitness activities he or she has participated in within the last 4 weeks. The second questionnaire will ask your child about his or her perceptions of what may or may not allow him or her to participate in fitness activities. This first part of the project should take about an hour. Our research assistants will travel to your child's school, and assist children in filling out the questionnaires during class time. For the first part of the research project, we will be collecting information from about 3000 Saskatoon children between the ages of 10 and 13.

In the second part of the study, we will ask 400 of these 3000 children to wear an accelerometer that we provide, and keep a log of their fitness activities for seven days. An accelerometer is a small device that measures movement levels -- whenever your child moves, the accelerometer will keep track of that movement and record the information for us. Children do not have to wear the accelerometer when they are sleeping, bathing, swimming or boating.

When we finish the study, we will use the results to write reports and academic articles and make presentations and recommendations to city planners, so they have more information on how they can design new neighbourhoods and modify existing ones so that children and families can be more active in them. Your child's participation is completely confidential, and there will be no way to identify an individual child from the reports, articles and presentations that we give. When we report results we will only be reporting on groups of children that will not be individually identified or identifiable. School counsellors will be made available to discuss issues that may evolve from questionnaires with at risk children.

When the study is finished, the completed questionnaires and accelerometer results will be kept by the principal investigator, Dr. Nazeem Muhajarine, a research faculty member of the Saskatchewan Population Health and Evaluation Research Unit (SPHERU, www.spheru.ca) in a locked cabinet at the University of Saskatchewan for five years. Your child's participation in this study is voluntary, and you are free to withdraw him or her from the study at any time. Your child is free not to answer any question if they so choose, or to withdraw at any time from the study without any penalty or loss of services from their school or from the University of Saskatchewan. If you or your child withdraws, then all the data already collected on your child will be destroyed. Once the data collection is complete and the data has been analyzed participants and parents will be invited to information sessions conducted at each school to see the results of the study.

For more information, you may contact the Research Ethics Office at the University of Saskatchewan (966-2084), Tracy Ridalls, Research Coordinator for the *Smart Cities, Healthy Kids* study at 966-2237 (office) Tracy.ridalls@usask.ca, or the Principal Investigator, Dr. Nazeem Muhajarine, Department of Community Health and Epidemiology, University of Saskatchewan (966-7940) Nazeem.muhajarine@usask.ca. Please feel free to call collect if necessary. This research has been approved by the University Advisory Committee on Ethics in Behavioural Sciences Research on October 22, 2009.

Please keep page one for your records and, if you are willing to allow your child to participate, sign page two and return it to your child's teacher.

Part 1 – Questionnaires
If you are willing to allow your child to participate by completing the two questionnaires in the first part of the study, please sign your name and fill in the date.

I,___________(print name)_______________understand the guidelines as described to me, and agree to let _____________(child's name)_ ______________________participate in the questionnaire portion of the research study. In addition, I understand that I can choose to withdraw my child from the study at any time without penalty or loss of services from my child's school or from the University of Saskatchewan.

Parent or Guardian's signature _______________________________ Date___________________

Part 2 - Accelerometry
If you are willing to allow your child to participate by wearing an accelerometer and keeping a log of their activities for 7 days in the second part of the study, please sign your name and fill in the date. Please note that although we are asking for your permission for this part of the study, your child may not be selected to participate in this part of the study.

I,___________(print name)_______________understand the guidelines as described to me and agree to let _____________(child's name)_ ______________________participate in the accelerometry portion of the research study. In addition, I understand that I can choose to withdraw my child from the study at any time without penalty or loss of services from my child's school or from the University of Saskatchewan.

Parent or Guardian's signature _______________________________ Date___________________

Researcher Date: February 16th, 2010

You are invited to participate in a study entitled ***Smart Cities, Healthy Kids***. Please read this form carefully, and make sure to ask any questions you might have.

