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Children's Physical Activity and the Built Environment: The Impact of Neighbourhood Opportunities and Contextual Environmental Exposure

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Graduate Program in Geography
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Abstract

Childhood obesity rates have risen dramatically since 1981, in part due to decreased physical activity (PA) levels. Research suggests that PA is influenced in part by an individual's exposure to and engagement with their built environment. Using a multi-tool protocol, this thesis examines how (a) neighbourhood opportunities facilitate or constrain children's moderate-to-vigorous PA (MVPA) and (b) contextual environmental exposure facilitates or constrains children's MVPA. Results suggest that children's MVPA is influenced by their built environment, but more so by the contextual environments that they are exposed to rather than their overall neighbourhood settings. Children are mobile and unlikely to never leave their neighbourhood, especially considering that more parents are driving their children to activities outside their neighbourhood. Examining contextual environmental exposure is a novel approach that should be used by researchers to clarify the settings that exert an influence on children's MVPA.

Keywords

Children; physical activity; built environment; GPS; GIS; accelerometer; neighbourhood; environmental exposure

Co-Authorship Statement

Each integrated article within this thesis will be submitted for publication in peer-reviewed journals. Chapters 3 and 4 were written by Christine Mitchell, with Dr. Jason Gilliland and Dr. Andrew Clark as co-authors. Christine Mitchell is the primary author and performed all data collection, analysis, and writing in each article. Dr. Jason Gilliland designed the original STEAM study, and both Dr. Gilliland and Dr. Clark were involved in the development of procedures for the analyses in all studies. Below are the journal targets for both integrated articles.

Chapter 3: Mitchell, C.A., Clark, A.F., & Gilliland, J.A. (2016). Built Environment Influences on Children's Physical Activity: Examining Differences by Neighbourhood Size and Sex. *International Journal of Environmental Research and Public Health*, 13(1), doi: 10.3390/ijerph13010130.

Chapter 4: Mitchell, C.A., Clark, A.F., & Gilliland, J.A. Examining the Influence of Contextual Environmental Exposure on Children's Physical Activity: A Novel Geospatial Approach from the STEAM Project. Prepared for *Pediatrics*.

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Chapter 1

1 Introduction

1.1 Research Context

Childhood and adolescent obesity rates in Canada have increased alarmingly over the past 30 in part due to decreased physical activity (Chaput et al., 2012; Janssen & LeBlanc, 2010). According to Tremblay (2010), “Children are taller, heavier, fatter and weaker than in 1981” (p. 11). Statistics Canada (2013) has found that 31% of children and youth aged 5-17 years old are overweight or obese, with boys being more likely to be obese than girls. The growing rate of obesity among children is particularly problematic because obesity is a risk factor for numerous health problems, including insulin resistance, type II diabetes, hyperlipidemia, liver disease, hypertension, orthopaedic complications, and polycystic ovary disease (Dietz, 1998). In addition to these physical health consequences, obesity is associated with sleep disorders (e.g. sleep apnea) and psychological outcomes including low self-esteem, depression, and increased anxiety (Dietz, 1998). These health problems are an economic burden on the Canadian health care system. The total direct costs of obesity on the Canadian public health care system have been estimated at \$6.0 billion in 2006, approximately 4.1% of the total health expenditures in Canada (Anis et al., 2010).

Obesity results from an energy imbalance which occurs when the energy consumed exceeds the energy expended (Hall et al., 2011). Physical activity is one of the complex factors that influence obesity as it increases energy expenditure (Davison & Birch, 2001). Regular physical activity during childhood helps to mitigate the risk factors associated with cardiovascular disease, including obesity, high cholesterol, and type II diabetes (Janssen & LeBlanc, 2010; Shaibi, Faulkner, Weigensberg, Fritschi, & Goran, 2008). It is important that children establish active lifestyles early because physical activity patterns developed during childhood are likely to persist into adulthood (Telama et al., 2005). In Canada, only 13% of boys and 6% of girls between the ages of 5 and 17 meet

Canada's recommended physical activity guidelines of 60 minutes of moderate-to-vigorous physical activity [MVPA] during most days of the week (Statistics Canada, 2015; Tremblay et al., 2011).

Current research suggests that physical activity is influenced in part by an individual's exposure to and engagement with their built environment; the built environment can constrain or facilitate physical activity by providing opportunities for children to be physically active (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Forsyth, Michael Oakes, Lee, & Schmitz, 2009; Giles-Corti, Kelty, Zubrick, & Villanueva, 2009; Handy, Cao, & Mokhtarian, 2008; Papas et al., 2007). Researchers from a number of fields, including urban planning, public health, epidemiology, and geography are interested in exploring the relationship between the environment and children's physical activity in an effort to reduce obesity levels among children. Consequently, a large body of work has developed over the last decade which focuses on how the built environment facilitates or constrains children's physical activity. Understanding how the built environment influences physical activity can strategically inform interventions that target population health (Sallis et al., 2006).

A large body of research has focused on neighbourhood settings in particular, and how the neighbourhood opportunities present within a child's neighbourhood around their home influences their physical activity levels. This body of research suggests that the neighbourhood affects children's health beyond individual- or family-level characteristics. For example, Tucker et al. (2009) found that greater access to neighbourhood recreational opportunities facilitates children's physical activity. Yet, Kwan (2012) cautions that research focusing only on neighbourhood settings may miss how children's mobility impacts the environments they use. Children are able to move around for normal activities and are unlikely to stay in one area throughout their day. As a result, children are able to move through neighbourhood boundaries and can be impacted by neighbourhoods beyond their home neighbourhood (Kwan, 2012). Researchers have been recently trying to clarify how children's built environmental

exposure - the spaces that use for physical activity regardless of neighbourhood boundaries - influences their physical activity levels. The recent development of portable location monitoring devices like Global Positioning Systems (GPS) allows researchers to directly record children's use of space in real time (Krenn, Titze, Oja, Jones, & Ogilvie, 2011; Maddison & Ni Mhurchu, 2009). In doing so, researchers are now able to move past just examining neighbourhood settings for physical activity and examine children's exposure to their environments in the context of physical activity.

This thesis aims to provide insight about the role of the physical environment on children's physical activity by examining both the neighbourhood opportunities that facilitate or constrain children's physical activity behaviours, as well as the environments that they are exposed to for physical activity. In doing so, this thesis hopes to provide more spatial accuracy about the environments that exert an influence on children's physical activity.

1.2 Theoretical Framework

In the past, physical activity research and practice have been dominated by frameworks and theories concerning the psychological and social influences on behaviour, such as Social Cognitive Theory, the Theory of Planned Behaviour, the Self-Determination Theory and the Transtheoretical Model (Glanz, Rimer, & Viswanath, 2008). A brief definition of these theories provided by Glanz et al. (2008) can be found in Table 1.1.

Table 1.1 Dominant theories and frameworks in physical activity research and practice provided by Glanz et al. (2008).

Name of Theory or Framework	Definition
Social Cognitive Theory	Social Cognitive Theory posits that behaviour, cognition, and other personal features have reciprocal relationships with environments. In addition, behaviour is influenced by observing others and receiving reinforcement. Self-efficacy has been found as the most powerful factor to consider when predicting behaviour.
Theory of Planned Behaviour	The Theory of Planned Behaviour posits that intention is the best predictor of behaviour. Intention is determined by one's attitude about the behaviour, perceptions about the behaviour, and perceived control over performing the behaviour.
Self-Determination Theory	Self-Determination Theory focuses on how a person acquires the motivation for starting new health behaviours and maintaining them. This theory states that human behaviour is driven to meet three basic needs: competence, autonomy, and relatedness. When these three basic needs are met, behavioural outcomes will be formed.
Transtheoretical Model	The Transtheoretical Model posits that adopting health behaviours and maintaining them is a cyclical process where individuals move through a series of stages. Each stage is characterized by different psychosocial and behaviour changes.

While these four theories and frameworks have different features, they share the same core principal: all of the models focus on changing the behaviour of the individual. Sallis, Owen, & Fisher (2008) describe how interventions guided by these theories, while effective, are limited by small effect sizes, modest recruitment rates, and poor maintenance of physical activity following the intervention. Consequently, Sallis et al. (2008) emphasize that it is unlikely that these programs will have population-wide impacts on physical activity behaviours.

Thus, there has been a growing interest in ecological models of health for physical activity promotion because they include environment and policy variables that are expected to influence physical activity. Ecological models of health consider that a range of factors at multiple levels ranging from intrapersonal (e.g., age, sex, knowledge, attitudes), interpersonal (e.g., household income, parental education, parental

occupation), environment (built, natural), and policy should be considered when planning and implementing health studies interventions (Sallis et al., 2006; Sallis et al., 2008) (see Figure 1.1).

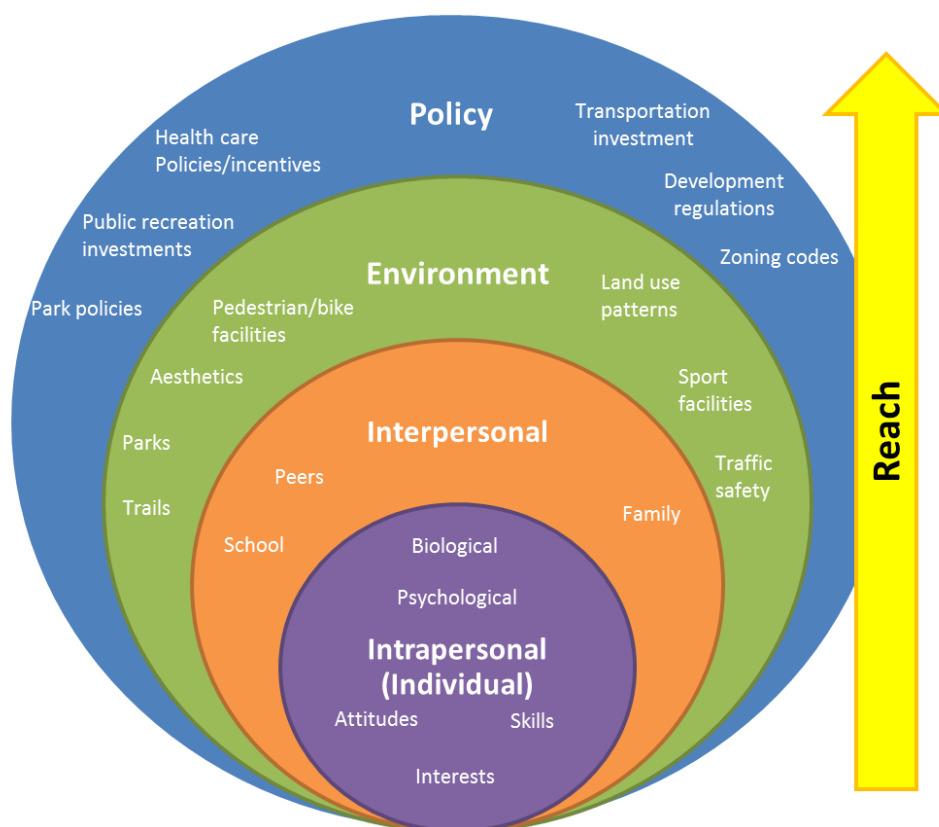


Figure 1.1 Ecological model of physical activity, adapted from Sallis et al. (2006) and Sallis et al. (2008).

Such an approach acknowledges that behaviour is affected by multiple levels of influence and is the primary reason why this thesis is guided by an ecological model of health. Physical activity is a complex health behaviour that affects multiple health outcomes, and the reasons for physical inactivity are in part due to the policy environment, the built environment, and the intrapersonal environment (Sallis et al., 2006). Ecological models are particularly well-suited for studying physical activity because physical activity occurs in specific places (Norman et al., 2006). Therefore, examining characteristics of places that facilitate or constrain physical activity is crucial.

In addition, an ecological model of health guides this thesis because this framework supports outcomes that inform multi-level interventions that target population-wide health behaviours instead of small groups or individuals (Sallis et al., 2008). Sallis et al. (2006) describes how zoning codes, development regulations, and transportation and recreation investment affect whole populations and are more plausible explanations of the widespread development of declining physical activity, while population-wide declines in knowledge, social support, and enjoyment relating to physical activity are less plausible. Consequently, research guided by an ecological model of health has the ability to potentially have population-wide impacts on physical activity behaviours.

1.3 Research Objectives and Questions

The overarching objective of this research is to contribute to the growing body of knowledge linking children's health to their environments. The primary objective of this thesis is to examine how the built environment influences children's physical activity. Specifically, this research aims to understand (1) how neighbourhood opportunities for physical activity facilitate or constrain children's physical activities, and (2) how contextual environmental exposure facilitates or constrains children's physical activity. This understanding is necessary to inform policymakers and decision-makers when deciding zoning codes, development regulations, and public recreation investments.

In order to meet these objectives, this research aims to answer the following research questions:

- (1) How do the opportunity structures present in a child's neighbourhood affect their physical activity levels?
- (2) How does a child's exposure to different features of their environment affect their physical activity levels?

In order to answer these research questions, this research links built environment characteristics to children's physical activity levels in a sample of elementary school children within London, Ontario. Physical activity is a complex health behaviour that is

influenced in part by the individual, neighbourhood socio-demographic, and built environments. Consequently, this thesis hypothesizes that environmental factors (which are influenced by policy factors) may be a cause of population-wide declines in physical activity and, thus, endeavours to uncover how children's physical activity is affected by the environment. This research accounts for several variables known to influence physical activity occurring at the individual and neighbourhood socio-demographic level.

1.4 The STEAM Project

This study draws data from the Spatial Temporal Environment and Activity Monitoring (STEAM) project, a three-year research study examining the effects of the built environment on health-related behaviours of children aged 9-14 years (www.steamproject.ca). This age is a critical life stage when children develop independent mobility and a sense of their own environment (Rissotto & Tonucci, 2002).

This study was approved by the Non-Medical Research Ethics Board of the University of Western Ontario (NM-REB #: 17918S) prior to the onset of the study (see Appendix A). All four school boards the (Thames Valley District School Board, London District Catholic School Board, Conseil scolaire Viamonde, and Conseil scolaire catholique Providence) and a private school (Montessori Academy of London) granted permission through their internal research ethics board to complete the STEAM protocol. Potential recruitment schools were selected to represent different urbanities (urban, suburban, rural), neighbourhood socio-economic status (low, mid, high), and built environments. Principals of the selected schools were asked for their permission to work with the grade 5 and grade 6 classes at their school. Once the principals granted their permission to conduct the STEAM project at their school, researchers gave a presentation that explained the project to recruit students. Students that were interested in the project brought home a letter of information and consent form for their parent and/or guardian (see Appendix B and C).

All children with parental permission for participation signed a child assent form to participate in the study (see Appendix D). During the study period, participants at the elementary schools completed an 8-day multi-tool protocol to record their neighbourhood activities, mobility, and experiences. Participants completed detailed daily activity diaries and wore portable accelerometers and GPS units during all waking hours for up to 8 days. Additionally, children and their parents/guardians completed detailed questionnaires about their demographics and the child's neighbourhood activities, behaviours, and perceptions. Data collected were integrated in a Geographic Information System (GIS) for analysis. Methods are further explained in the each integrated article (Chapter 3 and Chapter 4).

A number of graduate theses have been undertaken using STEAM data to answer questions about how the built environment influences children's healthy behaviours, including healthy eating (Rangel, 2013), sleep (McIntosh, 2014), active transportation (Hill, 2012; Fitzpatrick, 2013; Richard, 2014), neighbourhood mobility and activities (Loebach, 2013), and physical activity (Richard, 2014). This thesis complements these previous theses, but with research and methodological contributions unique to the physical activity literature.

Hill (2012) examined the influence of parents' and children's perceptions of their built and social environments on children's use of active transportation between home and school using survey data in conjunction with built environment variables made using ArcGIS. Similarly, Fitzpatrick (2013) examined the relationship between the built environment and children's active transportation between home and school using child-led perception mapping and ArcGIS analysis to determine how children's perceptions and use of their school neighbourhood varies according to their built environment.

While these theses provide valuable, in-depth information about children's perceptions about their environment, recent theses have also used objective activity monitoring through the use of accelerometry (to measure physical activity) and/or GPS tracking (to identify locations where children went) in order to gain insight about children's

behaviours. Loebach (2013) examined children's environmental perceptions, activities, and mobility within their neighbourhoods using child-led tours, focus groups, qualitative GIS, and GPS-tracking. Rangel (2013) examined different methodologies to characterize children's food environments by comparing network and Euclidean buffers with two measures of activity spaces. McIntosh (2014) examined the relationship between children's sleep duration and greenspace, using ArcGIS to characterize neighbourhood-level greenspace and GPS-tracking to identify the amount of time spent exposed to greenspace. Richard (2014) investigated how active and inactive commute to school impacts rural children's physical activity and bodyweight status while controlling for the home neighbourhood built environment. Richard (2014) used GPS tracking to identify children's routes to school (i.e., their commute), accelerometry to measure physical activity, and ArcGIS to characterize the home built environment.

This thesis complements the aforementioned theses by examining how the built environment influences children's physical activity using a combination of accelerometry, GPS-tracking, and ArcGIS. No other thesis using STEAM data has combined accelerometry and GPS-tracking in a similar way. Although Richard (2014) uses accelerometers to measure physical activity, she used GPS-tracking to identify children's routes to school while this thesis aims to use GPS-tracking to identify the spaces they are exposed to outside of school as a whole.

1.5 Thesis Format

This thesis is presented in an integrated article format, with two independent but complementary studies. Both studies examine how the built environment influences children's physical activity. Both studies involve children from the STEAM project within London, Ontario. While each study has the same overarching objective of examining built environment correlates of physical activity, each study defines the role of the built environment in the context of physical activity differently. In doing so, this thesis aims to provide more spatial accuracy about the environments influence on children's physical activity. Each thesis chapter will be described below:

Chapter 2 reviews existing literature examining children's objectively measured physical activity and the environment using a systematic review format. This review identifies gaps and methodological limitations in the current body of literature in order to justify the need for further research.

Chapter 3 examines how the opportunities present within a child's home neighbourhood facilitate or constrain their objectively measured daily average MVPA during weekdays outside of school hours. The secondary objective of this paper is to assess whether size of neighbourhood and the sex of a child affects associations between the built environment and physical activity during weekdays outside of school hours.

Chapter 4 investigates whether a child's exposure to different environmental contexts affects the proportion of time they spent in MVPA during non-school hours. A novel method is used, whereby a tessellated hexagon surface layer was created and used to spatially aggregate the integrated accelerometer-GPS point data for each individual participant and compare it against the environmental characteristics an individual participant is exposed to in each hexagon. By addressing how contextual environmental exposure influences MVPA, this study examines the micro-environment settings that exert contextual influences on physical activity.

Chapter 5 concludes by synthesizing and connecting the findings from each integrated article. This chapter provides policy implications, research limitations, and offers opportunities for future research.

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Chapter 2

2 A Systematic Review of the Objectively Measured Built Environment in Studies of Objectively Measured Physical Activity: Definitions and Methodological Considerations

2.1 Background

2.1.1 Physical Activity among Canadian Children

Canadian obesity rates have nearly tripled in the last three decades. According to Statistics Canada (2013), 31% of children and youth aged 5-17 years old are overweight or obese, with 15% of boys and 11% of girls classified as overweight or obese. This growing rate of obesity among children is cause for concern because obesity is associated with many negative health outcomes, including physical health and psychological outcomes (Dietz, 1998). Obesity is a complex health problem, with multiple mechanisms. Fundamentally, however, obesity results from an energy imbalance which occurs when the energy consumed exceeds the energy expended (Hall et al., 2011). Physical activity is one of the complex factors influencing obesity as it increases one's energy expenditure (Davison & Birch, 2001).

Canadian children's physical activity levels have decreased significantly since 1981 while rates of adiposity have simultaneously increased (Tremblay et al., 2010). According to the most recent Canadian Health Measures Survey, only 13% of Canadian boys and 6% of Canadian girls aged 5-17 meet Canada's recommended guidelines of accumulating at least 60 minutes of moderate-to-vigorous physical activity (MVPA) during most days of the week (Statistics Canada, 2015; Tremblay et al., 2011). Regardless of sex, physical activity levels have been found to dramatically drop as age increases (Janssen & LeBlanc, 2010; Sallis, Prochaska, & Taylor, 2000; Trost et al., 2002). Moreover, the physical activity habits developed at an early age tend to become habits throughout adulthood (Telama et al., 2005). Together, this evidence emphasizes

the importance of encouraging children to be physically active in order to not only meet the recommended physical activity guidelines but to also develop healthy habits that they can build and maintain over their lifetime.

Two major contributors to children's daily physical activity are the commute to school and participation in organized sports. Children using active modes of travel to and from school are more likely to be more active overall, meet daily MVPA recommendations, and expend more energy when active than those using inactive modes (Faulkner, Buliung, Flora, & Fusco, 2009; Mackett, Brown, Gong, Kitazawa, & Paskins, 2007a). Yet, since 1986, the number of Canadian children using active modes of travel to and from school has decreased (Buliung, Mitra, & Gaulkner, 2009). Similarly, sport participation in Canada has been on the decline since 1992. Boys' participation in sports has declined from 66% in 1992 to 56% in 2005; girls' participation in sports has declined from 49% in 1992 to 45% in 2005 (Clark, 2008).

