Université de Montréal

Features of neighbourhood environments associated with obesity and related health behaviours in children: using multiple statistical approaches to identify obesogenic environments

par
Andraea Van Hulst

Département de médecine sociale et préventive
École de santé publique

Thèse présentée à l'École de santé publique
en vue de l'obtention du grade de Philosophiae Doctor (PhD)
en Santé publique
option Épidémiologie

Mai, 2014

RÉSUMÉ

Contexte: L'obésité chez les jeunes représente aujourd'hui un problème de santé publique à l'échelle mondiale. Afin d'identifier des cibles potentielles pour des stratégies populationnelles de prévention, les liens entre les caractéristiques du voisinage, l'obésité chez les jeunes et les habitudes de vie font de plus en plus l'objet d'études. Cependant, la recherche à ce jour comporte plusieurs incohérences.

But: L'objectif général de cette thèse est d'étudier la contribution de différentes caractéristiques du voisinage relativement à l'obésité chez les jeunes et les habitudes de vie qui y sont associées. Les objectifs spécifiques consistent à:

1) Examiner les associations entre la présence de différents commerces d'alimentation dans les voisinages résidentiels et scolaires des enfants et leurs habitudes alimentaires;
2) Examiner comment l'exposition à certaines caractéristiques du voisinage résidentiel détermine l'obésité au niveau familial (chez le jeune, la mère et le père), ainsi que l'obésité individuelle pour chaque membre de la famille;
3) Identifier des combinaisons de facteurs de risque individuels, familiaux et du voisinage résidentiel qui prédisent le mieux l'obésité chez les jeunes, et déterminer si ces profils de facteurs de risque prédisent aussi un changement dans l'obésité après un suivi de deux ans.

Méthodes: Les données proviennent de l'étude QUALITY, une cohorte québécoise de 630 jeunes, âgés de 8-10 ans au temps 1, avec une histoire d'obésité parentale. Les voisinages de 512 participants habitant la Région métropolitaine de Montréal ont été caractérisés à l'aide de : 1) données spatiales provenant du recensement et de bases de données administratives, calculées pour des zones tampons à partir du réseau routier et centrées sur le lieu de la résidence et de l'école; et 2) des observations menées par des évaluateurs dans le voisinage résidentiel. Les mesures du voisinage étudiées se rapportent aux caractéristiques de l'environnement bâti, social et alimentaire. L'obésité a été estimée aux temps 1 et 2 à l'aide de l'indice de masse corporelle (IMC) calculé à partir du poids et de la taille mesurés. Les habitudes alimentaires ont été mesurées au temps 1 à l'aide de trois rappels alimentaires. Les analyses effectuées comprennent, entres autres, des équations d'estimation généralisées, des régressions multiniveaux et des analyses prédictives basées sur des arbres de décision.

Résultats: Les résultats démontrent la présence d'associations avec l'obésité chez les jeunes et les habitudes alimentaires pour certaines caractéristiques du voisinage. En particulier, la présence de dépanneurs et de restaurants-minutes dans le voisinage résidentiel et scolaire est associée avec de moins bonnes habitudes alimentaires. La présence accrue de trafic routier, ainsi qu'un faible niveau de prestige et d'urbanisation dans le voisinage résidentiel sont associés à l'obésité familiale. Enfin, les résultats montrent qu'habiter un voisinage obésogène, caractérisé par une défavorisation socioéconomique, la présence de moins de parcs et de plus de dépanneurs, prédit l'obésité chez les jeunes lorsque combiné à la présence de facteurs de risque individuels et familiaux.

Conclusion: Cette thèse contribue aux écrits sur les voisinages et l'obésité chez les jeunes en considérant à la fois l'influence potentielle du voisinage résidentiel et scolaire ainsi que l'influence de l'environnement familial, en utilisant des méthodes objectives pour caractériser le voisinage et en utilisant des méthodes statistiques novatrices. Les résultats appuient en outre la notion que les efforts de prévention de l'obésité doivent cibler les multiples facteurs de risque de l'obésité chez les jeunes dans les environnements bâtis, sociaux et familiaux de ces jeunes.

Mots clés: alimentation, activité physique, habitudes de vie, enfants, environnement alimentaire, environnement bâti, environnement familial, environnement social, étude QUALITY, indice de masse corporelle, jeunes, obésité, quartier, voisinage

SUMMARY

Background: Childhood obesity currently poses a major public health challenge worldwide. In an attempt to identify potential targets for population-based prevention strategies, neighbourhood environments are increasingly being investigated in relation to childhood obesity and its behavioural precursors. However, research to date is largely beset by inconsistencies in findings.

Purpose: The overarching goal of this thesis is to investigate the contribution of different features of neighbourhood environments in relation to obesity and antecedent behaviours in children. Specific objectives are:

1) To examine associations between children's residential and school neighbourhood food environments and their dietary intake and behaviours;
2) To examine shared exposure to features of residential neighbourhoods in relation to obesity among family triads (child, mother, and father) and among individual family members;
3) To identify specific combinations of individual, familial, and neighbourhood risk factors that best predict obesity in children, and determine whether these risk factor profiles also predict 2-year changes in obesity.

Methods: Data were drawn from the QUALITY Cohort, a Quebec-based study of 630 children aged 8-10 years at baseline with a parental history of obesity. Baseline residential neighbourhood environments of 512 participants living in the Montreal Metropolitan Area were characterised using: 1) geographically linked census and administrative data computed for road network buffers centered on the residential and school locations; and 2) in-person neighbourhood observations conducted within the participants' residential neighbourhoods. Neighbourhood measures included characteristics of the built, social, and food services environments. Obesity was determined using the body mass index (BMI) computed from measured weight and height at baseline and at follow up. Diet was measured using three 24-hour diet recalls at baseline. Different types of analyses were used including generalised estimating equations, multilevel regressions, and recursive partitioning.

Results: Findings point to specific neighbourhood features that are associated with childhood obesity and diet. Most notably, increased availability of convenience stores and fast food restaurants within residential and school neighbourhoods is associated with poorer diets among children. High street-level traffic and low neighbourhood prestige and urban development in residential neighbourhoods are associated with obesity among family triads. Lastly, findings suggest that obesogenic neighbourhood environments characterised by socioeconomic disadvantage, fewer parks, and more convenience stores jointly predict childhood obesity within unique combinations of individual and familial risk factors.

Conclusion: This thesis contributes to the literature on neighbourhood environments and childhood obesity by considering the influences of both residential and school neighbourhoods as well as familial environments, by objectively characterising neighbourhoods, and by using innovative statistical approaches. Findings furthermore support the notion that obesity prevention efforts should target multiple risk factors of childhood obesity within the built, social, and family environments of children.

Key words: body mass index, built environment, children, diet, family environment, food environment, lifestyle behaviours, neighbourhood, obesity, physical activity, QUALITY study, social environment, youth

TABLE OF CONTENTS

LIST OF TABLES

Manuscript 1: Associations between children's diets and features of their residential and school neighbourhood food environments

Manuscript 2: Neighborhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents

Manuscript 3: Identifying risk profiles for childhood obesity using recursive partitioning based on individual, familial, and neighborhood environment factors

Appendix E. The use of cluster analysis in studies on neighbourhoods and health

LIST OF FIGURES

LIST OF ABBREVIATIONS

BMI: body mass index

CDC: Centers for Disease Control and Protection

CI: confidence interval

CMA: Census Metropolitan Area

CVD: cardiovascular disease

DBP: diastolic blood pressure

GEE: generalised estimating equation

GPS: Global Positioning System

IOTF: International Obesity Task Force

MEGAPHONE: Montreal Epidemiological and Geographical Analysis of Population Health Outcomes and Neighbourhood Effects

MoNAT: Montreal Neighbourhood Assessment Tool

NALP: Neighbourhood Active Living Potential

OR: odds ratio

QUALITY: Quebec Adipose and Lifestyle Investigation in Youth

RFE: Retail Food Environment

SBP: systolic blood pressure

SPACES: Systematic Pedestrian and Cycling Environmental Scan

V&F: Vegetables and Fruit

WHO: World Health Organisation

Voor
Claratje

ACKNOWLEDGEMENTS

I wish to express my utmost gratitude to Dr. Tracie A. Barnett and Dr. Lise Gauvin for their support and guidance throughout my doctoral studies. They have been true mentors, encouraged me to go further than I thought I was capable off, and inspired me through their intellectual and personal strengths.

The past 5 years would not have been what they were without the people I have met. In particular, I am grateful for the education I have received in the Department of Social and Preventive Medicine thanks to several professors and to many of its brilliant students. I also wish to thank the researchers and students from the Team PRODIGY and the BEACH lab for their constructive critique on much of my doctoral work and for contributing to creating a highly stimulating learning environment, as well as the Centre de recherche du CHU Sainte-Justine for the supportive environment they provide to students. Lastly, I wish to thank the QUALITY Cohort families and research staff as well as Dr. Marie Lambert for their dedication to research and to the wellbeing of future generations.

Throughout my doctoral studies, I received financial support from the Fonds de la Recherche du Québec en Santé (FRQ-S), the Fondation pour la recherche en sciences infirmières (FRESIQ), the Canadian Institutes for Health Research (CIHR) and Heart and Stroke Foundation of Canada (HSFC) Training Grant in Population Interventions in Chronic Disease Prevention (PICDP), the Fondation CHU Sainte-Justine and Fondation des Étoiles. Thank you for your valuable partnership in this work.

Finally, to my friends and family, thank you for always being there, to Frédéric, for your endless love and patience, and to Clara, for demonstrating every day how determination and perseverance always brings us further.

CHAPTER 1. INTRODUCTION

1.1 Childhood obesity: prevalence and consequences

Over the past 20 to 30 years, the prevalence of overweight and obesity has increased worldwide amongst all age groups, particularly in economically developed countries (Kelly, Yang, Chen, Reynolds, & He, 2008; Wang & Lobstein, 2006). The 2007-2008 Canadian Health Measures Survey revealed that close to 1 in 4 Canadian adults are obese (24.3%), almost double from the proportion seen in the late 1970's (Shields & Tjepkema, 2006; Shields et al., 2010; Tjepkema, 2006). Among children, the most recent Canadian data revealed that 13% of 5 to 11 year olds and 10% of 12 to 17 year olds are obese (Roberts, Shields, de Groh, Aziz, & Gilbert, 2012). This is a significant increase in comparison to the prevalence estimates from the late 1970's when only 3% of children aged 2 to 17 years were found to be obese (Shields, 2006). This rising trend in the prevalence of childhood obesity was confirmed in other Canadian data (Tremblay et al., 2010; Willms, Tremblay, & Katzmarzyk, 2003). Moreover, there appears to be sex differences in obesity prevalence with almost double the proportion of boys (15%) compared to girls (8%) currently being obese (Roberts et al., 2012).

The rising prevalence of obesity is particularly worrisome among children and youth given that childhood obesity has been associated with concurrent biological cardiovascular disease (CVD) risk factors, including increased blood pressure, adverse changes in plasma lipoproteins, abnormal glucose homeostasis, inflammation, and the clustering of these CVD risk factors, which are linked to the acceleration of the atherosclerotic disease process in youth (Goran, Ball, & Cruz, 2003). Not only is there increasing evidence that childhood obesity is associated with early processes of atherosclerosis (Berenson, Srinivasan, & Nicklas, 1998; McGill et al., 2000; Raitakari, Juonala, & Viikari, 2005; Williams et al., 2002), childhood obesity has also been found to persist into adulthood, such that obese children are more likely to become obese adults (Serdula et al., 1993) and develop a range of comorbidities during adulthood, including diabetes, CVD, and some forms of cancer (Dietz, 1998).

Although rising trends in the prevalence of obesity have been reported between the 1980's and the early 2000's, recent studies have shown that, at least in some population subgroups of the United States, both childhood and adult obesity appear to have plateaued (Flegal, Carroll, Kit, & Ogden, 2012; Ogden, Carroll, Kit, & Flegal, 2012). These findings have been confirmed in other economically developed countries (Olds et al., 2011) including Canada (Roberts et al., 2012). The latest data from the United States even suggest a decrease in obesity prevalence from 2003-2004 to 2011-2012, but only among children aged 2 to 5 years, where prevalence decreased from 14% to 8.5% (Ogden, Carroll, Kit, & Flegal, 2014). Although obesity proportions may have stabilized or even decreased in some specific population subgroups over the past 10 years, there is yet to be strong evidence to suggest significant population-wide reductions in obesity, despite some public health action and individual interventions aimed at reducing the burden of obesity. To this day, obesity continues to exert tremendous health, social, and economic burden worldwide (Crawford, Jeffery, Ball, & Brug, 2010).

1.2 Risk factors for childhood obesity

Risk factors for obesity are multifactorial and encompass genetic, biologic, behavioural, and sociodemographic factors (Han, Lawlor, & Kimm, 2010). Obesity is a complex condition in which a myriad of risk factors interact within and between several levels of influence, as has been proposed in the Obesity System Map (Foresight, 2007). Although genetic and epigenetic factors have been implicated in the development of obesity, the relatively recent and steep increase in prevalence that has led to the current obesity epidemic is far more likely to have resulted from non-genetic risk factors including behavioural and societal risk factors (Hill & Peters, 1998). The most important behaviours associated with the development of obesity are physical inactivity and unhealthy diets. According to the 2009-2011 Canadian Health Measures Survey, only 7% of 5 to 11 year-olds and 4% of 12 to 17 year-olds met the current physical activity guidelines for children to engage in at least 60 minutes of moderate-to-vigorous physical activity daily (Active Healthy Kids Canada, 2009). Similarly, the

2004 Canadian Community Health Survey revealed that 59% of children did not consume the recommended number of daily servings of vegetables and fruit, and that these children were more likely to be obese compared to those who had five or more servings daily (Shields, 2006). According to a more recent Quebec study, 1 in 4 high-school aged teens consumed at least one serving of sugar-sweetened beverage daily (Institut de la statistique du Québec, 2012), a well-supported risk factor for obesity (Malik, Schulze, & Hu, 2006).

In addition to individual risk factors, the family-level environment exerts important influences in the development of childhood obesity. Obesity related risk factors and consequences tend to aggregate within families. It has been well established that children are more likely to be obese if their parents are obese (Fuentes, Notkola, Shemeikka, Tuomilehto, & Nissinen, 2002; Liu, Chen, Liang, & Wang, 2013; Reilly et al., 2005; Whitaker, Wright, Pepe, Seidel, & Dietz, 1997). Although similarities in child-parent weight status may be explained in part by genetics, shared lifestyle habits and environmental factors are also likely to be implicated (Saelens et al., 2012; Silventoinen, Rokholm, Kaprio, & Sorensen, 2010). Because childhood obesity does not occur in isolation from parental obesity, risk factors within the familial environment must be considered so as to better understand the complex etiology of childhood obesity.

1.3 Neighbourhoods and obesity

Striking differences in obesity prevalence between areas of residence have been reported (Bruner, Lawson, Pickett, Boyce, & Janssen, 2008; Grow et al., 2010; Veugelers & Fitzgerald, 2005; Willms et al., 2003; Zhang, Onufrak, Holt, & Croft, 2013). These findings have prompted researchers to investigate links between residential neighbourhood environments, obesity, obesity-related health behaviours (i.e., physical activity, diet), and cardiometabolic consequences of obesity (i.e., hypertension, dyslipidemias, and diabetes) (Black & Macinko, 2008; Dunton, Kaplan, Wolch, Jerrett, & Reynolds, 2009; Feng, Glass, Curriero, Stewart, & Schwartz, 2010;

Galvez, Pearl, & Yen, 2010; Leal & Chaix, 2011; Papas et al., 2007; Rahman, Cushing, & Jackson, 2011; Sallis, Floyd, Rodriguez, & Saelens, 2012). The attention to neighbourhood environment characteristics and health further arose from the realisation that purely individual-based explanations of causes of diseases were clearly insufficient, and that the characteristics of groups and contexts to which people belong have profound influences on the distribution of health and disease in populations (Diez Roux, 2001).

Specifically in relation to obesity, neighbourhoods and wider political and social contexts have been the subject of study in a growing body of literature. The term 'obesogenic environment' has been used to designate environments, such as residential, work or school settings that encourage increased energy intake and decreased energy expenditure, thereby favouring the development and maintenance of obesity (Swinburn, Egger, & Raza, 1999). It has been reasoned that the places where people live and conduct their daily activities may offer opportunities or barriers, structural and otherwise, that can influence energy balance and subsequent weight gain by facilitating maintenance of physical activity and dietary recommendations (Egger & Swinburn, 1997; Hill, Wyatt, Reed, & Peters, 2003). As a consequence, one strategy to offset the current obesity epidemic may require modifying environments so as to encourage and support behaviours associated with healthy weights (Swinburn et al., 1999). Although there is mounting evidence to suggest that neighbourhood environments may influence obesity in children (Dunton et al., 2009; Galvez et al., 2010; Rahman et al., 2011) and in adults (Mitola, Papas, Le, Fusillo, & Black, 2007; Sallis et al., 2012), findings have largely been inconsistent between studies (Feng et al., 2010). Conceptual and methodological challenges in the study of neighbourhood environments and obesity may, at least in part, explain these inconsistencies. While it is likely that neighbourhood and wider contextual elements impact obesity, the evidence base needed to inform practical public health interventions aimed at creating healthy places for children to live, learn and play, is unfortunately still lacking.

1.4 Thesis objectives and structure

Given the prevalence and consequences of childhood obesity as well as the potential influence of neighbourhood environment factors on obesity and associated health behaviours, the overarching goal of this thesis is to ascertain the contribution of different features of neighbourhood environments in increasing or decreasing obesity and antecedent health behaviours among children. The focus will be on obesity and dietary behaviours and the strategy consists of making use of advanced statistical methods. Towards this end, this article-based thesis addresses the three following specific objectives while employing unique and considered statistical approaches:

1) To determine whether features of residential and school neighbourhood food environments are associated with children's dietary intake and dietary behaviours;
2) To examine associations between attributes of neighbourhood environments with obesity among family triads (child, mother, and father) living at the same address, and explore whether associations differ between family members;
3) To determine optimal combinations of individual, familial, and neighbourhood environment characteristics that best predict childhood obesity, and to examine whether these combinations of characteristics are associated with 2-year changes in obesity.

The structure of this thesis is as follows. The second chapter starts by introducing the concept of place effects on health and provides a conceptual definition of neighbourhoods. Subsequently, a review of methodological considerations related to the study of neighbourhoods and health and of obesity and diet measurement issues in epidemiologic studies, are presented. This is followed by a section that reviews the literature on associations between neighbourhood environment attributes, obesity, and diet. Finally, this chapter describes a conceptual framework through which the varying levels of influence on obesity, including neighbourhood environments, can be understood, and concludes with a summary of identified research gaps which this thesis aims to address.

Chapter 3 provides a detailed description of the methodologies used in this thesis. In particular, the QUALITY (Quebec Adipose and Lifestyle Investigation in Youth) Cohort and the ancillary studies in which data were collected to characterise the residential and school neighbourhood environments of QUALITY participants are described. This chapter also presents the statistical analysis methods used in this thesis.

Chapters 4 through 6 each present an empirical manuscript in which results are provided to address the specific thesis objectives presented earlier. In the first manuscript (Chapter 4), published in the *Canadian Journal of Public Health*, associations between features of residential and school neighbourhood food environments and children's dietary intake and behaviours are examined using logistic regressions and generalised estimating equations. The second manuscript (Chapter 5) considers how obesity may cluster within families exposed to the same neighbourhood environment. Specifically, multilevel logistic regression analysis is used to determine whether shared exposure to neighbourhood environment features within family triads (children and both biological parents) residing at the same address makes the entire family more or less likely to be obese. This manuscript was published in the *International Journal of Obesity*. Lastly, the third manuscript (Chapter 6), currently under review, employs a less commonly used statistical method in studies on neighbourhoods and health, namely recursive partitioning analysis, which allows for the examination of complex nonlinear associations between multiple risk factors for obesity. This method is used to generate risk profiles for obesity among children based on individual, familial and neighbourhood environment risk factors, which are then examined in relation to 2-year changes in obesity.

Finally, Chapter 7 includes a discussion of the thesis' main research findings and contributions, as well as overall limitations and strengths. This is followed by a section which highlights the potential implications for public health stemming from this thesis, as well as directions for future research. Overall, this thesis is the product of five years of intensive learning, fruitful and stimulating exchanges with friends and colleagues, and professional and personal development.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

There has long been an interest in the potential health impacts of the places where people live and conduct their daily activities. As early as 400 BC, in his treatise entitled *On Airs, Waters, and Places*, Hippocrates invoked the notion that characteristics of the places where people lived influenced their health. Later, during much of the miasma era of the 1800's, it was believed that the unclean, unsanitary environmental conditions in which predominantly poor urban people lived had much to do with their poor health. Largely under the influence of Edwin Chadwick in England, the so-called Sanitary Movement led to unprecedented government interventions in urban environments, notably in the areas of domestic waste disposal and water supply. Although the miasma theory of disease causation was later discounted, the resulting sanitary reform and 1848 Public Health Act had major impacts on public health (Rosen, 1993).