Who is doing the research study? Dr. Nazeem Muhajarine, Saskatchewan Population Health and Evaluation Research Unit (SPHERU), University of Saskatchewan (966-7940) nazeem.muhajarine@usask.ca

What is this study about? The purpose is to find out how kids your age (between 10 and 13 years old) keep active and what helps them to stay active.

You will be asked to fill out two questionnaires. One will ask you about the kinds of fitness activities you participate in and the second will ask you questions about yourself, the food you eat, the activities you do and how you feel about participating in fitness activities. You will not have to put your name on any of the forms.

The forms will be filled out during school time but are not a part of your regular class work. It will take about an hour of your time to complete the questionnaires. For the first part of the research project we will be collecting information from about 3000 Saskatoon children between the ages of 10 and 13.

For the second part of the research 400 kids will be asked to wear something called an accelerometer for 7 days and to keep track of what kind of activities they are participating in during that time. An accelerometer is something that records movement; for instance, how many steps you are taking, if you are running or if you are not moving. This information will help us learn what kinds of activities kids like to do and how much energy they use up doing activities.

Why should I bother? It is your choice to take part in the study or not. Deciding to participate in the study or not will not have any impact on your school participation or grades. Good things that can come out of being part of the study include being a part of important research, and providing some clues to others about what kind of programs could be helpful to kids in your community.

Who will see the info I fill out? The forms will be completed anonymously (that means that no names will be asked for or included anywhere in the forms, except for this assent form and the form to be filled out by your parents). Your identity will remain secret. Kids from schools across the whole city are included in the study, so particular areas or groups of kids are not targeted by the study. The forms that you fill out will only be looked at by the researchers. Information learned from the study will only be written up as a summary of all people completing the forms. That means that individual people cannot be identified by the information. Information from individual people will not be included in the write-up. When we are all done collecting information, we will write about it in papers and articles and give presentations so that more people will learn about how you and other kids play and what kinds of stuff you like to do. We will not use your name on any of the papers that we produce and no one will be able to know that you participated in the project unless you tell them. When we are done Dr. Nazeem Muhajarine, Saskatchewan Population Health and Evaluation Research Unit (SPHERU), will keep all the questionnaires and other information locked up at the University of Saskatchewan for five years.

What if I start and then decide I want to quit? Taking part in the study or not is up to you. If you get started and then decide that you do not want to be part of it anymore, that's okay. If you withdraw from the study at any time, any information that you have filled out will be destroyed at your request. It is up to you if you want to answer these questions or not and you can stop whenever you want. You are free not to answer any question if you so choose, or to quit the study at any time and no one will be upset or angry with you.

If something bothers you any part of the project you can tell your parents about it and they can phone one of the names on the bottom of this paper School counsellors will be made available to discuss issues that may evolve from questionnaires with at risk children. Once the data collection is complete and the data has been analyzed participants and parents will be invited to information sessions conducted at each school to see the results of the study.

For more information, you may contact the Research Ethics Office at the University of Saskatchewan (966-2084), Tracy Ridalls, Research Coordinator for the *Smart Cities, Healthy Kids* study at 966-2237 (office), or the Principal Investigator, Dr. Nazeem Muhajarine, Department of Community Health and Epidemiology, University of Saskatchewan (966-7940). Please feel free to call collect if necessary. This research has been approved by the University Advisory Committee on Ethics in Behavioural Sciences Research on October 22, 2009.

If you want to take part in filling out the questionnaires please print your name below.

Child's name ______________________ Date__________________

If you would like to take part in wearing an accelerometer for 7 days please print or sign your name below.

Child's name______________________ Date__________________

Researcher Date: February 16th, 2010

APPENDIX E

Smart Cities Healthy Kids Questionnaire

University of Saskatchewan - Smart Cities, Healthy Kids Research Project

UNIVERSITY OF SASKATCHEWAN

NOTE TO ALL STUDENTS:

This is a survey with questions about youth physical activity and nutrition. Your answers will help the Smart Cities, Healthy Kids Project learn about how kids like to stay active and what may prevent them from participating in activities. The survey will take approximately 30 minutes to complete.