The physical, emotional, and social benefits of regular physical activity have been well documented. Regular physical activity during childhood can help to reduce body weight, blood pressure, and abdominal fat. Physical activity alleviates the risk factors associated with cardiovascular disease, type 2 diabetes, colon and breast cancer, sleep disorders, and osteoporosis (Janssen & LeBlanc, 2010; Shaibi, Faulkner, Weigensberg, Fritschi, & Goran, 2008; Warburton, Nicol, & Bredin, 2006). Participation in physical activity during childhood is also associated with improved psychological well-being by improving academic performance, and reducing anxiety and depression (Piko & Keresztes, 2006; Warburton et al., 2006).

Current physical activity trends among children are concerning. With mounting evidence looking at the benefits of physical activity and consequences of obesity in concert with trends showing decreasing physical activity among children, the need to understand the complex correlates of physical activity become vital.

2.1.2 Environmental Correlates of Physical Activity

There has been a growing recognition that individuals are influenced not only by intrapersonal characteristics (e.g., age, sex, psychological traits, attitudes) but also by the environments in which they live, play, and travel (Sallis, Owen, & Fisher, 2008).

Physical activity is a complex health behaviour and such an ecological approach recognizes that physical activity is likely to be influenced by a wide range of factors which interact with each other (Sallis et al., 2006). According to Sallis et al. (2008), ecological models that account for both intrapersonal and environmental correlates of physical activity are more appropriate and able to make population-wide changes than those focusing on only intrapersonal factors.

Current research has found that physical activity is influenced in part by the built environment. The built environment can constrain or facilitate physical activity by providing supportive settings for physical activity (Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Forsyth, Michael Oakes, Lee, & Schmitz, 2009a; Giles-Corti, Kelty, Zubrick, & Villanueva, 2009; Susan L. Handy, Boarnet, Ewing, & Killingsworth, 2002; Papas et al., 2007). Previous literature reviews have concluded that while there is evidence of associations between the built environment and physical activity, conceptual and methodological issues have led to inconsistencies about the mechanisms affecting physical activity (Black & Macinko, 2008; Booth, Pinkston, & Poston, 2005; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Papas et al., 2007).

2.1.3 Measuring Physical Activity

Physical activity is typically characterized by type, duration, and intensity (Doherty, 2009). Physical activity can be measured objectively and subjectively. Physical activity can be subjectively measured using self-report tools such as questionnaires and activity diaries (Matthews, 2002; Sallis & Saelens, 2000). Subjective measures of physical activity rely on and are limited by 'recall bias' (i.e. the participants' ability to remember the type, intensity, and duration of their own physical activity) (Doherty, 2009; Montoye, Kemper, Saris, & Washburn, 1996; Reilly et al., 2008; Sallis & Saelens, 2000).

Children's ability to recall their physical activity improves with age, and is considered adequately reliable in children as young as 10 (Sallis, Buono, Roby, Micale, & Nelson, 1993). However, physical activity has been found to be grossly overestimated by both parents and children for self-report measures (Reilly et al., 2008).

Physical activity can be objectively measured using physiological tools (e.g., heart-rate monitors) and passive motion detectors (e.g., accelerometers). Physiological measurement tools measure chemical processes produced by the body during physical activity (e.g. carbon dioxide production) (Montoye et al., 1996). These tools are usually expensive and inconvenient for use at home or in the community and are, therefore, seldom used in studies examining free-living physical activity (Boarnet & Crane, 2005; Dale, Welk, & Matthews, 2002; Montoye et al., 1996). Passive motion detectors provide objective measures of physical activity intensity and duration by detecting body motion. Accelerometers are the most frequently used device for assessing physical activity because of their small size, noninvasive nature, and ability to provide measures of physical activity intensity and duration over extended periods of time (Doherty, 2009; Montoye et al., 1996; Welk, 2002).

2.1.4 Measuring the Environment

Both subjective and objective measures can be used to characterize the built environments hypothesized to influence physical activity. The built environment can be subjectively measured using questionnaires, diaries, or interviews to gather information about environmental perceptions (Saelens, Sallis, Black, & Chen, 2003). In contrast, the built environment can also be objectively measured using a Geographic Information System (GIS) (Krenn, Titze, Oja, Jones, & Ogilvie, 2011).

Although environmental perceptions can provide valuable qualitative data, the reliability of these perceptions have been questioned, particularly when they do not match with objectively gathered built environment data (Leslie, Sugiyama, Ierodiaconou, & Kremer, 2010; Macintyre, Macdonald, & Ellaway, 2008; McGinn, Evenson, Herring, Huston, &

Rodriguez, 2007) Additionally, self-report data may be affected by self-selection bias (Sallis & Saelens, 2000). Children who are more physically active may be more aware of how their environment supports physical activity; consequently, active and inactive children in the same neighbourhood may perceive their neighbourhood differently which may not accurately reflect the true environment.

Technological advances in GIS software offer researchers powerful tools for objective measurement and characterization of the built environment. The built environment can be characterized using GIS to provide measures of environmental attributes, such as recreation amenities, land use, land use mix, road infrastructure, pedestrian infrastructure, transportation infrastructure, and traffic. GIS is considered the most powerful and efficient tool for collecting, synthesizing, and manipulating environmental data for large scale areas (Evenson et al., 2009; Porter, Kirtland, Williams, Neet, & Ainsworth, 2004).

Due to the development of lightweight, affordable Global Positioning System (GPS) data loggers, researchers are now able to provide the contexts for physical activity by examining the environments that children use. Portable GPS loggers produce latitude and longitude coordinates that can be imported into GIS and matched with simultaneous accelerometer data through date/time data recorded by each device (Krenn et al., 2011). Doing so improves our understanding of where children are physically active and for how long (Maddison & Ni Mhurchu, 2009; Rodriguez, Brown, & Troped, 2005). The major limitations of using GPS data are signal loss and imprecise recording due to interference of buildings and/or tree canopies (Krenn et al., 2011). These limitations are being addressed by further technological advancements which improve battery life, positional accuracy, and reception (Krenn et al., 2011).

Outcomes that have been based on subjective measurements of physical activity and/or the environment are prone to reporting bias and may be skewed. While they are useful for gaining insight into perceptions, objective measures of both physical activity and the environment represent a significant step forward in addressing how the built environment influences physical activity.

Given the methodological and conceptual challenges previously found in the literature, the main objective of this review is to clarify how the built environment within the context of physical activity is defined and measured in objective studies of both the environment and physical activity. A secondary objective is to summarize findings from these studies using objective measures of both physical activity and the built environment. A similar review has been conducted before, but the focus of that review was to only assess associations, not methodologies (McGrath, Hopkins, & Hinckson, 2015).

2.2 Methods

2.2.1 Eligibility Criteria

A systematic review was conducted to identify articles published since 2005 that examine the link between the built environment and physical activity and assess how the built environment was conceptualized and measured in the context of physical activity. Eligible studies were identified by searching electronic databases (as of January 2015) and reference lists of relevant articles. The search terms included “environment”, “urban form”, “activity space”, “neighbourhood” “physical activity”, “physical activities”, “physically active” and “active transportation”. Using variations of several key terms was important for obtaining relevant articles. The search terms were combined and applied in four electronic databases: PubMed, Engineering Village (GEOBASE, Inspec, and Compendex), Scopus, and Web of Science. PubMed was used to find studies from health related journals, while Engineering Village was used to find articles in the fields of engineering, applied science, technology, and transportation. Scopus and Web of Science were used to find articles in social and health science journals. Only studies written in English were included.

2.2.2 Search Strategy and Identification of Studies

Articles were required to meet the following inclusion criteria: focused on humans; included an analysis of the relationship between the built environment and moderate-to-

vigorous physical activity (MVPA); used an objective measure of physical activity (i.e., accelerometer or pedometer); used a Geographic Information System (GIS) for an objective analysis of the built environment; were written in English; and had MVPA as an outcome measure. Although direct observation is an objective measure of physical activity, it was not included in the inclusion criteria because it is only able to capture a small proportion of total physical activity in a highly specific context. The definition of the built environment was extended to include features which may be considered the natural environment (e.g., parks and greenspaces). In order to focus on the built environment, social, cultural, and economic environments were not examined; however, if these factors were included alongside the built environment, the article was included for further analysis.

Articles were excluded if they: only used MVPA as a mediating factor; examined only the effectiveness, validity, or reliability of a measure or method (e.g. a methodological assessment of combining global positioning systems (GPS), GIS, and accelerometry); and were set in a clinical/laboratory setting. No studies were excluded on the basis of sex or geographic location.

The initial search yielded 19,585 articles (see Figure 2.1). After examining the titles, 2,710 potentially relevant articles were identified from the electronic databases. Examination of titles resulted in the exclusion of 16,875 articles, while the exclusion of duplicates excluded a further 1,056 articles. Examination of abstracts resulted in the exclusion of 1,235 articles. The full text of 419 articles was assessed, and 314 were found not to meet the inclusion criteria (90 did not use an objective measure of physical activity, a further 197 did not use GIS for objective built environment analysis, and 27 were methodological assessments). A review of the reference lists of relevant articles identified an additional 3 articles for consideration. Of the remaining final 108 studies, 62 studied adults and 46 studied children. This review will focus on the 46 articles that examined children.

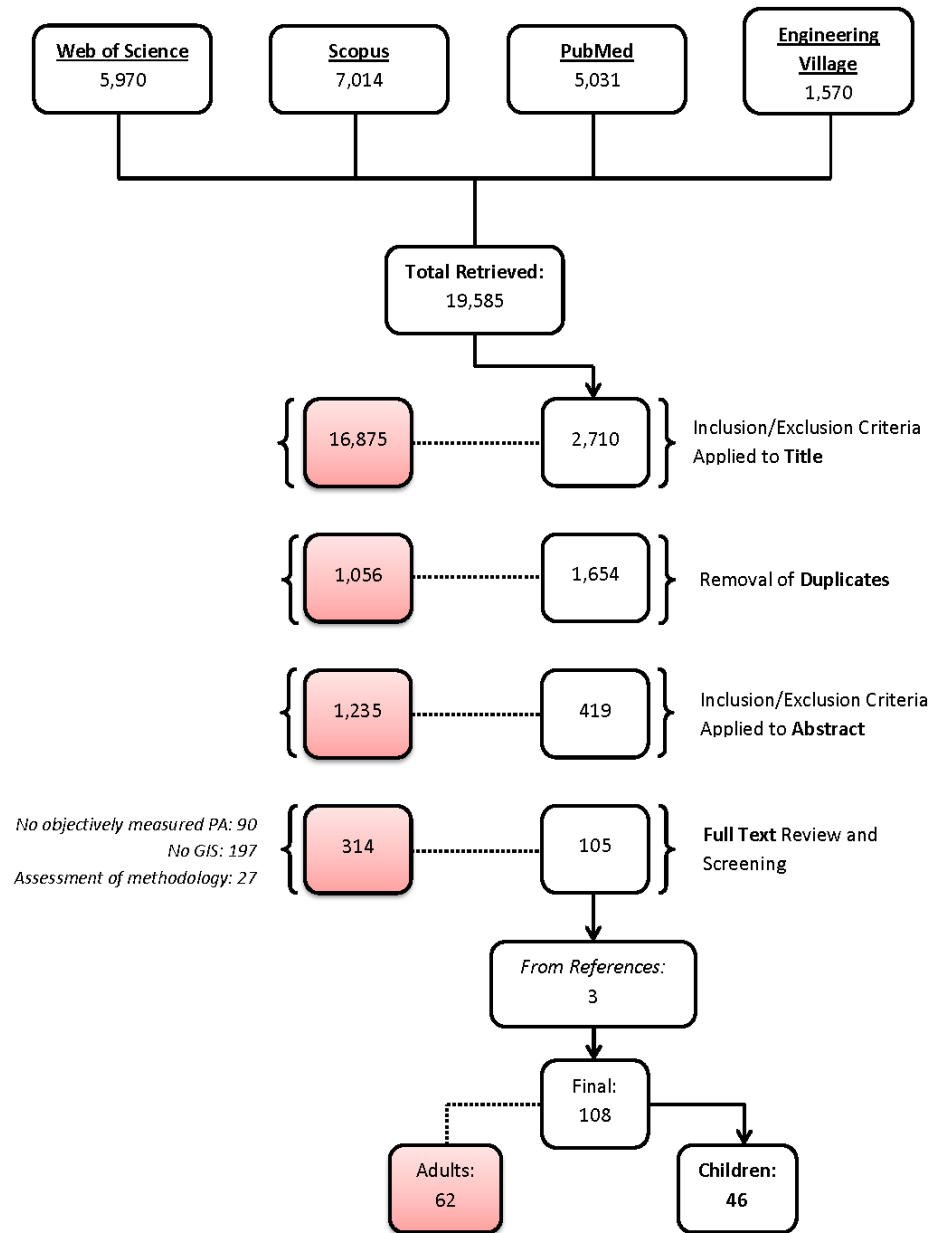


Figure 2.1 Systematic review inclusion/exclusion criteria flow chart

2.2.3 Data Extraction

Data on the study design, study region, total sample size, sample age, year of publication, measures of the environment, measures of physical activity, and findings were extracted for each paper and tabulated (see Appendix i at the end of this chapter). Only results of associations between objectively measured environmental variables and physical activity were considered; in other words, results for subjectively assessed measures were not included. Multiple entries for an association were reported for one study but only in terms of directionality (i.e., if a study found two significant positive results and one null result, the significant positive and null section of the table would both be given “1” to indicate that one study found significant positive associations and null associations). The number of associations was not of concern, just that there was an association found. Relationships were coded as follows: significant positive (+), null (0), and significant negative (-). A table was created such that each environmental variable had those three directionality columns.

2.3 Evidence Synthesis

2.3.1 General Characteristics of Reviewed Studies

Table 2.1 General characteristics of the papers reviewed (n=46)

General Characteristics of Paper	Number of Articles
Total Sample Size	
35 - 249	23
250 - 499	12
500 - 999	5
1,000 - 1,499	3
1,500 - 1,999	3
Not reported	0
Study Design	
Cohort	1
Cross-sectional	38
Intervention	2
Longitudinal	3
Quasi-Experimental	1
Not Reported	1
Sample age (years)	
Children (3-12)	24
Adolescents (13 - 18)	9
Both	13
Geographic Origin	
Australia	6
Belgium	1
Canada	4
England	4
Finland	1
Netherlands	2
New Zealand	4
Norway	2
Scotland	1
United Kingdom	1
USA	20
Year of Publication (Papers using GPS in Brackets)	
2006	3
2007	2
2008	2
2009	5 (2)
2010	9 (4)
2011	5 (1)
2012	10 (5)
2013	6 (4)
2014	4 (3)
Built Environment Measures	
Objective	31
Objective and Subjective	15
Physical Activity Measures	
Objective	34
Objective and Subjective	12

A total of 46 papers were reviewed. The majority of the studies reviewed were cross-sectional in design and conducted in North America (4 in Canada and 20 in the United States of America). There has been a steady growth in the number of papers in the last few years, with 73.9% of papers published between 2010-2014. The number of studies using GPS-based measures has rapidly grown over the past three years likely due to technological advances, with 63.2% of papers published between 2012-2014. Sample sizes ranged from 35 to 1,556, with a median of 209 participants. The majority of studies were conducted with children (aged 3-12), but there were still a large number of studies conducted with both children and adolescents. Although “children” was defined as being between the ages of 3 and 12 years old, the majority of studies were done with children between the ages of 8 and 12. While this review included only studies with objectively measured physical activity and the environment, a large number of studies still used subjective measures of physical activity and the environment alongside objective measures (Table 2.1). Results from subjective measures of physical activity and the environment were not considered in this review.

Table 2.2 Built environment measurement characteristics of the papers reviewed

Built Environment Measurement Characteristics of Paper	Number of Articles
Buffers	19
500 m	1
800 m (0.5 mile)	8
1600 m (1 mile)	6
2000 m	1
Multiple ring buffer	3
Administrative Units	7
Grid/sector	2
Census Tracts	1
Neighbourhood design	3
School catchment zone	1
Straight Line Distance (only)	1
GPS Tracks/points	19
GPS Tracks/points and buffer	6
Buffering GPS points	2
Buffering neighbourhood environment attributes	4
GPS tracks/points and administrative unit	1
GPS tracks/points and straight line distance	1
GPS tracks/points only	11

2.3.2 Defining the Built Environment in the Context of Physical Activity

Despite using objective measures of both physical activity and the environment, the studies considered for review exhibited a great heterogeneity of design and methodology. Methodologically, two major groups emerged: studies that used methods to examine the neighbourhood opportunities present in a child's home neighbourhood for physical activity; and studies that used methods to examine the spaces children used for physical activity (i.e., their exposure to environments for physical activity) (see Table 2.2).

2.3.3 Defining the Built Environment in the Context of Physical Activity: Neighbourhood Opportunity Structures

Of the 46 studies, 27 (58.7%) used methodologies to gain insight into neighbourhood opportunities for physical activity. Within these studies, there were three main ways of measuring and assessing the built environment for physical activity: buffers; administrative units; and straight-line distance.

Of the studies using these neighbourhood proxies, the majority of studies (19) used buffer-based measures (70.4%). Even within these buffer-based measures, there is no consensus on which buffer size best captures a child's neighbourhood environment. The majority of buffer-based studies (73.7%) used either a single 800 metre (0.5 mile) or 1600 metre (1 mile) buffer around the home. Multiple buffers were used in only 3 studies. The smallest buffer size used across all buffer-based studies was 200 metres and was in a study using multiple buffers (Van Loon, Frank, Nettlefold, & Naylor, 2014). The largest buffer size used across all buffer-based studies was 2000 metres (Crawford et al., 2010; Prins et al., 2011). 8 studies (29.6%) used administrative units (i.e., division of a region) as a measure of the environment. Similar to the studies using buffer-based measures, there is a great deal of heterogeneity regarding the type of administrative unit used.

In studies using neighbourhood proxies, the outcome measure was constrained by the use of a neighbourhood proxy. In these studies, the outcome was an *average* daily or weekly

(a) minutes of physical activity, (b) counts per minute or epoch, or (c) steps. Because the actual locations of physical activity are unknown, these studies have to assume that all physical activity occurred within their neighbourhood proxy and use the average estimates of physical activity.

Of the 27 studies using neighbourhood proxies, only 10 used objective measures of physical activity and objective measures of the built environment exclusively. The remaining 17 studies used a combination of objective measures and subjective measures. Four studies used objective and subjective measures of physical activity alongside objective measures of the environment. Ten studies used objective measures of physical activity alongside objective and subjective measures of the environment. Three studies used objective and subjective measures of physical activity alongside objective and subjective measures of the environment.

2.3.4 Defining the Built Environment in the Context of Physical Activity: Environmental Exposure

Of the 46 studies, 19 (41.3%) used methods to gain insight into the spaces that children used for physical activity. In other words, these studies assessed exposure to physical activity environments. Within these studies, there was one primary methodology used: combining GPS tracking with accelerometer data and integrating the data within a GIS. Despite using one main methodology across all studies, there were still methodological differences across the studies when characterizing the environment. In some studies, the GPS tracking was done alongside buffers, administrative units, and straight line distances.

Of the studies using accelerometer-GPS data, 6 (31.6%) used additional buffers. Two of these 6 studies buffered every accelerometer-GPS point while 4 of these 6 studies used GPS-accelerometer data alongside neighbourhood proxies to characterize the neighbourhood environment. In addition, 1 study used administrative units alongside the accelerometer-GPS tracking as a proxy for the child's neighbourhood, and 1 study used straight-line distance to the nearest park boundary from the participants' home address.

The remaining 11 studies (57.9%) used GPS tracking as the only way of measuring environmental exposure with simultaneous accelerometry.

The physical activity outcome measures in studies using simultaneous GPS tracking and accelerometry were diverse. Studies used a variety of outcomes ranging from bouts (the percentage of bouts, the number of bouts), METs (MET weighted MVPA, MET for each GPS point), activity counts (total number, counts per minute, mean, or the percentage of counts), the average daily/weekly number of minutes, counts, or steps, the time spent at different locations (the number of minutes, the proportion of time spent), and the probability of MVPA at each epoch.

Of the 19 studies using accelerometer-GPS data, 13 used objective measures of both physical activity and the environment exclusively. The remaining papers used subjective measures alongside objective measures. Four papers used objective and subjective measures of physical activity alongside objective measures of the environment. One study used objective measures of physical activity alongside objective and subjective measures of the environment. One study used objective and subjective measures of physical activity alongside objective and subjective measures of the environment. Overall, only 2 studies used subjective measures of the environment in addition to the GPS tracking (Table 2.3).

Table 2.3 Objectivity characteristics for each study

Measurement Characteristics of the Papers	Number of Papers
Studies Using Neighbourhood Proxies	27
Objective PA; Objective Environment	10
Objective and Subjective PA; Objective Environment	4
Objective PA; Objective and Subjective Environment	10
Objective and Subjective PA; Objective and Subjective Environment	3
Studies Using GPS Monitoring	19
Objective PA; Objective Environment	13
Objective and Subjective PA; Objective Environment	4
Objective PA; Objective and Subjective Environment	1
Objective and Subjective PA; Objective and Subjective Environment	1

2.3.5 Environmental Correlates of Physical Activity

Regardless of methodology used (i.e., neighbourhood proxies versus accelerometer-GPS data), there were marginally more null relationships found than significant (both positive and negative in direction) relationships (Tables 2.4 and 2.5). Several variables had inconsistent associations, particularly measures of parks and recreation facilities. Papers using neighbourhood proxies to measure the environment not only examined different environmental correlates of physical activity, but found different significant relationships compared to papers using accelerometer-GPS data.