A resurgence of interest in environments appeared many decades later, starting in the early 2000's, when the number of scientific articles linking features of neighbourhood environments with health, and particularly neighbourhood built environments and obesity, increased dramatically (Rahman et al., 2011). Among these publications, several have also focused on behaviours associated with obesity including physical inactivity and unhealthy diets (Black & Macinko, 2008; Casey et al., 2011; Chaix, 2009; Davison & Lawson, 2006; de Vet, de Ridder, & de Wit, 2011; Diez Roux & Mair, 2010; Ding & Gebel, 2012; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Dunton et al., 2009; Feng et al., 2010; Ferdinand, Sen, Rahurkar, Engler, & Menachemi, 2012; Papas et al., 2007; Sallis et al., 2012). This literature has contributed to a growing understanding that obesity and associated lifestyle behaviours are likely influenced by the contexts in which people live, and has identified promising levers for intervention. However, several conceptual and methodological challenges remain, which will be exposed later in this thesis.

To help situate the reader, this chapter starts by providing a conceptual definition of the notion of "neighbourhood". With the proposed definition in mind, I then summarize conceptual and methodological considerations, discussed in the literature, which are common to all studies on neighbourhoods and health, including obesity and associated behaviours. Thirdly, conceptual and operational definitions for the measurement of obesity and diet are presented. Building on these methodological considerations, a review of the literature on associations between neighbourhood environments, obesity, and diet is provided. This is followed by the presentation of a conceptual framework that supports the investigation of neighbourhood environments in relation to health, namely the social ecological model of health. Finally, a summary of gaps in the literature that this thesis will attempt to address through its specific objectives is presented.

2.2 A conceptual definition of neighbourhoods

In the field of urban studies, some authors have defined neighbourhoods as purely ecological in nature (e.g., "a physical or geographical entity with specific boundaries" (p72) (Golab, 1982)) while others have integrated a social dimension into definitions of neighbourhoods (e.g., "geographic units within which certain social relationships exist" (p 15) (Downs, 1981)). Although there is no consensus in the field of urban studies on how to conceptually define neighbourhoods, most would agree that neighbourhoods consist of both a spatial and a social organisation (Galster, 2009). In his paper "On the nature of neighbourhoods" Galster (Galster, 2001) defines neighbourhoods as a "bundle of spatially based attributes associated with clusters of residences, sometimes in conjunction with other land uses" (p 2112). Neighbourhood attributes may include infrastructural, demographic, environmental, proximity service, political, social-interactive and sentimental characteristics (Galster, 2001). Importantly, these attributes are spatially bound such that once a geographic location is specified, attributes can be measured and used to characterise neighbourhoods.

In this thesis, Galster's definition of the neighbourhood concept is retained (bundle of spatially based attributes). Although his definition focuses on clusters of residences, this thesis views neighbourhood attributes as also being associated with other types of land uses including schools, workplaces, and other destinations for human activities.

2.3 Methodological considerations in studies on neighbourhoods and health

While conducting my doctoral research and in reading many studies on neighbourhoods, obesity, and associated behaviours, I have developed an interest in the methodological aspects related to studying the potential effects of places on health. Methodological considerations common to most studies on neighbourhoods and obesity, and to neighbourhoods and health more generally, include 1) how to operationally define neighbourhoods including the spatial scales for which neighbourhoods are hypothesised to have an effect on health; 2) which neighbourhood attributes to measure and how to measure them; and 3) study design.

2.3.1 Operational definitions of neighbourhoods

Operationalization of neighbourhood boundaries

In order to pursue investigations of neighbourhood effects on health outcomes, it stands to reason that those very same neighbourhood environments that are hypothesised to influence health must be defined. This requires careful consideration because a range of methods may be available to operationalize neighbourhoods and the selected method may bear on the breadth of exposures and consequently on the findings derived therefrom (Bond Huie, 2001). The variability in neighbourhood operational definitions may be behind some of the heterogeneity in findings across previous studies (Feng et al., 2010).

Several methods for defining neighbourhood areas have been proposed and are described herein, including subjective (residents' reports) and objective (fixed delimitations, ego-centered areas, and real-time tracking) methods.

Residents' subjective reports of neighbourhood boundaries consist of asking study participants to identify and delimit on a map what, according to them, corresponds to the limits of their neighbourhood (Coulton, Korbin, Chan, & Su, 2001). This method has been used to define geographic exposure areas in studies on residential neighbourhoods and health in children (Hume, Salmon, & Ball, 2005; Morrow, 2001). It has been suggested that perceived neighbourhood boundaries may provide representations that are more meaningful and closer to residents' representations of neighbourhood constructs compared to objective neighbourhood delimitations based on administrative boundaries (e.g., census boundaries) (Burton, Price-Spratlen, & Beale Spencer, 1997). Not surprisingly, the subjective nature of perceived neighbourhood boundaries implies that neighbourhood definitions may be substantially different from one person to another. In fact, subjective neighbourhood delimitations have been found to differ even for individuals living in the same building (Coulton et al., 2001). Resident-perceived neighbourhood boundaries may also be different from objectively experienced neighbourhoods as participants may identify what they would like their neighbourhood to be as opposed to what their actual geographic exposure areas consist of (Guo & Bhat, 2007). Although both are of interest in the study of neighbourhoods and health, different research questions and conclusions may be reached with subjective versus objective neighbourhood delimitations (Chaix, 2009). Thus, depending on the underlying research questions, using subjective resident reports may be more appropriate for investigating perceptions rather than 'actual' neighbourhood exposures.

With objective methods, the researcher, rather than the resident/respondent delimits the geographic area for which neighbourhood attributes are to be measured. Traditionally, fixed delimitations based on **administrative boundaries** have been used. These may include census tracts and blocks, postal code areas, and service catchment areas. In most of the earlier studies on neighbourhoods and health, administrative boundaries have been used to operationalize neighbourhoods because of the relative ease of drawing on existing data available for such boundaries (e.g., census data) (Bond Huie, 2001; Diez Roux, 2001). For some research questions and related neighbourhood exposure measurement, administrative delimitations may be ideal (e.g., health and social services available to the population living within specific administrative territories). However, the main weakness associated with this type of delimitation is that there is no theoretical foundation for their relation to health and health behaviours as they are unlikely to capture neighbourhood exposures as experienced by individuals within these boundaries (Chaix, Merlo, & Chauvin, 2005). For example, the characteristics of a given census delimitation are potentially less adequate in representing the geographic exposure of individuals living near the limits of that census tract than for individuals located near the center of the area. As a result, associations with health outcomes may be misestimated due to neighbourhood environment characteristics not being adequately measured.

An alternative approach is to use **ego-centered areas** in which neighbourhoods are delimited as an zone centered on each individual's residence and for which the boundaries are defined by a given distance threshold from the center (Chaix, 2009). Instead of being fixed and mutually exclusive, these boundaries can be thought of as 'sliding' (i.e., moving with the exact location of interest) and overlapping one another (Chaix, Merlo, Evans, Leal, & Havard, 2009). Neighbourhoods defined as ego-centered areas may correspond to circular buffers or to local road network buffers of varying sizes (e.g., 500 m, 3 km, etc.) (Oliver, Schuurman, & Hall, 2007). There is no agreement in the literature on what might be the most appropriate zone or distance from the zone's center to consider. The relevant type and size of the buffer zone may depend on the research question, and notably if the interest is in populations who predominantly walk or drive in their exposure to neighbourhood features of interest (Ball, Timperio, & Crawford, 2006). However, because they are centered on individual residences, ego-centered neighbourhood delimitations are more likely to capture the conditions of the local, typically residential, environment to which individuals are exposed to in their daily lives.

Additionally, ego-centered areas can be created for other geographical locations than residential addresses such as the school, the work place, or other activity locations (Shareck, Kestens, & Frohlich, 2014). Conditions of these other environments can then be examined in relation to health outcomes. An advantage for using ego-centered areas is that, with a geographic information system, it is relatively straightforward to extract neighbourhood indicators for buffers of different sizes centered on different locations, thus allowing for sensitivity analyses (Leal & Chaix, 2011).

Yet another method to operationalize neighbourhoods consists of using **Global Positioning Systems** (GPS), which allow for real-time tracking of the places or ‘destinations’ people regularly go to as well as the routes between these points of interest. In recent years, GPS tracking has increasingly been used in neighbourhood and health research so as to identify the locations where certain health behaviours are more likely to occur (e.g., physical activity in parks) and to test associations between characteristics of the geographical locations visited and health behaviours (e.g., types of food establishments available at different places visited and dietary intake) (Lachowycz, Jones, Page, Wheeler, & Cooper, 2012; Zenk et al., 2011). GPS can be used to identify individuals’ exact locations and the time spent at each location. Combined with spatial data on physical and social environment characteristics from a geographic information system, the use of GPS tracking could overcome difficulties associated with identifying true geographic exposure environments, in both residential and non-residential areas (Boruff, Nathan, & Nijenstein, 2012; Krenn, Titze, Oja, Jones, & Ogilvie, 2011). Indeed, this method provides a comprehensive picture of the complex network of people’s activity spaces (i.e., the space within which people move about or travel in the course of their daily activities) as well as the routes between these activity spaces (Golledge & Stimson, 1996; Perchoux, Chaix, Cummins, & Kestens, 2013). However, the primary disadvantage of GPS use is the large amounts of data generated from which meaningful and useful activity location indicators must be derived in order to be used in studies on neighbourhoods and health (Perchoux, Kestens, et al., 2013; Thierry, Chaix, & Kestens, 2013).

Spatial scale in neighbourhood studies

Aside from methods to operationalize neighbourhoods, the geographic scale for which neighbourhood attributes should be measured deserves further attention. It has been suggested that geographic areas of different sizes are likely to be relevant for different neighbourhood health effects (Diez Roux, 2001). Smaller geographic areas may be more relevant for some neighbourhood health effects (e.g., neighbourhood safety and walking to school/work) whereas larger geographic areas may be more relevant for other neighbourhood health effects (e.g., access to different types of food establishments and diet) (Feng et al., 2010). The most relevant geographic scale for neighbourhood health effects may also vary according to characteristics of the population of interest. For example, children and older adults are generally considered to have smaller and fewer activity spaces and may therefore be more influenced by their immediate local residential environment compared to young and middle-aged adults who may have larger activity spaces (Papas et al., 2007). Similarly, people with low incomes may also have smaller and fewer activity spaces due to economic constraints, which can affect mobility through limited access to transportation (Papas et al., 2007; Shareck et al., 2014). Lastly, size of relevant geographic scales may vary according to geographic/environmental factors. For example, residents from rural and suburban areas are generally more likely to travel by car resulting in larger areas being toured with access to different services and commodities compared to residents from urban areas (Timperio, Ball, Roberts, Andrianopoulos, & Crawford, 2009; Veugelers, Sithole, Zhang, & Muhajarine, 2008).

In addition to having conceptual implications, the selection of a specific neighbourhood size also has statistical implications. When neighbourhoods are selected as too large areas, variation within neighbourhoods may be high while variation between different neighbourhoods may be low, which may impede detection of neighbourhood effects. (O'Campo, 2003). Statistical methods to select the appropriate spatial scale to use in neighbourhood studies have been proposed, including the Brown-Forsythe test (Root, 2012). This test identifies the area size within which there is enough variance in the outcome of interest for the effect to be detected, yet not too much variance which would suggest that the data are local or individualistic.

Although statistical tests may provide some insight with regards to the relevancy of different geographic scales, they cannot replace careful thinking on behalf of the researcher as to which geographical boundaries are most likely to influence health for a given neighbourhood exposure and health outcome in a given population. How neighbourhoods are operationalized can greatly influence the results of statistical analyses for associations between neighbourhood environment attributes and health outcomes (Bond Huie, 2001). This problem is inherent to all spatial analyses and relates to the modifiable areal unit problem (MAUP) (Openshaw, 1984) which occurs when results differ for the same analysis of spatial data that are aggregated to different scales (e.g., 500 m buffers vs. 1 km buffers) or to different areal shapes (e.g., road network buffer vs. circular buffer). Notwithstanding issues related to spatial scale and zoning, leading authors in research on neighbourhoods and health have stressed the importance of using operational definitions of neighbourhoods that best fit the research question and even using multiple definitions of neighbourhoods for different neighbourhood constructs within the same study since no single definition will suit all neighbourhood health processes of interest (Diez Roux, 2001; O'Campo, 2003).

Considering residential and non-residential neighbourhood environments

Also of importance within the study of neighbourhoods and health are which neighbourhood environments to consider. As mentioned previously, individuals are likely to be influenced by multiple geographic areas including residential and non-residential neighbourhoods. Indeed, most people, adults in particular, spend a considerable amount of time in other geographic areas than their residential neighbourhood (e.g., work, school, friends, leisure activities, etc.) (Chaix, 2009) and only recently has research started to examine influences of non-residential environments on health.

For children, the residential neighbourhood may be the main environment of exposure (Dunton et al., 2013) with other geographic areas of exposure including the school neighbourhood. Studies examining the school neighbourhood environment and routes linking residences with schools have reported associations with childhood obesity and antecedent behaviours, including associations that differed from those with residential neighbourhood environments only (Gilliland et al., 2012; Harrison et al., 2011; Nelson, Gordon-Larsen, Song, & Popkin, 2006; Xingyou Zhang, Kaufer Christoffel, Mason, & Liu, 2006). Considering the ensemble of geographic exposure environments from both residential and non-residential environments may limit misclassification of individual exposures associated with the consideration of only one type of neighbourhood environment (Kwan, 2009). However, thus far, the majority of studies on neighbourhoods and health have focused only on exposures from the residential neighbourhood environment.

In sum, central to the study of neighbourhood effects on health are considerations on how to operationalize the geographic areas of exposure referred to as neighbourhoods. Although earlier studies have given less attention to this question, it is now increasingly recognised that theoretically relevant geographical areas must be identified (Root, 2012), including within residential and non-residential neighbourhoods (Chaix, 2009). More importantly, hypotheses underlying how places may shape individuals' health and health behaviours need to be considered so that relevant geographic areas can be identified and attributes measured for these areas.

2.3.2 Measurement of neighbourhood environment attributes

An equally essential methodological consideration in studies on neighbourhoods and health consists of the conceptual definition and subsequent operationalization of neighbourhood attributes of interest. Several methods have been proposed to capture neighbourhood characteristics including measures obtained through residents' reports, measures derived from administrative and census data integrated in a geographic information system, and measures collected through systematic neighbourhood audits conducted by trained observers. These 3 methods are presented here, and advantages and disadvantages are described, but first, elements related to the conceptualisation of neighbourhood attributes are exposed.

Conceptualisation of neighbourhood attributes

Diez Roux has contributed several seminal papers to the literature on neighbourhoods and health (Diez Roux, 2001, 2003, 2007; Diez Roux & Mair, 2010). In her work, neighbourhood attributes are conceptualised as originating from two broad environmental domains, the physical and the social environment domains (Diez Roux, 2003). The **physical environment** includes elements of the natural environment such as the weather, noise and air pollution, as well as elements of the built environment. The latter comprises all aspects of the physical environment that are constructed or modified by humans, including usage of public spaces (urban design), transportation systems such as roads, sidewalks and bike lanes, parks and green spaces, availability of services such as food, health, and physical activity related, as well as the aesthetic quality of the environment (Papas et al., 2007). Elements of the built environment have received a great deal of attention in recent years, particularly in relation to obesity and physical activity (Rahman et al., 2011). The rationale underlying this interest is the modifiable nature of built environments: since they have been designed and constructed by humans, it implies that built environments can also be re-designed and modified in ways that have the potential to promote healthy lifestyles.

The second neighbourhood environment domain described by Diez Roux consists of the **social environment** also known as the social context or 'social milieu' (Diez Roux, 2003). The social environment refers to the social processes shared by individuals such as interconnections and trust between members of a group, shared resources that allow people to act collectively, and norms and values regarding acceptable behaviours (Kaplan, 1999). Attributes of the neighbourhood social environment most commonly studied in relation to obesity and associated behaviours include neighbourhood insecurity and criminality as well as neighbourhood social cohesion and capital (Leal & Chaix, 2011). Because these underlying group-level social processes are difficult to measure, area-level socioeconomic status indicators are often used as proxy measures of the social environment (O'Campo, 2003; Pickett & Pearl, 2001). Area-level socioeconomic status indicators are easily computed using aggregated individual-level data on socioeconomic status available from national census surveys (e.g., level of education, unemployment, annual household income, etc.).

Other more detailed neighbourhood environment dimensions than the physical/social environment dichotomy have been proposed. In his theoretical model describing the hypothesised processes linking neighbourhood environments with CVD, Chaix (Chaix, 2009) identified 4 neighbourhood dimensions that could influence health and which have been examined in relation to various CVD risk factors (Chaix et al., 2010; Leal, Bean, Thomas, & Chaix, 2012; Van Hulst et al., 2012). Most notably, this conceptualisation distinguishes the **neighbourhood services environment** from **neighbourhood physical/built environment** as previously described by Diez Roux. The neighbourhood services environment includes elements of the food environment, sports and recreation facilities, healthcare resources, other destinations, and transportation services. These elements are typically captured as the number and density of service destinations or as proximity to different service destinations (Charreire et al., 2010). Additionally, within the social environment domain described by Diez Roux, Chaix considers 2 types of environments: the **neighbourhood sociodemographic environment** which includes area-level income and level of education, ethnic composition, population turnover or stability, and the **neighbourhood social interactions environment** which includes elements of social cohesion/capital, social disorder (e.g., criminality level, insecurity), neighbourhood identities and stigma, as well as shared knowledge, norms and cultures.

Although efforts to conceptualise relations between attributes of neighbourhood environment and health are increasing, important work remains to be done. It has been suggested that often neighbourhood attributes are examined in relation to health simply because specific data are available, without a clear conceptualisation of why and how neighbourhood attributes 'get under the skin' and shape individual health (Ball et al., 2006).

Operationalization of neighbourhood environment attributes

One method to capture neighbourhood environment attributes consists of using **resident reports** in which residents are asked to complete a survey questionnaire with items related to the neighbourhood exposures of interest. Several tools have been developed for different populations and contexts (Adams et al., 2009; Fone, Farewell, & Dunstan, 2006; Mujahid, Diez Roux, Morenoff, & Raghunathan, 2007; Rosenberg et al., 2009). However, a limitation of this method is the potential for same-source bias which may occur when information on both neighbourhood exposures and health outcomes is provided by the same participants (or parents of participants when young children are being studied) (Diez Roux, 2007). For example, sedentary participants may report having lower access to neighbourhood sports facilities than their more active counterparts, irrespective of the actual conditions in the neighbourhood, thus potentially leading to spurious associations.

Another limitation of using resident reports relates to the measurement error associated with individuals' perceptions of their neighbourhood characteristics. Combining the responses of several residents for each neighbourhood of interest, thereby averaging out the associated measurement errors over several individuals, has been used to obtain more valid measures of neighbourhood constructs. However, because simply aggregating perceptions of residents nested within neighbourhoods does not take the multilevel nature of neighbourhood data into account, principles of ecometrics have been proposed as yielding more valid aggregated information of the assessments of several residents of a given neighbourhood (Raudenbush & Sampson, 1999). To do so, three-level random-effect models (questionnaire items for a given neighbourhood construct nested within individuals and individuals nested within neighbourhoods) are used, with responses to the neighbourhood survey items as model outcomes. The estimated neighbourhood-level random effect then serves as a predictor variable for the underlying neighbourhood construct to be examined in relation to health outcomes. Examples of this method are available in the literature (Chaix et al., 2011; Mujahid et al., 2007). Resident perceived assessments may be particularly appropriate to measure neighbourhood constructs that exist in residents' perspectives and are mostly invisible to an outside observer (e.g., neighbourhood identities and stigma) (Chaix, 2009).

A second method to measure neighbourhood attributes consists of making use of **geographically linked administrative data** (e.g., census, land use, business and service establishments, etc.). Over the past years, the latter has significantly facilitated the characterisation of the built environment (e.g., land use, street connectivity, etc.) as well as geographic accessibility of services and resources (e.g., density of, and distance to, different types of resources) (Chaix, 2009; Diez Roux, 2007). These data are easily aggregated at geographical scales and zones of interest using a geographic information system to produce different neighbourhood-level indicators (Matthews, 2012). Geographic information system derived indicators allow for objective measurement of neighbourhood features that is inexpensive because new data collection is typically not required. However, because secondary data collected for other purposes are used, the quality of the data may vary or may not be known and features that change frequently (e.g., some types of businesses and food establishments) may not be up to date. Although georeferenced administrative databases offer excellent potential measures for some neighbourhood characteristics (e.g., socio-demographics, land use type, availability of services, etc.), they are not well suited for the measurement of qualitative aspects of the built environment, as well as elements of the social environment such as social disorder and social capital (Chaix, 2009).

Lastly, **systematic neighbourhood audits**, which entail sending trained observers to visit neighbourhoods and complete a checklist of observable neighbourhood characteristics and resources, can be used to measure neighbourhood attributes of interest. In recent years, several tools have been developed and validated for this method (Gauvin et al., 2005; Paquet, Cargo, Kestens, & Daniel, 2010; Pikora et al., 2002; Vernez-Moudon & Lee, 2003; Zenk et al., 2007). When audits are conducted by more than one observer within the same neighbourhoods, ecometric methods described previously can be used to aggregate multiple observers' assessments into neighbourhood-level variables (checklist items for a given neighbourhood construct nested within observers, and observers nested within neighbourhoods) (Gauvin et al., 2005; Raudenbush & Sampson, 1999). Neighbourhood audits enable objective measurement of the quality of environmental characteristics (e.g., whether houses/buildings are well maintained) and other street level features usually not available from geographically linked administrative data (e.g., presence of traffic-calming measures and pedestrian aids). Moreover, because trained observers conduct neighbourhood audits, measurements are not influenced by residents' characteristics (the neighbourhood composition), as is the case with resident-perceived measures.