NBHD-SCHL	CHILD ID
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9

MARKING INSTRUCTIONS

- **Use an HB pencil only.**
- **Do not use ink, ball point, or felt tip pens.**
- **Make solid marks that fill the response completely.**
- **Erase cleanly any marks you wish to change.**

CORRECT: ● **INCORRECT:** ⊘☒◒◔

01091

DO NOT WRITE IN THIS BOX

Section A : About Me and My Family

1. I am a .... ◯ Boy ◯ Girl
2. What grade are you in? .... ◯ 5 ◯ 6 ◯ 7 ◯ 8
3. How old are you? .... ◯ 9 ◯ 10 ◯ 11 ◯ 12 ◯ 13 ◯ 14 ◯ 15
4. What is the name of your School? .... ________________________
5. Please write your **Street Address** .... __________________ (eg. 123 Main Street)

   Please write your **Postal Code** .... __________________ (eg. S7L1E6)

   This information will only be used to confirm your neighborhood.

6. Do you identify as an Aboriginal person (First Nations, Métis, Inuit)? ◯ Yes ◯ No
7. Where do you live most of the time?
   - ◯ Both parents (biological or adopted)
   - ◯ Mother only
   - ◯ Father only
   - ◯ Mother part time/ Father part time
   - ◯ Other relative (Grandmother, Aunt, Uncle, etc.)
   - ◯ Group home or Foster home
   - ◯ Other
8. How many brother and sisters do you have that live with you right now?
   - ◯ None
   - ◯ 2
   - ◯ 4
   - ◯ 6
   - ◯ 1
   - ◯ 3
   - ◯ 5
   - ◯ 7 or more
9. What is the highest level of schooling that your father completed?
   - ◯ Less than high school
   - ◯ Finished high school
   - ◯ Trade School (ex., mechanic, technician, journeyman, librarian)
   - ◯ Some university
   - ◯ Finished university
   - ◯ Don't know or Doesn't Apply
   - ◯ Other

Page 1 of 5 ...

10. What is the highest level of schooling that your mother completed?
- ◯ Less than high school
- ◯ Finished high school
- ◯ Trade School (ex. mechanic, technician, journeyman, librarian)
- ◯ Some university
- ◯ Finished university
- ◯ Don't know or Doesn't Apply
- ◯ Other

11. Would you describe your family's money situation as (please choose only one answer):
- ◯ Wealthy
- ◯ Average
- ◯ Difficult
- ◯ Poor
- ◯ Don't know

	Excellent	Very Good	Good	Fair	Poor
12. In general would you say that your health is:	◯	◯	◯	◯	◯

13. Is it hard for you to do physical activities because of health problems that have lasted 6 months or longer?
- ◯ Yes
- ◯ No
- ◯ Don't Know/Not Sure

14. This next question is about your weight. Choose the answer that is closest to how you feel:
- ◯ I think I'm overweight (by 5 pounds or more)
- ◯ I think my weight is Okay
- ◯ I think I'm underweight (by 5 pounds or more)

15. How well are you doing in school this year?
- ◯ Above average
- ◯ Average
- ◯ Below average

16. This year, where have most of your marks been?
- ◯ 90% or higher
- ◯ 80 - 89%
- ◯ 70 - 79%
- ◯ 60 - 69%
- ◯ 50 - 59%
- ◯ 49% or lower

Section B. About My Family

17. In the **last 30 days** how often did you see any of your family members participate in sports or exercise?
- ◯ Never
- ◯ Once or Twice
- ◯ 3 or 4 times
- ◯ 5 times or more