Table 2.4 Number of papers with significant relationships for each environmental attribute in studies using neighbourhood proxies

Objectively Measured Environmental Variables	Results Count		
	+	0	-
Recreation Environment			
Parks (access/density/proximity)	5	10	1
Recreation facilities (access/density/proximity)	1	7	4
Neighbourhood Design			
Accessibility index	0	0	0
Commercial density	1	1	0
Cul-de-sac density	1	0	2
Employment density	1	1	0
Land Use Mix	2	2	0
Neighbourhood type	3	3	3
Population Density	1	2	0
Residential Density	1	3	1
Street connectivity	1	3	0
Urbanicity (significant difference between groups)	2	0	1
Walkability	4	3	0
Transportation Environment			
Pedestrian aesthetics	2	2	1
Pedestrian amenities	3	6	0
School (distance)	0	4	4
Traffic speed/volume	4	6	0
Other			
Beaches	0	0	0
Farmland	0	0	0
Gardens	0	0	0
Grassland	0	0	0
Greenspace/NDVI	0	1	0
Non-recreational buildings	0	1	1
Open space	1	2	1
Other built land (e.g. playground)	1	2	0
Roads/pavements	2	0	0
Woodland	0	0	0

2.3.6 Environmental Correlates and Physical Activity: Neighbourhood Opportunity Structures

Papers using neighbourhood proxies to understand how place affects physical activity focused primarily on studying attributes of the recreation environment (parks and recreational facilities), neighbourhood design attributes (density, connectivity, and indices of walkability, land use mix, and accessibility), and the transportation environment (pedestrian aesthetics and amenities, traffic speed/volume). Other environmental attributes like specific land uses (e.g., farmland, gardens, grassland, woodland) were rarely if at all examined.

Several variables had inconsistent associations. For park access, density, and proximity, 5 papers found significant positive relationships, 10 papers found null relationships, and 1 paper found a significant negative relationship with physical activity. For recreation facility access, density, and proximity, 1 paper found a significant positive relationship, 7 papers found null relationships, and 4 papers found significant negative relationships. In both instances, there were more studies finding null relationships than significant relationships. Similarly, walkability, pedestrian amenities, traffic speed/volume, population density, street connectivity, and residential density showed as many studies finding null relationships as significant relationships. Although many environmental variables had inconsistent associations with physical activity, some environmental attributes had studies that found more significant relationships than null relationships, including cul-de-sac density, employment density, land use mix, neighbourhood type, urbanicity (significant differences between groups), pedestrian aesthetics, non-recreational buildings, open space, and roads/pavements.

Table 2.5 Number of papers with significant relationships for each environmental attribute in studies using accelerometer-GPS data

Objectively Measured Environmental Variables	Results Count		
	+	0	-
Recreation Environment			
Parks	5	5	2
Recreation facilities	0	2	0
Neighbourhood Design			
Accessibility index	0	0	0
Commercial density	0	0	0
Cul-de-sac density	0	0	0
Employment density	0	0	0
Land Use Mix	0	0	0
Population Density	1	1	0
Residential Density	0	0	0
Street connectivity	0	0	0
Urbanicity (significant difference between groups)	3	2	0
Neighbourhood type	0	2	0
Walkability	0	0	0
Transportation Environment			
Pedestrian aesthetics	0	0	0
Pedestrian amenities	0	0	0
School (distance)	1	0	0
Traffic speed/volume	0	0	0
Other Land Use Related			
Beaches	0	2	1
Farmland	0	2	1
Gardens	2	0	2
Grassland	1	2	1
Greenspace/NDVI	4	3	0
Non-recreational buildings	1	5	2
Open space	0	0	0
Other built land (e.g. playground)	0	4	2
Roads/pavements	2	5	1
Woodland	2	4	1

2.3.7 Environmental Correlates and Physical Activity: Environmental Exposure

Papers using accelerometer-GPS data to understand how children's environmental exposure affects their physical activity focused primarily on studying attributes of the recreation environment (parks and recreational facilities) and specific land uses. There was less emphasis on neighbourhood design attributes because the underlying assumption when using accelerometer-GPS data is that physical activity can take place outside of the home neighbourhood. There was an emphasis on land use for each accelerometer-GPS

point, so composite indices like accessibility, walkability, and land use mix were never examined.

Exposure to recreation facilities yielded only null associations with physical activity. Conversely, exposure to gardens, grassland, and greenspace/NDVI yielded more studies with significant (positive and negative) associations than null associations. Despite using a more precise measure of environmental exposure, several variables had inconsistent associations. Exposure to park spaces, beaches, farmland, non-recreational buildings, other build land uses (e.g., playgrounds), roads/pavements, and woodland yielded positive, negative, and null associations with physical activity.

2.4 Discussion and Conclusion

2.4.1 Main Findings

The most prominent result of this systematic review is the lack of consistency about how the built environment should be defined and measured, even within studies using objective measures of both physical activity and the environment. This finding is consistent with other reviews (Black & Macinko, 2008; Booth et al., 2005; Ding et al., 2011; Papas et al., 2007). Despite only examining studies using objective measures, a plethora of measures were used across all studies with little consensus on which measure(s) should be used. Two ways of defining the built environment for physical activity emerged. In half of the studies, the relationship between the built environment and physical activity was defined as the relationship between built environment neighbourhood opportunity structures and children's physical activity. In contrast, the remaining studies relationship between the built environment and physical activity was defined as the relationship between built environment exposure and children's physical activity. In the former, the neighbourhood built environment is defined as the environment with the most influence a child while the latter places more emphasis on the environments a child actually experienced and frequented (even outside their own neighbourhood). Consequently, it is difficult to compare studies defining this built environment-physical activity relationship differently.

It becomes even more challenging to compare studies because no two studies have measured the built environment in the same way and used the same measures. There has been mounting research attributing physical activity, in part, to the built environment but there remains inconsistent evidence to identify a clear and strong role for the built environment. The environmental measures used yielded both significant and null relationships regardless of whether neighbourhood proxies or environmental exposure measures were used to assess the environment. Some attributes only had significant results, but this is likely because sufficient evidence is lacking. This issue is particularly problematic for studies using accelerometer-GPS data because these studies are still relatively new. This is also a problem for studies using neighbourhood proxies because the built environment measures that are assessed vary across studies – while some studies assess the role of pedestrian amenities within a neighbourhood, others do not.

Despite only considering studies using objective measures of both the environment and physical activity, there still remains much heterogeneity across studies which limits generalizability and makes it difficult to identify the strength of the role of the built environment in influencing children's physical activity.

2.4.2 The Built Environment in Physical Activity Literature: Definitions and Methodological Considerations

This review identified two primary approaches to defining the built environment for physical activity among studies using objective measures of physical activity and the environment: neighbourhood opportunity structures and environmental exposure.

Neighbourhood opportunity structures are hypothesized to influence physical activity by providing opportunities or sites that either facilitate or constrain physical activity to occur (Feng et al., 2010; Forsyth, Michael Oakes, Lee, & Schmitz, 2009b; Handy, Boarnet, Ewing, & Killingsworth, 2002; Tucker et al., 2009). These studies make the assumption that the neighbourhood is the most important contextual place relevant to a child and that the majority, if not all, physical activity occurs within the home neighbourhood. These studies use measures that define the neighbourhood setting most appropriate to facilitate

or constrain physical activity, including buffers and administrative units. Although buffers and administrative units represent two forms of neighbourhood proxies, the studies examined in this review rarely, if at all, justified the use of one over another.

There is no clear definition of neighbourhood across studies using neighbourhood proxies. Buffer sizes range from 200m to 2000m, and administrative units range from the statistical sector to the Census Tract level. Different buffer sizes capture different environments which can influence physical activity behaviours, and the most relevant buffer size will differ by the environment, behaviour, and the population of interest (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). There have been only three studies that use multiple buffers in order to better understand how neighbourhood size affects the associations found between built environment measures and physical activity (Cohen, Ashwood, Scott, Overton, Evenson, Staten, et al., 2006; Prins et al., 2011; Van Loon et al., 2014). Previous research has found that boys have more independent mobility, providing them with more access to the opportunities present within their neighbourhood (Brown, Mackett, Gong, Kitazawa, & Paskins, 2008; Mackett, Brown, Gong, Kitazawa, & Paskins, 2007). This evidence suggests that girls and boys have different neighbourhood domains due to mechanisms like parental restrictions and feelings of safety. As a result, it would be appropriate to use multiple buffer sizes and define the most relevant built environment context differently for girls and boys. Similarly, if one hypothesizes that a child's neighbourhood is only as large as what they can walk, a buffer size within walking distance would be appropriate (Cavanga, Franzetti, & Fuchimoto, 1983). The choice of neighbourhood definition will influence the associations found between the neighbourhood environment and children's physical activity (Brownson et al., 2009). For studies defining the built environment in the context of physical activity as neighbourhood opportunity structures, there is no consensus on (a) what defines a child's neighbourhood, and (b) what metrics should be used to best capture neighbourhood opportunity structures around the home and school.

The remaining studies define the built environment for children's physical activity as the spaces children are actually "exposed" to (as captured by GPS-tracking) for different

activity intensities and duration. In order to capture the spaces children are actually using, these studies use simultaneous GPS-tracking alongside accelerometry. Accelerometer-GPS data offers momentary activity assessment and location monitoring which allows a researcher to calculate exposure measures (Maddison & Ni Mhurchu, 2009).

Environmental exposure, then, is the measure of interest as opposed to broad measures of the neighbourhood environment. While using accelerometer-GPS data eliminates the need to define a child's "neighbourhood", these studies fail to define what is meant by environmental exposure. In the studies examined for this review using accelerometer-GPS data, point-by-point analysis is conducted which suggests that these studies define environmental exposure as a single point in time with direct environmental contact.

Analyzing only direct exposure, however, rests on the assumption that the nearby micro-environment does not exert a contextual influence on a child. Consequently, these studies may miss how contextual exposure may influence physical activity (Shareck, Frohlich, & Kestens, 2014). Contextual environmental exposure offers an additional perspective which may clarify what settings exert an influence on children's physical activity (Kwan, 2012; Shareck et al., 2014).

While accelerometer-GPS data represent a step forward in assessing how the built environment influences physical activity, using accelerometer-GPS data can introduce selective mobility bias by only examining the spaces children were exposed to for MVPA (Chaix et al., 2013). By failing to account for spaces children were exposed to for other activity intensities (i.e. sedentary and light intensity), it becomes difficult to make causal inferences about the relationship between the environment and physical activity. Children who are more physically active may be more likely to seek out spaces that support physical activity, and thus appear more "exposed" to those spaces (Chaix et al., 2013). Care must therefore be taken when interpreting results from studies only examining exposure to spaces for MVPA alone.

2.4.3 Strengths and Limitations

This systematic review is strengthened by its systematic search of several major databases, comprehensive list of search terms, and systematic review of articles and data extraction. Studies only using objectively measured physical activity and environment measures were included for review. Stratifying the results based on methodology provided more insight about how the built environment is defined and measured.

This review is not without limitations. This systematic review did not consider effect size, only statistical significance and direction. Without accounting for effect size, comparisons cannot be made about which associations were stronger or weaker.

Additionally, this review did not stratify MVPA by type of physical activity because the review aimed to assess all environmental associations with physical activity in general. This review acknowledges that built environment physical activity associations can be domain specific.

2.4.4 Recommendations for Future Studies

Defining the built environment to examine its role in influencing health behaviours is complex. Examining neighbourhood opportunity structures or built environmental exposure can both be appropriate depending on the primary objective of the study. While environmental exposure measures have been able to capture the settings children use for MVPA, neighbourhood proxies have been able to capture how the opportunity structures available in a child's neighbourhood (or lack thereof, an area that environmental exposure metrics are typically unable to capture) influences their physical activity.

The development of measures will depend on how the built environment is defined within the context of physical activity. However, there is no consensus on what measures should be used and how the measures should be defined, even among studies that define the built environment for physical activity similarly. This may be why, despite growing research linking physical activity in part to the built environment, there remains inconsistent evidence to identify the strength of the built environment. Without a consensus on built environment measures, it is challenging to make meaningful

comparisons between studies and have confidence about associations that are found. As a result, there should be more transparency about defining the built environment along with using common measures across studies so that: (a) studies can be compared meaningfully; (b) results can be aggregated to better clarify causal associations; and (c) policymakers and planners are able to make appropriate changes.

For studies investigating how the opportunities present in a child's neighbourhood influence their physical activity, there is a need for future research to clarify what best defines a child's neighbourhood, and what measures should be used to best capture neighbourhood opportunity structures. Using multiple buffer sizes to capture different neighbourhood environments offers a step towards addressing what best defines a child's neighbourhood.

For studies using accelerometer-GPS data to address environmental exposure, there is a need for future research to examine contextual environmental exposure and how it may influence children's physical activity. In addition, studies using accelerometer-GPS data should endeavour to examine environmental exposure for all activity intensities to avoid selective mobility bias that can be introduced when only examining the spaces used for MVPA.

Future research should also endeavor to compare neighbourhood opportunity structures with built environmental exposure in order to build a better understanding of how the opportunities present nearby in a child's home neighbourhood differs from the spaces they actually frequent for physical activity. Doing so may contribute additional knowledge about how to best define and measure the built environment for physical activity.

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Appendix i: Full Tables with Data Extracted from Studies Included in the Systematic Review

Table 2.6 Systematic review table with data extracted from articles examining neighbourhood opportunity structures

Neighbourhood Opportunity Structures									
Basic Information		Study Design					Built Environment		
<i>Author, Year</i>	<i>Country</i>	<i>Study Design</i>	<i>Objectivity of Measures (O=objective, S=subjective, P=physical activity, E=environment analysis)</i>	<i>Study Population: Child (3-12) or Adolescent (13-18)</i>	<i>Sample Size</i>	<i>Time Frame (if not all waking hours)</i>	<i>Objective Environment Measurement Tool</i>	<i>How the Built Environment is Measured</i>	<i>Details</i>
(Carver, Timperio, & Crawford, 2008)	Australia	Cross-sectional	OP (adolescents), SP (children), OE	Both	534	-	GIS	Buffer (home)	800 metre
(Carver, Timperio, Hesketh, & Crawford, 2010)	Australia	Longitudinal	OP (adolescents), SP (children), OE	Both	446	-	GIS	Buffer (home)	800 metre
(Cohen, Ashwood, Scott, Overton, Evenson, Voorhees, et al., 2006)	USA	Longitudinal	OP, OE	Children	1,554	-	GIS	Buffer (home)	0.5 mile

(Cohen, Ashwood, Scott, Overton, Evenson, Staten, et al., 2006)	USA	Cross-sectional	OP, OE, SE	Children	1,556	Non-school hours	GIS	Buffer (home)	0.5 mile - 1 mile depending on variable
(Cradock, Melly, Allen, Morris, & Gortmaker, 2009)	USA	Cross-sectional	OP, OE	Children	152	Weekends only	GIS	Administrative units within buffer (schools)	Administrative units: 150m grid; Buffer: 800 metre
(Crawford et al., 2010)	Australia	Longitudinal	OP, OE, SE	Children	301	-	GIS	Buffer (home)	2 km
(De Meester et al., 2012)	Belgium	Cross-sectional	OP, SP, OE	Adolescent	637	-	GIS	Administrative Units	Statistical sector
(Dowda et al., 2007)	USA	Cross-sectional	OP, SP, OE, SE	Children	1,556	Non-school hours	GIS	Buffer (home)	1 mile
(Eslinger, COpeland, Barnes, & Tremblay, 2005)	Canada	Cross-sectional	OP, OE	Both	455	-	GIS	Administrative units	Children grouped according to design of neighbourhood in which they live
(Kneeshaw-Price et al., 2013)	USA	Cohort	OP, SE, OE	Children		-	GIS	Administrative unit	Census block
(Lovasi et al., 2011)	USA		OP, OE	Children	428	-	GIS	Buffer: (a: home, b:home and daycare). Straight line distance (home to daycare)	0.5 km
(Maddison et al., 2009)	New Zealand	Cross-sectional	OP, SP, OE, SE	Adolescent	110	-	GIS	Administrative Units	School catchment zone

(McDonald et al., 2012)	USA	Cross-Sectional	OP, OE	Adolescent	344	-	GIS	Network distance buffer (home)	1600 metre
(Moore, Brinkley, Crawford, Evenson, & Brownson, 2013)	USA	Cross-sectional	OP, OE, SE	Children	284	-	GIS	Network distance buffer (home)	0.5 mile
(Norman et al., 2010)	USA	Cross-sectional	OP, OE	Adolescent	871	-	GIS	Buffer (home)	1 mile
(Patnode et al., 2010)	USA	Cross-sectional	OP, OE, SE	Both	294	-	GIS:	Buffer and street network distance (home)	1 mile
(Prins et al., 2011)	Australia	Cross-sectional	OP, OE, SE	Adolescent	209	Non-school hours	GIS	Buffer (home)	400 metre, 800 metre, and 2000 metre
(Quigg, Reeder, Gray, Holt, & Waters, 2012)	New Zealand	Intervention	OP, SP, OE, SE	Children	184	-	GIS	Straight line distance	
(Ries et al., 2009)	USA	Cross-sectional	OP, OE, SE	Adolescent	316	Non-school hours (but school hours still measured)	GIS	Buffer (home)	1 mile (parks) and 0.5 mile (number of crimes per square mile within 0.5 mile radius)

(Ries, Yan, & Voorhees, 2011)	USA	Cross-sectional	OP, OE, SE	Adolescent	327	Non-school hours (but school hours still measured)	GIS	Buffer (home)	1 mile
(Roemmich et al., 2006)	USA	Cross-sectional	OP, OE	Children	59	-	GIS	Buffer (home)	0.5 mile radius around home
(Roemmich, Epstein, Raja, & Yin, 2007)	USA	Cross-sectional	OP, SP, OE	Children	88	Non-school hours	GIS	Buffer (home)	0.5 mile radius around home
(Stevens & Brown, 2011)	USA	Cross-sectional	OP, SP, OE, SE	Children	187	-	GIS	Administrative units	Children grouped according to the design of the neighbourhood in which they live
(Stone, Faulkner, Mitra, & Buliung, 2012)	Canada	Cross-sectional	OP, OE	Children	1,027	-	GIS	Administrative units	Children grouped according to design of neighbourhood in which they live
(Timperio et al., 2008)	Australia	Cross-sectional	OP, OE, SE	Both	163	Non-school hours	GIS	Buffer (home)	800m
(Van Loon et al., 2014)	Canada	Cross-sectional	OP, OE	Children	366	-	GIS	Buffer (home); Shortest distance along street network between home and activity sites	200, 400, 800, and 1600 metre

(Villanueva et al., 2012)	Australia	Cross-sectional	OP, OE, SE	Children	1480	-	GIS	Network distance buffer (school and home).	School: 2km. Home: 800m. Distance to available green space; distance to access point
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Table 2.7 Systematic review table with data extracted from articles examining environmental exposure

Environmental Exposure									
Basic Information		Study Design					Built Environment		
<i>Author, Year</i>	<i>Country</i>	<i>Study Design</i>	<i>Objectivity of Measures (O=objective, S=subjective, P=physical activity, E=environment analysis)</i>	<i>Study Population: Child (3-12) or Adolescent(13-18)</i>	<i>Sample Size</i>	<i>Specific Time Frame (other than all waking hours)</i>	<i>Objective Environment Measurement Tool</i>	<i>How the Built Environment is Measured</i>	<i>Details</i>
(Almanza, Jerrett, Dunton, Seto, & Ann Pentz, 2012)	USA	Quasi-Experimental	OP, OE	Both	208	Non-school hours	BT-335 portable GPS and GIS	GPS points/tracks	
(Collins, Al-Nakeeb, Nevill, & Lyons, 2012)	England	Cross-sectional	OP, SP, OE	Adolescent	50	-	Garmin Forerunner 305 GPS and GIS	GPS points/tracks	
(Coombes, van Sluijs, & Jones, 2013)	England	Cross-sectional	OP, OE	Children	100	Non-school term	Garmin Forerunner 205 GPS and GIS	GPS points/tracks	

(Dessing et al., 2013)	Netherlands	Cross-sectional	OP, OE	Children	76	Weekdays	Travel recorder X, BT-Q1000X, Qstarz International Co) GPS and GIS	GPS points/tracks and buffer (around points)	10 metre buffers to account for positional accuracy
(Dessing, de Vries, Graham, & Pierik, 2014)	Netherlands	Cross-sectional	OP, OE	Children	79	-	GPS and GIS	GPS points/tracks and straight line distance (home to school)	
(Dunton, Almanza, Jerrett, Wolch, & Pentz, 2014)	USA	Cross-sectional	OP, OE, SE	Both	135	-	BT-335 Bluetooth GPS and GIS	GPS points/tracks, buffer (home), and Euclidian distance	500 metre radial buffer: Park availability and number of parks. Euclidian distance: park proximity - distance to nearest park boundary from each participant's home address
(Fagerholm & Broberg, 2011)	Finland	Cross-sectional	OP, SP, OE	Children	35	-	Enfora Mini MT GSM2228 GPS and GIS	GPS points/tracks within multiple ring buffer (home), point density analysis	500 metre distance <i>between</i> each ring, 50 metre cell size used for point density analysis
(Fjørtoft, Kristoffersen, & Sageie, 2009)	Norway	Cross-sectional	OP, OE	Children	61	During school break (recess)	Garmin Forerunner GPS and GIS	GPS points/tracks	
(Fjørtoft, Løfman, & Halvorsen Thorén,	Norway	Cross-sectional	OP, OE	Adolescent	81	During lunch recess/breaks	Garmin Forerunner 305 GPS and GIS	GPS points/tracks	