However, systematic neighbourhood audits may be less reliable for elements that are not consistently observable or for which the meaning may not be clear to an 'outsider'. For example, elements often used to describe social disorder may not be consistently observable over a given time period (e.g., public drunkenness, litter). Other elements may have complex meaning to an outside observer (e.g., loitering) (Chaix, 2009). Additionally, systematic neighbourhood auditing requires intensive training of observers to reach high inter-observer agreement, and even so, agreement may be difficult to obtain for more subjective measurement items (Bird et al., 2012). Because on-site in-person neighbourhood audits may require extensive travel time to and from neighbourhoods, the use of Google Street View to complete audits has been investigated. The latter appears to be both cost-effective and reliable, particularly for elements of the built environment (Badland, Opit, Witten, Kearns, & Mavoa, 2010;

Rundle, Bader, Richards, Neckerman, & Teitler, 2011), but also for some elements of the social environment (Odgers, Caspi, Bates, Sampson, & Moffitt, 2012).

It has been suggested that lower measurement error associated with objective measures compared to subjective measures may, in part, explain the more consistent findings reported for associations of objectively measured neighbourhood with obesity and associated behaviours (Ding et al., 2011). Although it is recognised that resident perceived measures, particularly when used with ecometric methods, are highly valuable to capture some neighbourhood exposures (e.g., neighbourhood stigma), in this thesis, the focus will be on objective measures of neighbourhood environments.

2.3.3 Study design in research on neighbourhoods and health

From cross-sectional to longitudinal study design

Thus far, the majority of studies on neighbourhood environments and health have been cross-sectional such that neighbourhood exposures are ascertained at the same time as health outcomes. These present some limitations, namely in terms of the identification of possible causal pathways through which neighbourhoods may influence health. Particularly in the case of obesity, which usually takes several years to develop, it is much more likely that the cumulative exposure to neighbourhood environments over several years relates to the development of obesity. Some cross-sectional studies have accounted for the duration of residence at their current residential address (Powell-Wiley et al., 2013; Sundquist, Winkleby, Ahlen, & Johansson, 2004).

In recent years, more longitudinal studies on neighbourhood environments and childhood obesity have been published. However, most look at relatively short term changes in health outcomes for a given neighbourhood environment (Bell, Wilson, & Liu, 2008; Crawford et al., 2010; Ewing, Brownson, & Berrigan, 2006; Gose et al., 2013; Leung et al., 2011; Timperio et al., 2010). How changes in neighbourhood environments (i.e., moving from one neighbourhood to another or changes within a given neighbourhood) relate to changes in health outcomes have rarely been studied (Giles-Corti et al., 2013; Jongeneel-Grimen, Droomers, van Oers, Stronks, & Kunst, 2014; Ludwig et al., 2011; Veitch, Ball, Crawford, Abbott, & Salmon, 2012). Neighbourhoods may change slowly or rapidly in response to larger societal processes (e.g., economic, demographic changes, etc.) and changing norms and expectations (e.g., greater presence of bicycle paths in response to greater use of cycling as a mode of transportation) (O'Campo, 2003). Longitudinal data on both neighbourhood environment attributes and on individuals (e.g., health outcomes, places of residence, duration of residence in each place) are needed to better understand neighbourhood health effects (Jongeneel-Grimen et al., 2014). This may be particularly important for outcomes such as obesity, which typically develops slowly over several years.

Longitudinal analyses of neighbourhood exposures and health would furthermore help to address concerns related to reverse causation (Diez Roux, 2003). Commonly cited in the literature is the possibility that individual dietary habits might cause different types of food establishments to flourish in different neighbourhoods rather than the other way around in which the availability of different types of food establishments influence residents' dietary habits. Longitudinal studies in which changes in neighbourhood food environments are examined in relation to changes in dietary patterns would address concerns related to reverse causality.

A related concern is that of neighbourhood self-selection bias according to which individuals may be selected into different types of neighbourhoods based on individual-level characteristics, which may themselves be related to the outcomes of interest (Chaix, 2009; Diez Roux, 2003; Zenk et al., 2011). For example, selective population migration may occur whereby more active individuals will seek to establish themselves into areas where the neighbourhood conditions are more supportive of physical activity. As a result, associations between neighbourhood exposures and health outcomes may be observed due to the neighbourhood composition (characteristics of individuals selected within given neighbourhoods) rather than of the actual neighbourhood context. The problem of self-selection bias (also called selective migration bias) can be minimized through appropriate statistical control of individual-level characteristics that act as confounders in associations of interest (Leal & Chaix, 2011). However, longitudinal data on neighbourhood exposures and health outcomes would help to clarify whether these individual factors act as mediators, confounders, or both, in associations of interest, thereby leading to a better understanding of underlying processes.

Randomised controlled trials

In addition to a need for longitudinal study designs, community-based randomised trials and neighbourhood intervention studies will further help in the identification of neighbourhood health effects (Berkman, 2004). In randomised community trials, a neighbourhood-level “treatment”, or intervention, is randomly assigned to a random set of communities (Oakes, 2004). Treatments could include initiatives targeting the built environment (e.g., increasing the level of greenery, implementing street level traffic-calming measures, etc.), the social environment (e.g., implementing community policing initiatives), or both (e.g., brining neighbours together to bring about change to a desired neighbourhood aspect, for example through participatory research). Although randomised community trials are not without challenges (e.g., concerns about contamination of the intervention between communities, selection of communities to be randomised, etc.), when well conducted, they are expected to lead to true measurements of neighbourhood effects (Lemon et al., 2013; Oakes, 2004). Because randomised community trials may not always be feasible or ethical, taking advantage of natural experiments of changes in neighbourhood environments and how these translate into changes in health outcomes provide useful study designs to further help the identification of neighbourhood effects (i.e., quasi experimental study designs). Examples in the literature include consequences on physical activity levels following park improvements, increasing street connectivity, or residential relocations (Fitzhugh, Bassett, & Evans, 2010; Giles-Corti et al., 2013; Kapinos & Yakusheva, 2011; Veitch et al., 2012).

In sum, methodological considerations surrounding the study of neighbourhood effects on health relate to identifying and operationalizing relevant geographic exposure areas for which neighbourhood attributes are measured, ensuring that neighbourhood attributes are adequately conceptualised and operationalized, and relying on study designs that will get us closer to estimating true neighbourhood effects. As will be seen in a later section of this chapter, the often inconsistent findings that have been reported in the literature with respect to associations between neighbourhood environment attributes, obesity, and diet might be explained, at least in part, by methodological challenges described earlier.

2.4 Measurement of obesity and diet in epidemiologic studies

Methods used to measure obesity and diet are described here. The aim is to provide a succinct review of construct definition and methodological considerations for health outcomes considered in this thesis within the population of interest, that is, obesity in children and in adults, and diet in children. Before describing outcome specific methodological considerations in more detail, issues common to the measurement of both obesity and diet are briefly mentioned.

In the context of epidemiologic studies, issues to consider when selecting a method for the measurement of obesity and diet include the desired degree of precision, the cost of administration, the level of subject and staff burden, the method's practicality, and the participants' age or developmental stage (particularly when working with paediatric populations). Another issue relates to the use of objective or self-reported outcome measures. As will be discussed in more detail later, assessment of diet intake in free-living individuals usually requires some degree of self-reporting, although methods based on direct observation and on food photography have been developed (Ball, Benjamin, & Ward, 2007; Martin et al., 2012). With regards to obesity, self-reported (or parent-reported) measures of weight and height have been used extensively to estimate obesity in studies examining associations with neighbourhood environment features (Leal & Chaix, 2011). Yet, it appears that adults generally under-report their weight and over-report their height (Connor Gorber, Tremblay, Moher, & Gorber, 2007). For children, parents have been found to underestimate both weight and height compared to direct measures (Shields, Connor Gorber, Janssen, & Tremblay, 2011). This will necessarily result into some degree of misclassification in obesity estimates based on the BMI as described in the next section.

2.4.1 Measurement of obesity

The human body is composed of both a fat-free mass, which consists of muscles, bones and organs, and a fat mass, which consists of the entire body's adipose tissue. Obesity, also termed excess adiposity, is a condition characterised by an excess in the body's fat mass relative to the total body mass (Flegal & Ogden, 2011; Goran, 1998). Importantly, it is an excess body fat mass (i.e., obesity), and not an excess in total body mass relative to height (i.e., overweight), which has been most strongly associated with the development of cardiometabolic diseases in both children (Goran et al., 2003) and adults (Bastien, Poirier, Lemieux, & Després, 2014).

Obesity is known to vary according to demographic characteristics including age, sex and ethnicity. Sex differences in levels of body fat generally appear during puberty with females attaining higher percentages of body fat than males (Hu, 2009). Furthermore, some ethnic groups, in particular individuals from South Asian ethnicity, have been found to be more sensitive to the cardiometabolic consequences of excess body fat and are thus considered obese at a lower percentage of body fat than Caucasians (Hu, 2009).

In addition to obesity defined as an excess in total body fat, the distribution of fat within the body also has important clinical significance. Excess abdominal visceral fat has been associated with increased metabolic risk (e.g., insulin resistance, dyslipidemia, increased triglycerides, etc.) irrespective of overall obesity, as measured by the BMI in both children and adults (Bastien et al., 2014; Zimmet et al., 2007). Waist circumference can be used as a relatively simple anthropometric measure of abdominal obesity. In adults, waist circumference > 102 cm in men and > 88 cm in women are used as cut-offs for abdominal obesity (Bastien et al., 2014). In children, there is currently no single consistent definition for waist circumference cut-offs (Zimmet et al., 2007). However, cut-offs based on age- and sex-specific waist circumference percentile curves have been proposed for use in paediatric populations (Eisenmann, 2005; Fredriks, van Buuren, Fekkes, Verloove-Vanhorick, & Wit, 2005).

Different approaches to measure obesity

Direct methods to measure body fat mass and thus obesity are limited (e.g. in vivo neutron activation (Mattsson & Thomas, 2006)), but there are several indirect methods that have been developed and are used in both clinical and research contexts (Goran, 1998). These include anthropometrics (e.g., skinfold thickness), density-based methods (e.g., densitometry), scanning methods (e.g., dual-energy x-ray absorptiometry, magnetic resonance imaging), and bioelectrical impedance analysis methods (Sweeting, 2007). Currently, there is no agreed-upon gold standard for the measurement of obesity; although imperfect, dual-energy x-ray absorptiometry has frequently been used as criterion reference for the measurement of obesity in children (Ellis, Shypailo, Pratt, & Pond, 1994; Goran, Driscoll, Johnson, Nagy, & Hunter, 1996; Shypailo, Butte, & Ellis, 2008).

Body mass index as a measure of obesity

Different measures of weight in relation to height have been proposed to estimate overall obesity of which BMI (total body weight in kg divided by height in m^2) is most widely used for clinical and research purposes. BMI is simple and easy to calculate in different settings, and standard procedures for the reliable measurement of weight with a calibrated scale and height with a standiometer have been developed (Lohman, Roche, & Martorell, 1998; Paradis et al., 2003). Moreover, standardized cut-offs to define obesity have been provided for use in both children and adults (Hu, 2009).

The main limitation of BMI as a measure of obesity is that it does not distinguish fat mass from fat-free mass, and has therefore been criticised as an imperfect estimate of obesity (Hu, 2009; Prentice & Jebb, 2001). Nevertheless, BMI has been found to be moderately to strongly correlated with body fat mass estimated with dual energy x-ray absorptiometry and bioelectrical impedance analysis in children (Boeke et al., 2013; Eisenmann, Heelan, & Welk, 2004; Hu, 2009). Despite its limitations, BMI offers a reasonable measure of obesity in children and in adults because of its simplicity in measurement and because of the availability of standard cut-offs.

Because BMI is known to vary according to age, sex and ethnicity, the significance of a given BMI varies according to these individual characteristics. As a result, different cut-offs are used for different population subgroups. Caucasian adults are considered obese for BMI $\geq$ 30 kg/m^2 (and overweight for BMI $\geq$ 25 kg/m^2) (Expert Panel on the Identification Evaluation and Treatment of Overweight in Adults, 1998). These cut-offs have been identified based on the associated cardiometabolic risk for BMI exceeding these values.

For children, age- and sex-specific percentiles are first computed based on an existing reference population distribution of BMIs of which the Centers for Disease Control and Prevention (CDC) and the World Health Organisation (WHO) reference populations have been most widely used. According to the CDC reference population, children aged 2 to 20 years are considered obese if their BMI is $\geq$ 95th percentile of the age- and sex-specific BMI distribution (and overweight for BMI $\geq$ 85th percentile) (Barlow & Dietz, 1998). According to the WHO reference population, children aged 5 to 19 years are considered obese if their BMI is $\geq$ 97th percentile of the age- and sex-specific BMI distribution (and overweight for BMI $\geq$ 85th percentile) (World Health Organisation, 2014). In addition to the CDC and WHO growth references, the

International Obesity Task Force (IOTF) proposed a different approach to monitor growth in children by extrapolating adult overweight and obesity cut-offs backwards to sex- and age-specific cut-offs for children and adolescents (Cole, Bellizzi, Flegal, & Dietz, 2000).

Until recently, health professionals in Canada used the CDC reference population to monitor growth and obesity in children. In 2010, a statement was issued by The Canadian Paediatric Society, in collaboration with the College of Family Physicians of Canada, Dieticians of Canada and Community Health Nurses of Canada, in support of the use of the WHO growth standards (Secker, 2010). The latter was favoured namely because it is based on anthropometric measures from an international multiethnic population sample of infants with optimal growth conditions (i.e., exclusively breastfed from birth to 4 to 6 months) and because it is based on older data that precede the obesity epidemic (World Health Organisation, 2014). The use of one BMI-based definition over another will impact obesity prevalence estimates (Shields & Tremblay, 2010); however, in terms of clinical significance to detect cardiometabolic abnormalities among children, both were found to be similar (Kakinami et al., 2012).

To summarize, for the measurement of obesity in large epidemiological studies, BMI is an imperfect yet practical, low cost method, presenting a low burden for subjects and staff. BMI provides a reasonable estimate of obesity and thus remains a measurement of choice, particularly in large epidemiologic studies, for public health surveillance, and for individual clinical assessment (Barlow & Dietz, 1998; 1998).

2.4.2 Measurement of diet

Because of the complexity of the human diet, and because everyone is exposed to foods, measurement of diet in epidemiologic studies poses several challenges (Willett, 2008). Different components of the human diet have been studied over the past years. Diet intake can be conceptualised in terms of its nutrient content (e.g., fat, vitamin D), specific foods (e.g., sugar-sweetened beverages), food groups (e.g., vegetables and fruit, dairy products), or in terms of overall dietary patterns (e.g., the Mediterranean Diet) (Willett, 2008). Among studies on neighbourhood environments and diet, the majority have focused on associations with intake of specific foods and food groups. Analyses of foods consumed have often been based on whether dietary recommendations are met, such has those recommended in Canada (Health Canada, 2007b).

Different methods have been used to measure dietary intake in children. The gold standard for measuring total energy intake is doubly labeled water. This method provides an objective measure of energy intake but not of nutritional intake. Moreover, it is not a practical method for use in large epidemiological studies due to high cost, subject burden, and technical and research facilities needed for analysis. This method is therefore not discussed in this thesis. Methods described include 24-hour diet recalls, food records, and food frequency questionnaires because they are most commonly used in epidemiologic studies. Although each has its advantages and disadvantages, the choice of one method over another largely depends on the dietary information needed to address specific research questions (Freudenheim, 1993).

24-hour diet recalls and food records

The 24-hour diet recall method consists of a structured interview administered by a trained person to the child or parent to generate an exhaustive list of everything the child ate or drank over a specified time period, usually the previous day (Burrows, Martin, & Collins, 2010). It includes detailed information for all foods, including brand names, ingredients for prepared dishes, food preparation methods, and serving sizes. The widely used multiple-pass diet recall method starts by obtaining a quick list of all foods and beverages consumed, followed by a detailed description review for each food and beverage, as well as the use of 2- or 3-dimentional models to assist the participant in estimating portion sizes (Johnson, Driscoll, & Goran, 1996). Due to high intra-individual variation in diet intake, 24-hour recalls are usually repeated on multiple days and averages are computed to obtain usual dietary intake. Food records are similar to 24-hour diet recalls except that they consist of a written record, self-completed by the participant, of foods and beverages consumed during a specific period of time, including details on brand names, preparation methods, and serving size (Freudenheim, 1993).

Food frequency questionnaire

Food frequency questionnaires consist of providing the respondent with a detailed list of foods from which to report the frequency of consumption for each food over a defined period of time in the past week, month, or year (Freudenheim, 1993). With this method, measures of usual dietary intake instead of actual intake are obtained. When portion sizes are assessed in addition to frequency of consumption, total energy intake can be estimated; if portion sizes are not assessed, existing data on average portion sizes for the population being studied can be used to estimate total energy intake (Cade, Thompson, Burley, & Warm, 2002). Since usual intake is measured, measurements from food frequency questionnaires may be less vulnerable to daily variations in dietary intake (Willett, 2008). Food frequency questionnaires are frequently used in epidemiological studies because of their lower cost compared to diet recalls or food records. Again, because children have difficulty accurately recalling past intake, parent administered rather than child administered questionnaires may be more valid (Jenner, Neylon, Croft, Beilin, & Vandongen, 1989).

Dietary intake and measurement error

The methods described above all rely on respondents' reports and memory. Children younger than 8 years cannot accurately recall and report dietary intake; however, between the ages of 8 to 12 years, children have been found to be increasingly capable of reporting their intakes depending on the assessment method used (Burrows et al., 2010). Nevertheless, dietary assessments are prone to recall bias and social desirability bias. In most cases, the misreporting of dietary intake results in an underestimation of the actual energy intake, particularly among heavier and older children (Forrestal, 2011; Livingstone, Robson, & Wallace, 2004). In a recent review it was found that, compared to doubly labeled water, 24-hour diet recalls using the multiple-pass method over at least a 3-day period, including at least 1 week day and 1 weekend day, is the most accurate method to estimate total energy intake in children, although this method was associated with some over-reporting of intake (Burrows et al., 2010). Largest biases were found to occur in the case of food records; recall bias and related misreporting may be minimised when foods and beverages are recorded at the time of consumption, although the researcher has little control on this (Forrestal, 2011). Lastly, food frequency questionnaires with lengthier and more detailed lists of foods from which to report usual intake generally showed better validity compared to food frequency questionnaires with shorter lists of broad food categories (McPherson, Hoelscher, Alexander, Scanlon, & Serdula, 2000).

Dietary behaviours

Besides dietary intake, research has also focused on dietary behaviours associated with obesity including the frequency and timing of snacking, locations where foods and beverages are consumed, as well as daily family practises surrounding the consumption of foods and beverages. Questionnaires completed by parents and/or children have been developed to capture these overall behaviours associated with eating (Institut de la statistique du Québec, 2002, 2012).

To summarize, this section described methodological issues common to the measurement of obesity and diet, as well outcome specific methodological issues. Although there are no perfect measures of obesity and diet, both in terms of psychometric properties and in terms of practicality, knowing the methods limitations allows for a better appraisal of findings for potential determinants of obesity and diet.

2.5 Neighbourhood attributes: associations with obesity and diet

Building on the methodological considerations related to the study of neighbourhoods and health and to the measurement of obesity and diet described earlier, I now provide a summary of study findings, limitations and knowledge gaps for associations between attributes of neighbourhood environments, obesity, and diet. The focus will be on literature pertaining to children and adolescents with some references to adults, namely to highlight important conceptual and substantive differences in findings.

Since the literature on associations between attributes of neighbourhood environments and obesity has grown considerably in the past 15 years, a number of review studies, including reviews of review studies (de Vet et al., 2011; Ding & Gebel, 2012; Safron, Cislak, Gaspar, & Luszczynska, 2011), have been published in recent years. Comparatively far fewer studies have been published on dietary intake and behaviours, particularly in paediatric populations (Kirk, Penney, & McHugh, 2010). Because of the abundance of studies on neighbourhoods and obesity, findings from review studies are mostly included in the first section covering neighbourhood associations with obesity. For associations with diet presented in section 2.5.2, findings from individual studies are reviewed.

2.5.1 Neighbourhoods and obesity

Most studies available in the literature consider associations between neighbourhood environments and overweight, while fewer focus specifically on associations with obesity. Others have used BMI or percent fat mass as continuous outcomes or have looked at changes in these measures over time. Conceptual and operational definitions of overweight and obesity have been described in an earlier section. Due to heterogeneity with respect to the definition and measurement of weight status between studies reviewed here, the term adiposity will be used to refer to all levels of body fat irrespective of measurement approach. This reduction to a single term, although not ideal, is done to facilitate reading and because ultimately all studies seek to identify neighbourhood-level determinants of excess body fat, or greater adiposity.