18. In the ~~last 30 days~~ how often have your family members (mom, dad, grandma, grandpa, brothers, sisters etc.)...

	Never	Once or Twice	3 or 4 Times	5 times or more
a. Said that you were good at the physical activities that you did?	◯	◯	◯	◯
b. Got upset about the physical activities that you did?	◯	◯	◯	◯
c. Said that physical activity was good for you?	◯	◯	◯	◯
d. Offered to be active with you? (ex. ride bikes, throw a ball, etc.)	◯	◯	◯	◯
e. Ordered you to be active?	◯	◯	◯	◯
f. Paid for programs or equipment to help you stay active?	◯	◯	◯	◯
g. Helped you to learn or improve the skills you use when you are being active (ex. for playing sports)?	◯	◯	◯	◯
h. Talked to you about how much fun physical activity is?	◯	◯	◯	◯
i. Watched you participate in physical activity or play sports?	◯	◯	◯	◯
j. Encouraged you to do sports or physical activity?	◯	◯	◯	◯
k. Provided transportation to a place where you can do physical activity?	◯	◯	◯	◯
l. Done a physical activity or played sports with you (ex. walked or biked)?	◯	◯	◯	◯

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19. During a typical week, how often:	Never	1-2 days	3-4 days	5-6 days	Every Day	I have no siblings
a. Do your brother(s) and/or sister(s) encourage you to do sports or exercise?	○	○	○	○	○	○
b. Do your brother(s) and/or sister(s) do physical activity or play sports with you?	○	○	○	○	○	○

Section C. About My Friends

20. During a typical week, how often:	Never	1-2 days	3-4 days	5-6 days	Every Day
a. Do your friends encourage you to do sports or physical activities?	○	○	○	○	○
b. Do your friends do physical activities or play sports with you?	○	○	○	○	○
c. Do your friends or classmates tease you about not being good at physical activities or sports?	○	○	○	○	○
d. Do your friends ask you to walk or to bike to school or to a friend's house?	○	○	○	○	○
e. Do your friends tell you that you are doing well in physical activities or sports?	○	○	○	○	○

21. In the **last 30 days**, how often:	Never	1-2 days	3-4 days	5-6 days	Every Day
a. Did you see any of your friends participate in physical activity?	○	○	○	○	○
b. Did any of your friends say that physical activity was good for you?	○	○	○	○	○
c. Did any of your friends force you to be active?	○	○	○	○	○
d. Did any of your friends help you to learn/improve the skills that you use to be active?	○	○	○	○	○
e. Did any of your friends come to watch you when you were doing physical activity?	○	○	○	○	○
f. Did any of your friends say that you were good at doing physical activity?	○	○	○	○	○

22. How many of your closest friends exercise regularly?

○ None ○ 1-2 Friends ○ 3-4 Friends ○ 5 or More Friends

Section D: Reasons I might not be active

23. How often have the following things kept you from being active?

	Never	Rarely	Sometimes	Often	Always
a. I felt lazy	○	○	○	○	○
b. I didn't feel like it	○	○	○	○	○
c. It makes me look uncool	○	○	○	○	○
d. I didn't have the money	○	○	○	○	○
e. The activity is not close to my home	○	○	○	○	○
f. I couldn't get a ride	○	○	○	○	○
g. I didn't have enough time	○	○	○	○	○
h. I had too much homework	○	○	○	○	○
i. It gets in the way when I want to hang out with friends	○	○	○	○	○
j. I was injured	○	○	○	○	○
k. The weather was bad	○	○	○	○	○
l. The equipment was broken	○	○	○	○	○
m. I had family responsibilities (ex. chores, looking after brother or sister, etc.)	○	○	○	○	○
n. The area was not safe	○	○	○	○	○
o. It was too crowded	○	○	○	○	○

Section E: About Me and Activities

24. In an average week, when you are in school, on how many days do you go to gym classes?

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

25. In an average week, about how many hours a day, in total, do you watch TV, videos/DVDs, play video games or use the computer?