2010)									
(Jerrett et al., 2013)	USA	Intervention	OP, OE	Both	147	Non-school hours	GlobalSat BT-335 portable GPS and GIS	GPS points/tracks and buffer (home)	Within 500 m buffer = inside neighbourhood, beyond 500m = outside neighbourhood
(Jones, Coombes, Griffin, & van Sluijs, 2009)	England	Cross-sectional	OP, SP, OE	Children	100	-	Garmin Forerunner 205 GPS and GIS	GPS points/tracks	
(Lachowycz, Jones, Page, Wheeler, & Cooper, 2012)	England	Cross-sectional	OP, OE	Children	902	Non-school hours	Garmin Fortrex 201 GPS and GIS	GPS points/tracks	
(Maddison et al., 2010)	New Zealand	Cross-sectional	OP, OE	Adolescent	79	-	Garmin Forerunner 305 GPS and GIS	GPS points/tracks and buffer (home and school)	Home: 150m, school: 1km
(McMinn et al., 2014)	Scotland	Cross-sectional	OP, OE	Children	39	Trip home from school	Trackstick Super GPS and GIS	GPS points/tracks	
(Quigg, Gray, Reeder, Holt, & Waters, 2010)	New Zealand	Cross-sectional	OP, OE	Children	184	-	Globalsat DG-100 GPS and GIS	GPS points/tracks	
(Rainham et al., 2012)	Canada	Cross-sectional	OP, OE	Both	380	-	EM-408 SiRF III 12-channel GPS receiver and GIS	GPS points/tracks	
(Rodríguez et al., 2012)	USA	Cross-sectional	OP, OE	Adolescent	293	Any point falling in or within 60 m of a school property or home was	Foretrex 201 GPS unit and GIS	GPS points/tracks and buffer (around each GPS-accelerometer)	Accelerometer-GPS point (50m), home (800m)

						excluded		<i>point</i> and the home), and administrative units (census block)	
(Wheeler, Cooper, Page, & Jago, 2010)	United Kingdom	Cross-sectional	OP, OE	Children	1,307	After school on weekdays	Garmin Foretrex 201 GPS receiver and GIS	GPS points/tracks	Each matched point was classified as greenspace or non-greenspace
(Yin et al., 2013)	USA	Cross-sectional	OP, SP, OE	Both	40	-	Garmin Fortrex GPS and GIS	GPS points/tracks, GIS (buffer around home)	Network distance buffer: 0.5 mile. Buffers: increments of 0.5 mile radius to a total of 4 miles

Chapter 3

3 Built Environment Influences on Children's Physical Activity: Examining Differences by Neighbourhood Size and Sex

3.1 Introduction

Obesity rates among Canadian children and adolescents have risen dramatically over the last 30 years, in part due to decreasing levels of physical activity (Chaput et al., 2012; Janssen & LeBlanc, 2010; Janssen et al., 2005). Obesity is a complex health problem with numerous mechanisms, but it is generally agreed that obesity is the result of an energy imbalance that occurs when the energy consumed exceeds the energy expended (Hall et al., 2011). Physical activity increases energy expenditure and therefore helps prevent obesity (Davison & Birch, 2001). Regular physical activity during childhood also helps to mitigate risk factors associated with cardiovascular disease and improve psychological well-being by improving academic performance and reducing anxiety and depression (Piko & Keresztes, 2006; Warburton, Nicol, & Bredin, 2006). Yet, few Canadian children are achieving Canada's recommended physical activity guidelines of at least 60 minutes of moderate-to-vigorous physical activity [MVPA] during most days of the week (Statistics Canada, 2015; Tremblay et al., 2011). Canadian children now spend the majority of their time engaging in sedentary activities like watching television or playing on the computer (Statistics Canada, 2015).

Physical activity is a complex behaviour and there is growing interest in ecological models of health to explain how a diverse range of mechanisms influence physical activity at multiple levels ranging from intrapersonal (e.g., age, sex, preferences, attitudes), interpersonal (e.g., household income, parental education, parental occupation), environmental (i.e., built and natural), and policy (Sallis, Owen, & Fisher, 2008). At the intrapersonal level, boys tend to be more physically active than girls, with recent research finding that 13% of boys aged 5-17 and only 6% of girls aged 5-17 meet Canada's recommended physical activity guidelines (Statistics Canada, 2015). Research has found that girls prefer different activities, have different motivations for being physically active,

and face different barriers to physical activity than boys (Mota & Esculcas, 2002; Posner & Vandell, 1999). For example, boys have more independent mobility providing them greater access to opportunities in their neighbourhood (Brown, Mackett, Gong, Kitazawa, & Paskins, 2008; Mackett, Brown, Gong, Kitazawa, & Paskins, 2007). In addition, the mode a child uses to travel between home and school has been found to contribute to a significant proportion of their overall physical activity levels. Children who use active modes of travel between home and school (i.e., walking or biking) tend to be more physically active and are more likely to meet daily MVPA recommendations than those using inactive modes (Faulkner, Buliung, Flora, & Fusco, 2009).

At the interpersonal level, physical activity levels have been found to be lower among certain ethnic/racial groups (e.g., black children and youth) and lower socio-economic classes (Gordon-Larsen, McMurray, & Popkin, 1999; Gordon-Larsen, Nelson, Page, & Popkin, 2006; Sallis, Zakarian, Hovell, & Hofstetter, 1996). It is hypothesized that these groups experience unequal access to physical activity opportunities in their neighbourhood, which in turn may affect whether or not they engage in physical activity (Gordon-Larsen et al., 2006; Powell, Chaloupka, Slater, Johnston, & O'Malley, 2007). At the environmental level, the built environment can facilitate or constrain physical activity by providing or restricting opportunities for physical activity (Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Forsyth, Michael Oakes, Lee, & Schmitz, 2009; Handy, Boarnet, Ewing, & Killingsworth, 2002; Tucker et al., 2009). The neighbourhood opportunities for physical activity may be particularly important for children and youth due to extrinsic constraints on their independent mobility (e.g., parental rules, too young for a driver's license), which typically limit their activities to locations that they can access by walking or biking (Loebach & Gilliland, 2014).

Land use patterns, transportation infrastructure, and urban design have been conceptualized as built environment correlates of physical activity (Frank, Engelke, & Schmid, 2003; Handy et al., 2002). Land use patterns affect the distribution of opportunities for physical activity, such as the presence of neighbourhood park spaces (Frank et al., 2003). Land use mix is frequently used because it is able to characterize complex land use patterns in one measure (Brownson, Hoehner, Day, Forsyth, & Sallis,

2009; Handy et al., 2002). Transportation infrastructure affects how well children are connected with facilities and also affords a site for physical activity, such as intersection density (Frank et al., 2003; Handy et al., 2002). Intersection density (i.e., connectivity) affects the route options available in a neighbourhood and better connected neighbourhoods may be easier to traverse (Grow et al., 2008; Kerr et al., 2006; Saelens & Handy, 2008). Urban design affects the appearance and arrangement of physical features within spaces, such as recreation facility and park design or quality (Frank et al., 2003; Handy et al., 2002; Prins et al., 2011; Timperio et al., 2008).

There is a need to better investigate the role of neighbourhood size because there is little agreement regarding what best defines child's neighbourhood (Brownson et al., 2009). Both buffer-based measures and administrative units have been used to define a child's neighbourhood. Although many accelerometer-based studies of the built environment-physical activity relationship use a buffer size of 800 metres (m) or 1000 m (Carver, Timperio, Hesketh, & Crawford, 2010; Roemmich, Epstein, Raja, & Yin, 2007; Timperio et al., 2008; Villanueva et al., 2012), some have used home-based buffers as small as 200m (Van Loon, Frank, Nettlefold, & Naylor, 2014) and as large as 2 kilometres (km) (Crawford et al., 2010; Prins et al., 2011). Different buffer sizes capture different environments and the most relevant buffer size differs according to the environmental context, the behaviour of interest, and the group being studied (Brownson et al., 2009). It is important, then, to consider and conceptualize the neighbourhood built environment at different sizes and examine what best defines a child's neighbourhood.

Few studies have examined the role of neighbourhood size, particularly with objectively measured physical activity and objectively measured environment contexts. Van Loon et al. (2014) examined associations between the neighbourhood built and social environment and MVPA using 200m, 400m, 800m, and 1600m buffer sizes and found that the largest buffer size best explained MVPA compared to smaller buffer sizes. Prins et al. (2011) investigated relationships between availability of parks and sports facilities and MVPA using 400m, 800m, and 2000m buffer sizes and found no associations between objectively measured availability of facilities within different buffer sizes and objectively assessed MVPA. Both studies failed to distinguish between weekdays and weekend day

physical activity. Children's physical activity may differ during weekdays than on weekends, and similarly, children's physical activity may differ during weekday school hours compared to out of school hours. Examining non-school hour physical activity is important to separate the impact of the neighbourhood built environment from school activities. The contexts used when calculating MVPA may affect physical activity outcomes and, thus, the relationships between physical activity and the built environment.

As a result, this research has three main objectives: (1) to examine whether the opportunities present in children's neighbourhood built environments influence objectively measured average daily MVPA during weekdays outside of school hours; (2) to assess if there are sex differences when examining whether neighbourhood built environment opportunities influence MVPA; and (3) to assess whether the conceptualization of neighbourhood size affects associations between the built environment and MVPA.

3.2 Methods

This study draws data from a multi-year study called the Spatial Temporal Environment and Activity Monitoring (STEAM) project to investigate the effects of the built environment on health related behaviours of children aged 9-14. The STEAM project had two data collection periods (8 days in the spring and 8 days in the following fall) for each year, 2011-2013 inclusive. Only data from the spring collection phase was used in this study. This study was approved by the Non-Medical Research Ethics Board of the University of Western Ontario (NM-REB #: 17918S) prior to the start of the study. All children with parental permission for participation were required to sign a child assent form to participate in the study.

During the study period, participating students from 34 elementary schools across the four school boards within Southern Ontario completed an 8-day multi-tool procedure to record their neighbourhood activities, mobility, and environmental perceptions. Participants completed detailed daily activity diaries, wore portable accelerometers during all waking hours for up to 8 days, wore portable Global Positioning System (GPS) monitors during all waking hours for up to 8 days (GPS data were used only to determine the home

location of each child), and both children and parents completed detailed surveys about demographics and their child's neighbourhood behaviours and perceptions.

The sample used in this study is a subset of a larger sample (n=851) of children from 34 schools in London and surrounding area who had demographic data from the child and/or parent surveys, had valid physical activity data in the spring, and lived and attended school in London, Ontario. Of the 851 participants in the larger STEAM sample, 101 were excluded from this analysis because they were part of the pilot year (2010), which used different accelerometer calibration methods than non-pilot years. A further 226 participants were excluded because they did not live within the city limits of London, Ontario. Participants were excluded from further analyses if they had fewer than two valid weekdays of accelerometer data (n=41). Participants were excluded if demographic data from the child or parent surveys was unavailable (n=48), resulting in a final sample size of 435 students with both objective neighbourhood built environment data and physical activity data. The 435 students came from 20 schools spread across the city of London in urban and suburban settings of varying socio-economic status.

3.2.1 Measures

3.2.1.1 Physical Activity

Physical activity was measured using Actical® Z accelerometers with 30-second epochs (summed to 60 seconds) worn on the hip. Participants were asked to wear the accelerometer for 8 consecutive days (including 4-6 weekdays) during all waking hours, only removing it for sleeping, bathing, and swimming. Participants were required to have at least 2 valid weekdays of data to be included in analyses, a common practice for analyzing children's accelerometer data (Dössegger et al., 2014; Mattocks et al., 2008; Østbye et al., 2013; Verloigne et al., 2012). A valid day was defined as at least ten hours of wear. Motionless bouts (extended periods of zero counts) of 60 consecutive minutes or longer were considered non-wear time and excluded from analysis. A valid day has been defined as 8 to 10 hours of wear time in previous studies of children's physical activity (Cain, Sallis, Conway, Van Dyck, & Calhoun, 2013). Cut-points for children classified the accelerometer data and defined the threshold at which the data would be categorized

as moderate-to-vigorous (> 1500 counts/minute) (Puyau, Vohra, Zakeri, & Butte, 2004). Differences in individual school and recess start and end times were accounted for in the analyses. The number of minutes spent in MVPA during non-school hours for each valid weekday was averaged over the total number of valid weekdays observed to calculate average daily MVPA for weekdays during non-school hours. To determine the average time spent in MVPA during other time blocks (i.e., during class time, recess, all weekday hours), the number of minutes spent in MVPA during those specific time blocks were averaged over the total amount of valid days observed.

3.2.1.2 Independent Variables

Following the ecological model of health, this study uses three levels of independent variables: intrapersonal; neighbourhood socio-economic status (SES); and the neighbourhood built environment (Note: policy is not considered as a variable in this analysis because it is the same across all participants).

Individual level variables were used to account for factors specific to each child that may influence their physical activity as hypothesized in the literature. These variables used include (with the reference category italicized): sex (*male* versus female); age in years (continuous); the most frequently used mode of travel to and from school during a normal school week (*active* [mostly walk or bike] versus inactive [mostly car or bus]); and the presence of a sibling (*only child* versus has sibling versus prefer not to answer). The variables used were collected from multiple sources, including child surveys, parent surveys, and data recorded for each child when calibrating their accelerometer.

Median family income (CAD) was used as a measure of the **neighbourhood SES** and used as a control. Median family income was defined as the area-level SES in the census dissemination area in which their home is located. Neighbourhood SES can act as a proxy for other household demographic variables such as parental education and occupational status.

The **neighbourhood built environment** was objectively measured using a Geographic Information System (GIS) (ArcGIS 10.2). Each child's home addresses was identified by

using the spatial means of their GPS tracks and then used as the centroid for all measures. The neighbourhood built environment was measured using two types of spatial analyses: (1) the shortest distance along the street network between home and specific activity sites for children (e.g., recreation centres and schools); and (2) multiple ring buffers (500m and 800m) around children's home addresses. These buffer sizes were chosen because children are typically limited to the immediate area within which they are able (or permitted) to walk or cycle. Previous research has found that children at 12 years of age can walk up to 5 km/hr (Cavanga, Franzetti, & Fuchimoto, 1983), so an 800m buffer is equivalent to about a 10 minute walking distance and a 500m buffer is equivalent to about a 6 minute walking distance for an average child. In addition, previous evidence has found that boys have more independent neighbourhood mobility than girls (Brown et al., 2008; Mackett et al., 2007), so using a 500m buffer in addition to the 800m buffer accommodates flexibility. Both 500m and 800m buffers have been used in previous studies exploring children's neighbourhoods (Larsen et al., 2009; Timperio et al., 2008; Tucker et al., 2009; Villanueva et al., 2012). Euclidean buffers were used instead of road network buffers because some neighbourhood opportunity structures may not be captured due to a lack of road network access (e.g. a park or school yard).

After creating buffers around each child's home location, built environment measures were developed in order to characterize the neighbourhood opportunity structures within these areas. Existing research informed the selection of measures used to address a range of the hypothesized mechanisms influencing physical activity (Frank et al., 2003; Handy, Boarnet, Ewing, & Killingsworth, 2002). A description of the built environment variables used in this study and their definitions are found in Table 3.1. All of the environmental data were supplied by the Planning Division of the City of London (2014).

Table 3.1 Description of the built environment variables included in this study

Built Environment Variable	Description
Open space parks (#/km ²)	The number of parks per square km within each buffer without any built recreational amenities.
Parks with at least one sports field (#/km ²)	The number of parks per square km within each buffer containing at least one sports field (defined as tennis courts, soccer fields, baseball diamonds, and football fields).
Parks with at least one playground (#/km ²)	The number of parks per square km within each buffer containing at least one playground.
Parks with both at least one sports field and playground (#/km ²)	The number of parks per square km within each buffer containing at least one sports field and at least one playground.
Distance to the nearest school (km)	The shortest distance along the street network between each child's home and the nearest public, Catholic, or private school in the City of London.
Distance to the nearest recreational site (km)	The shortest distance along the street network between each child's home and the nearest arena or public/private recreational facility.
Land use mix	An entropy measure between 0 and 1 reflecting the distribution of land-use.
Multi-use path space (km ²)	The amount of multi-use path area within each buffer.
Intersection count (#/km ²)	The number of 3- and 4- way intersections within each buffer.

3.2.2 Statistical Analyses

Statistical analyses were performed with STATA SE 13 (StataCorp, 2015). Linear regression models with robust standard errors (cluster) were used to analyze the relationship between average daily non-school MVPA during weekdays and attributes of the built environment. Selecting the cluster option accounts for observations that are clustered into groups (i.e. elementary schools) and that these observations may be correlated within schools. Individual level and neighbourhood SES variables were included if bivariate analyses revealed a significant association with average daily MVPA

during outside of school hours ($p < 0.10$). Several of the variables were skewed and transformed using either logarithmic or square root transformations.

3.3 Results

3.3.1 Descriptive Statistics

Descriptive statistics about the sample can be found in Table 3.2 and Table 3.3. The majority of participants were between 11 and 12 years old (73.10%). Of the participants, 59.31% were girls. Most participants had a sibling (80.92%) and used an inactive mode of travel between home and school (63.22%). The median family income (in CAD) was \$71,758.

Participants spent on average 63.98 minutes of MVPA per day during weekdays (Table 3.3). Boys engaged in 20.24 minutes more MVPA per day than girls during weekdays (in school and out of school). During class time, boys engaged in 5.17 minutes more MVPA than girls, a significant difference ($p < 0.05$). During recess time, boys engaged in 9.69 minutes more MVPA than girls, a significant difference. On average, participants spent 30.36 minutes per day in MVPA outside of school hours; boys spent significantly more time on average in MVPA outside of school hours than girls ($p < 0.05$).

Table 3.2 Descriptive statistics about the sample (n=435)

Variable	n	%
Age		
9	10	2.30
10	69	15.86
11	187	42.99
12	131	30.11
13	36	8.28
14	2	0.46
Sex		
Boy	177	40.69
Girl	258	59.31
Presence of a Sibling		
Only child	54	12.41
Has sibling(s)	352	80.92
Prefer not to answer	29	6.67
Mode of travel		
Active	160	36.78
Inactive	275	63.22
	Mean	SD
Median family income in CAD (in thousands)	71.76	26.89

Table 3.3 Descriptive statistics for average daily minutes of MVPA by sex (n=435)

Variable	Average Daily Minutes of MVPA During Weekdays							
	During Class Time		Recess		Non- School Time		All Weekdays	
	Mean	<i>p</i> -Value	Mean	<i>p</i> -Value	Mean	<i>p</i> -Value	Mean	<i>p</i> -Value
Sex								
Boys	19.43	0.000	23.67	0.000	33.78	0.009	75.99	0.000
Girls	14.26		13.98		28.01		55.75	
Total Sample	16.37	-	17.93	-	30.36	-	63.98	-

Note: Mann-Whitney U test used to test differences between sex.

3.3.2 Model Specification

A series of models were specified to assess associations between neighbourhood opportunity structures and children's MVPA while accounting for age, sex, mode of travel, the presence of siblings, and neighbourhood SES (Table 3.4 and 3.5). Models were stratified according to sex because of anticipated sex differences in relationships, but a model using the entire sample was developed to detect smaller statistical effects with a larger sample size.

3.3.3 Model Results

Model results assessing associations between built environment characteristics and MVPA are found in Table 3.4. At the individual level, girls and those using inactive modes of travel between home and school had significantly lower average daily MVPA during non-school hours. In contrast, students in the sample with a sibling had significantly higher average daily MVPA during non-school hours. Significant associations were found between average daily MVPA and the density of parks with sports fields and multi-use path area at both 500m and 800m buffer sizes. Despite using different buffer sizes, the 500m and 800m buffers in the full model yielded similar results, with the same significant variables and model fit. Variables were assessed for multicollinearity using Variance Inflation Factors (VIFs) because one assumption of ordinary least squares regression is the absence of high multicollinearity. No variables were found to be highly collinear, with a maximum VIF of 1.72.

Sex stratified models were created to examine associations that may be unique to males and females (Table 3.5). Sex-specific associations were found at the individual level. Both boys and girls that used inactive modes of travel between home and school had significantly lower average daily MVPA during non-school hours than those using active modes; however, this was only significant for boys in the 800m model. Boys with siblings had significantly higher average daily MVPA, regardless of buffer size. Median family income was positively associated with girls' average daily MVPA in both 500m and 800m models. The model for boys' average daily MVPA indicated a significant positive association with the density of parks with sports fields, and a significant negative

association with the density of parks with playgrounds. Both 500m and 800m models had the same significant predictors, but the 800m model exhibited a better model fit than the 500m model. After accounting for several individual level variables and neighbourhood SES, the model for girls' MVPA indicated significant associations between MVPA and the density of parks with sports fields. The density of parks with sports fields was only found to be significant in the 800m model, not the 500m model. The 500m model had a slightly better fit than the 800m model. No variables were found to be collinear, with a maximum VIF of 1.74. The sex-stratified models better explained the relationship between average daily MVPA outside of school hours during weekdays and the built environment.