Physical/built environment

Elements of the physical or built environment that have been most consistently reported to be associated with adiposity include urban sprawl, mixity of land use, and level of urbanisation (Black & Macinko, 2008; Feng et al., 2010; Kerr, Frank, Sallis, & Chapman, 2007; Leal & Chaix, 2011). Urban sprawl is characterised by the expansion of cities into typically low population density suburban areas in which residential and non-residential land uses are highly segregated, and where there are few proximity destinations. Such environments may be less conducive to active transportation and leisure walking, thus decreasing opportunities for physical activity behaviours (Saelens, Sallis, & Frank, 2003; Salmon, Salmon, Crawford, Hume, & Timperio, 2007; Timperio et al., 2006). With respect to street connectivity specifically, evidence for associations with adiposity is mixed among children while more consistent among adults (Ding et al., 2011). This could reflect the different functions that streets may have in relation to physical activities practiced by children and adults. Street connectivity refers to the extent to which routes are direct, often measured as a function of the density of street intersections, street block length, and dead-end streets within the neighbourhood. For adults, high street connectivity may result in more active transportation and lower adiposity because of the ease of walking from place to place. For children, highly connected streets may also provide more opportunities for active transportations; however, less connected streets with more dead-end streets and lower traffic may provide more opportunities for safe active outdoor play resulting in lower adiposity.

Other elements of the built environment, such as street level pedestrian aids and traffic-calming infrastructures (e.g., zebra crossings, traffic street lights, speed bumps, and lower speed limits) have been understudied in relation to childhood adiposity (Ding et al., 2011). There is nevertheless some inconsistent evidence suggesting possible associations for street-level pedestrian aids with physical activity and adiposity in children (Hume et al., 2009; Sallis & Glanz, 2006; Timperio, Crawford, Telford, & Salmon, 2004; Timperio, Salmon, Telford, & Crawford, 2005).

Services and amenities

In terms of services and amenities available within neighbourhoods, greater access to parks, green spaces, playgrounds, and sports and recreational centers has been associated with lower adiposity in children, in both cross-sectional (Dunton et al., 2009; Galvez et al., 2010) and longitudinal studies (Pate et al., 2013). For example, one study found that residential neighbourhood acres of park space and number of recreational resources were inversely associated with 8-year changes in body mass index (BMI) among children and youth, with a stronger effect seen among boys compared to girls (Wolch et al., 2011). Similarly, Bell et al. found that a higher level of greenness in residential neighbourhoods measured using satellite images was associated with a lower likelihood of children increasing their BMI over a 2-year period (Bell et al., 2008). These associations are believed to be mediated by physical activity: more studies report associations for neighbourhood access to parks, green spaces, and sports and recreation centers with physical activity (Ding et al., 2011) and active transportation (Pont, Ziviani, Wadley, Bennett, & Abbott, 2009) than with adiposity among children.

Others have considered neighbourhood services and amenities related to food establishments near children's residences, such as fast food restaurants, convenience stores, supermarkets, and fruit and vegetable stores in relation to adiposity. Overall, associations between access to different types of food stores within the residential neighbourhood and adiposity are more consistent among adults than among children (Black & Macinko, 2008; Feng et al., 2010). In children, greater access to grocery stores and supermarkets has been associated with lower adiposity while greater access to fast food restaurants and convenience stores has been associated with higher adiposity (Galvez et al., 2010; Pate et al., 2013; Powell, Auld, Chaloupka, O'Malley, & Johnston, 2007). In comparison to fast food restaurants and convenience stores, grocery stores and supermarkets provide a greater number and a larger variety of healthy foods. One longitudinal analysis reported that increased availability of convenience stores near girls' residences was associated with an increase in BMI after a 3-year follow up, even after adjusting for family socioeconomic status (Leung et al., 2011). In contrast, greater access to farmers markets near their residence was associated with a lower adiposity at follow up. However, other cross-sectional and longitudinal studies reported no associations between access to different types of food establishments and adiposity (An & Sturm, 2012; Shier, An, & Sturm, 2012). Elements that could explain these inconsistencies include inadequate statistical control for confounders, notably both individual and neighbourhood socioeconomic status, the need to consider access to food establishments located in non-residential neighbourhood environments where children and families spend a great deal of time (e.g., school neighbourhood), and the need to consider in-store food availability in addition to food establishment type (Farley et al., 2009; Glanz, Sallis, Saelens, & Frank, 2005; Y. Kestens et al., 2012).

Area-level socioeconomic characteristics

In studies on neighbourhoods and health, area-level socioeconomic status is predominantly captured using aggregated individual-level data on socioeconomic status available from national census surveys, such as average income, proportion of people unemployed, or proportion of people living below the poverty level for given administrative areas (Pickett & Pearl, 2001). Numerous studies have reported that children and adults living in low socioeconomic status neighbourhoods are more likely to have higher levels of adiposity, regardless of individual levels of socioeconomic status (Carter & Dubois, 2010; Leal & Chaix, 2011; Schreier & Chen, 2013). In their study, Grow et al. found that neighbourhood disadvantage as measured by a number of census tract socioeconomic status measures explained 24% of the geographic variability in adiposity among children in an urban US county (Grow et al., 2010). Data from the Canadian National Longitudinal Survey of Children and Youth revealed higher levels of adiposity among children aged 2 to 3 years at baseline and followed up 8 years later for those living in the poorest neighbourhoods, even after adjusting for parental socioeconomic status (Oliver & Hayes, 2008).

Social environment

Other features of neighbourhood social environments have been considered, although less often, as elements that could play a role in childhood obesity (Franzini et al., 2009). Feelings of insecurity within one's neighbourhood have been considered as a risk factor for increased adiposity (Carroll-Scott et al., 2013; Cecil-Karb & Grogan-Kaylor, 2009) and associated health behaviours (Datar, Nicosia, & Shier, 2013; Molnar, Gortmaker, Bull, & Buka, 2004). One major limitation is that authors do not always distinguish safety from crime and safety from traffic in their measurement of neighbourhood-level insecurity, yet different public health strategies are needed to address different concerns about safety. Moreover, it is unclear whether it is more useful to rely on self-reported (or parent-reported) or objectively measured safety, as both may be differently associated with adiposity (Carver, Timperio, & Crawford, 2008). Objective measure of safety from crime and from traffic include criminality data and traffic density data, respectively, aggregated at the neighbourhood-level using a geographic information system. Additionally, in-person neighbourhood audits have been used to assess observer perceived level of safety (e.g., presence of security bars on windows and doors, signs of vandalism, etc.) (Paquet et al., 2010). More studies are needed to better understand how the different dimensions of insecurity, measured using different approaches, relate to childhood adiposity.

Finally, additional elements of the social environment that have been examined in relation to childhood adiposity include measures of collective efficacy, social capital, and physical disorder which have generally shown that higher collective efficacy and social capital, and lower physical disorder are associated with lower adiposity in children (Cohen, Finch, Bower, & Sastry, 2006; Grafova, 2008; Singh, Kogan, & van Dyck, 2008).

2.5.2 Neighbourhoods and diet

I now turn to associations between neighbourhood attributes and diets, for which attributes of the food environment are most conceptually relevant. The food environment can be broadly defined to include foods available within homes, those available within communities (e.g., neighbourhoods, schools, work places), and those available within the media and information environment (e.g., food advertisement) (Glanz et al., 2005). Of these different dimensions of the food environment, in-home availability and accessibility to foods has been reported as being the strongest determinant for children's diet, particularly for vegetable and fruit intake (Blanchette & Brug, 2005; McClain, Chappuis, Nguyen-Rodriguez, Yaroch, & Spruijt-Metz, 2009). While children may have limited control over which foods are purchased and how they are prepared, it has been proposed that broader neighbourhood availability and accessibility to different types of food establishments may influence parental food purchasing behaviours, which in turn may influence their children's diet. As they age and increasingly make their own decisions, environments external to the home are expected to exert more direct influences on children's diet.

For the purpose of this thesis, the focus is on access to foods in broader contextual neighbourhood environments and not specifically within children's homes because the former offers greater potential as a target for public health strategies. The neighbourhood food environment is thus defined to include the different places where foods can be purchased within the local geographic areas called neighbourhoods.

Neighbourhood food environment

The most commonly used method to characterise neighbourhood food environments is based on geographically linked data for different types of food establishments available within a delimited area. Indicators that are typically computed include diversity and proximity measures (Charreire et al., 2010). Diversity consists of a measure of the density of food establishments while proximity consists of the distance, usually based on road networks, between the residence and the nearest food establishment. Types of food establishments most commonly studied are supermarkets, grocery stores and fruit and vegetable stores which are hypothesized to provide access to healthier foods including a greater variety of vegetables and fruits (Morland, Diez Roux, & Wing, 2006). These are distinguished from convenience stores and fast food restaurants which generally offer less healthy foods.

Overall, findings from studies on the availability of different types of food stores within residential neighbourhoods and diet have shown less consistent findings in children than in adults (Auchincloss et al., 2013; Larson, Story, & Nelson, 2009). In their review of review studies de Vet et al. (de Vet et al., 2011) found no neighbourhood-level factors that were consistently associated with diet in children and adolescents. Although some studies report associations between access to supermarkets and children's vegetable and fruit intake, other studies report no associations (Pearce, Hiscock, Blakely, & Witten, 2008; Skidmore et al., 2010; Timperio et al., 2008). Greater access to convenience stores has been found to be associated with lower vegetable and fruit intake (Pearce et al., 2008; Timperio et al., 2008), and higher intake of sweet/salty snacks (Skidmore et al., 2010), and sugar-sweetened beverages in youth (Jennings et al., 2011). Similarly, some (Jennings et al., 2011; Timperio et al., 2008) but not all studies (An & Sturm, 2012; Skidmore et al., 2010; Timperio et al., 2009) have reported associations between the availability of fast food restaurants near children's residence and their diets.

Foods available around schools

Other studies have considered the foods available within the surroundings of schools. Children travel to and from school and are thereby exposed, to some extent, to the neighbourhood surrounding their school on almost on a daily basis during the academic year. Exposure to the school neighbourhood environment increases as children age with secondary school-aged youth generally having more opportunities to leave the school grounds to access food establishments in the vicinity (Casey et al., 2011; Mitola et al., 2007). This may be of concern given that fast food restaurants and convenience stores are known to cluster within short distances from schools (Gebauer & Laska, 2011; Y Kestens & Daniel, 2010). However, due to the dearth of studies on school neighbourhood food environments and children's diet it is not clear to what extent it influences children's diet (Rahman et al., 2011; Timperio et al., 2009; Wasserman et al., 2014).

In sum, given the conflicting results presented in the above literature review, there is a need to clarify the associations of neighbourhood environments attributes with childhood obesity and diet. To date, there is only a small body of evidence supporting associations between specific neighbourhood environments attributes, obesity, and diet in children. Yet, stronger evidence would enhance the implementation of public health strategies, targeted towards children and their family, to combat obesogenic neighbourhood environment (Huybrechts, De Bourdeaudhuij, & De Henauw, 2010). Inconsistencies in findings may, to some extent, be related to methodological differences between studies and more generally to methodological challenges common to studies on neighbourhoods and health which have been described previously.

2.6 Proposed conceptual framework

Traditionally, obesity and other CVD risk factors have been viewed as depending extensively on individual behaviours and on access to medical care. Within this 'individual' paradigm of health, interventions were geared mainly towards modifying lifestyle behaviours, through health education and personal motivation, and towards early treatment efforts (Jain, 2005).

Since the 1980's, the contributions of broader environmental and social contexts in determining health have gained increased recognition, particularly in the field of health promotion (Richard, Gauvin, & Raine, 2011). This has led to the development of an ecological approach to health that posits the importance of a multitude of determinants, external to individuals, in addition to individual determinants, which shape health. In particular, social ecological models of health consider the dynamic relations between people and their surroundings. Thus, instead of focusing on individual behaviours as potential causes of diseases, these models encompass the influences and interrelations between wider societal and environmental determinants on individual behaviours that in turn determine health and disease (Stokols, 1996).

Social ecological models are often depicted using concentric circles with the individual at its center surrounded by each level of influence from the most proximal to the most distal to individuals (Sallis et al., 2012). Levels of influence may include intrapersonal (biological and psychological), interpersonal (social and cultural), and broader organisational, community, physical environmental, and policy levels (Sallis, Owen, & Fisher, 2008). In addition to being used to guide the development of health promotion interventions, these models can be used to understand the aetiology of health behaviours and diseases that have multifaceted origins (Bronfenbrenner, 1979; Glass & McAtee, 2006; Moos, 1980; Sallis et al., 2008).

Social ecological models have often been used to understand the aetiology of obesity, dietary behaviours, and physical activity (Davison & Birch, 2001; French, Story, & Jeffery, 2001; Glanz et al., 2005; Robinson, 2008; Sallis et al., 2006; Sallis & Glanz, 2009; Spence, 2003). It has been suggested that the current obesity epidemic is too complex to be understood from single levels of analysis and therefore require more comprehensive approaches that take multiple levels of influence into consideration (Huang & Glass, 2008). Social ecological models are thus well suited to help understand the myriad of risk factors of obesity and related health behaviours, which encompass wide ranging determinants from genetic and psychological factors to environmental, social, cultural, and policy factors (Hill & Peters, 1998).

This thesis is thus grounded within the foundations of a social ecological approach to health. The specific model retained for this thesis draws on the Ecological Systems Theory proposed by Bronfenbrenner (Bronfenbrenner, 1979) and further adapted to childhood obesity by Davison and Birch (Davison & Birch, 2001). Although the Ecological Systems Theory provides a comprehensive understanding of multiple influences at multiple levels, including non-linear associations and cross-level interaction, modeling such complex associations is a challenge. I therefore opted to isolate specific elements pertaining to the neighbourhood built, social and services environments, and to examine them in relation to obesity and dietary behaviours, while also considering the role of individual and familial factors (Figure 1). Moreover, a linear funnel-like representation was favoured over that of concentric circles to more easily illustrate the directions of hypothesised relations, although it is acknowledged that, in reality, relations are more complex (e.g., feedback loops, etc.).

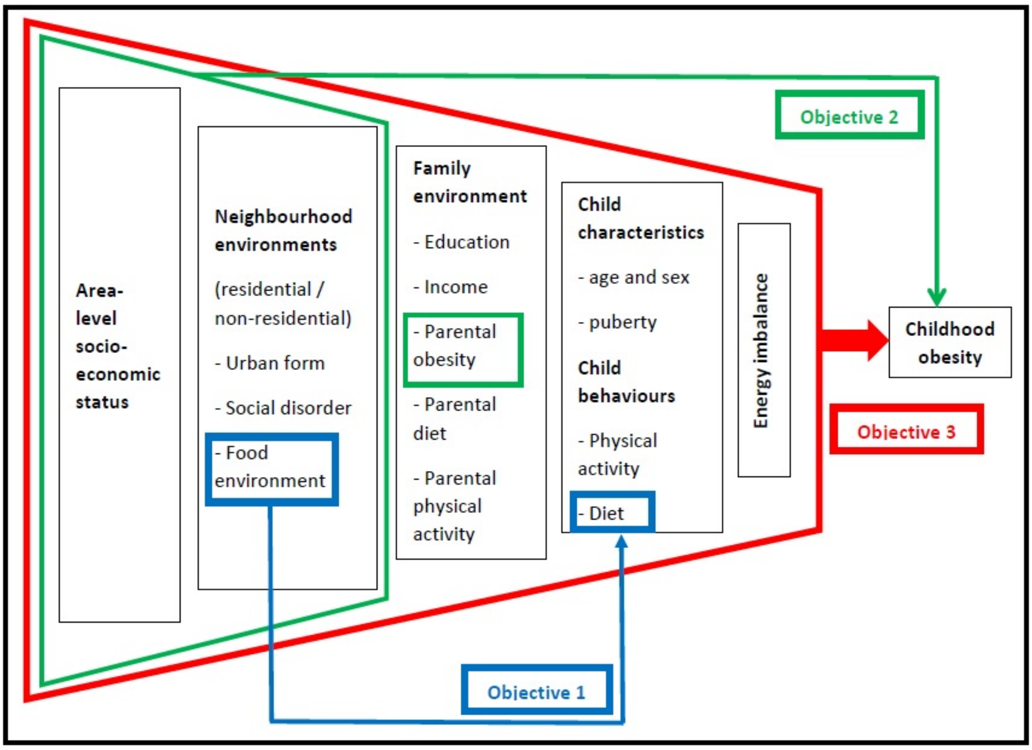
Figure 1 furthermore illustrates how each specific objective of this thesis are linked within a broader conceptual framework, namely:

Objective 1) To determine whether features of residential and school neighbourhood food environments are associated with children's dietary intake and dietary behaviours;

Objective 2) To examine associations between attributes of neighbourhood environments with obesity among family triads (child, mother, and father) living at the same address, and explore whether associations differ between family members;

Objective 3) To determine optimal combinations of individual, familial, and neighbourhood environment characteristics that best predict childhood obesity, and to examine whether these combinations of characteristics are associated with 2-year changes in obesity.

Figure 1. Conceptual framework proposing links between attributes of neighbourhood environments and childhood obesity



2.7 Summary and gaps addressed in this thesis

In Canada, close to 1 in 10 children is currently obese. Given the immediate and long term consequences of childhood obesity, it is of prime importance to better understand the aetiology of obesity, from individual to wider societal risk factors, so as to inform successful obesity prevention interventions. Social ecological models of health allow us to appreciate the multiple levels of influence that constitute obesogenic environments in which imbalances between energy intake and energy expenditure are favoured. Population approaches to obesity prevention that target the broader environmental, social and political determinants of obesity are needed; however, it remains unclear which specific elements to target. This thesis aims to contribute to the body of literature on neighbourhood environments, obesity and diet by addressing the following specific gaps:

1) Valid and reliable methods to characterise neighbourhood environments are needed, particularly to address measurement error and same-source bias associated with the use of resident-reported (subjective) measures. In addition to the use of administrative and census data integrated in a geographic information system, in-person neighbourhood assessment conducted by trained observers offers another objective method to characterise neighbourhood environments that remains infrequently exploited.

2) Thus far, there has been a predominance of studies examining characteristics of residential neighbourhood environments in relation to childhood obesity and associated behaviours, while comparatively fewer have focused on non-residential environments that may be of importance to children, notably the school neighbourhood environment.

3) To date, few studies have examined the links between neighbourhood food environments and children's diet. Multiple 24-hour diet recalls, considered the gold standard for the measurement of dietary intake in children, are rarely used in available studies.

4) Studies do not systematically distinguish overweight from obese children in associations with neighbourhood environment characteristics. Although overweight children are more likely to become obese over time, obesity has been associated with deleterious cardiometabolic health consequences. There is a need for more studies that identify neighbourhood-level determinants of obesity specifically.

5) Most studies reviewed in section 2.5 (Neighbourhood attributes: associations with obesity and diet) do not consider the unique influence of the familial context within associations between neighbourhood environments, obesity, and diet in children. When elements of the familial context are considered, it is often only statistically controlled for. Although the family context is known to be an important determinant of childhood obesity, little is known on the influences of the family context within associations between neighbourhood environment contexts and obesity.

CHAPTER 3. METHODOLOGY

3.1 Study description

3.1.1 Study design

This thesis relies on data from the first and second waves of the QUALITY (Quebec Adipose and Lifestyle Investigation in Youth) Cohort, an ongoing longitudinal study designed to answer the following question: "What is the natural history of the development of childhood obesity, its determinants, and its metabolic and cardiovascular consequences?" The QUALITY study has many specific objectives, including: 1) to study the genetic, biological, environmental, behavioural and psychosocial determinants of obesity and related cardiometabolic consequences; and 2) to examine the relation between obesity, cardiometabolic complications, and subclinical markers of atherosclerosis. QUALITY is designed and conducted by an interdisciplinary team of researchers from five universities (Université de Montréal, McGill University, Concordia University, Université Laval, INRS-Armand Frapier). It received funding from the Canadian Institutes for Health Research, the Fonds de la recherche du Québec en santé, and the Heart and Stroke Foundation of Canada. A detailed description of the study design and methods was published in the *International Journal of Obesity* (Cohort Profile) (Lambert et al., 2012).

This thesis also draws on data from two studies complementary to the QUALITY Cohort: the Residential Study (funded by the Heart and Stroke Foundation of Canada) and the School Study (funded by the Fonds de la recherche du Québec en santé). These studies provide measures of the characteristics of the built and social environments in the residential and school areas for participants residing in the Montreal Metropolitan Area at baseline.