○ I don't have any screen time in a day ○ Less than 1 hour a day ○ 1 to 2 hours a day
○ 3 to 4 hours a day ○ 5 to 6 hours a day ○ 7 or more hours a day

26. In the **last 30 days** how often have you:	Never	1 or 2 times	3 or 4 times	5 times or more
a. Played sports or done physical activities **without** a coach or an instructor (ex. biking, skateboarding, etc.)?	○	○	○	○
b. Played sports **with** a coach or instructor other than in gym class? (ex. swimming lessons, baseball, hockey, etc.)?	○	○	○	○
c. Taken part in dance, gymnastics, karate, or other groups or lessons other than in gym class?	○	○	○	○
d. Taken part in art, drama, or music groups, clubs, or lessons?	○	○	○	○
e. Taken part in clubs or groups such as Guides or Scouts, 4-H club, community, church or other religious groups?	○	○	○	○
f. Done a hobby or craft (ex. drawing, model building, etc.)?	○	○	○	○

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Section F: Where I go to do activities

27. Here is a list of places where people can exercise. Which ones do you go to that are somewhere you could **walk** or **ride your bike** to easily? (Mark all that apply)

- ◯ Fitness facility
- ◯ Basketball court
- ◯ Bike lane or trails
- ◯ Golf Course
- ◯ Public park
- ◯ Running track
- ◯ Skating rink/outdoor rink
- ◯ Swimming Pool
- ◯ Walking/hiking trails
- ◯ Tennis courts
- ◯ Dance studio
- ◯ Playing field (soccer, football, softball, etc.)
- ◯ Other
- ◯ There are no places close to my house

28. For the places that you marked in **Question 27**, how often would you walk or bike to these places in a typical month?

◯ Once a month ◯ 2-4 times a month ◯ 5 or more times a month

29. How long does it take you to walk to the closest park from your house?

◯ Less than 5 mins ◯ 5-10 mins ◯ 10-20 mins ◯ More than 20 mins

30. In the **last 30 days**, how often have you walked or biked to school?

- ◯ Never
- ◯ Once a week
- ◯ Two to four times a week
- ◯ Every day

31. When you didn't walk or bike to school was it because (Mark as many reasons as apply) ...

- ◯ School is too far from my house
- ◯ I didn't have time
- ◯ My parents or guardians drove me
- ◯ The weather wasn't good for walking or biking
- ◯ I take the bus instead
- ◯ I was sick or injured and couldn't walk or bike
- ◯ It was not safe
- ◯ Other - explain ______________________

32. In a typical week, how much time do you spend walking	Less than an hour	About an hour	1-5 hours	More than 5 hours
a. For fun (ex. just walking with friends)	◯	◯	◯	◯
b. To do errands(ex. going to get the mail or to the store)	◯	◯	◯	◯
c. To get someplace (ex. to the park or playground)	◯	◯	◯	◯

33. How often do you walk or bike to each of the following places in a typical week?

	Never	1-2 times	3-4 times	5 or more times
a. Corner store/Convenience Store	◯	◯	◯	◯
b. Bus stop	◯	◯	◯	◯
c. Library	◯	◯	◯	◯
d. Church or place of worship	◯	◯	◯	◯
e. Friend or relatives' house	◯	◯	◯	◯
f. Restaurant	◯	◯	◯	◯
g. Shopping Mall	◯	◯	◯	◯
h. Grocery store	◯	◯	◯	◯
i. Entertainment outlet (ex.Video store, Ruckers, Movie Theatre, etc.)	◯	◯	◯	◯

34. If you answered **'Never'** to any of the options in **Question 33,** mark as many of the following reasons that apply....

- ◯ It is too far from my house
- ◯ I didn't have time
- ◯ My parents or guardians drove me
- ◯ The weather wasn't good for walking or biking
- ◯ I took the bus instead
- ◯ I was sick or injured and couldn't walk or bike
- ◯ It was not safe
- ◯ Other - explain ______________________

35. Please fill in the circle beside each item that you have in your home, yard or apartment complex. (Mark all that apply).