Table 3.4 Results of full model assessing associations between environment characteristics by buffer size and average daily minutes of MVPA outside of school hours during weekdays (n=435)

Variables	Regression Coefficients by Buffer Size			
	500m ^a		800m ^b	
	B.	<i>p</i> -Value	B.	<i>p</i> -Value
Age (years)	0.097	0.918	0.160	0.853
Sex (base: male)				
Female	-4.779	0.015	-4.973	0.007
Siblings (base: only child)				
Has sibling(s)	5.933	0.027	6.496	0.027
Prefer not to answer	2.858	0.507	3.207	0.430
Mode of Travel (base: active)				
Inactive	-11.202	0.000	-11.255	0.000
Median family income in CAD (10 ⁻³)	0.033	0.496	0.021	0.696
Open space park: #/km ²	-0.824	0.135	-0.060	0.956
Park with sports field: #/km ²	0.929	0.016	2.653	0.020
Park with playground: #/km ²	-1.721	0.070	-3.088	0.184
Park with more than one unique feature: #/km ²	-2.645	0.063	-3.966	0.090
Distance to nearest recreational facility ^c : km	-2.094	0.102	-1.607	0.175
Distance to nearest school ^c : km	1.116	0.661	0.146	0.949
Land Use Mix (x10)	0.002	0.998	-0.558	0.539
Multi-use path: m ² (10 ⁻³)	1.407	0.018	0.580	0.031
Road connectivity: # of intersections/km ²	0.042	0.280	0.035	0.636
Constant	32.898	0.038	34.318	0.024

Note: Table entries expressed as B values (unstandardized regression coefficients);

^a R-squared= 0.1695; ^b R-squared =0.1675; ^c Street-network based measures;

Table 3.5 Results of sex-stratified models assessing environment characteristics by buffer size and average daily minutes of MVPA outside of school hours during weekdays

Variables	Regression Coefficients by Buffer Size							
	Boys (n=177)				Girls (n=258)			
	500m ^a		800m ^b		500m ^c		800m ^d	
	B.	p-Value	B.	p-Value	B.	p-Value	B.	p-Value
Age (years)	-0.134	0.957	-0.119	0.957	0.339	0.700	0.261	0.753
Presence of a sibling (base: only child)								
Has sibling(s)	10.077	0.003	11.984	0.004	2.164	0.443	1.694	0.561
Prefer not to answer	4.575	0.589	8.412	0.282	-0.679	0.900	-1.409	0.780
Mode of Travel (base: active)								
Inactive	-8.275	0.089	-9.940	0.041	-11.654	0.000	-11.184	0.000
Median family income in CAD (10 ⁻³)	-0.054	0.554	-0.091	0.262	0.099	0.034	0.103	0.032
Open space park: #/km ²	-1.370	0.256	-0.445	0.848	-0.424	0.459	-0.098	0.915
Park with sports field: #/km ²	1.363	0.020	3.657	0.048	0.880	0.055	2.760	0.032
Park with playground: #/km ²	-3.403	0.042	-8.082	0.026	-0.171	0.866	1.237	0.603
Park with more than one unique feature: #/km ²	-3.941	0.106	-6.996	0.098	-1.651	0.271	-1.187	0.544
Distance to nearest recreational facility ^e : km	-3.754	0.190	-2.721	0.334	-1.499	0.358	-1.318	0.370
Distance to nearest school ^e : km	4.939	0.340	2.984	0.461	-0.789	0.780	-1.230	0.633
Land Use Mix (x10)	-0.326	0.681	-1.564	0.158	0.414	0.567	0.407	0.682
Multi-use path: m ² (10 ⁻³)	1.421	0.822	0.770	0.072	1.257	0.091	0.358	0.326
Road connectivity: # of intersections/km ²	-0.022	0.052	0.016	0.926	0.087	0.100	0.055	0.383
Constant	42.992	0.148	48.789	0.085	18.858	0.159	18.250	0.143

Note: Table entries expressed as B values (unstandardized regression coefficients);

^a R-squared= 0.1616; ^b R-squared =0.1796; ^c R-squared =0.1961; ^d R-squared =0.1895; ^e Street-network based measures;

3.4 Discussion and Conclusions

This study examined whether the opportunities present in a child's neighbourhood built environment predicted objectively measured average daily MVPA during weekdays outside of school hours by 1) the sex of the child and 2) neighbourhood size (i.e., 500m and 800m). Results show sex differences and neighbourhood size differences in associations between the neighbourhood built environment and children's MVPA.

3.4.1 Children's Weekday Physical Activity: Overall and During School Hours

Boys engaged in significantly more daily MVPA than girls during weekdays, with boys achieving, on average, 20.24 more minutes of daily MVPA than girls. This finding is consistent with evidence finding that girls consistently achieve less daily MVPA than boys (Statistics Canada, 2015; Trost et al., 2002). Although boys engaged in significantly more daily MVPA than girls, the girls in the sample averaged 55.75 minutes of MVPA across all valid days during weekdays, which falls just short of Canada's recommended physical activity guidelines (> 60 minutes per day).

A similar pattern emerges when investigating children's physical activity during school hours. Although both boys and girls participate in within-school physical activity (i.e. Daily Physical Activity, physical education classes) where similar levels of MVPA might be achieved, boys, on average, engaged in significantly more MVPA than girls both during class time and recess time. This may be a result of girls participating in more passive activities like socializing, an activity popular among girls this age, instead of physical activity during both in-school physical activity and recess (Posner & Vandell, 1999). Recess, in particular, appears to be a significant contributing factor to MVPA during school hours. As a result, efforts should be made to develop programs that specifically target and engage girls in MVPA during recess times to increase the intensity of activity within this context.

3.4.2 Children's Weekday Physical Activity During Non-school Hours: Individual level and Neighbourhood SES Influences

In-school time MVPA only accounted for a portion of children's physical activity, reinforcing the need to examine children's MVPA outside of school time. Boys engaged in significantly more daily MVPA outside of school hours than girls, supporting the need for sex-specific models. This study investigated associations between built environment characteristics and children's physical activity in two dimensions: child sex and neighbourhood size using two buffers (i.e. 500m and 800m). Findings from this study show sex differences between neighbourhood built environment opportunities and MVPA. This finding is consistent with Van Loon et al. (2014).

One of the strongest predictors of MVPA was mode of travel between home and school for both sexes, although the relationship was stronger for girls. While both boys and girls who use inactive modes of travel to school engage in less MVPA than those using active modes of travel, girls who use inactive modes of travel engage in even less MVPA than boys who use inactive modes of travel. These findings suggest that girls achieve a majority of MVPA outside of school hours through mode of travel alone. Active transportation can contribute to a large amount of a child's daily physical activity, so these findings emphasize the importance of encouraging children to use active modes of travel, particularly for girls (Faulkner et al., 2009; Mackett et al., 2007).

Results from this study found that girls from higher income neighbourhoods are more likely to engage in MVPA. Although girls engaged in less MVPA than boys, those girls from more affluent neighbourhoods were more likely to be physically active than girls from less affluent neighbourhoods. These results suggest that policymakers and programmers should develop physical activity interventions appropriate for girls, especially girls from low income households.

3.4.3 Physical Activity During Non-school Hours: Neighbourhood Built Environment Influences

Children from neighbourhoods with greater access to parks with sports fields and higher multi-use path area had significantly higher average daily MVPA during non-school hours. Neighbourhoods with greater access to sports fields afford opportunities for both structured (i.e. sports teams) and unstructured (i.e. playing with friends) physical activity. This diversity may engage more children in physical activity than a space solely designed for structured or unstructured physical activity (Mota & Esculcas, 2002). Multi-use paths primarily afford the opportunity for unstructured physical activity, especially active transportation (Larsen, Gilliland, & Hess, 2012). Significant associations did not differ by neighbourhood size in the model for all children. However, given that sex has been found to significantly influence MVPA both in this study and the literature, sex-stratified models are necessary to examine whether neighbourhood size and related findings are sex specific.

Sex-stratified models revealed sex differences in significant associations and the most relevant neighbourhood size. The neighbourhood size that best predicted girls' MVPA was 500m, smaller than the 800m neighbourhood that best predicted boys' MVPA. This finding highlights that boys may have a wider neighbourhood to engage in MVPA with than girls. Coupled with the fact that more significant neighbourhood built environment relationships were found for boys, this study's findings suggest that boys may have access to and engage in more neighbourhood physical activity than girls. This might explain why boys engaged in significantly more physical activity outside of school hours compared to girls; boys might be allowed by their parents to play more independently in their neighbourhood. Research has found that boys have more independent mobility than girls, granting them greater access to physical activity opportunities present within their neighbourhood (Brown et al., 2008; Mackett et al., 2007).

Significant associations were found between average daily MVPA during non-school hours on weekdays and the density of parks within each buffer in the sex-stratified models, but these associations differed according to the recreational amenities present within the park. Both boys and girls from neighbourhoods with greater access to parks with sports fields were found to have significantly higher MVPA, emphasizing the importance of planning and developing recreational spaces designed to support physical activity for all children. In contrast, boys from neighbourhoods where park designs tended to be centered around playgrounds had significantly lower MVPA. Together, these findings suggest that boys engage differently with parks having sports fields than with parks having playgrounds. This may be a result of age; the boys are nearing early adolescence and may perceive playgrounds as spaces for socializing rather than physical activity. This may also be a result of unsupportive equipment; the playground equipment found at parks may not be challenging or complex enough for active play (Isenberg & Quisenberry, 2002).

Although some significant results were found, many built environment attributes showed no association with average daily weekday MVPA during non-school hours. Of the studies using objectively measured physical activity and buffer-based neighbourhood measures, several have found significant associations (Roemmich et al., 2006; Timperio et al., 2008; Van Loon et al., 2014), but others have found no significant associations (Ries et al., 2009; Ries, Yan, & Voorhees, 2011). This study did not differentiate between specific physical activity contexts (e.g. sport activities, free play, active transportation); the primary objective was to examine overall physical activity. A more in-depth examination of different activity contexts may reveal more specific associations with the neighbourhood built environment. In addition, the lack of significant findings may be because neighbourhood proxies are unable to capture children's direct exposure to their environments. Buffers are useful for helping to characterize a subject's general neighbourhood opportunities, but are insufficient for assessing children's actual exposure to different features in their environments and identifying the importance of difference contexts for physical activities.

The use of GPS technologies in combination with acceleometry shows promise for assessing children's real exposure to their environments (Maddison & Ni Mhurchu, 2009). Neighbourhood proxies, like buffers, rest on the assumption that all physical activity occurred within that area, which may explain why studies have yielded mixed results. The combination of GPS tracking alongside accelerometry, however, allows researchers to understand physical activity within the neighbourhood context but also outside of that context. This is particularly important because children are mobile and unlikely to spend all of their time within their neighbourhood, especially considering that more parents are now driving their children to structured activities (Karsten, 2005; Kwan, 2012). While GPS technologies still face technological and financial limitations, the combination of GPS and accelerometry allows researchers to answer questions about where MVPA and sedentary activities occurred. Buffers are useful to answer questions about how neighbourhood built environments influence physical activity behaviours (including characteristics of places people choose not to frequent), but the combination of GPS tracking alongside accelerometry shows promise for assessing children's real exposure to their environments.

This study is strengthened by the objective measures used for both predictor and outcome variables, thus avoiding self-report bias. Further, the present study is strengthened by its use of different sized buffers to define the neighbourhood built environment and better understand children's neighbourhoods. Findings from this study highlight the need to consider more specific neighbourhood boundaries to better capture children's neighbourhood built environments. In particular, sex-differences in the most relevant neighbourhood size should be taken into consideration when trying to better understanding the environments that influence behaviour. Future research should investigate the role of neighbourhood on weekend MVPA in order to better compare temporal contexts of children's activities. Future research should also endeavor to combine GPS tracking technologies with accelerometry to investigate the different built environment contexts influencing physical activity and whether these contexts also represent opportunities for physical activity present within a child's neighbourhood.

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Chapter 4

4 Examining the Influence of Contextual Environmental Exposure on Children's Physical Activity: A Novel Geospatial Approach from the STEAM Project

4.1 Introduction

In the last 30 years, Canadian children have become heavier and fatter. Corresponding with these anthropometric changes, physical activity levels of Canadian children have also decreased dramatically in the last 30 years (Tremblay et al., 2010). The majority of Canadian children between the ages of 5 and 17 fail to meet the recommended physical activity guidelines of at least sixty minutes of moderate-to-vigorous physical activity [MVPA] during most days of the week (Statistics Canada, 2015; Tremblay et al., 2011). Decreasing levels of physical activity during childhood contribute to increased risk factors associated with cardiovascular disease, including obesity, high blood pressure, high cholesterol, and type II diabetes (Janssen & LeBlanc, 2010; Shaibi, Faulkner, Weigensberg, Fritschi, & Goran, 2008).

The purpose of this study was to examine how children's physical activity levels may be influenced by their exposure to different elements in their everyday environments. This study was informed by an ecological model of health which posits that multiple factors at different levels should be considered when trying to understand health-related behaviours and outcomes. These factors include the intrapersonal (i.e., individual level factors such as age and sex), interpersonal (e.g., household factors and peer relationships), community (e.g., built and natural environments), and societal (e.g., governmental or school board policies) (Sallis et al., 2006; Sallis, Owen, & Fisher, 2008).

At the individual level, physical activity levels have been found to differ according to sex, age, self-efficacy, goal motivation, perceptions of safety, parental and peer support, the presence of a sibling, and mode of travel to and from school (Heitzler, Martin, Duke,

& Huhman, 2006; Sallis, Prochaska, & Taylor, 2000; Van Der Horst, Paw, Twisk, & Van Mechelen, 2007). Recent research has found that only 13% of boys and 6% of girls meet the recommended guidelines for daily physical activity (Statistics Canada, 2015). Compared to boys, girls prefer to participate in different activities, have different motives for participating in those activities, and face different barriers to participation (Mota & Esculcas, 2002; Posner & Vandell, 1999). While physical activity levels differ according to sex, physical activity levels have been found to decrease with increasing age regardless of sex (Janssen & LeBlanc, 2010; Sallis et al., 2000; Trost et al., 2002). In addition, children who use active modes of travel between home and school (e.g., walking, cycling, scootering) tend to be more physically active at other times of the day, are more likely to meet daily MVPA recommendations, and expend more energy daily than those using inactive modes of travel (Faulkner, Buliung, Flora, & Fusco, 2009; Mackett, Brown, Gong, Kitazawa, & Paskins, 2007).

Research has found that physical activity is lower among children from certain racial/ethnic groups (e.g., black children and youth) and lower socio-economic classes (e.g., lower income, lower educational attainment) (Gordon-Larsen, McMurray, & Popkin, 2000; Gordon-Larsen, Nelson, Page, & Popkin, 2006; Gordon-Larsen, McMurray, & Popkin, 1999; Heath, Pratt, Warren, & Kann, 1994; Kimm et al., 2002; Sallis, Zakarian, Hovell, & Hofstetter, 1996). Socio-economically distressed populations may face unequal and inequitable access to environmental opportunities that are supportive of physical activity (Gilliland, Holmes, Irwin, & Tucker, 2006; Gordon-Larsen et al., 2006; Powell, Chaloupka, Slater, Johnston, & O'Malley, 2007). Although rates of physical activity have been found to be lower among those of lower socio-economic status and certain visible minority racial/ethnic groups, several systematic reviews have found generally mixed associations (Sallis et al., 2000; Van Der Horst et al., 2007).

There is growing interest in identifying built environment constraints and facilitators for physical activity in children. By better identifying aspects of the built environment that

facilitate or constrain physical activity, it may be possible to modify these environments to increase physical activity levels. Previous research has identified three key characteristics of built environments that facilitate and/or constrain physical activity: land use patterns; transportation infrastructure; and urban design (Frank, Engelke, & Schmid, 2003; Handy, Boarnet, Ewing, & Killingsworth, 2002). Land use patterns refer to how activities are distributed across space and are regulated according to zoning policies. Land uses are typically grouped into broad categories such as residential, commercial, recreational, park/open space, institutional, industrial, and agricultural land. Land uses provide both opportunities and barriers to physical activity by providing supportive or unsupportive settings for physical activity (Frank et al., 2003; Handy et al., 2002).

Transportation infrastructure refers to the underlying structures designed to support the movement of people and, therefore, help to connect people with facilities and/or services that are potentially supportive of physical activity. Transportation infrastructure includes roads, trails, sidewalks, bike paths and multi-use paths, and the way these elements are configured within a transportation network or system also has an impact on the accessibility of facilities (Frank et al., 2003; Handy et al., 2002). Intersection density (i.e., “connectivity”), for example, affects the route options available in a neighbourhood and better connected neighbourhoods have been hypothesized as being easier to walk in (Bungum, Lounsbery, Moonie, & Gast, 2009; Crawford et al., 2010; Frank, Kerr, Chapman, & Sallis, 2007; Giles-Corti et al., 2011; Grow et al., 2008; Kerr et al., 2006; Larsen, Gilliland, & Hess, 2012; Saelens & Handy, 2008; Schlossberg, Greene, Phillips, Johnson, & Parker, 2007).

Urban design affects the appearance and arrangement of physical features within spaces (Frank et al., 2003; Handy et al., 2002). For example, although several studies have found positive associations between recreation facility availability and physical activity (Cohen et al., 2006; Dowda et al., 2007; Gordon-Larsen et al., 2006; Jago, Baranowski, & Baranowski, 2006; Patnode et al., 2010; Powell et al., 2007; Ries, Yan, & Voorhees, 2011; Roemmich et al., 2006; Timperio et al., 2008; Van Loon, Frank, Nettlefold, &

Naylor, 2014), research is limited about facility characteristics beyond availability and accessibility (i.e. the type of programs offered at the facility, facility design, and facility quality) which may impact facility use and, thus, physical activity (Cohen et al., 2006; Prins et al., 2011; Romero, 2005; Timperio et al., 2008).

Although numerous studies have found significant associations between certain attributes of the built environment and physical activity, recent systematic reviews have revealed inconsistent evidence and methods across studies which makes it challenging to state strong conclusions about the specific role of the built environment (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Feng, Glass, Curriero, Stewart, & Schwartz, 2010).

Many previous studies focus on the environmental opportunities present within close proximity of a child's home that facilitate or constrain their physical activity, rather than the places to which they are actually exposed. According to Kwan (2012) when describing the Uncertain Geographic Context Problem (UGCoP), many measures of neighbourhood opportunities ignore how time and human mobility affect one's exposure to their environment. Studies relying on neighbourhood proxies (e.g. census boundaries and buffers) to characterize neighbourhood opportunities for physical activity rest on the assumption that all physical activity occurs within a geographically delineated area around the home. These proxies are static and it is problematic to not consider the temporal scales of children's lives. Children move around for normal activities (whether independently or with their parents) and are unlikely to stay in one place throughout a whole day. Children are able to move through different neighbourhood boundaries and can be affected by neighbourhood environments beyond their home neighbourhood (Kwan, 2012). Neighbourhood proxies are useful to help characterize a child's neighbourhood environment, but there is a need to assess children's real exposure to their environments and how this influences their levels of physical activity.

With the development of lightweight Global Positioning System (GPS) loggers, a number of recent studies have been able to use GPS monitoring simultaneously with accelerometry and Geographic Information Systems (GIS) databases. The combination of GPS, GIS, and accelerometry allows researchers to collect precise activity and location data from children to track their movement through their environments and gain insight about the spaces they frequent (Maddison & Ni Mhurchu, 2009; Rodriguez, Brown, & Troped, 2005). Studies using this methodology typically focus on activity behaviours at school within playgrounds (Dessing et al., 2013; Fjørtoft, Kristoffersen, & Sageie, 2009; Fjørtoft, Löfman, & Halvorsen Thorén, 2010), the commute to and from school (Dessing, de Vries, Graham, & Pierik, 2014; McMinn et al., 2014; Rainham et al., 2012), and free-living physical activity during non-school hours (Almanza, Jerrett, Dunton, Seto, & Ann Pentz, 2012; Collins, Al-Nakeeb, Nevill, & Lyons, 2012; Coombes, van Sluijs, & Jones, 2013; Dunton, Almanza, Jerrett, Wolch, & Pentz, 2014; Lachowycz, Jones, Page, Wheeler, & Cooper, 2012; Quigg, Gray, Reeder, Holt, & Waters, 2010; Rainham et al., 2012; Rodríguez et al., 2012; Wheeler, Cooper, Page, & Jago, 2010).

Despite using a methodology to better assess environmental exposure and make stronger connections between the environment and behaviour, these studies rarely explicitly define environmental exposure. In the majority of studies using accelerometer-GPS data, environmental exposure is defined as direct physical contact with an exact point in space and time which may miss how *contextual exposure* – the nearby micro-environment of places experienced by the child – exerts an influence on physical activity levels (Shareck, Frohlich, & Kestens, 2014). By only analyzing direct exposure, these studies rest on the assumption that the nearby micro-environment does not exert a contextual influence on a child. Very few studies have used such an approach. Dessing et al. (2013) buffered each accelerometer-GPS point with a 10 metre buffer, but this step was to account for positional accuracy. Rodríguez et al. (2012) used 50 metre buffers around each accelerometer-GPS point and faced computational constraints.

To address these limitations, this study uses simultaneous GPS tracking and accelerometry to investigate the relationship between contextual environmental exposure and children's physical activity. By moving beyond point-based exposure methods, this study proposes a method of calculating contextual environmental exposure which may further future research concerning environmental influences on children's physical activity. The main objectives of this current study are to: (1) advance a novel methodology for combining accelerometer and GPS data to better understand contextual environmental factors on physical activity; and (2) examine how exposure to different built environmental contexts influence the proportion of time spent in MVPA during non-school hours.