3.1.2 Study population and sampling strategy

A school-based sampling strategy was used to identify potential study participants. From 2005 to 2008, recruitment flyers were distributed to parents of children in Grades 2 to 5, in 1 040 primary schools located within 75 km of either of Montreal, Quebec City, or Sherbrooke (Quebec, Canada). These schools represent 89% of all the schools approached within the study regions. Of 3 350 interested families who contacted the research coordinator, 1 320 met the study inclusion criteria. Eligibility criteria, verified over the phone, required participating children to be Caucasian, aged 8–10 years at recruitment, to have at least one obese biological parent based on self-reported measurements of weight, height and waist circumference (i.e., BMI $\geq$ 30 kg/m^2 and/or waist circumference > 102 cm in men and > 88 cm in women), and both biological parents had to be available to participate at baseline. Only Caucasian families were recruited to reduce genetic admixture. Families were not eligible to participate if the mother was pregnant or breastfeeding at the baseline evaluation, or if the family had short term plans to move out of the province. Children with any of the following were also excluded: 1) a previous diagnosis of Type 1 or 2 diabetes; 2) a serious illness, psychological condition, or cognitive disorder which hindered participation in some or all of the study components; 3) treatment with anti-hypertensive medication or steroids (except if administered topically or through inhalation); or 4) following a very restricted diet (< 600 kcal/day).

Of 1320 eligible families, a total of 630 families (including the participating child and both biological parents) completed the baseline visit and 564 completed a 2-year follow up visit. Of these, 512 at baseline and 462 at follow up lived in the Montreal Metropolitan Area and thus constitute the study sample for this thesis (see Appendix A for participant flow chart). Following measurement of parental baseline anthropometrics, 35 of the 512 baseline study sample (6.8%) did not have at least one obese parent based on measured weight, height, and waist circumference. Self-report measurement error and weight loss between study inclusion and baseline assessment most likely explain these discrepancies. However, because the eligibility criteria were based on parent-reports, and because the vast majority of these participants had at least one borderline obese parent, these 35 participants were retained in the study sample.

Of the remaining eligible families, 668 (52%) chose not to participate in the study. Reasons provided for non-participation of these families were: (i) no longer interested in the study, 81%; (ii) one biological parent did not agree or was not available to participate, 11%; (iii) child refused to participate, 4%; (iv) reported living too far from either study centre, 2%; (v) not enough time to participate, 1%; and (vi) other, 1%. No other information is available for these families thus precluding any comparisons to be made between participating and non-participating eligible families.

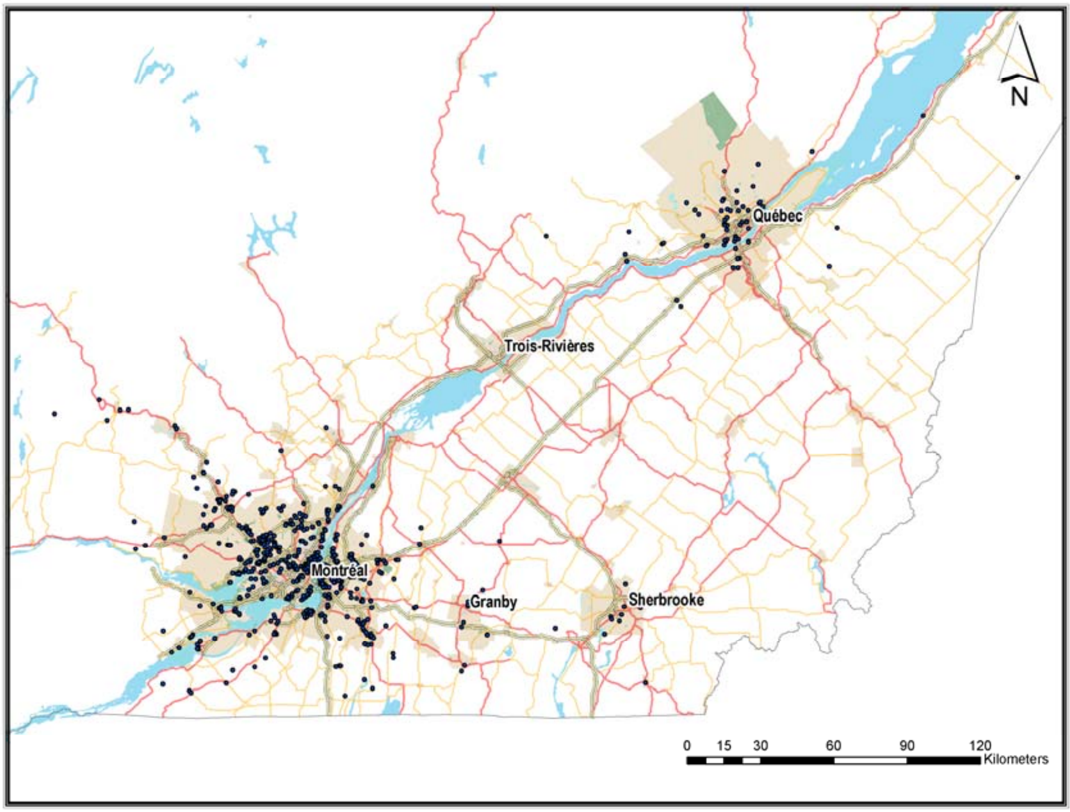
The QUALITY Cohort was not intended to be representative of the Quebec population of families with children aged 8-10 years between 2005 and 2008. Comparison of baseline characteristics with those of a representative sample of Quebec children of similar age showed that children in the QUALITY study are of higher socioeconomic status, more likely to live with both parents, to reside in urban regions, to be overweight or obese, to have a worse lipid profile, and to report less time watching television (Lambert et al., 2012). Although the generalizability of QUALITY may be restricted to Caucasian children with a parental history of obesity, this group comprises a large segment of the population, with close to 1 in 4 Canadian adults currently being obese (Shields et al., 2010). Moreover, compared to clinic-based recruitment, recruitment through schools is expected to enhance the generalizability of findings. However, since the main goal of this doctoral research is to describe environmental determinants of childhood obesity and associated dietary behaviours rather than to describe the prevalence of these conditions in Quebec, lack of generalizability of prevalence data is not a major limitation here.

3.1.3 Ethical procedures

Ethical approval for the QUALITY study (#2040), the Residential Study (#2631), the School Study (#2696) as well as for this doctoral research (#3880) was obtained from the Research Ethics Committee of the Centre de recherche du Centre Hospitalier Universitaire Sainte-Justine (see Appendix B for ethical certificate).

Written informed consent was obtained from parents, and children provided assent prior to baseline assessments.

Figure 2. Residential location of QUALITY study participants at baseline



3.2 Data collection procedures

3.2.1 Individual-level data collected within the QUALITY Study

Baseline data collection for the QUALITY study involved a clinic visit during which questionnaires were completed and biological and physiological measurements were obtained. Baseline visits were completed between September 2005 and December 2008. The first follow up when youth were aged 10-12 years (Visit 2) was completed between September 2008 and March 2011, and Visit 3 data are currently being collected. To date, retention for Visit 3 is acceptable (70%). A full description of variables measured during Visits 1 through 3 is available elsewhere (Lambert et al., 2012).

3.2.2 Neighbourhood-level data collected within the Residential and School Studies

Within the Residential and the School neighbourhood studies, two types of data were obtained at baseline for families residing in the Montreal Metropolitan Area (n=512): data from a geographic information system and data collected through in-person neighbourhood audits.

MEGAPHONE: a Montreal-based geographic information system

Data were extracted from MEGAPHONE (Montreal Epidemiological and Geographical Analysis of Population Health Outcomes and Neighbourhood Effects), a spatial data infrastructure that combines administrative, census, and observation data to a geographic information system to describe physical and social environments in the Montreal Metropolitan Area (Megaphone Catalogue, 2009). MEGAPHONE mainly includes secondary data collected for purposes other than health-related research such as data on land use, transportation systems, institutions, services and businesses, and census data, as well as some primary data from systematic neighbourhood observation (Megaphone Catalogue, 2009). Variables found in MEGAPHONE can be obtained for, and aggregated at, different spatial scales. A geographer hired specifically for the Residential and School Studies and supervised by a health geographer co-investigator computed all geocoded data used in the context of this research.

In-person residential neighbourhood audits

Trained observers conducted in-person neighbourhood audits in geographic zones surrounding each child's residential and school address. Only methods used for assessments in residential neighbourhoods are described since data from audits of school neighbourhoods are not used in this thesis.

For the Residential Study, a neighbourhood assessment tool (see Appendix C) was developed from existing tools, namely the Montreal Neighbourhood Assessment Tool (MoNAT) (Paquet et al., 2010), the Systematic Pedestrian and Cycling Environmental Scan (SPACES) tool (Pikora et al., 2002), and the Neighbourhood Active Living Potential (NALP) tool (Gauvin et al., 2005). To complete their assessments, observers were provided with a map created by the geographer hired for the study (see Appendix D). The map identified the street segment where the participant's residence is located and up to nine first and second degree connecting streets located within a 500 m road network buffer centered on the residence. This map also identified all parks located within 1 km of the participant's residence.

The Neighbourhood Observation Checklist was used to conduct detailed neighbourhood audits for each (up to 10) pre-identified street segments. Next, the General Impression Checklist was completed after observers walked all remaining street segments contained in the 500 m road network buffer centered on the residence. Observers also assessed equipment and infrastructures available in up to three parks near the participant's residence (Bird et al., 2012).

All assessments were conducted by pairs of trained observers who independently audited residential neighbourhoods. Observer training occurred over a period of nine days beginning in May 2008. On the first day, observers were introduced to the purpose of the study and attended a presentation of the observation checklists that contained photo illustrations of answers for each item. Observers were provided with the manual of procedures and were requested to read it thoroughly prior to the first day of on-site training. On training days two through six, observers and trainers began running on-site test observations in various streets located in Montreal. At first, after each street segment had been independently assessed, observers and trainers would meet to compare responses. When there was discordance, the group would return to the street/neighbourhood element in question to identify what the "correct" answer should be based on the trainer's response, considered the gold standard. Eventually, as agreement improved, observers and trainers would meet at the end of the training day at the research center to compare responses and clarify items. Additionally, following training days, items on the neighbourhood assessment tool were revised and adjusted as needed by the principal investigator in efforts to improve clarity and inter-observer reliability. The most common change was a reduction in the response scale (e.g., from four to three responses).

During the iterative on-site observer training sessions, a pen-and-paper version of the tool was used to record answers (shown in Appendix C). Following training day six, the revised tool was sent to the co-investigators for finalization. On training day 7, the observers began to use a digital personal agenda (Pocket PC iPaq 110) to record answers and once again audited test neighbourhoods with a proceeding follow up discussion to address discordance. This process was repeated with the digital agendas for two more training days. On day 10 (13 June 2008), observers began evaluating neighbourhoods around the homes of the QUALITY participants. Participants' neighbourhoods were audited during clement weather between the hours of 8 am and 5 pm in 2008 (76%), 2009 (21%), and 2010 (3%) between the months of June and December, prior to the first snow on the ground.

Upon completing the data collection, inter-rater reliability was assessed for each item using percentage agreement and kappa coefficients. When pairs of observers disagreed on their assessment, items were re-assessed by a third observer on another occasion to obtain consensus. In rare circumstances when re-assessment was too unwieldy (e.g., neighbourhood far away from the research center, or too few discordant items for a specific neighbourhood to justify revisiting it), consensus was obtained using Google Street View. The latter has been found to offer a feasible and reliable method to conduct virtual neighbourhood audits (Odgers et al., 2012; Rundle et al., 2011). Lastly, and even less frequently, if Google Street View was not available for the area, one of the two discordant observations was randomly selected as the consensus answer (≤ 0.6% of observations per items assessed on the Neighbourhood Observation Checklist) (details on the frequency each method to obtain consensus was used are presented in Manuscript 2).

3.3 Variable description

3.3.1 Individual-level variables

Obesity

Child and parent anthropometrics were measured according to standardized protocols (Lambert et al., 2007) with children and parents dressed in light indoor clothing without shoes, using a stadiometer for height and an electronic scale for weight. Height was measured upon maximal inspiration. Parents' waist circumference was measured using a standard measurement tape at the mid-distance between the last floating rib and the iliac crest at the end of a normal expiration. Measurement of height, weight and waist circumference were repeated on two occasions and recorded at the nearest 0.1 cm for height and waist circumference, and 0.1 kg for weight. If measurements differed by > 0.2 cm for height and waist circumference, and > 0.2 kg for weight a third measurement was taken and the average of the two nearest measurements was kept. Baseline test-retest reliability was high for measurements of weight and height in children and parents (ICC > 0.98), and waist circumference in parents (ICC > 0.95) (Lambert et al., 2012).

For children, CDC-based age- and sex-specific BMI percentiles were computed using the available program for SAS version 9.2 (Cary, NC). Children were categorized as obese if their BMI was ≥ 95^{th} percentile, and normal weight or overweight otherwise (dichotomous variable). BMI percentiles were strongly correlated with the percentage of total body fat mass obtained using dual energy x-ray absorptiometry (r=0.86) suggesting that in the QUALITY study, BMI is a valid measure of obesity.

For parents, BMI was computed as weight (kg) divided by height squared (m^2); they were categorized as obese if their BMI was ≥ 30 kg/m^2 and normal weight or overweight otherwise. Abdominal obesity was determined using standardized cut-offs for waist circumference in adults (> 88 cm for mothers and > 102 cm for fathers) (Bastien et al., 2014).

Pubertal development stage

Pubertal development stage was assessed by a nurse using the 5-stage Tanner scales (Marshall & Tanner, 1969, 1970). Because the majority of children at baseline and approximately to 1 in 3 at follow up were pre-pubertal, Tanner stage was dichotomized as pre-pubertal (Tanner 1) vs. puberty initiated (Tanner > 1) for both baseline and follow up.

Diet

At baseline, trained dieticians conducted three 24-hour diet recalls on non-consecutive days including on one weekend day. Except in unusual circumstances, the recalls were collected within a 4-week period following the baseline clinic visit. Diet recall interviews were done by telephone first with the child and then confirmed with the parent who prepared the meals using the multiple-pass method (Johnson et al., 1996). At the baseline clinic visit, instructions were provided on the specific procedure and the family was given a set of disposable containers (bowl, plate, cup and ruler) to help estimate portion sizes during the recall interviews.

All reported foods were entered into CANDAT (London, ON, Canada), a nutrient calculation program, by trained data entry staff and each recall was entered by one individual and then verified by another or double verified. Every 10th entry was audited by a research dietician who supervised the staff. Final entries were verified for outlying values. Entered foods were then converted to nutrients using the 2007b Canadian Nutrient File (Health Canada, 2007a). Children's dietary intake was measured based on mean values of the three 24-hour diet recalls in order to reduce intra subject day-to-day variability.

Daily servings of vegetables and fruit (V&F) were based on portion sizes from Canada's Food Guide and include V&F juices. A dichotomous variable was developed based on recommended servings of V&F for children aged 8-10 years: ≥ 5 servings/day vs. less (Health Canada, 2007b).

Intake of sugar-sweetened beverages was computed as the mean daily mL of soft drinks and other sugar-sweetened drinks, but excluding juices made from real fruits. Given a substantial positive skewness in the distribution of this variable and the lack of standard cut-offs, sugar-sweetened beverage intake was dichotomised to > 50 mL/day vs. less, which corresponds to approximately one can of soft drink per week.

In addition to the diet recalls, data on dietary behaviours were collected using an interviewer-administered questionnaire to the child that was completed during the QUALITY baseline clinic visit (Paradis et al., 2003). The questionnaire included the following items:

"During the past seven days, how many times did you…?

A. Eat a meal in a restaurant? _______ Times

B. Have a snack in a restaurant? _______ Times

C. Have food delivered from a restaurant to your home? _______ Times"

For meals and snacks consumed in a restaurant, children were instructed to include foods and beverages consumed in restaurants, fast food restaurants, snack bars, etc. For having foods delivered home, children were instructed to include foods delivered directly to their door as well as take-out foods. These items were then used to compute two measures of children's dietary behaviours: 1) having a meal or snack in a food establishment at least once in the past week, and 2) consuming delivered or take-out food at least once in the past week.

Accelerometry

Participants' level of physical activity was measured using a uniaxial activity monitor (Actigraph LS 7164 activity monitor, Actigraph) for 7 days during the week following the baseline clinic visit. For consistency purposes with current procedures used by the Canadian Health Measures Survey (Colley et al., 2011), a minimum of 4 wear-days was required and days were excluded when the accelerometer was worn for < 10 h. These criteria for accelerometry data were found to provide valid measures of physical activity in children (Troiano et al., 2008). Children were classified as meeting physical activity guidelines if they accumulated at least 60 minutes of moderate to vigorous physical activity per day (Active Healthy Kids Canada, 2013).

Sociodemographics

Sociodemographic variables used in this thesis include child's sex and age, parental education, and household income. Child's sex was recorded by the interviewer who administered the questionnaire to the child while all other sociodemographic variables were collected using parent-completed questionnaires. The child's age was computed in years using the child's birth date and the date of the clinic visit. Highest parental educational attainment of either parent was computed from the following question and subsequently categorised as i) two parents with secondary school or less, ii) ≥ 1 parent with technical/vocational/trade school degree, and iii) ≥ 1 parent with university degree:

“What is the highest level of education completed by the biological mother and father of the child participating in the study?” (question complete by each parent)

A. No formal schooling or did not complete elementary school

B. Primary school

C. Did not complete high school (grade 7 to 11)

D. Graduated from high school (grade 12)

E. Graduated from vocational or trade school

F. Graduated from college (Cegep)

G. Graduated from university

Lastly, total annual household income was obtained from parent-completed questionnaires during clinic visits, and was adjusted for the number of people living in the household:

“What was your total household income for the last completed fiscal year, before taxes and deductions (i.e., total income of everyone living in the same residence where your child usually lives, and who share expenses)?

A. Less than 10 000$

B. 10 000$ - 14 999$

C. 15 000$ - 19 999

D. 20 000$ - 29 999$

E. 30 000$ - 39 999$

F. 40 000$ - 49 999$

G. 50 000$ - 59 999$

H. 60 000$ - 79 999$

I. 80 000$ - 99 999$

J. 100 000$ - 119 999$

K. 120 000$ - 139 999$

L. 140 000$ and more

3.3.2 Neighbourhood-level variables

Neighbourhood food environment

MEGAPHONE includes data from an exhaustive list of businesses and services located in the Montreal Metropolitan Area, acquired from Tamec Inc. in May 2005. The business name, address, postal code and Standard Industry Classification code were available. A validity study of food establishments from this list, verified by onsite field visits, showed good agreement (0.77), sensitivity (0.84) and positive predictive value (0.90) (Paquet, Daniel, Kestens, Leger, & Gauvin, 2008). All businesses were geocoded using GeoPinPoint™, version 2007.3 (DMTI Spatial Inc.). The types of food establishments considered were supermarkets, fast food restaurants, convenience stores and specialty food stores (e.g., bakeries, fruit and vegetable stores, gourmet, meat and fish markets).

Residential and school neighbourhood food environments were characterised using proximity- and density-based indicators, and direct counts. Proximity measures were established using ArcGIS Network Analyst (Esri. Redlands, CA) and defined as the road network distance between the child's residence and the nearest supermarket, fast food restaurant, and convenience store, and between the child's school and the nearest of each food establishment type. Density based indicators were computed using kernel density estimation. This non-parametric method, commonly used in geography, allows for the extrapolation of point-based data over entire spatial areas as opposed to fixed delimitations (Carlos, Shi, Sargent, Tanski, & Berke, 2010). It furthermore allows to take into account an attenuation of influence with increasing distance such that food establishments that are further away but still in the neighbourhood boundary have a lower importance in the overall density measure. Using this method, the average density of supermarkets, fast food restaurants, and convenience stores were computed for 500 m, 750 m, and 1 km road network buffers centred on 1) the child's residence and 2) the child's school. Because of highly skewed distributions, proximity- and density-based indicators were categorized into tertiles corresponding to farthest, intermediate and shortest distances for proximity measures, and to lowest, intermediate and highest for density measures. In addition to proximity and density measures, direct counts of food establishments within road network buffers were also computed, namely the number of fast food restaurants and the number of convenience stores within 500 m road network buffers centred on the child's residence.

Although densities and direct counts were available for different scales, 1 km road network buffers were chosen for Manuscript 1 to capture sufficient variability in neighbourhood food environment measures. Indeed, many participants living at the outskirts of the Montreal Metropolitan Area did not have access to food establishments within smaller geographic scales (e.g., 500 m or 750 m buffers). Similarly, although the count of food establishment type was measured for different scales, a 500 m road network buffer was used in Manuscript 3 for the sake of consistency in neighbourhood definition as was available for other neighbourhood environment measures (i.e., in-person neighbourhood audits which were conducted for 500 m road network buffer).

One additional global measure of the neighbourhood food environment was created, the Retail Food Environment index (Spence, Cutumisu, Edwards, Raine, & Smoyer-Tomic, 2009). This index is based on the ratio of the number of fast food restaurants and convenience stores to supermarkets and specialty food stores. Higher scores are indicative of neighbourhoods characterised by a larger number of unhealthy relative to healthy options. In cases where there were no supermarkets or specialty stores within the neighbourhood boundaries, a value of 1 was substituted to the denominator in order to compute the index. The RFE index was computed for 1 km network buffers centred on each of the residential and school locations. Because a substantial proportion of QUALITY participants lived in suburban areas, a larger buffer was also examined (3 km radius buffers) based on previous reports that the RFE index computed for larger areas may be more relevant in associations with obesity among suburban residents (California Centre for Public Health Advocacy & Policy Link, 2008). Within the Residential and School Studies, indicators for $\geq$ 3 km buffer zones were computed for circular rather than road network buffers to capture a greater number of food establishments given that, at this distance, they would likely be visited by car, including through less direct routes. The RFE index was categorized according to the approximate 75th percentile of each variable's distribution, corresponding to cut-offs of ≥ 2.0 vs. less for the 1 km buffer and ≥ 2.5 vs. less for 3 km buffer.