- ◯ Treadmill, Stair climber, Stationary Bike
- ◯ Bicycle (for outside)
- ◯ Trampoline
- ◯ Running shoes
- ◯ Swimming Pool
- ◯ Step aerobics, Slide aerobics
- ◯ Ice Skates or Roller Blades
- ◯ Balls or Racquets
- ◯ Weight lifting equipment (ex. free weights, Nautilus, Universal)
- ◯ Snowboard
- ◯ Canoe, row boat, kayak
- ◯ Skis (snow or water)
- ◯ Basketball hoop
- ◯ Backyard rink
- ◯ Hockey nets or sticks
- ◯ Wii fit or Dance Dance revolution
- ◯ I have no equipment

36. How much do you agree with the following statements?

	Strongly Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Strongly Agree**
a. At home there are enough supplies and pieces of sports equipment (like balls, bicycles, skates) to use for physical activity....................	◯	◯	◯	◯
b. It is difficult to walk or jog in my neighbourhood because of things like traffic, no sidewalks, gangs, etc.	◯	◯	◯	◯
c. There are playgrounds, parks, or gyms, that are close to my home or that I can get to easily	◯	◯	◯	◯
d. It is safe to walk or jog in my neighbourhood during the day	◯	◯	◯	◯
e. It is safe to ride my bike on the road in my neighbourhood	◯	◯	◯	◯

37. Please fill in the circle beside each item on the list that is found in your neighbourhood. (Mark all that apply).

- ◯ Sidewalks
- ◯ Heavy Traffic
- ◯ Hills
- ◯ Street lights
- ◯ Dogs that are loose
- ◯ Enjoyable scenery/Parks
- ◯ Frequently see people walking or exercising
- ◯ High Crime

38. How **safe** do you feel **walking** in your neighbourhood during the day?

◯Very Unsafe ◯Pretty Unsafe ◯Safe ◯Pretty Safe ◯Very Safe

39. How **safe** do you feel **riding your bike** in your neighbourhood during the day?

◯Very Unsafe ◯Pretty Unsafe ◯Safe ◯Pretty Safe ◯Very Safe

40. How **safe** do you feel **crossing the street** in your neighbourhood during the day?

◯Very Unsafe ◯Pretty Unsafe ◯Safe ◯Pretty Safe ◯Very Safe

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41. How **easy** is it to **cross the street** in your neighbourhood during the day?

- Very hard
- Pretty hard
- Pretty easy
- Very Easy

Section G: Food I eat

42. In the **last 30 days**, how often did you eat breakfast before you came to school?

- Seldom or never
- 1-2 times a week
- 3-4 times a week
- 5 times a week

43. In the **last 30 days**, how often did you go hungry because there was not enough food?

- Never
- Rarely
- Sometimes
- Most of the time
- Always

44. In the **last 30 days**, how many times per day did you eat fruit?

- I did not eat fruit in the last 30 days
- Less than one time per day
- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- 5 or more times per day

45. In the **last 30 days**, how many times per day did you eat vegetables?

- I did not eat vegetables in the last 30 days
- Less than one time per day
- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- 5 or more times per day

46. In the **last 30 days**, how many times per day did you drink pop, fruit drinks or energy drinks?

- I did not drink pop, fruit drinks or energy drinks in the last 30 days
- Less than one time per day
- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- 5 or more times per day

47. In the **last 30 days**, how many times per day did you drink milk (including soy milk and rice milk)?

- I did not drink milk in the last 30 days
- Less than one time per day
- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- 5 or more times per day

48. In the **last 30 days**, how many times per day did you eat food from a fast food restaurant; include food that you ordered in as take out (ex. McDonalds, KFC, Taco Time, Pizza Hut, etc.)?

- I did not eat fast food in the last 30 days
- Less than one time per day
- 1 time per day
- 2 times per day
- 3 times per day
- 4 times per day
- 5 or more times per day

49. What do you think your school can do to help kids your age become more physically active?

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50. Can you tell us what you think would make the park closest to your house better?

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51. Is there anything else you would like to share with us about being physically active?

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THE END

☺ THANK YOU FOR YOUR HELP! ☺