4.2 Methods

This study draws data from the Spatial Temporal Environment and Activity Monitoring (STEAM) project, a three-year research study examining the effects of the built environment on health related behaviours of children aged 9-14. The study design involves two data collection periods: 8 days in the spring and 8 days in the fall. The present study used only the spring. This study was approved by the Non-Medical Research Ethics Board of the University of Western Ontario (NM-REB #: 17918S). Before participating in the study, children must have received signed parental consent and were also required to provide assent.

4.2.1 Recruitment

During the study period, participants at 34 elementary schools across the 4 school boards in London, Ontario, and surrounding area completed an 8-day multi-tool procedure to record their neighbourhood activities, mobility, and experiences. Participants completed detailed daily activity and travel diaries, wore portable accelerometers and GPS units during all waking hours for up to 8 days, and both children and parents/guardians completed detailed questionnaires about their demographic profile and their child's neighbourhood activities, behaviours, and perceptions. Research staff recharged GPS

units after each day of use and monitored equipment and activity diary compliance each day.

4.2.1.1 Inclusion Criteria and Scope of Analysis

This study's sample is a subset of a larger sample of children from 34 schools in London and surrounding area (n=851) who had demographic data from child and/or parent surveys, had valid physical activity data and GPS data, and spent at least 80% of their time within London, Ontario. Of the 851 participants in the STEAM sample, 101 were excluded because they were part of the pilot year (which used different accelerometer data collection methods than non-pilot years). Participants were excluded if they did not have a minimum of 8 hours of valid non-school accelerometer-GPS data per student (n=39). Conditions of exclusion include missing data, outlier data [activity counts per minute < 20,000], and accelerometer non-wear (non-wear time was defined as motionless bouts [extended time periods of zero counts] of 60 consecutive minutes or longer, commonly used to determine a valid day in child studies (Cain, Sallis, Conway, Van Dyck, & Calhoun, 2013)). This study focused on non-school hours to separate the effect of environment features from school-time activities.

A further 203 participants were excluded because more than 20% of their GPS data occurred outside of London, Ontario. Participants were excluded if demographic data from the child or parent surveys was unavailable (n=43), resulting in a final sample size of 466 students with objective environment exposure and physical activity data from the Spring. Descriptive statistics about the sample are shown in Table 1. The 466 students attend 21 schools spread across the City of London in urban and suburban settings.

4.2.2 Assessing Physical Activity, Spatial Behaviour and Exposure

4.2.2.1 Measurement of Physical Activity

Physical activity was measured using **Actical® Z Accelerometers** with 30 second epochs worn on the hip (Heil, 2006). Participants were asked to wear the accelerometer

during all waking hours for 8 consecutive days but were able to remove it for sleeping, bathing, and swimming. Non-wear time, defined as motionless bouts (extended time periods of zero counts) of 60 consecutive minutes or longer, was excluded from analysis.

4.2.2.2 Measurement of Spatial Behaviour

Each child's location was measured by passively tracking students using a VisionTac VGPS-900 **GPS logger** with 1-second recording intervals. Participants were asked to wear the GPS during all waking hours for 8 consecutive days unless they were sleeping, bathing, or swimming. This GPS continuously records data on time/date, speed, altitude, trip distance and spatial location (accuracy within 2.5m).

4.2.2.3 Measurement of Environmental Exposure

A tessellated hexagon grid surface over London, Ontario was developed in ArcGIS v10.1 (ESRI, Redlands, CA) to assess built **environment exposure**. Hexagons form a continuous grid, offer a more symmetric nearest neighbour than a rectangle, and reduce potential sampling bias from edge effects due to a shorter perimeter compared to a square (Birch, Oom, & Beecham, 2007). The circumradius for each hexagon measures 10 metres, giving each hexagon an area of 259.808 m². A circumradius of 10 metres was selected because it was deemed what could be reasonably seen by a child and could therefore exert a contextual influence on a child. Built environment variables associated with children's physical activity participation were integrated with the tessellated hexagonal grid surface to address a range of the hypothesized exposure mechanisms influencing physical activity.

Before developing the measures, the accelerometer and GPS data were merged and processed in Stata SE 13 (64 bit) (StataCorp, 2015) to form one spatial database. The GPS tracks for each student were superimposed on (see Figure 4.1), and then joined to the tessellated hexagon surface. Each GPS point was assigned the hexagon ID corresponding to the hexagon that point falls within, allowing the total amount of time spent within each hexagon to be calculated (see Figure 4.2). Epoch differences between

the GPS and accelerometer data were accounted for by assigning the physical activity intensity measure to each GPS point, matched by date and time.

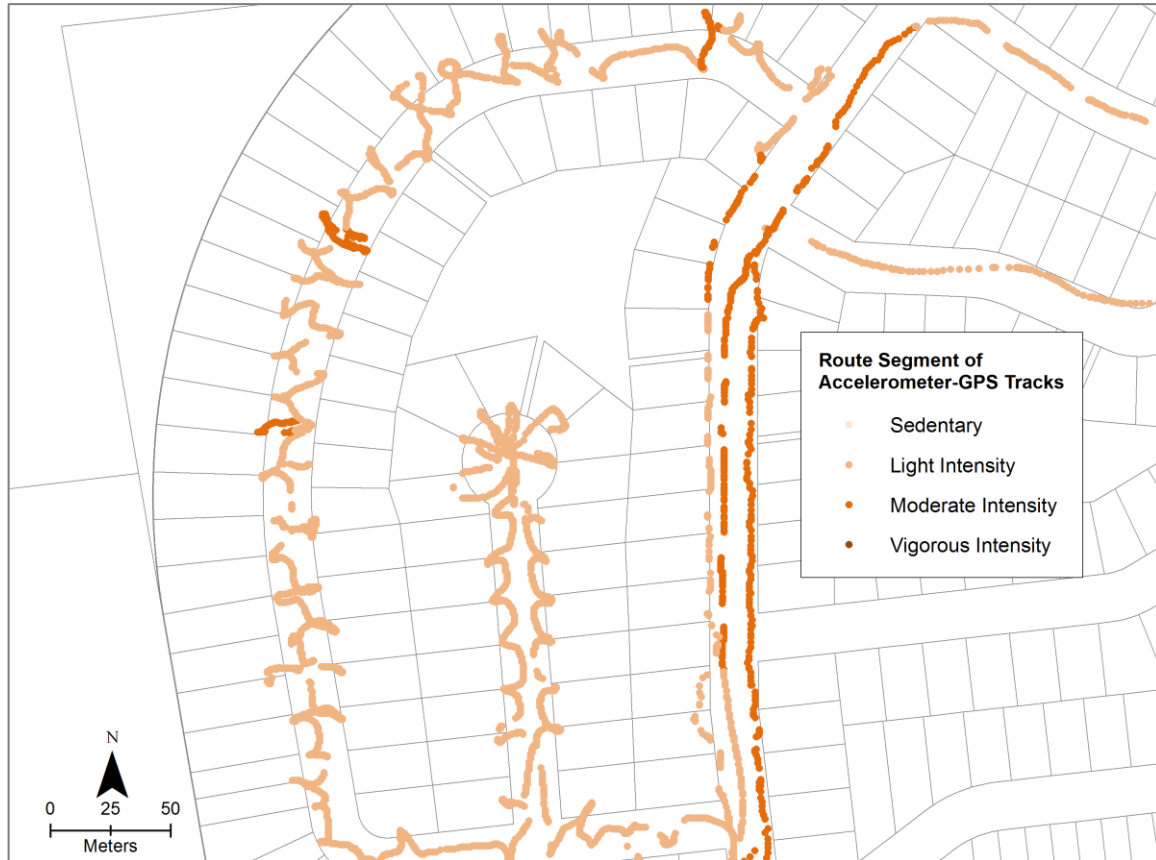


Figure 4.1 Segment of a child's GPS tracks showing their after school newspaper delivery route and corresponding physical activity levels based on matched accelerometer data.



Figure 4.2 GPS data is overlaid with a hexagonal surface which is used to spatially integrate multiple built environment datasets.

4.2.3 Measures

4.2.3.1 Dependent Variable

The dependent variable was the proportion of total time spent in MVPA (classified as > 1500 counts/min) outside of school for each child. Validated cut-points for children were used to classify the accelerometer-GPS data by defining the minimum threshold at which physical activity would be classified as moderate-to-vigorous (Puyau, Vohra, Zakeri, & Butte, 2004). Using a proportion accounts for individual wear time which influences the number of data points measured.

4.2.3.2 Independent Variables

This study uses three groups of independent variables, following an ecological model of health: individual level; neighbourhood socio-economic status (SES); and the built environment.

Individual level variables account for factors specific to each child that may influence their physical activity. The individual level variables include (with the reference category in italics): sex (*male* and female); age in years (continuous variable); travel mode, i.e., the most frequently used mode of travel to and from school (*active* [mostly walk or bike] and inactive [mostly take a car or bus]); and the presence of a sibling (*only child*, has a sibling, and prefer not to answer). These variables were collected from multiple sources, such as child surveys, parent surveys, and data recorded when calibrating each child's accelerometer.

As individual level household income was largely unavailable for participants (i.e., too many parents chose prefer not to answer), we used **neighbourhood socio-economic status (SES)**, as defined by the median family income of the census dissemination area (DA) in which the child's home is located.

Environmental exposure is expressed as the proportion of time spent exposed to each **built environment** attribute over all valid days of data. Environmental exposure was calculated for all accelerometer data (i.e. sedentary, light, moderate, and vigorous) to avoid the *selective mobility bias* problem described by Chaix et al. (2013), where children who want to be physically active will seek out environments that support physical activity, thereby making them appear to be more “exposed” to physical activity opportunities. The environmental variables assigned to each hexagon on the tessellated hexagon surface were selected to address a range of the hypothesized exposure mechanisms positively and negatively influencing physical activity (Frank et al., 2003; Frank & Engelke, 2001; Handy et al., 2002). A description of these variables and their

definitions are below (Table 4.1). Each variable is calculated at the level of individual hexagons.

Table 4.1 Description of the built environment measures included in the study

Built Environment Measure	Description
Open space parks (m ²)	Area of land use in each hexagon that is part of a larger park without any built recreational amenities
Parks with at least one sports field (m ²)	Area of land use in each hexagon that is part of a larger park with at least one sports field
Parks with at least one playground (m ²)	Area of land use in each hexagon that is part of a larger park with at least one playground
Parks with at least one sports field and playground (m ²)	Area of land use in each hexagon that is part of a larger park with both at least one sports field and playground
Recreation space (m ²)	Area of recreational land use
Commercial space (m ²)	Area of commercial land use
Residential space (m ²)	Area of residential land use
Institutional space (m ²)	Area of institutional land use
Industrial space (m ²)	Area of industrial land use
Multi-use path area (m ²)	Area of multi-use path area
Intersection count (#)	The number of 3- and 4- way intersections

The built environment data was obtained from the City of London (2014). Only accelerometer-GPS points within the boundaries of London, Ontario were considered in this analysis.

A binary environmental variable was calculated for each accelerometer-GPS point. Because each accelerometer-GPS point was assigned a hexagon ID value corresponding to the hexagon cell in which it was located, a count of accelerometer-GPS points for each hexagon ID was determined and represented the time spent (in seconds) in each hexagon (see Figure 4.3). To determine the time spent exposed to each built environment (rather than each hexagon), a binary variable was created for each environmental attribute whereby if the variable was present within the hexagon, a value of 1 was assigned. If a variable was not present within the hexagon, a value of 0 was assigned. The number of seconds spent within each hexagon was multiplied by 0 or 1 for each binary

environmental variable to calculate the time spent exposed to each environmental attribute. The environmental variables were then summed for each participant to provide the number of seconds spent exposed to each environmental variable (regardless of hexagon) over the study period. The independent variables were transformed to reflect wear time and to determine a value for the proportion of time a participant was exposed to each built environment.

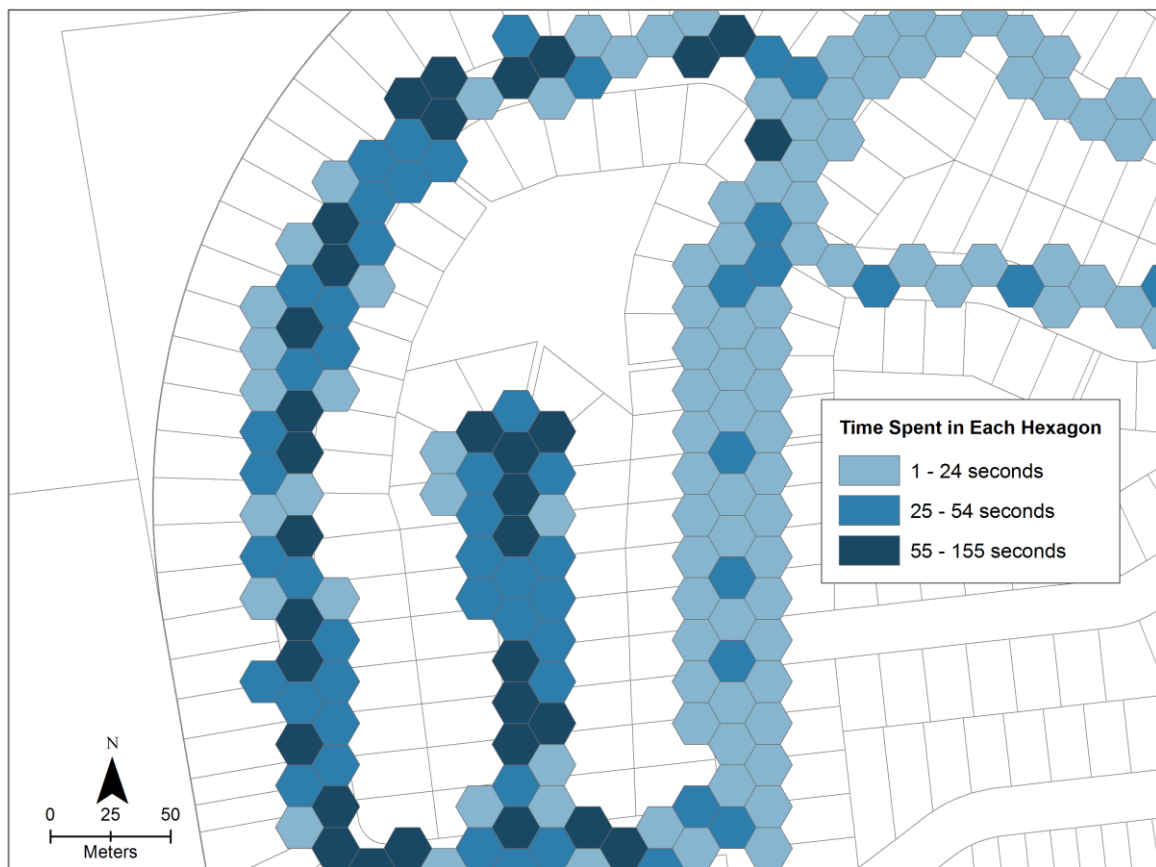


Figure 4.3 Point-level GPS data are aggregated within the hexagon to calculate time spent in each hexagon micro-environment.

4.2.4 Statistical Analysis

The proportion data are bound between 0 and 1 so the logit function is most appropriate. Specifically, weighted least squares logistic regression for grouped data modelling was

used to analyze the relationship between the proportion of time spent exposed to different built environments and the proportion of time spent in physical activity. Weighted least squares logistic regression for grouped data accounts for different sized denominators (*numerator*: time spent in MVPA during non-school hours; *denominator*: time spent in all activity intensities during non-school hours) and, thus, different variances across participants (Baum, 2008). Individual level and neighbourhood SES variables were selected if bivariate analyses showed a significant relationship with the dependent variable ($p < 0.10$). Statistical analysis was performed with STATA SE 13 (64 bit) (StataCorp, 2015).

4.3 Results

4.3.1 Descriptive Statistics

Descriptive statistics about the sample can be found in Table 4.2. The majority of participants were between 11 and 12 years old (73.39%). Of the participants, 55.79% were girls and 44.21% were boys. Most participants had a sibling (79.40%) and used an inactive mode of travel between home and school (66.74%). The median family income (in CAD) was \$70,462.

Table 4.3 summarizes the mean proportion of time spent exposed to various built environments outside of school hours for the whole sample and by sex. The majority of environmental exposure took place in residential spaces (likely the child's home). The average proportion of time spent exposed to park spaces was relatively low overall for both sexes, but boys were marginally more exposed to park spaces than girls. Similarly, the average proportion of time spent exposed to recreational spaces was relatively low (though much higher than park spaces) for both sexes, but boys were more exposed to recreational spaces than girls. Comparatively, a relatively high proportion of time was spent exposed to institutional spaces (likely the child's school) outside of school hours for both sexes, with boys having higher levels of exposure than girls. Girls were significantly

more exposed to commercial spaces than boys ($p=0.001$). Boys spent significantly more time proportionally in MVPA than girls ($p=0.032$) (Table 4.4).

Table 4.2 Descriptive statistics about the sample (n=466)

Variable	n	%
Age		
9	10	2.15
10	76	16.31
11	204	43.99
12	137	29.40
13	36	7.73
14	2	0.43
Sex		
Male	206	44.21
Female	260	55.79
Presence of a Sibling		
Only child	68	14.59
Has sibling(s)	370	79.40
Prefer not to answer	28	6.01
Mode of travel		
Active	155	33.26
Inactive	311	66.74
	Mean	SD
Median family income in CAD (in thousands)	70.46	32.05

Table 4.3 Proportion of time spent exposed to different environments for all activity intensities by sex

Proportion of Time Spent Exposed To:	Boys (n=206)		Girls (n=260)		p-Value
	Mean (%)	SD	Mean (%)	SD	
Open space parks	1.54	6.52	1.04	5.07	0.853
Park with at least one sports field	1.15	3.87	0.83	3.68	0.132
Park with at least one playground	0.51	2.75	0.36	1.35	0.825
Park with at least one sports field <i>and</i> playground	0.96	2.91	0.88	2.64	0.592
Commercial space	6.02	7.90	7.25	6.81	0.001
Residential space	79.97	16.95	80.97	13.76	0.508
Recreational space	5.28	9.30	3.72	6.70	0.540
Institutional space	8.38	10.55	7.89	7.67	0.772
Industrial space	0.92	1.97	1.22	3.06	0.068
Multi-use path space	0.57	2.47	0.41	1.23	0.714
Intersection count (3-way or 4-way)	1.01	1.02	1.20	1.40	0.014

Note: Mann-Whitney U test was used to test differences by sex in the proportion of time spent exposed to different environments.

Table 4.4 Physical activity characteristics of the sample by sex

Variable	Proportion of Total Time Spent in MVPA Outside of School Hours	
	Mean (%)	p-Value
Sex		
Boys	8.31	0.032
Girls	7.03	
Total Sample	7.59	-

Note: Mann-Whitney U test was used to test differences by sex in the proportion of total time spent in MVPA outside of school hours.

4.3.2 Model Specification

A series of models were developed to assess associations between the proportion of time spent exposed to environmental attributes and the proportion of time spent in MVPA while accounting for age, sex, mode of travel, the presence of siblings, and neighbourhood-level SES. Sex-stratified models were developed because of anticipated sex differences in relationships, but a model using the entire sample was created to detect smaller effects with the power of a larger sample size. Although the full model accounts for sex, sex-stratified models are necessary to identify whether associations are specific to girls or boys. Model results are found in Table 4.5.

4.3.3 Model Results

Table 4.5 shows the results for the full weighted least squares logistic regression for grouped data. The odds of MVPA are lower for females compared to males and are lower for children using inactive modes of travel (e.g., car or bus) versus active modes (e.g., walking or biking). The proportion of time spent in MVPA outside of school was also significantly associated with the presence of a sibling, comparing to those with a sibling or those who preferred not to answer. The proportion of MVPA outside of school was not related to median family income. The odds of MVPA increase as the proportion of time spent exposed to institutional space increases. In contrast, the proportion of time spent exposed to open space parks was associated with lower odds of MVPA.

Table 4.5 also shows the results for the sex-stratified weighted least squares logistic regression for grouped data. Several significant individual level and environmental variables were sex-specific. There were no significant differences according to area-level socioeconomic status, as represented by median household income in the home neighbourhood census dissemination area.

For boys, the odds of MVPA decrease with age and are lower for those using inactive modes of travel to and from school versus active modes. The proportion of time spent in

MVPA was significantly associated with the presence of a sibling and for those who preferred not to answer. Exposure to a variety of built environments positively influenced boys' proportion of MVPA: parks with at least one sports field, parks with more than one unique feature, commercial space, and institutional space.

For girls, the proportion of time spent in MVPA outside of school was significantly negatively associated with those using inactive modes of travel to and from school. Exposure to sites for recreation influenced girls' total proportion of MVPA; the odds of MVPA decrease as the proportion of time spent exposed to open space parks increases, while the odds of MVPA increase as the proportion of time spent exposed to recreational space and multi-use path space increases. The girl-stratified model had the strongest model fit.