Neighbourhood sociodemographics

Data from the 2006 Canadian census were used to obtain residential and school neighbourhood-level socioeconomic measures. The Pampalon material deprivation index was computed which combines the proportion of people with no high school diploma, the proportion who are employed, and the average income for people aged ≥ 15 years at the level of census dissemination areas (Pampalon & Raymond, 2003). Population-weighted proportions of dissemination areas overlapping 1 km road network buffers centred on residential locations were computed. The index was then categorised into quintiles of lowest to highest material deprivation. A material deprivation index for school neighbourhoods was computed using the same approach. These socioeconomic status measures were used in the first manuscript.

In the second manuscript, a slightly different measure of neighbourhood socioeconomic status was used. Instead, % households with low income, % single parent families, % unemployment, % residents with a university degree, % owner occupied houses, % who have moved in the past year and average residential housing values were used. Here, population-weighted proportions or averages of dissemination areas overlapping 500 m road network buffers centered on the family's residential location were computed, again to keep the same neighbourhood definition as for other neighbourhood-level variables used in the second manuscript. These variables were then summarized into two indicators using principal components analysis, which explained 73% of the variance in variables, namely neighbourhood disadvantage and neighbourhood prestige (see full description in Manuscript 2).

Lastly, 2006 Canadian census data were used to obtain a measure of population density for both residential and school neighbourhood environments defined as 1 km road network buffers. A median split categorization was used for measures of population density due to a highly skewed distribution of the variable towards lower values.

Neighbourhood built environment

Land use information from CanMap (DMTI Spatial Inc.) was used to characterise the neighbourhood built environments of participants for 500 m road network buffers centered on the family's residential location. Measures include residential density, presence of at least one park, % of the neighbourhood area covered by parks (none, at least 5%, more than 5%), number of three or more way intersections, total length of streets with normal traffic at rush hour, % streets that have high traffic at rush hour (none, at least 2%, more than 2%) and total length of streets with high traffic at rush hour (none, at least 1 500 m, more than 1 500 m). Categories were created for variables that were not normally distributed. Land use measures were then summarized into two indicators using principal components analysis, namely neighbourhood level of urbanicity and neighbourhood traffic, which explained 65% of the variance in variables (see full description in Manuscript 2).

Signs of physical disorder

In-person neighbourhood audits were used to measure the extent to which visible signs of physical disorder were present using four items from the Neighbourhood Observation Checklist (see Appendix C); these items were adapted from the MoNAT (Paquet et al., 2010). Items were: visible signs of graffiti (none vs. some) (item 19a), the presence of litter/rubbish on the street segment (including front yards) to fill a small grocery bag (yes vs. no) (item 19c), and the presence of major deterioration on the roadway in need of repair (yes vs. no) (item 10). One additional item developed specifically for the Residential Study measured whether the buildings along the street segment were well maintained (less than ½ well maintained vs. other) (item 26).

Number of parks

Neighbourhood audits were used to obtain the exact number of parks in the residential neighbourhood. Observers walked over all streets within a 500 m road network buffer centered on the participant's residence to confirm the presence of pre-identified parks on observer maps (based on MEGAPHONE land use data) and to identify any additional park that had been omitted. If a pre-identified park was discovered to be something other than an area in which children could engage in active play (e.g., a grassy lot, cemetery or golf course), it was not included in the count. Conversely, parks identified on site where none were initially identified by the geographic information system were included in the count.

Traffic-calming measures and pedestrian aids

Lastly, five items of the Neighbourhood Observation Checklist (see Appendix C) assessed street-level traffic-calming measures and pedestrian aids, adapted from the MoNAT (Paquet et al., 2010) and SPACES tool (Pikora et al., 2002). These included the presence of a ≤ 30 km/hour speed limit sign on the street segment (item 16e), whether there was an all-direction stop sign at the street segment intersection (item 15d), the presence of mid-street segment stop signs (item 15e), and the presence of zebra crossings (items 14c and 14d) and pedestrian crossing signs (item 16a) at the intersection or anywhere along the street segment.

3.4 Statistical analysis methods

Different statistical analysis methods have been employed in studies examining associations between neighbourhood environment attributes, obesity and diet. Among these, multilevel statistical analyses have contributed extensively to the understanding of how a number of health outcomes vary according to place of residence (Diez Roux, 2004; Subramanian, 2004). Multilevel statistical methods allow researchers to examine associations between contextual exposures and health while controlling for, and concurrently examining association with, individual-level variables. However, the required hierarchically structured data (i.e., participants nested into neighbourhoods) is not always available, as in the QUALITY study. Moreover, the nature of neighbourhood data (e.g., multicollinearity between exposure measurements) and the complexity of the underlying causal pathways linking broader contexts, including neighbourhoods, to health, must be taken into account in statistical models. In my doctoral research, I sought to use various alternative statistical approaches that are best suited to the thesis research questions and to the QUALITY data. These approaches are presented here.

3.4.1 Taking the non-independence of data into account

In the School Study, a total of 296 schools from 18 school boards, located in the Montreal Metropolitan Area, and frequented by 506 QUALITY participants were considered. Generalized estimating equations (GEE) is used in Manuscript 1 to take the correlation between measures of participants attending the same schools into account. GEE is a marginal model such that how individuals vary within schools (random effects) cannot be examined. Instead, non-independence is treated as a nuisance and is controlled using a specified correlation structure.

Although the Residential Study data are not structured hierarchically at the neighbourhood level, they are structured hierarchically at the family level. Obesity was measured in the participating child, the biological mother and the biological father. Due to shared genetics and lifestyle behaviours, it is expected that weight status within family members are correlated. However, it is not known how shared exposure to neighbourhood environments influence familial obesity. Manuscript 2 takes advantage of the unique data structure available in QUALITY to answer this question. Random effects (individuals within families), fixed effects (families within neighbourhoods), and cross-level interactions between family members and neighbourhood characteristics are estimated using multilevel logistic regression analysis.

3.4.2 Cluster analysis to identify neighbourhood typologies

A statistical problem often encountered in the study of neighbourhood effects on health relates to the fact that many neighbourhood entities are highly correlated with one another. For example, neighbourhoods with high densities of fast food restaurants (a presumably unfavourable neighbourhood exposure) are often also characterised by higher densities of sport facilities (a presumably favourable neighbourhood exposure). The fact that many neighbourhood characteristics are strongly correlated with one another limits the ability to disentangle effects of one variable over another or to consider the combined effects of exposure to multiple co-occurring neighbourhood environment attributes on obesity and diet (Leal et al., 2012). Multicollinearity between neighbourhood exposure variables can be addressed by creating composite scores for several variables pertaining to the same domain (for example, using principal component analysis). However, this may not be ideal to summarize correlated variables from different conceptual domains.

An alternative analytic approach, which I have explored during my doctoral studies, consists of using cluster analysis on a large number of sometimes strongly correlated neighbourhood environment characteristics to construct a typology of neighbourhoods. The resulting typology groups together neighbourhoods that are substantively comparable on selected characteristics regardless of their geographical location (Appendix E) (Van Hulst et al., 2012). This study, conducted in the context of a research internship, was based on the data from the RECORD (Residential Environment and Coronary Heart Disease) Study involving 7290 adults (aged 30 to 79 years) residing in the Paris Metropolitan Area. Although the sample population is different from that of the QUALITY Study (e.g., adults vs. children), the neighbourhood environment measures are largely similar. Since then, the expertise gained on cluster analysis has been put to use in different ongoing analysis projects with QUALITY data.

3.4.3 Recursive partitioning analysis to identify obesogenic environments

Recent review studies on neighbourhood environments and obesity have identified the need to examine moderators of associations between neighbourhood environment characteristics and obesity (Ding & Gebel, 2012; Leal & Chaix, 2011). Potential moderators may include psychosocial variables, sociodemographic characteristics, familial characteristics, as well as other neighbourhood environment characteristics (Davison & Birch, 2001; Ding & Gebel, 2012). To date, interactions have typically been tested using interaction terms in generalised linear models; however, this approach is not ideal for modeling complicated nonlinear associations, such as higher order interactions. An alternative non-parametric technique consists of using recursive partitioning methods which produces a classification tree following a series of binary splits dividing participants into higher- and lower-risk subgroups for a given outcome based on a series of predictor variables (Breiman, Friedman, Olshen, & Stone, 1998). Recursive partitioning methods are particularly useful to examine higher order interactions, for example between multiple individual and neighbourhood characteristics, yet they have rarely been used in studies on neighbourhoods and health (Keegan et al., 2012; King et al., 2006). This novel statistical approach in the study of neighbourhoods and health is exploited in the third manuscript of this thesis.

3.4.4 Spatial autocorrelation

A short note on spatial autocorrelation is added to this section on statistical analysis methods. When working with spatial data, elements that are closer to one another within a geographic space are more likely to be similar than elements that are farther away. When present, this dependence within the data, also known as spatial autocorrelation, requires adequate analytic approaches (e.g., spatial autoregressive models). Based on the neighbourhood definition used in the QUALITY study (areas centered on each participants exact residence), some residential neighbourhoods are known to overlap, particularly when neighbourhoods are defined using larger spatial scales (i.e., 1 km buffers). However, spatial autocorrelation was assessed in the context of this thesis and was not found to be a major issue given that all Moran I values are relatively close to zero (see Appendix F).

3.5 Contributions to the QUALITY, Residential and School Studies

Although my doctoral research is integrated into the Residential and School Studies as well as the QUALITY Cohort study, I have made significant conceptual and methodological contributions to these studies.

I contributed to the Residential Study at its very outset, starting with the preparation of the study proposal. I also played an important role in the development of the in-person neighbourhood assessment tool. This included reviewing the literature to locate existing tools, consolidating unique items from the different relevant tools, and with my primary supervisor, doing an initial selection of items to include in our adapted tool. I was also involved in pre-testing and adapting the tool to the Montreal context and to our pediatric population. Once the final tool was developed, I produced a training manual, which explained the response choices for each item, what to include and exclude from assessments, and how to proceed with any special circumstances on the grounds. I also put together a presentation with pictures of the different neighbourhood elements to assess which was used during the observer training session.

In terms of data collection for the Residential Study, I was involved in the recruitment of 10 research assistants who completed the neighbourhood assessments. I furthermore conducted the training of research assistants, coordinated data collection procedures, and ensured quality control throughout the data collection period. I was responsible for transferring data from the electronic questionnaire to the database, and for addressing any issues reported by observer pairs during their neighbourhood visits or upon their return.

Upon completion of the neighbourhood audit data collection, I supervised the research assistant who conducted data cleaning and validation procedures, and I conducted the inter-observer reliability analyses (percent agreement, kappa coefficients) for items of the residential neighbourhood assessment tool. In terms of data management, I created the program that integrated the different methods used to obtain consensus in the case of discordances in specific items by pairs of observers.

My contributions to the School Study were significantly less as this study was planned and conducted in part while I was studying for my doctoral courses and comprehensive exams. I nevertheless contributed to the development of the school neighbourhood and school ground audit tools as well as to the school principal questionnaire, and to the development of the data collection procedure by providing input and expertise gained from the Residential Study.

Contributions beyond what was originally planned in the original studies include the utilisation of different statistical analysis approaches to be used with data from the Residential and School Studies, including cluster, multilevel and recursive partitioning analysis. Moreover, because I have a good understanding of the data collection methods and procedures for the Residential and School Studies, I have mentored students and advised post-doctoral fellows working with the data over the past years. Lastly, I worked closely with the former primary investigator of the QUALITY Cohort, Dre Marie Lambert, to write a lead publication describing the QUALITY Cohort and its general methods for the *International Journal of Epidemiology*. My important contributions to this manuscript gave me a second authorship among a team of 21 co-authors.

CHAPTER 4: MANUSCRIPT 1

Associations between children's diets and features of their residential and school neighbourhood food environments

Associations between children's diets and features of their residential and school neighbourhood food environments

Running Title:
Neighbourhood food environments and diet

Andraea Van Hulst[1,2]
Tracie A. Barnett[1,2]
Lise Gauvin[1,3,4]
Mark Daniel[1,5,6]
Yan Kestens[1,3]
Madeleine Bird[1,2]
Katherine Gray-Donald[7]
Marie Lambert[2,8]

[1] Département de médecine sociale et préventive, Université de Montréal, Montréal, Canada;

[2] Centre de recherche du Centre Hospitalier Universitaire Sainte-Justine, Montréal, Canada;

[3] Centre de Recherche du Centre Hospitalier de l'Université de Montréal , Montréal, Canada;

[4] Centre de Recherche Léa-Roback sur les Inégalités Sociales de Santé de Montréal, Université de Montréal, Montréal, Canada;

[5] School of Health Sciences, University of South Australia, Adelaide, Australia;

[6] Department of Medicine, St Vincent's Hospital, The University of Melbourne, Melbourne, Australia;

[7] School of Dietetics and Human Nutrition, McGill University, Montréal, Canada;

[8] Département de pédiatrie, Université de Montréal, Montréal, Canada

Article published in the November/December 2012 Supplement on Built Environments and Health Research of the *Canadian Journal of Public Health*, vol 103, Suppl. 3, S48-54.

Authors' contributions:

Andraea Van Hulst conceptualised the manuscript, conducted the data analysis, wrote the first draft of the manuscript, reacted to and integrated co-authors comments.

Tracie A. Barnett contributed to the conceptualisation of the manuscript and data analysis, contributed to writing and reviewing the manuscript, was responsible for the neighbourhood data collection as principal investigator of the Residential and School Studies.

Lise Gauvin contributed to the conceptualisation of the manuscript, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Mark Daniel contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Yan Kestens contributed to conceptualising the spatial component of the manuscript, contributed to data analysis, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Madeleine Bird contributed to writing and reviewing the manuscript.

Katherine Gray-Donald contributed to the conceptualisation of the manuscript and data analysis, contributed to writing and reviewing the manuscript, was responsible for the diet intake data as co-investigator of the QUALITY study.

Marie Lambert contributed to the conceptualisation of the manuscript, was responsible for the QUALITY study as principal investigator.

Corresponding author:

Counts:

Abstract: 255

Main text: 3222

Tables: 4

Abbreviations:

BMI, Body Mass Index; CMA, Census Metropolitan Area; GEE, generalised estimating equations; GIS, Geographic Information System; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth; RFE, Retail Food Environment; V&F, Vegetables and Fruit

Acknowledgements:

The QUALITY study is funded by the Canadian Institutes of Health Research, the Heart and Stroke Foundation of Canada, as well as the Fonds de la recherche en santé du Québec. The QUALITY Residential and School Built Environment complementary studies were funded by the Heart and Stroke Foundation of Canada and the Canadian Institutes of Health Research, respectively. A Van Hulst received support from a CIHR/Heart and Stroke Foundation of Canada Training Grant in Population Intervention for Chronic Disease Prevention, and a doctoral scholarship from the Fonds de la recherche en santé du Québec. TA Barnett and Y Kestens are Fonds de la recherche en santé du Québec research scholars. L Gauvin holds a Canadian Institutes of Health Research/Centre de Recherche en Prévention de l'Obésité Chair in Applied Public Health on Neighbourhoods, Lifestyle, and Healthy Body Weight. M Bird received a masters' scholarship from the Fondation du CHU Sainte-Justine.

Dr. Marie Lambert passed away on February 20th, 2012. Her leadership and devotion to the QUALITY cohort will always be remembered and appreciated.

Conflict of interest: None to declare

4.1 Abstract

Objectives: Among studies of the built environment, few examine neighbourhood food environments in relation to children's diets. We examined the associations of residential and school neighbourhood access to different types of food establishments with children's diets.

Methods: Data from QUALITY (Quebec Adipose and Lifestyle Investigation in Youth), an ongoing study on the natural history of obesity in 630 Quebec youth aged 8-10 years with a parental history of obesity, were analysed (n=512). Three 24-hour diet recalls were used to assess dietary intake of vegetables and fruit, and sugar-sweetened beverages. Questionnaires were used to determine the frequency of eating/snacking out and consumption of delivered/take-out foods. We characterised residential and school neighbourhood food environments by means of a Geographic Information System. Variables included distance to the nearest supermarket, fast food restaurant and convenience store, and densities of each food establishment type computed for 1 km network buffers around each child's residence and school. Retail Food Environment indices were also computed. Multivariable logistic regressions (residential access) and generalized estimating equations (school access) were used for analysis.

Results: Residential and school neighbourhood access to supermarkets was not associated with children's diets. Residing in neighbourhoods with lower access to fast food restaurants and convenience stores was associated with a lower likelihood of eating and snacking out. Children attending schools in neighbourhoods with a higher number of unhealthful relative to healthful food establishments scored most poorly on dietary outcomes.

Conclusions: Further investigations are needed to inform policies aimed at shaping neighbourhood-level food purchasing opportunities, particularly for access to fast food restaurants and convenience stores.

KEY WORDS: built environment, children, diet, food environment, QUALITY Cohort, residential neighbourhood, school neighbourhood

4.2 Introduction

In recent years, the role of neighbourhoods has been increasingly investigated with respect to obesity in children.[1-3] Neighbourhood built environments may promote childhood obesity by favouring antecedent behaviours, including physical inactivity and unhealthful diets. Compared with physical activity, fewer studies have addressed children's diets.[1]

Most studies examining associations between local neighbourhood availability of food establishments and residents' diets have focused on adults.[4] Overall, findings from studies involving children are less consistent, notably for associations between access to supermarkets and vegetable and fruit (V&F) intake.[5-7] Greater access to convenience stores, which typically offer limited fresh produce, has been found to be associated with lower V&F intake[5, 7] and higher intake of sweet/salty snacks[6] and sugar-sweetened beverages[8] in youth. Although some studies have reported associations between the availability of fast food restaurants near children's residence and their diets,[7, 8] others do not support such findings.[6, 9, 10] Given the conflicting results in the literature, there is a need to clarify the relation between neighbourhood food environments and children's diets.

In addition to residential neighbourhoods, school neighbourhood environments are relevant activity spaces and should be investigated in relation to obesity-related behaviours in children.[11,12] During the academic year, travel to and from school exposes children to school neighbourhood food environments. Recently, policies have targeted in-school food environments, but initiatives aimed at regulating food opportunities in school neighbourhoods have yet to be widely implemented. Fast food restaurants and convenience stores are known to cluster within short distances from schools.[13,14] However, it is not clear to what extent the availability of the latter is associated with children's diet.[2,9]

The aim of this study was to determine whether features of residential and school neighbourhood food environments were associated with children's dietary intake (V&F and sugar-sweetened beverages) and selected dietary behaviours (eating/snacking out and consuming delivered/take-out food).

4.3 Methods

Participants were drawn from the QUALITY (Quebec Adipose and Lifestyle Investigation in Youth) study, an ongoing longitudinal investigation of the natural history of obesity and cardiovascular risk in youth with a history of parental obesity. Recruitment flyers were distributed to parents of children in Grades 2 to 5 in 1,040 primary schools (89% of schools approached) located within 75 km of each of Montreal, Quebec City and Sherbrooke, QC. Of 3350 interested families who contacted the research coordinator, 1320 met the study inclusion criteria. Eligibility criteria required participating children to be Caucasian, aged 8–10 years at recruitment, to have at least one obese biological parent (i.e., body mass index [BMI] ≥ 30 kg/m^2 and/or waist circumference > 102 cm in men and > 88 cm in women, based on self-reported measurements of weight, height, and waist circumference), and both biological parents available to participate at baseline. Of eligible families, a total of 630 (48% of eligible families, composed of the participating child and two biological parents) completed the baseline visit between September 2005 and December 2008. Baseline data collection involved a clinic visit during which questionnaires were completed and biological and physiological measurements obtained, as well as follow up telephone interviews. Written informed consent was obtained from parents, and assent was provided by children. The ethics review boards of Centre Hospitalier Universitaire Sainte-Justine and Laval University approved the study. A detailed description of the study design and methods is available elsewhere.[15]

Characteristics of the built and social environments in children's residential neighbourhood were obtained for the study baseline using a Geographic Information System (GIS) for 512 children residing in the Montreal Census Metropolitan Area

(CMA). Of these, 506 attended some 296 schools located within the Montreal CMA, for which school neighbourhood GIS data were also obtained.

Dietary Assessment

Children's dietary intake was measured using mean values of three 24-hour diet recalls conducted by trained dieticians on non-consecutive days including one weekend day.[16] Data from recalls were available for 498 participants considered in this study. Except in unusual circumstances, the recalls were collected within a 4-week period after the baseline clinic visit. Diet recall interviews were done by telephone with the child and then confirmed with the parent who prepared the meals.

Foods reported on the recalls were entered into CANDAT (London, ON) and converted to nutrients using the 2007b Canadian Nutrient File.[17] Daily servings of V&F were based on portion sizes from Canada's Food Guide and include V&F juices. A dichotomous variable was developed on the basis of recommended servings of V&F for children aged 8-10 years: ≥ 5 servings/day vs. less.[18] Intake of sugar-sweetened beverages was computed as the mean daily number of mililitres of soft drinks and other sugar-sweetened drinks, but excluding juices made from real fruits. Given a substantial positive skewness in its distribution, sugar-sweetened beverage intake was dichotomized to > 50 mL/day (approximately one can of soft drink per week) vs. less.