Table 4.5 Weighted least squares logistic regression models for grouped data

Variables	All Children (n=466) ^a		Boys (n=206) ^b		Girls (n=260) ^c	
	OR	p-Value	OR	p-Value	OR	p-Value
Age	0.967	0.301	0.898	0.046	0.998	0.967
Sex (reference: male)						
Female	0.863	0.014	-	-	-	-
Siblings (reference: only child)						
Has sibling(s)	1.242	0.019	1.478	0.007	1.059	0.611
Prefer not to answer	1.258	0.120	1.688	0.045	1.056	0.750
Mode of Travel (reference: active)						
Inactive	0.612	0.000	0.752	0.002	0.487	0.000
Median family income in CAD (10 ⁻³)	1.001	0.597	1.000	0.977	1.001	0.562
Proportion of time spent exposed to:						
Open space parks	0.974	0.007	0.980	0.203	0.951	0.002
Park with at least one sports field	0.993	0.294	1.033	0.031	0.982	0.077
Park with at least one playground	1.015	0.340	1.026	0.212	0.963	0.275
Park with at least one sports field <i>and</i> playground	1.007	0.617	1.067	0.015	0.972	0.130
Commercial space	1.006	0.166	1.012	0.041	1.001	0.919
Residential space	0.998	0.394	0.998	0.563	0.997	0.415
Recreational space	1.014	0.058	0.998	0.873	1.052	0.000
Institutional space	1.013	0.001	1.013	0.009	1.006	0.363
Industrial space	1.002	0.903	0.997	0.895	0.100	0.983
Multi-use path space	1.028	0.244	0.964	0.366	1.092	0.005
Intersection count (3-way or 4-way)	1.036	0.064	1.009	0.823	1.034	0.121
Constant	0.100	0.000	0.184	0.011	0.089	0.000

Note: Odds ratio; ^a Adjusted R-squared= 0.222; ^b Adjusted R-squared =0.202; ^c Adjusted R-squared=0.298

4.4 Discussion and Conclusion

This study adds to a growing and active field of research in simultaneous activity assessment and location monitoring. By using a tessellated hexagon surface as a GIS-based data integration tool, the current study contributes a novel methodology to examine contextual environmental exposure and how contextual exposures affect children's MVPA. Contextual environmental exposure offers additional knowledge to clarify the spaces that exert influences on children's physical activity.

Findings are consistent with past research reporting higher levels of physical activity among boys than girls (Sallis et al., 2000; Statistics Canada, 2015; Van Der Horst et al., 2007), emphasizing the importance of examining environmental exposure within the context of sex differences. The findings from this study support existing research, which found that boys' proportion of MVPA decreases with age (Janssen & LeBlanc, 2010; Trost et al., 2002). These results suggest that boys may be particularly sensitive to the impact of age on physical activity levels. Together, these findings underscore the importance of planning and developing policies that promote physical activity in children, particular given that previous research has shown physical activity habits developed as a child continue into adulthood (Telama et al., 2005).

Previous research has found that children prefer to engage in MVPA with other children, so it is not surprising that the proportion of boys' MVPA is positively influenced by having a sibling (Veitch, Salmon, & Ball, 2010). This research did not account for age or sex differences of the siblings, which makes it difficult to account for why the presence of a sibling only affected boys' overall proportion of MVPA. Nevertheless, efforts could be made to develop physical activity programming specifically targeted to those without siblings.

Physical activity is negatively associated with those using inactive modes of travel to and from school, regardless of sex. Girls who use inactive modes of travel between home and

school are even less likely to engage in MVPA than boys who use inactive modes of travel. These findings emphasize that efforts should be made to encourage children's active transportation (e.g., programs focused on active and safe routes to school, or walking school buses), especially among girls. Active transportation can contribute to a large proportion of a child's physical activity in a day, so it is important to encourage children to use active modes of travel (Faulkner et al., 2009; Mackett et al., 2007).

Results provide supporting evidence that children's physical activity is influenced by contextual exposure to diverse environments outside the home and in school. In particular, contextual environmental exposures influence the physical activity behaviours outside of school of boys and girls differently, underscoring the complexity of the built environment physical activity relationship.

For girls, the proportion of MVPA outside of school was only associated with exposure to sites specifically designed to support physical activity (parks, recreation spaces, and multi-use path spaces) which suggests that spaces specifically designed with the purpose of supporting physical activity have a stronger influence on girls. Recreation spaces – typically recreational facilities – afford opportunities for organized and structured physical activity programming. Previous research has found that girls are more likely to participate in structured physical activities than boys, suggesting that recreation spaces may be used because they support structured physical activity (Mota & Esculcas, 2002). Conversely, multi-use paths are conducive to unstructured physical activity and active transportation, like walking, wheeling, running and skipping (Larsen et al., 2012). This result is consistent with previous research finding that adolescent girls who live near more parks with amenities that encourage walking (e.g., multi-use paths) engage in more non-school hour MVPA (Cohen et al., 2006). Planners and policymakers should consider planning more recreation space and developing more multi-use paths to increase physical activity levels among girls, particularly given that girls tend to be less physically active than boys.

Boys, on the other hand, appear to be influenced by a variety of spaces (parks, commercial spaces, and institutional spaces), not just sites for recreation. Commercial and institutional spaces afford opportunities for both structured and unstructured activities. For example, a commercial venue with physical features like railings and stairs affords the opportunity for skateboarding or parkour. Although boys' physical activity was associated with their exposure to institutional and commercial spaces, girls still spent significantly more time in commercial spaces and both sexes spent similar amounts of time in institutional spaces. Together, these results suggest that commercial and institutional spaces may provide girls with different leisure opportunities than boys, perhaps for more passive activities like hanging out, leisure programs (e.g., Girl Guides), or socializing (Meeks & Mauldin, 1990; Posner & Vandell, 1999). Future testing of these significant differences between boys and girls might provide more insight.

Exposure to park spaces influenced the proportion of time spent in MVPA, with sex-based differences depending on amenities present in the park. These findings suggest that planners and policymakers involved in designing and managing park spaces should pay particular attention to amenities to promote children's physical activity. Research has found that sport is a more important characteristic of boy's non-school physical activity than girls (Meeks & Mauldin, 1990; Trew, 1997), providing some explanation as to why exposure to parks with sports fields influences their physical activity. These children are also approaching the end of early childhood and parks with amenities afford more complex and challenging opportunities for physical activity which may engage a child (Isenberg & Quisenberry, 2002). For example, open space parks (i.e. parks without amenities) may afford girls the opportunity for more passive leisure activities like socializing, an activity found to be popular among girls this age, instead of physical activity (Meeks & Mauldin, 1990; Posner & Vandell, 1999).

Results from this momentary and simultaneous activity assessment and location monitoring analyses provide evidence that contextual exposure to the built environment is important for better understanding and clarifying physical activity behaviours. This study,

therefore, highlights the importance of planning and developing diverse built environments to encourage and support physical activity for children. Further, the results from this study highlight unique sex differences between contextual environmental exposure and physical activity. Because findings were sex-specific, this study provides supporting evidence that the built environment is complex, and matters differently for physical activity depending on a child's sex. Researchers, planners, and policymakers should therefore consider how boys and girls use spaces differently when researching, designing, and creating places to support physical activity; a one size fits all approach when developing places may not be appropriate.

Findings emphasize the need for research about the settings that exert *contextual* influences on physical activity for both sexes. While simultaneous GPS tracking and accelerometry offer a step forward in improving measurement and identifying the spaces children frequent for activities, more research is needed using accelerometer-GPS data to clarify how the contextual micro-environment (and not just direct exposure) influences children's physical activity. In particular, future research should endeavor to differentiate how contextual environments differ according to the type (e.g. MVPA versus light activity intensity) and context (e.g. structured versus unstructured) of physical activity. Using a tessellated hexagonal grid surface appears to be a useful method for assessing contextual environmental exposure, though more research is needed on the appropriate size of hexagon cell that should be used to best represent children's contextual exposure.

This study is not without technological and methodological challenges. Only accelerometer points with matching GPS data were considered in this analysis. Despite wearing the GPS unit simultaneously with the accelerometer, there is the likelihood with any GPS device that no positional data was recorded due to concrete canyons or heavy tree canopies. Further, GPS data may be misclassified because the locational data has some degree of variable precision. Nevertheless, superimposing and joining the accelerometer-GPS tracks on the tessellated hexagon surface does minimize this impact

by absorbing the margin of error associated with current GPS technology such as the GPS device used in this study.

This study makes multiple important contributions to the literature on built environment influences to physical activity. Broadly, this study is strengthened by its large dataset and relatively large sample of children. No other study has used a similar approach of merging accelerometer and GPS data and overlaying accelerometer-GPS tracks on a tessellated hexagon surface to analyze *contextual* environmental exposure. This is, in part, because until recently, few studies have had access to simultaneous GPS and accelerometer data and of those studies, most use a point-by-point (i.e. not aggregate) analysis to examine direct physical exposure to the environment. By addressing contextual environment exposure to understand the characteristics of places experienced by a child, this study offers a novel alternative for studies using GPS-accelerometry that may help to address the UGCoP, in addition to contributing empirical evidence to research about environmental influences on physical activity.

Empirically, this study offers more spatial accuracy about the settings influencing a child's physical activity. Results from this study can help inform policymakers and decision-makers when deciding zoning codes, development regulations, and public recreation investments to encourage and support children's physical activity and reduce obesity rates.

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Chapter 5

5 Synthesis

5.1 Summary of Studies

The two studies included in this thesis examined the relationship between the built environment and children's physical activity in distinct but complementary ways. Both studies had the same overarching objective to investigate how the built environment influences children's physical activity levels outside school hours, but each study defined and measured the built environment in different ways, and took different approaches to measuring children's engagement with the built environment.

Study 1 (Chapter 3) examined the influence of children's neighbourhood built environments on objectively measured moderate-to-vigorous physical activity (MVPA) during non-school hours for children (aged 9 – 14). This study focused on the characteristics of built environments in children's home neighbourhoods, which were defined at two scales: 500 and 800 metres (m) around the home. This study found that neighbourhood settings have an influence on children's MVPA, particularly for boys. This study underscores the importance of accounting for sex-based differences in the most relevant neighbourhood context when planning and developing neighbourhood-based policies, programs, and practices to encourage children to be physically active. This study's findings suggest that boys may engage in more neighbourhood physical activity may be influenced by a wider neighbourhood than girls. In addition, this study found that boys and girls engage differently with parks depending on the amenities present; boys from neighbourhoods with greater access to parks with sports fields were found to have significantly higher levels of MVPA, whereas boys from neighbourhoods where park designs tended to be centered around playgrounds had significantly lower levels of MVPA. This may be because the boys in our sample are nearing adolescence and may perceive playgrounds as either spaces for socializing, or may perceive playgrounds as not being challenging or complex enough for active play. Parks with

sports fields were also positively associated with girls' MVPA, highlighting the importance of spaces specifically designed to support physical activity for both sexes.

This study also investigated the use of different sizes of neighbourhood proxies for examining built environment correlates of physical activity. While this study generated some significant findings, most of the built environment variables examined showed no association with MVPA. Buffer-based measures are useful for helping to characterize a subject's general neighbourhood environment, but are insufficient for assessing children's actual exposure to different features in their environments. This finding highlights the importance of the environmental context for physical activity. This is particularly important because children are able to move through different neighbourhoods throughout their day, especially since many parents drive their children to structured activities (Karsten, 2005; Kwan, 2012).

Elaborating on the methodological insights gained from the first study, study 2 (Chapter 4) aimed to examine how contextual environmental exposure influences children's MVPA during non-school hours. To investigate this aim, children's spatial behaviours during non-school hours on weekdays were tracked using portable global positioning system (GPS) units in conjunction with portable accelerometers to record physical activity. Data from both devices were matched and integrated within a geographic information system (GIS) for spatial and statistical analysis. This study used a novel method of superimposing and aggregating GPS point data within a tessellated hexagon surface in ArcGIS to measure contextual environmental exposure. In doing so, this study was able to assess children's contextual exposure to their environments and clarify which environmental contexts are important for supporting physical activity. While this method of measuring children's environmental exposure is still new, it stands that simultaneous location monitoring and activity assessment represents the best way to capture the spatial contexts of children's physical activities. This study found that both individual and environmental level factors influenced children's MVPA, reinforcing the need for health research to use an ecological framework and consider multiple levels of influence on

health outcomes. Boys' MVPA was significantly positively associated with contextual environmental exposure to parks with sports fields, parks with sports fields and playgrounds, commercial spaces, and institutional spaces. Girls' MVPA was significantly positively associated with recreational spaces, and multi-use path spaces, and significantly negatively associated with open space parks (i.e. parks with no built recreational amenities). Results from this study provide supporting evidence that children's physical activity is influenced by contextual exposure to environments outside the home and at school. In particular, the environmental contexts that influence physical activity differ for boys and girls, underscoring the complexity of the built environment physical activity relationship.

5.2 Research Contributions

Comparison of results from both studies reveals some findings which are common to both studies, and which align with previous research concerning the built environment for children's physical activity. Both studies found that multiple factors influence children's physical activity ranging from the individual level to the built environment, reinforcing the importance of an ecological framework to consider that multiple factors at different levels influence health outcomes.

Study 1 and study 2 both emphasize the importance of factors at the individual level that influence physical activity. In both studies, boys were more physically active than girls. This is consistent with recent findings that boys between the ages of 5-17 are more physically active than girls (Statistics Canada, 2015). Sex-stratified models in both studies also revealed sex-based differences in the relative importance of the built environment in influencing physical activity. This is further discussed below.

Previous studies have consistently shown age to be an important factor related to children's physical activity, with physical activity levels decreasing as age increases (Janssen & LeBlanc, 2010; Sallis, Prochaska, & Taylor, 2000; Trost et al., 2002). Both study 1 and study 2 used data from the STEAM project, where participating students

were between the ages of 9 and 14. Consistent with previous studies, in study 2, age was found to be a significant predictor of the proportion of time spent in MVPA; however, this finding was only significant for boys, suggesting that boys may be more sensitive to age and are less active as they get older. In study 1, however, age was not found to be a significant predictor of MVPA for either sex. This may be because the sample of children is nearing adolescence (9-14, with the majority being 11-12) and relatively close in age. Nevertheless, these results suggest that while numerous studies has shown negative relationships between age and physical activity, more research is needed to clarify the sensitivity of this relationship.

Similarly, children with siblings in the sample tended to be more physically active than those who are an only child, which is also consistent with previous research (Hohepa, Scragg, Scholfield, Kolt, & Schaaf, 2007; Liu, Wiehe, & Aalsma, 2014; Sallis et al., 2000). When stratified according to sex, however, both studies found that the presence of a sibling only influenced the physical activity of boys. Boys, perhaps, engage in more unstructured physical activity with siblings. It is unclear why the presence of a sibling only influenced the physical activity of boys, but this may indicate that girls are more sensitive to the age and sex of a sibling, factors that this research was unable to account for.

Both studies also reinforce the importance of using active modes of travel between home and school. In both study 1 and study 2, all models showed significant associations between physical activity and the mode of travel (i.e., active vs inactive) most frequently used between home and school. In these models, mode of travel was one of the strongest predictors. This finding is consistent with previous research which has found that children using active modes of travel between home and school tend to be more physically active overall and are more likely to meet the Canadian daily physical activity recommendations than those using inactive modes of travel between home and school (Faulkner, Buliung, Flora, & Fusco, 2009; Mackett, Brown, Gong, Kitazawa, & Paskins, 2007; Tremblay et al., 2011). In both studies, girls who used inactive modes of travel

between home and school were less likely to be physically active than boys who use inactive modes of travel. These findings emphasize that any efforts to encourage children's active transportation, should pay particular attention to the barriers to active travel faced by girls. Active transportation can contribute to a large proportion of a child's daily physical activity so it is important to encourage children to use active modes of travel wherever possible.

Previous studies have tended to identify lower levels of physical activity among children and adults categorized as lower socio-economic status; however, evidence about the role of socio-economic status on physical activity remains mixed (Gordon-Larsen, McMurray, & Popkin, 2000; Gordon-Larsen, Nelson, Page, & Popkin, 2006; Gordon-Larsen, McMurray, & Popkin, 1999; Heath, Pratt, Warren, & Kann, 1994; Kimm et al., 2002; Sallis, Zakarian, Hovell, & Hofstetter, 1996). In study 1, area-level socio-economic status as represented by median family income was found to be significantly associated with girls MVPA, suggesting that girls from higher income neighbourhoods are more likely to be physically active overall. Although girls engaged in less MVPA than boys overall, those girls from more affluent neighbourhoods were more likely to be physically active than girls from less affluent neighbourhoods. In study 2, however, the proportion of time spent in MVPA was not found to be associated with area level socio-economic status in the home neighbourhood for either boys or girls. These mixed results suggest that more research is needed to clarify the relationship between children's physical activity and socio-economic status, particularly for girls.

Both studies identified features of the built environment that influenced physical activity. A systematic review of the objectively-measured built environment in studies of objectively-measured physical activity (presented in Chapter 2) found that, regardless of method used, results are mixed about the relationship between various attributes of the built environment and physical activity. Findings from study 1 and study 2 of this thesis, however, may provide supporting evidence to clarify some of these mixed relationships. In addition, differences between study 1 and study 2 help to provide methodological

considerations for future research. Both study 1 and study 2 found that park spaces influenced both boys' and girls' physical activity, with sex-based differences in the relationship depending on amenities present. These findings suggest that the amenities present in a park influence children's physical activity, so those involved in developing municipal park space should pay particular attention to recreational amenities. Because findings were sex-specific, both studies provide supporting evidence that the built environment is complex, and matters differently for children's physical activity, depending on sex.

Consistent with study 1, results from study 2 show that exposure to environments that influence physical activity behaviours outside of school differ according to sex, underscoring the complexity of the built environment physical activity relationship. Although features of the built environment were found to influence physical activity in both studies, study 2 found more significant associations between the proportion of MVPA and contextual exposure to different built environments. For girls, the proportion of MVPA outside of school was only associated with exposure to sites specifically designed to support physical activity, which suggests that spaces specifically designed with the purpose of supporting physical activity may influence girls more strongly. Boys, on the other hand, appear to be influenced by a variety of spaces, not just sites specifically designed for recreation. Although boys' physical activity was associated with their exposure to institutional and commercial spaces, girls still spent significantly more time in commercial spaces and both sexes spent similar amounts of time in institutional spaces. Together, these results suggest that commercial and institutional spaces might provide girls with different opportunities than boys, such as socializing or leisure activities (Meeks & Mauldin, 1990; Posner & Vandell, 1999). Results from study 2 provide supporting evidence that children's physical activity is influenced by contextual exposure to diverse environments outside the home and at school.

Study 1 found that the neighbourhood size that best predicted boys' MVPA was 800m, larger than the 500m neighbourhood that best predicted girls' MVPA. This finding hints

that boys may have a wider neighbourhood to engage in MVPA with than girls. Considering that the built environment had a stronger influence on boys' MVPA, this study's findings suggest that boys may engage in more neighbourhood physical activity and have a larger neighbourhood to use than girls. Previous research has found that boys have fewer restrictions for independent play than girls (Brown, Mackett, Gong, Kitazawa, & Paskins, 2008; Mackett et al., 2007). However, study 2 found that the built environments influenced both boys and girls, with numerous associations found between different environmental attributes and physical activity. While study 1 found that girls may not engage in as much neighbourhood MVPA as boys, study 2 suggests that girls may be engaging in physical activity outside of their neighbourhood, perhaps structured activities that take place in specialized venues outside the neighbourhood. While girls are less physically active overall than boys, it is worth noting that the neighbourhood may not be the only source for physical activity and strategies aiming to raise girls' physical activity should look beyond the neighbourhood or should seek to identify and remove barriers to physical activity in the neighbourhood.

5.3 Methodological Contributions

Both studies contribute evidence about the role of built environment within the context of children's physical activity, but suggest that more research is needed to further clarify the strength of this relationship. Results from both studies reinforce the need for better techniques to address the spatial contexts of children's activities.

In particular, the use of simultaneous GPS tracking and accelerometry offers a significant improvement in measuring and identifying the spaces children inhabit and shows promise for clarifying how the built environment influences physical activity. Findings of this thesis confirm that simplified measures of the home neighbourhood, while useful for helping understand neighbourhood opportunities for physical activity, are unable to assess children's exposure to these environments and the importance of different environment contexts for activities. Children are mobile and it is unlikely that they spend all of their time within their neighbourhood, especially considering that many parents

drive their children to activities in different neighbourhoods (Karsten, 2005; Kwan, 2012). It is important to identify the spatial contexts for physical activity to provide specific and detailed recommendations about the built environment for policymakers, planners, and programmers.

The findings of this thesis suggest that future studies investigating how the built environment influences physical activity should endeavour to use GPS tracking to measure environmental exposure rather than simple neighbourhood measures of opportunity and density. In particular, study 2 emphasizes that more research is needed to clarify not only how environmental exposure influences children's physical activity, but also how contextual micro-environments influence children's physical activity. Advances in the development of lightweight and affordable GPS loggers and activity monitors should help researchers develop studies that are able to take advantage of simultaneous location monitoring and activity assessment. Taken together, both studies emphasize the need for better techniques to address the spatial contexts of children's activities in order to better inform the development of policy, programming, and practices.

5.4 Limitations

Both studies draw from data that was collected during the spring. As a result, the physical activity that was captured will be specific to this season. A systematic review conducted by Tucker & Gilliland (2007) found that physical activity levels vary by season. Consequently, the results from both studies will likely differ if the data was collected over a different season.

Although accelerometers are often used to objectively measure physical activity and are preferred to self-report measures, accelerometers are not without limitations.

Accelerometers are only able to record movement of the body segment the sensor is placed on; if an activity monitor is attached to the wrist, it will be more likely to record movements that are not necessarily physical activity. This research required participants to wear the accelerometer on their hip in order to reduce recording unrelated motions. In

addition, accelerometers have difficulty recording nonweight bearing activities (e.g. cycling) and activities performed on an incline, which may underestimate overall physical activity (Heil, 2006). Accelerometers are also unable to provide contextual information, such as the type of physical activity a child is engaging in. Researchers should consider methodological triangulation (e.g. using GPS monitoring and activity diaries in conjunction with accelerometers) to capture different activity contexts.

In study 1, many built environment attributes showed no relationship with children's MVPA. This study did not differentiate between the different contexts for physical activity (e.g. sports, free play, active transportation) because the primary objective was to examine overall physical activity. Looking at different physical activity contexts might have revealed more specific associations with the neighbourhood built environment. In addition, this study is limited by its use of buffers to capture the neighbourhood built environment. While buffers are able to characterize the opportunities present within a child's general neighbourhood, buffers cannot capture the places that children actually frequent and for what duration.

Study 2 attempted to address the limitations of study 1 by using GPS tracking alongside simultaneous physical activity assessment. However, the inclusion of GPS data resulted in several technological challenges. This study required matching accelerometer-GPS data, so there was data loss due to unmatched GPS or accelerometer data points.

Unmatched data occurred when participants did not wear the equipment properly or when no locational data was recorded on the GPS due to concrete canyons or tree canopies. Researchers tried to mitigate compliance issues by visiting participants every day to charge the equipment and ensure that the equipment was being worn. In addition, GPS data may be misclassified because the locational data has some degree of variable precision. Superimposing and joining the accelerometer-GPS data on the tessellated hexagon surface helped to minimize the impact of misclassified GPS data by absorbing the margin of error associated with the GPS device.

5.5 Implications for Policy and Practice

This research aimed to explore how the built environment influences children's physical activity. In particular, this thesis aimed to clarify how a) neighbourhood opportunities for physical activity facilitate or constrain children's physical activity and b) exposure to different environment contexts facilitates or constrains children's physical activity. A number of recent studies have suggested that physical activity is influenced in part by an individual's exposure to and engagement with their built environment. The built environment can constrain or facilitate physical activity by providing (or failing to provide) opportunities for children to be physically active (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Forsyth, Michael Oakes, Lee, & Schmitz, 2009; Giles-Corti, Keltz, Zubrick, & Villanueva, 2009; Handy, Cao, & Mokhtarian, 2008; Papas et al., 2007). Findings from both studies in this thesis provide supporting evidence that the built environment *in part* influences children's physical activity.

This research makes it clear that there are many factors influencing children's physical activity and there is no simple answer to improving children's physical activity. Both studies reiterate the importance of sex by showing that boys are not only more physically active than girls, but also that there are unique sex differences in how the built environment influences their physical activity. Previous research has found that girls prefer different types of activities for physical activity, have different motivations for being physically active, and face different barriers to physical activity than boys (Mota & Esculcas, 2002; Posner & Vandell, 1999) so it is not surprising that study 1 and study 2 found that the built environment influences physical activity in different ways for boys and girls. As a result, this research supports policy that considers sex differences in physical activity, particularly when researchers, planners, and policymakers need to make decisions about funding and developing programs, policies, and practices to improve children's physical activity.

Moreover, both studies reiterate the importance of active travel by demonstrating that children who use active modes of travel between home and school are significantly more physically active overall than those using inactive modes. Many schools in London, Ontario have implemented School Travel Plans through Active and Safe Routes to School, a group of community organizations aiming to encourage children's active travel between home and school (see www.activesaferoutes.ca). This research provides evidence which lends support to these types of policies and programs which aim to increase active transportation among children.

Findings from this research help to identify the spatial contexts of physical activity so that planners can make targeted improvements to the environment and increase children's physical activity. Improvements in the built environment alone, however, may not have an influence on children's physical activity if they do not account for sex-based differences in the spatial contexts of physical activity. This research highlights the importance of planning and developing diverse built environments to encourage and support children's physical activity, with an emphasis that the built environment is complex and matters differently for physical activity depending on a child's sex. Study 1 shows that the neighbourhood context most relevant to children depends on sex, with findings suggesting that boys may engage in more neighbourhood physical activity and have a wider neighbourhood to use than girls. Study 2 highlights that while exposure to places designed to support physical activity (i.e. parks, recreation facilities, and multi-use paths) influenced girls' physical activity, boys' physical activity, conversely, was influenced by exposure to a diverse range of places (i.e. parks, institutional space, and commercial space). If park planners, for example, only focus on making general improvements to parks to encourage physical activity for both boys and girls, investment in specific infrastructure for recreational amenities may not be considered. By not considering how the amenities present in a park influence the physical activity of boys and girls differently, the ability of the park to support physical activity may be limited. Similarly, if neighbourhood-based policies and programming fail to acknowledge that girls may have restricted access to their neighbourhood, the ability to target girls'

physical activity may be compromised. Researchers, planners, and policymakers should therefore consider not only the places that influence children's physical activity, but also how *boys* and *girls* use places differently when researching, developing, and creating spaces and programming to support physical activity; a one-size fits all approach is not appropriate.

5.6 Future Research

Findings from both studies emphasize the need to provide more spatial accuracy about the environments that exert an influence on children's physical activity. With greater spatial accuracy about what environments influence children's physical activity, policymakers and planners will be able to make more targeted and appropriate changes in the environment to improve children's physical activity and, thus, their health.

Findings from study 1 highlight the need to consider more specific neighbourhood boundaries to better capture children's neighbourhood built environments. In particular, sex-differences in neighbourhood size should be taken into consideration when trying to better understand the environments that influence behaviour. Future research should investigate the role of neighbourhood size, particularly on weekend MVPA, in order to compare the spatial and temporal contexts of children's activities.

Findings from study 2 underscore that future research is needed to clarify how contextual exposure to diverse environments outside the home and school differs according to activity intensity (i.e. what environments exert a contextual influence on children for MVPA versus sedentary activity versus light activity). In addition, future research should "zoom in" and investigate the specific features of what children are being exposed to for physical activity (e.g. instead of stating a child was exposed to a park with a sports field, future research could identify whether this sports field was a football field, tennis court, or baseball diamond).

5.7 Conclusion

The purpose of this research was to examine how neighbourhood environment opportunities and exposure to different built environment contexts facilitate or constrain children's physical activity. Several associations were found between the built environment and children's physical activity. When examining neighbourhood opportunities for physical activity, findings suggest that boys may engage in more neighbourhood physical activity and have a wider neighbourhood to use than girls. When examining how exposure to different environmental contexts influences physical activity, findings provide supporting evidence that exposure to environment contexts influences physical activity differently for boys and girls, highlighting the complexity of the built environment physical activity relationship. Both studies place emphasis on developing policy, programs and practices that are relevant to a child's sex, with both studies finding sex-based differences in the strength of associations. Both studies provide important findings for policymakers, planners, and programmers who all have a vested interest in children's physical activity and wellbeing.

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Appendices

Appendix A Research Ethics Approval Forms for Use of Human Participants (Redacted)

RE-issued



Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Jason Gilliland
Review Number: 17918S
Review Level: Delegated
Approved Local Adult Participants: 1200
Approved Local Minor Participants: 1200
Protocol Title: Identifying casual effects on the built environment on physical activity, diet, and obesity among children.
Department & Institution: Social Science\Geography, University of Western Ontario
Sponsor: Canadian Institutes of Health Research
 Heart and Stroke Foundation of Canada

Ethics Approval Date: June 08, 2011 **Expiry Date:** August 31, 2014

Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Other	Revised Healthy Neighbourhood Survey for Parents.	
Other	Revised Health Neighbourhoods Survey for Youth	
Other	Revised Activity and Travel Diary for School Days and Weekend Days.	

This is to notify you that The University of Western Ontario Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the applicable laws and regulations of Ontario has granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above.

This approval shall remain valid until the expiry date noted above assuming timely and acceptable responses to the NMREB's periodic requests for surveillance and monitoring information.

[Redacted] who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussions related to, nor vote on, such studies when they are presented to the NMREB.

The Chair of the NMREB is Dr. Riley Hinson. The NMREB is registered with the U.S. Department of [Redacted] under the IRB registration [Redacted]

[Redacted]

Ethics Officer to Contact for Further Information

<input checked="" type="checkbox"/> Grace Kelly	<input type="checkbox"/> Janice Sutherland
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This is an official document. Please retain the original in your files.

The University of Western Ontario
 Office of Research Ethics
 Support Services Building Room 5150 • London, Ontario • CANADA - N6G 1G9
 PH: 519-661-3036 • F: 519-850-2466 • ethics@uwo.ca • www.uwo.ca/research/ethics

Appendix B Research Ethics Letter of Information for Parents (3 pages)



Examining the Influence of the Neighbourhood Environment on Children's Health and Well-Being

Dear parent or guardian,

We would like to invite you and your child to participate in a study aimed at understanding how the neighbourhood environment around your child's school affects his or her health. The study involves grade 5, 6 and 7 classes at elementary schools across South Western Ontario.

What is being studied?

Our research team is studying the various places or facilities in their neighbourhood that children use (or intentionally don't use) on a regular basis for recreational or physical activities, including the way they travel to these places – for example, how they travel to and from school each day. We are also interested in looking at some of their eating patterns, especially the locations in their neighbourhoods where they might eat or purchase food. In addition, we'd like to learn more about how children feel about their local environments, and how this may affect the activities they do, or how and where they travel around their neighbourhood.

What will happen in this study?

If you and your child agree to participate in our project, **your child will be asked to:**

1. **Complete the *Healthy Neighbourhoods Survey for Youth*.** This survey primarily asks children about how they feel about their neighbourhood environments, the local facilities (such as parks) that they use for activities, places they may go to eat or buy food, and how they travel around their neighbourhood. Surveys usually take about 20-30 minutes to fill out and will be done in their classroom at a time decided by their teacher. (Note: students not filling out the survey will be given quiet activities by their teacher to do at their desks). Our research team will be on hand to help children fill out their surveys and to answer questions. All children will be given as much time as they need to complete the survey.
2. **Wear two small pieces of equipment each day during the hours they are awake, for two 7-day periods about 6 months apart – once during their Gr.5 or 6 year (Spring) and again in their Gr.6 or 7 year (in the Fall).** The lightweight 'GPS Logger', worn on a collapsible neck strap, maps out the general places the child visits in the neighbourhood and the routes taken to get from place to place. The tiny 'Accelerometer', worn on a thin elastic belt around the student's waist (can be worn under clothes), is like a pedometer that counts steps but it can also tell how 'intense' the activity of the student is. These tools will help us to see patterns in children's neighbourhood activities and travel. Because students will wear the tools during two different weeks we can also better understand how children's activities change over time.
3. **Complete a short activity diary for each day** they wear the 2 pieces of equipment, briefly telling us about their activities and any food purchases that day.
4. **OPTIONAL** – If they would like, participating students can also meet together with the researchers and classmates for a **group discussion** to talk more about how they feel about their neighbourhood and how their local environment helps or prevents them from enjoying the recreational activities they like, or easily buying the foods they want, or travelling easily around the neighbourhood. There will be about 10-20 students in a group. The discussion will take place either at lunch recess or outside school hours, and will last about 1 hour. It will be held at the school or another community location. Participation is completely voluntary; a child can decide not to join in the group discussion and still be allowed to join in Steps 1-3.

As the child's parent/guardian, **you will be asked to:**

1. **OPTIONAL - Complete the *Healthy Neighbourhoods Survey for Parents*.** The survey asks many of the same questions as the Youth survey, as well as questions about your home and family and your own feelings about your neighbourhood. It usually takes about 15-25 minutes to fill out. The Parent Survey is completely voluntary – your child can still join the study themselves even if you decide not to fill it out. However, it gives us valuable information from the point of view of parents so we would really appreciate your participation.
2. **OPTIONAL -** Parents of participating students will also have a chance to meet together with the researchers and other local parents for a **group discussion** about your neighbourhood environment and how it helps or prevents you and your family from doing the activities you like, buying the foods you need, or travelling easily around your neighbourhood. There will be about 8-12 parents in each group. The discussion will take place at a time outside school hours, and will last about 1-1.5 hours. It will be held at the school or another nearby community location. Participation in the group discussion is completely voluntary; a parent can decide not to participate and their child will still be allowed to participate in their own part of the study as outlined above.

Do we have to participate in this study?

Your participation in this study is completely voluntary. You and your child do not have to participate. You can each refuse to answer any survey questions, and can choose to leave the study at any time. Your decision will not affect your child's academic record in any way.

What are the benefits and risks if my child participates?

Recent research shows that our health is not only related to our personal lifestyle, such as the food we eat or physical activity we undertake, but also to the characteristics of the neighbourhood(s) we live in. This study will help us to better understand the links between our neighbourhoods, our activities, and our health. The results may help local municipal planners and school boards make decisions that will help plan healthier local communities.

There are no costs to you or your child for participating in this study. However, during each 7-day periods in which they participate, your child will receive \$2 each day from the research team when your child hands in their completed activity diary for the previous day and data from their equipment is collected. Your child will receive an additional \$1 on the last day when they return all their equipment. The total for EACH completed 7-day period is \$15.

The equipment in this study is easy to use, and the researchers will spend time with your child to make sure they understand how to use and care for the equipment. But, if any pieces of equipment break or become lost during the time your child is using them, we will give them a replacement unit right away without any cost to you or your child.

There may be risks to your child if he/she participates in this study. Getting tired or becoming disinterested in continuing with the project for the full 7 days are considered the largest risks. However, each piece of equipment weighs less than 60g (0.12 pounds) and should not be difficult for a child to carry. And a child can decide to quit the project at any time. The height and weight of your child will also need to be measured before they start in order to properly set up the accelerometer. These measurements will be taken in a private room at the child's school in the presence of a trusted adult (e.g. school nurse or teacher); no other children or people outside of the research team will be present. The equipment used to measure a child's weight also has no visible display - the measurements are automatically sent wirelessly to a laptop and so will not be visible to either your child or anyone else in the room.

There is little risk that you or your child will be identified or identifiable in any of the documents related to the study. All of the information collected in this study is kept strictly confidential. You and your child will be assigned a unique identification code – your name or personal information will not appear on any materials or data files. Also, materials and data files will ONLY be viewed by members of the research team and will be stored in a locked filing cabinet or on a password protected computer in a secure room at the University of Western Ontario. Parents and children who participate in the group discussions will be asked to keep everything they hear confidential and not to discuss it outside of the meeting. However, we cannot guarantee that confidentiality will be maintained by other participants in the focus group. Children can ask to see the maps of their own travel patterns and to change any information that feel is incorrect. However, to protect the privacy of each child, parents will not be able to view children's data or maps.

If you or your child decides to leave the study at any time (even up to 30 days AFTER the study has been completed), any of personal data collected from you or your child will be immediately destroyed and excluded from the study analysis.

You do not waive any of the legal rights you would otherwise have as a participant in a research study.

Follow Up

As the study involves a second round of participation this coming Fall (approximately 6 months after the first round this Spring), we may need to contact you at your home by phone or email in order to find out if your child changed schools between Spring and Fall. **We would therefore ask that you include one or both of these pieces of information on the attached consent form.**

Who do I contact if I have any other questions?

Should you have any questions or concerns about participating in this project, you can contact the lead researcher, Dr. Jason Gilliland, at the University of Western Ontario. [REDACTED] or email: [REDACTED]

If you have any further questions regarding your rights as a study participant, please contact the Office of Research Ethics at [REDACTED] or at [REDACTED]

Research Team

Dr. Jason Gilliland, Department of Geography, University of Western Ontario
 Dr. William Avison, Department of Sociology, University of Western Ontario
 Dr. Harry Prapavessis, Department of Health and Rehabilitation Sciences, University of Western Ontario
 Dr. Paul Hess, Department of Geography and Planning, University of Toronto
 Dr. Kathy Speechley, Department of Paediatrics, University of Western Ontario
 Dr. Piotr Wilk, Department of Epidemiology, University of Western Ontario
 Dr. Colleen Gobert, Division of Food & Nutrition Sciences, Brescia University College
 Mr. John Fleming, Director of Planning, City of London

This letter is for you to keep. Please return the attached Parent/Guardian consent form. You will also be given a copy of this consent form once it has been signed.

Appendix C Research Ethics Parent Consent Form



Examining the Influence of the Neighbourhood Environment on Children's Health and Well-Being

Parent / Guardian Consent Form

Regardless of whether you are consenting to let your child to participate in this study, we would ask that you return this form to school with your child, sealed in the envelope provided. Envelopes will be collected by your child's teacher. Thank you!

Consent: I, _____ (*name of parent/guardian- please print*), have read this letter and have been given the opportunity to ask questions. Any questions I had have been answered to my satisfaction. (Check all boxes that apply):

- I agree to participate by completing the *Healthy Neighbourhoods Survey for Parents* (**optional**; if yes, please seal the survey in the envelope provided and return with signed consent form)
- I am interested in being contacted about participating in a group discussion for parents (**optional**; if yes, please provide either phone or email contact information below)

Please select one of the following 2 options:

- I agree to let my child _____ (*child's full name – please print*) participate in the full 14 days (two 7-day periods within the next 6-8 months) of the project as outlined. **REQUIRED: My child has health issues which restrict their ability to walk/exercise or otherwise participate in this study** YES NO

OR if your child is not interested in the full project but would still like to participate in the survey

- I agree to let my child _____ (*child's full name – please print*) participate **ONLY** by way of completing the *Healthy Neighbourhoods Survey for Youth* (to be administered at child's school) rather than the full study.

Parent / Guardian's signature

Date

If your child IS participating, please provide a phone and/or email address (both is preferable) so that we may contact you this Fall to confirm whether or not your child has changed schools since the Spring. This information will be kept strictly confidential.

Parent/Guardian Email Address

Home or Cell Phone

Appendix D Research Ethics Child Assent Form



How Healthy is the Environment in Your Neighbourhood?

Hello! We are researchers from the University of Western Ontario and we are doing a study in your neighbourhood! We need students in Grades 6, like you, to help us with this project!

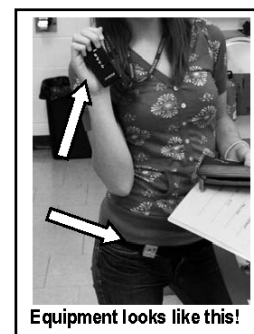
What are we going to study?

We all know that getting lots of exercise and eating the right foods can help keep us healthy. We'd like to know if the places or services that you have and use in your neighbourhood also help to keep you healthy.

What would you have to do?

If you agree to be in the study there are 4 things we would like you to do:

- 1.** Wear 2 small pieces of equipment every day for a week this Spring. A small GPS unit will help to make a map of all the places you visit every day. You would also wear a 'loonie'-sized piece of equipment on an elastic band around your waist that will tell us when you are doing physical activity, like running or playing sports. Both pieces of equipment are very light and easy to use. We will also come to your school every day in case you need help.
- 2.** Fill out a short 1-page diary everyday about the activities you did that day.
- 3.** Fill out a short survey on what you think about your neighbourhood. You will fill this out one day at school with your classmates. It takes about 20-30 minutes to finish but you can take as much time as you need.
- 4.** Then you would wear the equipment and fill out the diary again for a week later this Fall when you are in grade 7 (even if you are then going to a different school).



After both weeks are done, you could also join in a group discussion with some of your classmates to talk to us about where you like to go in your neighbourhood and the activities you like to do. You do not have to join in this group activity. The talk will take place at your school. We would like to audio record our talk.

To work some of the equipment we'll need to measure your height and weight. We'll do this in a private room at your school. Your teacher can be in the room. We won't share the information with anyone else.

Do you have to join this project?

No – you will only join if you would like to. You can also decide at any time that you would like to stop. We will never share your information with anyone else, even your parents, but you can ask to see it at any time. You can ALWAYS talk to your teacher or the researchers if you have any questions or worries.

I want to participate in this study!

If you would like to join this study in some way, choose one of the following two options:

- I want to participate in the full 2 week study OR I only want to complete the in-class survey

Print First and Last Name of Child

Signature of Child

Age of Child

Date

Signature of Person Obtaining Assent

Date

Curriculum Vitae

Name: Christine A. Mitchell

Post-secondary Education and Degrees: The University of Western Ontario
London, Ontario, Canada
Sept 2013- Feb 2016 (Expected) M.A.

The University of Western Ontario
London, Ontario, Canada
2009-2013 B.A. (Hons) *with distinction*

Honours and Awards: Social Science and Humanities Research Council (SSHRC)
Canada Graduate Scholarship – Master’s
2014-2015

Ontario Graduate Scholarship (Declined)
2014 – 2015

The University of Western Ontario
Gold Medal (BA Geography)
2013

The University of Western Ontario
Class of 1985 Best Undergraduate Thesis Award
2013

Canadian Association of Geographers
Canadian Association of Geographers Prize
2013

National Council for Geographic Education
National Council for Geographic Education Excellence of
Scholarship Award
2013

Society of Industrial and Office Realtors
Society of Industrial and Office Realtors Best Project Award
2013

Related Work Experience: Research Associate, Project Coordinator
Human Environments Analysis Laboratory

2013 – Present

Teaching Assistant
The University of Western Ontario
2013 – 2015

**Conference
Presentations:**

GIS in Education and Research Conference (ESRI) 2015
Toronto, Ontario
*“Examining the influence of contextual environmental exposure on
children’s physical activity: a novel geospatial approach from the
STEAM project”*