Two additional measures of children's diets were obtained from a questionnaire administered to the child during the clinic visit: having a meal or snack in a food establishment at least once in the previous week, and consuming delivered or 'take-out' food at least once in the previous week.

Neighbourhood Assessment

The exact addresses of each participating child's residence and school were geocoded. The availability of food establishments within the residential and school neighbourhood environment was measured using a GIS, which included data from an exhaustive list, acquired from Tamec Inc., of businesses and services located in the region in May 2005. The business name, address, postal code and Standard Industry Classification code were available. A validity study of food establishments from this list, verified by onsite field visits, showed good agreement (0.77), sensitivity (0.84) and positive predictive value (0.90).[19] All businesses were geocoded using GeoPinPoint^{TM}, version 2007.3 (DMTI Spatial Inc.). Types of food establishment included in this study were supermarkets, fast food restaurants,[14] convenience stores and specialty food stores (e.g., bakeries, fruit and vegetables, gourmet, meat and fish markets).

Neighbourhood food environments were described by proximity- and density-based indicators. Proximity measures were established using ArcGIS Network Analyst (Esri. Redlands, CA) and defined as the road-network distance between the child's residence and the nearest supermarket, fast food restaurant, and convenience store, and between the child's school and the nearest of each food establishment type. Because of highly skewed distributions, indicators were categorized into tertiles corresponding to farthest, intermediate and shortest distances. Kernel density was used to estimate the average density of each type of food establishment within 1 km street network buffers centred on 1) the child's residence and 2) the child's school. Kernel density estimations are frequently used in geography to evaluate the local density of point-based data[20] and have been used previously to describe neighbourhood access to food establishments.[21] A quartic kernel function was used with adaptive bandwidth composed of 1% of the observations for each type of food establishment (n=1,929 for convenience stores, n=1,118 for fast food restaurants and n=828 for supermarkets) and cell spacing of 100 m. Exposure categories for each type of food establishment were based on tertiles corresponding to lowest, intermediate and highest densities.

Additionally, a Retail Food Environment (RFE) index was computed.[22] This index is based on the ratio of the number of fast food restaurants and convenience stores to supermarkets and specialty food stores. Higher scores are indicative of neighbourhoods characterized by a higher number of unhealthful relative to healthful options. The RFE index was computed for 1 km network buffers and for 3 km radius circular buffers centred on each of the residential and school locations. A larger buffer was examined to capture greater variation among neighbourhoods in RFE indices. The index was subsequently categorized according to the approximate 75th percentile of each variable's distribution, corresponding to cut-offs of ≥ 2.0 vs. less for 1 km buffers and ≥ 2.5 vs. less for 3 km buffers.

Other neighbourhood-level measures included a material deprivation index computed from 2006 Census data.[23] The index combines the proportion of people with no high school diploma, the proportion who are employed and the average income, for people aged ≥15 years in census dissemination areas. Population-weighted proportions of dissemination areas overlapping 1 km street network buffers centred on resident's location were computed. The index was classified into quintiles of lowest to highest deprivation. A material deprivation index for school neighbourhoods was computed using the same approach. Population density for both residential and school neighbourhood environments was computed from 2006 Census data for 1 km street network buffers. A median split categorization was used for measures of population density.

Individual Socio-demographic Measures

Individual-level data used as adjustment variables included child's age and sex, and mother's BMI. Highest parental educational attainment (2 parents with secondary school or less, ≥1 parent with technical/vocational/trade degree, ≥1 parent with university degree) and total annual household income adjusted for the number of people living in the household were obtained from parent-completed questionnaires during the clinic visit.

Analysis

This study was not designed to allow multilevel analyses of participants nested into neighbourhoods; instead, an ego-centred approach was used whereby individual neighbourhood measures were computed for each child's residential and school locations.[24] Moreover, no evidence of spatial autocorrelation resulting from the dependency of properties within geographic spaces was found, indicating that nearby entities did not share more similarities than entities that were further apart.

Unadjusted associations among indicators of residential neighbourhood food environment and dietary outcomes were examined using logistic regression. Subsequently, multivariable associations were analyzed adjusting for child's age and sex, as well as for potential confounders, namely parental education, household income, residential neighbourhood material deprivation and residential population density (as a measure of level of urbanicity). For analyses involving school neighbourhoods, generalized estimating equations (GEE) with a logit link function and with an independent working correlation structure were used to allow for clustering of dietary outcomes among children attending the same schools. Multivariable GEE models were adjusted for child's age, sex, parental education, household income, school neighbourhood material deprivation, and school neighbourhood population density. Given the high correlations between proximity-based indicators and between density-based indicators of each type of food establishment (r=0.7 to 0.9), each variable was examined in separate models for residential and school neighbourhoods using the 'best access' (i.e., closest or densest tertile) as the reference category. For RFE indices, values below the cut-offs were used as the reference category. Odds ratios (OR) and 95% confidence intervals (CIs) are presented. All analyses were conducted using SAS, version 9.2 (Cary, NC).

In secondary analyses, we restricted the sample to children who lived > 1.5 km walking distance from their school, i.e., those who were more likely to have distinct residential and school neighbourhood food environments, since there would be minimal overlap between respective 1 km network buffers centred on each location. Associations between the density of food establishments and dietary outcomes were examined in this subgroup in an attempt explore which of the residential or school neighbourhood food environment features were most strongly associated with dietary outcomes.

4.4 Results

Overall, 34% of the 512 children consumed the recommended daily intake of ≥ 5 servings of V&F per day (average of 4.3 servings), 58% drank > 50 mL of sugar-sweetened beverages daily, 44% had a meal/snack in a food establishment, and 35% consumed delivered/take-out foods at least once per week (Table 1, p. 97). Overall, supermarkets, fast food restaurants and convenience stores were more accessible around schools than around residences, as shown by shorter distances to and higher densities of each type of food establishment in school neighbourhoods. Thirty-eight percent (n=193) lived > 1.5 km from their school.

Tables 2 and 3 (p. 99-101) show covariate-adjusted associations of proximity, density and retail food environment measures with children's dietary outcomes for both residential and school neighbourhood environments, respectively. Living in a residential neighbourhood with a lower density of fast food restaurants was associated with a 48% (OR=0.52, 95% CI: 0.30-0.91) and 40% (OR=0.60, 95% CI: 0.36-0.99) lower likelihood of eating/snacking out, for lowest and intermediate densities, respectively. Similar associations were found for convenience stores, the lowest density compared with the highest density was associated with a 56% (OR=0.44, 95% CI: 0.25-0.80) lower likelihood of eating/snacking out. Residential neighbourhood proximity-based indicators were not associated with children's diets, nor were residential RFE indices. Access to food establishments in the school environment was only marginally associated with dietary outcomes (Table 3, p. 101). For example, intermediate (vs. shortest) distance between attended school and the nearest fast food restaurant was associated with an increased likelihood of consuming recommended servings of V&F (p=0.08). Similarly, attending schools in neighbourhoods with the lowest density of supermarkets (vs. highest density) was associated with a decreased likelihood of eating/snacking out (p=0.08); an intermediate density of supermarkets (vs. highest density) was associated with an increased likelihood of consuming sugar-sweetened beverages (p=0.07); and intermediate density of fast food restaurants (vs.

highest density) was associated with an increased likelihood of consuming delivered/take-out foods ($p=0.09$).

The residential neighbourhood RFE Indices were not associated with dietary outcomes (Table 2, p. 99). Attending a school in a neighbourhood with a 3 km buffer RFE index ≥ 2.5 (i.e., 2.5 fast food restaurants/convenience stores for 1 supermarket/specialty store) was associated with a 61% (OR=1.61, 95% CI: 1.01-2.56) greater likelihood of consuming sugar-sweetened beverages, after adjusting for individual and neighbourhood covariates (Table 3, p. 101). Similarly, an elevated RFE index within 1 and 3 km buffers around schools was marginally associated with a lower likelihood of consuming recommended servings of V&F.

Among children living > 1.5 km from their school, lowest (vs. highest) school neighbourhood density of fast food restaurants was associated with a higher likelihood of consuming recommended servings of V&F, and intermediate (vs. highest) school neighbourhood density of fast food restaurants was associated with a higher likelihood of consuming delivered/take-out food (Table 4, p. 103). The residential density of convenience stores remained positively associated with eating/snacking out.

Last, when V&F intake was treated as a continuous variable using linear regression models, children living farthest from fast food restaurants had a 0.5 additional serving of V&F daily ($\beta=0.50$, 95% CI: 0, 1.00) compared with those living at the shortest distance. Moreover, living in or attending a school in a neighbourhood with 3 km RFE indices ≥ 2.5 was associated with up to a half serving less of V&F ($\beta=-0.40$, 95% CI: -0.81, 0.005 for residential neighbourhood and $\beta=-0.50$, 95% CI: -0.91, -0.09 for school neighbourhood).

4.5 Discussion

We examined associations between indicators of neighbourhood food environments and dietary outcomes among children with a family history of obesity. Findings suggest that the availability of fast food restaurants and convenience stores in children's neighbourhood environments may be associated with their intake of V&F, and the likelihood of eating/snacking out and consuming delivered/take-out foods. This extends recent research on built environments and children's diets. Although associations tended to be weak in magnitude, observed associations are overall consistent with current research on obesogenic environments and health.

As previously reported,[5-7] we found no consistent associations between a greater availability of supermarkets and more favourable dietary outcomes. Supermarkets typically offer a large variety of healthful foods, including vegetables and fruits, at lower costs.[25] However, there appear to be very few 'food deserts' in Montreal, i.e. neighbourhoods where residents are considered to have poor access to supermarkets.[26] Associations between the availability of supermarkets and diets may be more likely to emerge in areas with less equitable distributions of supermarkets and may be more relevant to adult populations. In contrast to supermarket availability, we found more evidence that the availability of fast food restaurants and convenience stores was associated with children's diets, particularly with the likelihood of eating or having a snack in a food establishment. These findings suggest that easy access to unhealthful foods may be more of a concern than poor access to more healthful foods.[27]

Geographic clustering of fast food restaurants and convenience stores around schools has been described previously,[14] although our findings suggest that associations between access to these food establishments and children's diets were more consistent for residential than for school neighbourhood exposures. This may be related to the relatively young age of participants; school neighbourhoods may become more important during adolescence when students attending secondary school are typically authorized to leave school grounds.[28]

Use of the RFE indices revealed that children residing in or attending a school in neighbourhoods with a preponderance of unhealthful food establishments scored most poorly on dietary outcomes.[29] An indicator of relative access to types of food establishments is a useful complement to proximity- and density-based indicators, as commercial destinations tend to be geographically clustered such that higher numbers of fast food restaurants are often associated with more supermarkets and fruit and vegetable stores as well.

Restricting analyses to the subgroup of children living > 1.5 km from their school allowed us to partially distinguish associations with residential neighbourhood environments from associations with school neighbourhood environments. However, the results of these sub-analyses are likely not generalizable to the entire sample. In this subgroup, children who lived farther away from their school were more likely to be driven to or from their school than to travel by bus. A higher likelihood of car travel may lead to more opportunistic purchases by parents, including those at drive-through restaurants, given the extended potential path area.[9,30] This may, in part, explain the higher fast food intake among children living farther away from fast food restaurants.

Initiatives to create zones around schools with limited access to fast food restaurants and convenience stores have been proposed.[31] Such initiatives may have a positive impact on children's diet, particularly in the context of ecological interventions in which multiple levels of obesogenic environments are targeted. Although school neighbourhoods might be more compelling targets, policies to limit access to unhealthful food establishments in residential neighbourhoods should be further investigated.

The strengths of this study include the use of a valid and reliable method to measure children's diet and the use of objective measures to characterize neighbourhood food environments. Overall, the findings should be interpreted with caution, given the number of associations tested and the increased risk of type-1 error. The results should thus be seen as exploratory and in need of confirmation in future studies. Other limitations include the possibility that children with certain dietary patterns were self-selected through their parents to reside in neighbourhoods with particular food establishment profiles. Moreover, because the majority of children lived within a short walking distance of their school, it was not possible to distinguish entirely between the associations of residential vs. school neighbourhood environments with children's diets. While we used a GIS to quantify the availability of various types of food establishment,[32] others have used measures of perceived access.[33] Parents and children may incorporate aspects other than local availability to formulate perceptions of access, such as car ownership, parental permissiveness and available pocket money; this should be examined in future research that includes both GIS and perceived measures. Last, since the children in this study were relatively young (8-10 years), associations of interest may be mediated and/or confounded by parental diet; however, there were no measures of parent diet in the QUALITY study. Maternal BMI was considered as a proxy for mother's diet but was not retained because its inclusion in the models did not change main exposure coefficients substantively and because the study design required at least one parent to be obese.[1]

In conclusion, our findings suggest that among children aged 8-10 years, residential neighbourhood food environments are more strongly associated with dietary outcomes than are school neighbourhood food environments. Although the magnitude of associations is relatively small, the potential to affect population dietary behaviours and related health outcomes may be substantial. Frequent and widespread food purchasing opportunities within children's environments may be one factor amenable to interventions in order to improve diets.

---

[1] If maternal BMI (as a proxy measure for maternal diet) was a confounder or mediator in the associations of interest, one could expect that its inclusion in the regression models would have led to an attenuation of measures of association. As per Hosmer and Lemeshow (Applied Logistic Regression, 2000), a 10% change between the unadjusted and adjusted odds ratio can be used as a criterion to determine whether confounding/mediation is present. In this case, given that associations were already, at least in part, controlled for maternal BMI by design through the selection of children with at least one obese parent, we did not expect measures of associations to be affected by the inclusion of maternal BMI. We nevertheless chose to confirm this for maternal BMI but also for paternal BMI (even though it is not mentioned here). To keep models more parsimonious, we chose not to retain maternal or paternal BMI in the final models presented in this manuscript.

4.6 References

1. Galvez MP, Pearl M, Yen IH. Childhood obesity and the built environment: a review of the literature from 2008-2009. *Curr Opin Pediatr* 2010;22(2):202-7.

2. Rahman T, Cushing RA, Jackson RJ. Contributions of built environment to childhood obesity. *Mt Sinai J Med* 2011;78(1):49-57.

3. Dunton GF, Kaplan J, Wolch J, Jerrett M, Reynolds KD. Physical environmental correlates of childhood obesity: a systematic review. *Obes Rev* 2009;10(4):393-402.

4. Larson NI, Story MT, Nelson MC. Neighborhood environments. Disparities in access to healthy foods in the U.S. *Am J Prev Med* 2009;36(1):74-81.

5. Pearce J, Hiscock R, Blakely T, Witten K. The contextual effects of neighbourhood access to supermarkets and convenience stores on individual fruit and vegetable consumption. *J Epidemiol Community Health* 2008;62(3):198-201.

6. Skidmore P, Welch A, van Sluijs E, Jones A, Harvey I, Harrison F, et al. Impact of neighbourhood food environment on food consumption in children aged 9-10 years in the UK SPEEDY (Sport, Physical Activity and Eating behaviour: Environmental Determinants in Young people) study. *Public Health Nutr* 2010;13(7):1022-30.

7. Timperio A, Ball K, Roberts R, Campbell K, Andrianopoulos N, Crawford D. Children's fruit and vegetable intake: associations with the neighbourhood food environment. *Prev Med* 2008;46(4):331-5.

8. Jennings A, Welch A, Jones AP, Harrison F, Bentham G, van Sluijs EM, et al. Local food outlets, weight status, and dietary intake: associations in children aged 9-10 years. *Am J Prev Med* 2011;40(4):405-10.

9. Timperio AF, Ball K, Roberts R, Andrianopoulos N, Crawford D. Children’s takeaway and fast-food intakes: associations with the neighbourhood food environment. *Public Health Nutr* 2009;12(10):1960-4.

10. An R, Sturm R. School and residential neighborhood food environment and diet among California youth. *Am J Prev Med* 2012;42(2):129-35.

11. Casey R, Oppert J-M, Weber C, Charreire H, Salze P, Badariotti D, et al. Determinants of childhood obesity: What can we learn from built environment studies? *Food Quality and Preference*; 2011; doi:10.1016/j.foodqual.2011.06.003.

12. Papas MA, Alberg AJ, Ewing R, Helzlsouer KJ, Gary TL, Klassen AC. The built environment and obesity. *Epidemiol Rev* 2007;29:129-43.

13. Gebauer H, Laska MN. Convenience stores surrounding urban schools: an assessment of healthy food availability, advertising, and product placement. *J Urban Health* 2011;88(4):616-22.

14. Kestens Y, Daniel M. Social inequalities in food exposure around schools in an urban area. *Am J Prev Med* 2010;39(1):33-40.

15. Lambert M, van Hulst A, O'Loughlin J, Tremblay A, Barnett TA, Charron H, et al. The Quebec Adipose and Lifestyle Investigation in Youth (QUALITY) Cohort. *Int J Epidemiol* 2011;Epub July 23.

16. Johnson RK, Driscoll P, Goran MI. Comparison of multiple-pass 24-hour recall estimates of energy intake with total energy expenditure determined by doubly labeled water method in young children. *J Am Diet Assoc* 1996;96(11):1140-4.

17. Health Canada. Canadian Nutrient File. Available at: http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/cnf_downloads-telechargement_fcen-eng.php. Accessed November 15, 2011.

18. Health Canada. Eating well with Canada's Food Guide. A resource for educators and communicators. Available at: http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/index-eng.php. Accessed Nov 15, 2011.

19. Paquet C, Daniel M, Kestens Y, Leger K, Gauvin L. Field validation of listings of food stores and commercial physical activity establishments from secondary data. *Int J Behav Nutr Phys Act* 2008;5:58.

20. Carlos HA, Shi X, Sargent J, Tanski S, Berke EM. Density estimation and adaptive bandwidths: a primer for public health practitioners. *Int J Health Geogr* 2010;9:39.

21. Lebel A, Kestens Y, Pampalon R, Thériault M, Daniel M, Subramanian SV. Local context influence, activity space, and foodscape exposure in two Canadian metropolitan settings: is daily mobility exposure associated with overweight? *J Obes* 2012;2012:912645. Epub 2011 Dec 28.

22. Spence JC, Cutumisu N, Edwards J, Raine KD, Smoyer-Tomic K. Relation between local food environments and obesity among adults. *BMC Public Health* 2009;9:192.

23. Pampalon R, Hamel D, Gamache P, Raymond G. A deprivation index for health planning in Canada. *Chronic Dis Can* 2009;29(4):178-91.

24. Chaix B, Merlo J, Evans D, Leal C, Havard S. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc Sci Med* 2009;69(9):1306-10.

25. Diez Roux AV, Mair C. Neighborhoods and health. *Ann N Y Acad Sci* 2010;1186:125-45.

26. Apparicio P, Cloutier M-S, Shearmur R. The case of Montreal's missing food deserts: evaluation of accessibility to food supermarkets. *Int J Health Geogr* 2007;6(4).

27. Hackett A, Boddy L, Boothby J, Dummer TJB, Johnson B, Stratton G. Mapping dietary habits may provide clues about the factors that determine food choice. *J Hum Nutr Diet* 2008;21(5):428-37.

28. Laska MN, Hearst MO, Forsyth A, Pasch KE, Lytle L. Neighbourhood food environments: are they associated with adolescent dietary intake, food purchases and weight status? *Public Health Nutr* 2010;13(11):1757-63.

29. Babey SH, Wolstein J, Diamant A. Food environments near home and school related to consumption of soda and fast food. Los Angeles, CA: UCLA Center for Health Policy Research,2011.

30. Páez A, Gertes Mercado R, Farber S, Morency C, Roorda M. Relative accessibility deprivation indicators for urban settings: definitions and application to food deserts in Montreal. *Urban Studies* 2012;47(7):1415-38.

31. Association pour la santé publique du Québec. The school zone and nutrition: courses of action for the municipal sector. Available at:

http://www.aspq.org/documents/file/guide-zonage-version-finale-anglaise.pdf. Accessed November 15, 2011.

32. Charreire H, Casey R, Salze P, Simon C, Chaix B, Banos A, et al. Measuring the food environment using geographical information systems: a methodological review. *Public Health Nutr* 2010;13(11):1773-85.

33. Veugelers P, Sithole F, Zhang S, Muhajarine N. Neighborhood characteristics in relation to diet, physical activity and overweight of Canadian children. *Int J Pediatr Obes* 2008;3(3):152-9.

Table 1. Characteristics of participants residing within the Montreal CMA (n=512) from the Quebec Adipose and Lifestyle Investigation in Youth (QUALITY) study

Characteristic	
Age, years, mean (SD)	9.6 (0.9)
Sex, boys, % (n)	54.5 (279)
Annual household income, $, mean (SD)*	43063 (18722)
Highest level of education of either parent, % (n)	
2 parents with secondary school or less	8.3 (42)
1 or 2 parents with technical/vocational/trade degree	38.5 (196)
1 or 2 parents with university degree	53.2 (271)
Mother's BMI, kg/m^2, mean (SD)	29.5 (6.6)
Father's BMI, kg/m^2, mean (SD)	30.8 (5.6)
Daily servings of V&F, mean (SD)	4.3 (2.1)
≥ 5 servings of V&F per day, % (n)	33.7 (168)
> 50 mL of sugar-sweetened beverages per day, % (n)	58.0 (289)
Eat/snack out at least once per week, % (n)	43.8 (224)
Delivered/take-out food at least once per week, % (n)	35.0 (179)
Residential neighbourhood	
Population density per km^2, median (IQR)	2715 (1926 - 3815)
% aged ≥ 15 years with no high school diploma, mean (SD)	32.6 (9.0)
% aged ≥ 15 years who are employed, mean (SD)	67.0 (8.3)
Average total income of households, $, mean (SD)	85793 (23197)
Walking distance from residence to school, meters, median (IQR)	1121 (631 - 2535)
Proximity measures (distance to nearest), metres	
Supermarket, median (IQR)	1375 (739 - 2434)
Fast food restaurant, median (IQR)	1326 (784 - 2256)
Convenience store, median (IQR)	779 (425 - 1327)
Kernel density measures (for 1 km network buffer), no./km^2	
Supermarket, median (IQR)	0.08 (0.03 - 0.2)
Fast food restaurant, median (IQR)	0.2 (0.08 - 0.8)
Convenience store, median (IQR)	0.3 (0.1 – 1.0)
Retail Food Environment index	
1 km network buffer, median (IQR)	1.0 (0 - 2.0)
3 km circular buffer, median (IQR)	1.8 (1.2 - 2.5)
School neighbourhood†	
Population density per km^2, median (IQR)	2990 (2093 - 4087)
% aged ≥ 15 years with no high school diploma, mean (SD)	32.9 (9.1)
% aged ≥ 15 years who are employed, mean (SD)	64.0 (8.1)
Average total income of households, $, mean (SD)	81478 (20793)
Proximity measures (distance to nearest), metres	
Supermarket, median (IQR)	1008 (540 - 1999)
Fast food restaurant, median (IQR)	950 (572 - 1889)
Convenience store, median (IQR)	541 (311 - 931)
Kernel density measures (for 1 km network buffer), no/km^2	
Supermarket, median (IQR)	0.1 (0.03 - 0.3)
Fast food restaurant, median (IQR)	0.3 (0.1 – 1.0)

Convenience store, median (IQR)	0.5 (0.2 - 1.6)
Retail Food Environment index	
1 km network buffer, median (IQR)	0.8 (0 - 1.8)
3 km circular buffer, median (IQR)	1.7 (1.2 - 2.4)

*Adjusted for the number of people living in the household.

†School neighbourhood data available for 296 schools localised within the Montreal CMA attended by 506 QUALITY study children (6 attended a school outside the study area).

CMA=Census Metropolitan; BMI=body mass index; V&F=vegetables and fruit Area; IQR= inter-quartile range; SD=standard deviation

Table 2. Covariate-adjusted associations (OR and 95% CI) between measures of the residential neighbourhood food environment and dietary outcomes in the QUALITY study*

	≥ 5 servings of V&F / day (n=493)§	> 50mL sugar-sweetened beverages / day (n=493)	Eating/snacking out ≥ once / week (n=506)	Delivered/take-out food ≥ once / week (n=506)
Proximity measures				
Model 1 - Distance to nearest supermarket				
Farthest (>2000m)	1.09 (0.62; 1.91)	0.82 (0.48; 1.39)	1.04 (0.62; 1.73)	0.96 (0.56; 1.65)
Intermediate (965 to 2000m)	1.07 (0.65; 1.74)	0.84 (0.52; 1.35)	1.12 (0.71; 1.77)	1.47 (0.92; 2.36)
Shortest (<965m)	1	1	1	1
Model 2 - Distance to nearest fast food restaurant				
Farthest (>1835m)	1.39 (0.81; 2.40)	0.82 (0.49; 1.37)	1.03 (0.63; 1.68)	1.03 (0.61; 1.73)
Intermediate (940 to 1835m)	1.27 (0.77; 2.10)	0.98 (0.61; 1.58)	1.08 (0.69; 1.71)	1.40 (0.87; 2.24)
Shortest (<940m)	1	1	1	1
Model 3 - Distance to nearest convenience store				
Farthest (>1090m)	0.99 (0.57; 1.72)	0.85 (0.50; 1.44)	1.15 (0.70; 1.90)	0.93 (0.55; 1.56)
Intermediate (545 to 1090m)	0.98 (0.59; 1.63)	0.87 (0.54; 1.40)	1.23 (0.78; 1.96)	1.02 (0.63; 1.64)
Shortest (<545m)	1	1	1	1
Density measures				
Model 4 - Density of supermarkets				
Lowest	1.11 (0.63; 1.93)	1.20 (0.70; 2.05)	0.63 (0.37; 1.05)‡	0.91 (0.53; 1.58)
Intermediate	0.87 (0.52; 1.48)	1.38 (0.84; 2.29)	0.78 (0.48; 1.26)	1.40 (0.85; 2.29)
Highest	1	1	1	1
Model 5 - Density of fast food restaurants				
Lowest	1.22 (0.68; 2.22)	1.19 (0.67; 2.11)	0.52 (0.30; 0.91)†	1.11 (0.63; 1.98)
Intermediate	1.01 (0.59; 1.74)	1.24 (0.74; 2.08)	0.60 (0.36; 0.99)†	1.10 (0.66; 1.84)
Highest	1	1	1	1
Model 6 - Density of convenience stores				
Lowest	1.02 (0.55; 1.91)	1.25 (0.69; 2.27)	0.44 (0.25; 0.80)†	0.93 (0.51; 1.70)
Intermediate	1.17 (0.68; 2.04)	1.19 (0.70; 2.03)	0.60 (0.36; 1.02)‡	1.15 (0.68; 1.95)
Highest	1	1	1	1
Retail food environment measures				
Model 7 - 1 km buffer RFE index				
≥ 2 (27.3%)	0.90 (0.58; 1.42)	0.93 (0.61; 1.43)	1.01 (0.67; 1.52)	1.35 (0.89; 2.05)
< 2 (72.7%)	1	1	1	1
Model 8 - 3 km buffer RFE index				
≥ 2.5 (26.2%)	0.77 (0.49; 1.21)	0.94 (0.62; 1.44)	0.88 (0.59; 1.33)	1.22 (0.80; 1.87)
< 2.5 (73.8%)	1	1	1	1

*Separate logistic regression models for each main exposure and each outcome, adjusted for child's age, sex, parental education, household income, residential neighbourhood material deprivation and residential population density.
[§]When treated as a continuous outcome, farthest (vs. shortest) distance to the nearest fast food restaurant was associated with V&F intake (Beta=0.50, 95% CI: 0, 1.00); and 3 km RFE index ≥ 2.5 (vs. less) was associated with V&F intake (Beta=-0.40, 95% CI: -0.81, 0.005).
[†]$p \leq 0.05$; [‡]$p \leq 0.10$
OR=odds ratio; CI=confidence interval; RFE=retail food environment; V&F=vegetables and fruit

Table 3. Covariate-adjusted associations (OR and 95% CI) between measures of the school neighbourhood food environment and dietary outcomes in the QUALITY study*

	≥ 5 servings of V&F / day (n=489)§	**> 50mL sugar-sweetened beverages / day (n=489)**	**Eating/snacking out ≥ once / week (n=502)**	**Delivered/take-out food ≥ once / week (n=502)**
Proximity measures				
Model 1 - Distance to nearest supermarket				
Farthest (>1565m)	1.03 (0.63; 1.68)	0.93 (0.56; 1.55)	1.05 (0.67; 1.65)	1.14 (0.70; 1.86)
Intermediate (670 to 1565m)	1.26 (0.77; 2.06)	1.00 (0.62; 1.62)	1.20 (0.79; 1.81)	1.14 (0.73; 1.78)
Shortest (<670m)	1	1	1	1
Model 2 - Distance to nearest fast food restaurant				
Farthest (>1460m)	1.18 (0.66; 2.10)	0.87 (0.51; 1.48)	1.23 (0.79; 1.94)	1.34 (0.84; 2.14)
Intermediate (680 to 1460m)	1.59 (0.95; 2.64)‡	0.77 (0.48; 1.23)	1.39 (0.89; 2.17)	1.22 (0.77; 1.93)
Shortest (<680m)	1	1	1	1
Model 3 - Distance to nearest convenience store				
Farthest (>834m)	1.13 (0.66; 1.91)	0.99 (0.58; 1.68)	1.10 (0.69; 1.77)	1.08 (0.68; 1.71)
Intermediate (370 to 835m)	1.10 (0.68; 1.81)	1.48 (0.91; 2.39)	0.94 (0.61; 1.47)	0.69 (0.43; 1.10)
Shortest (<370m)	1	1	1	1
Density measures				
Model 4 - Density of supermarkets				
Lowest	0.99 (0.55; 1.78)	1.37 (0.74; 2.51)	0.63 (0.37; 1.06)‡	0.97 (0.56; 1.67)
Intermediate	0.82 (0.49; 1.35)	1.64 (0.96; 2.79)‡	0.78 (0.48; 1.28)	1.55 (0.91; 2.64)
Highest	1	1	1	1
Model 5 - Density of fast food restaurants				
Lowest	1.59 (0.85; 2.94)	0.97 (0.54; 1.75)	0.85 (0.50; 1.47)	1.25 (0.71; 2.20)
Intermediate	1.25 (0.69; 2.25)	1.06 (0.64; 1.76)	0.96 (0.58; 1.57)	1.53 (0.93; 2.50)‡
Highest	1	1	1	1
Model 6 - Density of convenience stores				
Lowest	1.34 (0.69; 2.60)	1.04 (0.56; 1.93)	0.71 (0.38; 1.35)	0.75 (0.41; 1.35)
Intermediate	1.39 (0.80; 2.41)	0.98 (0.59; 1.61)	0.81 (0.47; 1.41)	1.03 (0.61; 1.73)
Highest	1	1	1	1
Retail food environment measures				
Model 7 - 1 km buffer RFE index				
≥ 2 (21.9%)	0.63 (0.39; 1.04)‡	0.96 (0.60; 1.51)	0.74 (0.47; 1.15)	0.93 (0.61; 1.41)
< 2 (78.1%)	1	1	1	1
Model 8 - 3 km buffer RFE index				
≥ 2.5 (22.9%)	0.67 (0.41; 1.08)‡	1.61 (1.01; 2.56)†	0.83 (0.53; 1.30)	1.25 (0.81; 1.91)
< 2.5 (77.1%)	1	1	1	1

* Separate GEE (generalized estimating equations) model with logit link function for each main exposure and each outcome, adjusted for child's age, sex, parental education, household

income, school neighbourhood material deprivation and school neighbourhood population density

[†]$p \leq 0.05$; [‡]$p \leq 0.10$

[§]When treated as a continuous outcome, 3 km RFE index ≥ 2.5 (vs. less) was associated with V&F intake (Beta=-0.50, 95% CI: -0.91, -0.09)

OR=odds ratio; CI=confidence interval; V&F=vegetables and fruit; RFE=retail food environment

Table 4. Covariate-adjusted associations (OR and 95% CI) of residential and school neighbourhood densities of food establishments and dietary outcomes in children living more than 1.5 km from their school, QUALITY study

	≥ 5 servings of V&F / day (n=189)	> 50mL sugar-sweetened beverages / day (n=189)	Eating/snacking out ≥ once / week (n=191)	Delivered/take-out food ≥ once / week (n=191)
Residential environment*				
Model 1 - Density of supermarkets				
Lowest	1.01 (0.38; 2.69)	1.00 (0.38; 2.63)	0.66 (0.25; 1.72)	1.27 (0.44; 3.66)
Intermediate	0.79 (0.33; 1.88)	1.32 (0.56; 3.12)	0.70 (0.30; 1.63)	2.13 (0.86; 5.31)‡
Highest	1	1	1	1
Model 2 - Density of fast food restaurants				
Lowest	0.91 (0.32; 2.53)	1.69 (0.62; 4.64)	0.67 (0.25; 1.79)	3.45 (1.10; 10.84)†
Intermediate	0.67 (0.27; 1.65)	1.22 (0.51; 2.95)	0.79 (0.34; 1.87)	1.81 (0.70; 4.73)
Highest	1	1	1	1
Model 3 - Density of convenience stores				
Lowest	0.71 (0.24; 2.08)	1.53 (0.53; 4.40)	0.32 (0.11; 0.93)†	1.78 (0.57; 5.60)
Intermediate	0.56 (0.21; 1.45)	1.45 (0.57; 3.69)	0.41 (0.16; 1.05)‡	1.67 (0.62; 4.51)
Highest	1	1	1	1
School environment**				
Model 4 - Density of supermarkets				
Lowest	1.70 (0.63; 4.60)	0.72 (0.28; 1.88)	0.76 (0.31; 1.90)	0.80 (0.26; 2.48)
Intermediate	1.06 (0.49; 2.30	1.01 (0.45; 2.26)	1.17 (0.54; 2.53)	1.49 (0.60; 3.71)
Highest	1	1	1	1
Model 5 - Density of fast food restaurants				
Lowest	2.87 (1.16; 7.10)†	1.04 (0.46; 2.37)	1.63 (0.70; 3.82)	1.51 (0.58; 3.93)
Intermediate	0.87 (0.34; 2.21)	1.31 (0.54; 3.19)	1.76 (0.83; 3.72)	2.84 (1.16; 6.97)†
Highest	1	1	1	1
Model 6 - Density of convenience stores				
Lowest	2.21 (0.76; 6.47)	0.58 (0.20; 1.68)	1.26 (0.47; 3.35)	0.53 (0.16; 1.81)
Intermediate	0.93 (0.37; 2.37)	0.70 (0.25; 1.92)	1.19 (0.53; 2.69)	0.98 (0.32; 3.04)
Highest	1	1	1	1

* Separate logistic regression models for each exposure and each outcome, adjusted for child's age, sex, parental education, household income, residential neighbourhood material deprivation, and residential population density

**Separate GEE (generalized estimating equations) models with logit link function for each exposure and each outcome, adjusted for child's age, sex, parental education, household income, school neighbourhood material deprivation, and school neighbourhood population density

†, p≤0.05; ‡, p≤0.10

OR=odds ratio; CI=confidence interval; V&F=vegetables and fruit

CHAPTER 5: MANUSCRIPT 2

Neighborhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents

Neighborhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents

Running Title:
Neighborhood environments and familial obesity

Andraea Van Hulst[1,2]
Lise Gauvin[1,3,4]
Yan Kestens[1,3,4]
Tracie A. Barnett[2,5]

[1] Département de médecine sociale et préventive, Université de Montréal, Montréal, Canada;

[2] Centre de recherche du Centre Hospitalier Universitaire Sainte-Justine, Montréal, Canada;

[3] Centre de Recherche du Centre Hospitalier de l'Université de Montréal , Montréal, Canada;

[4] Centre de Recherche Léa-Roback sur les Inégalités Sociales de Santé de Montréal, Université de Montréal, Montréal, Canada;

[5] Department of Exercise Science, Concordia University, Montreal, Canada.

Article published in the October 2013 issue of the *International Journal of Obesity*, vol 37, no 10, 1328-35.

Authors' contributions:

Andraea Van Hulst conceptualised the manuscript, conducted the data analysis, wrote the first draft of the manuscript, reacted to and integrated co-authors comments.

Lise Gauvin contributed to the conceptualisation of the manuscript and to data analysis, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Yan Kestens contributed to conceptualising the spatial component of the manuscript, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Tracie A. Barnett contributed to the conceptualisation of the manuscript and data analysis, contributed to writing and reviewing the manuscript, was responsible for the neighbourhood data collection as principal investigator of the Residential and School Studies.

Corresponding author:

Counts:
Abstract: 300
Main text: 3467
Tables: 3
Figures: 1
Supplementary Tables: 2

Abbreviations:
BMI, Body Mass Index; CDC, Centers for Disease Control and Protection; GIS, Geographic Information System; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth

Acknowledgements:
Dre Marie Lambert (July 1952 - February 2012), pediatric geneticist and researcher, initiated the QUALITY cohort. Her leadership and devotion to QUALITY will always be remembered and appreciated. The QUALITY cohort is funded by the Canadian

Institutes of Health Research, the Heart and Stroke Foundation of Canada, as well as the Fonds de la recherche en santé du Québec. The QUALITY Residential Built Environment complementary study was funded by the Heart and Stroke Foundation of Canada. A Van Hulst received support from a CIHR/Heart and Stroke Foundation of Canada Training Grant in Population Intervention for Chronic Disease Prevention, and a doctoral scholarship from the Fonds de la recherche en santé du Québec. TA Barnett and Y Kestens are Fonds de la recherche en santé du Québec research scholars. L Gauvin holds a Canadian Institutes of Health Research/Centre de Recherche en Prévention de l'Obésité Chair in Applied Public Health on Neighborhoods, Lifestyle, and Healthy Body Weight.

Conflict of interest:

The authors declare no conflicts of interest.

5.1 Abstract

Objective: To examine associations between characteristics of neighborhood built and social environments and likelihood of obesity among family triads living at the same residential address and to explore whether these associations differ between family members.

Methods: Data were from the baseline wave of QUALITY (Quebec Adipose and Lifestyle Investigation in Youth), an ongoing study on the natural history of obesity in 630 Quebec youth aged 8-10 years with a parental history of obesity. Weight and height were measured in children and both biological parents and body mass index (BMI) was computed. Residential neighborhood environments were characterised using a Geographic Information System and in-person neighborhood audits. Principal components analysis allowed for identification of overarching neighborhood indicators including poverty, prestige, level of urbanicity, traffic, physical disorder and deterioration, and pedestrian friendliness. Multilevel logistic regressions were used to examine associations between neighborhood indicators and obesity within multiple family members residing at the same address while controlling for household-level sociodemographic variables.

Results: A total of 417 families were included in analyses. Families residing in lower and average prestige neighborhoods were more likely to be obese (OR = 1.69, 95% CI: 1.16, 2.44, and OR = 1.51, 95% CI: 1.09, 2.11, respectively) than those residing in higher prestige neighborhoods. Residing in lower traffic neighborhoods was associated with less obesity (OR = 0.69, 95% CI: 0.50, 0.95). Other neighborhood indicators may have differential effects across family members. For example, as neighborhood poverty increased, obesity was more likely among children but less likely among fathers and no different for mothers.

Conclusion: Findings indicate that some shared neighborhood exposures are associated with greater risk of obesity for entire families whereas other exposures may heighten obesity risk in some but not all family members. Patterns may reflect differences in the way in which family members use residential neighborhood environments.

KEYWORDS: body mass index; built environment; familial risk; neighborhood characteristics; obesity; social environment

5.2 Introduction

Over the past 20 to 30 years, the prevalence of overweight and obesity has increased worldwide in all age groups.[1, 2] Although the prevalence of obesity may have plateaued in North America,[3, 4] it remains much too high and has resulted in increased weight-related morbidity including diabetes, cardiovascular diseases, and some forms of cancer.[5] Features of residential neighborhood environments have been increasingly studied because of their possible role in the development and maintenance of obesity in both children[6-8] and adults.[9-11] It has been hypothesized that neighborhood environments may offer opportunities or barriers that can influence energy balance and subsequent weight gain by facilitating maintenance of physical activity and dietary recommendations.[12, 13]

The built environment has been defined as all aspects of physical environments that are created or modified by humans. It encompasses urban design (physical elements and their design within cities), land use (distribution of activities across space), and transportation systems (roads, bridges, sidewalks, etc.).[14] Although there is some evidence to suggest that the built environment may influence excess weight through physical activity and dietary behaviors, existing literature does not allow for identification of the specific features of the built environment that are related to overweight and obesity.[11]

In both children and adults, urban sprawl and low land use mix have been most consistently associated with excess weight.[11, 15, 16] Specifically, neighborhoods characterized by low population density, low street connectivity, and homogeneous and segregated land use with few proximity destinations have been associated with more overweight/obesity.[17-21] Such environments may be less conducive to active transportation and leisure walking thus decreasing opportunities for physical activity behaviors.[22-24] Similarly, dense street traffic within residential neighborhoods has been associated with obesity in adults[25, 26] and in children.[27-29] On the other hand, traffic calming measures such as speed bumps, lower speed limits, zebra crossings, and traffic street lights have been found to facilitate walking which may favor healthier weight status.[30-33]

In addition to the built environment, features of neighborhood social environments have been considered, although less often, as elements that could play a role in obesity.[27] Studies on neighborhood social environments have focused on neighborhood socioeconomic status generally showing that residents of low socioeconomic status neighborhoods are more likely to be overweight/obese regardless of individual levels of socioeconomic status.[34-38] Although socially disadvantaged neighborhoods were found to have high 'walkability' scores based on characteristics of urban design, socially disadvantaged neighborhoods also had higher crime and traffic related accidents, lower observer-perceived safety, and lower quality and maintenance of pedestrian infrastructures.[39, 40] As a consequence, residents of low socioeconomic status neighborhoods may be more likely to be exposed to less safe neighborhoods and to physical disorder and deterioration while walking in their neighborhoods.[40, 41]

To date, studies have typically examined the role of the built and social neighborhood environments on children and adults separately.[42] However, studies have not examined associations within multiple family members exposed to the same residential neighborhood environment. Children and their parents residing at the same address share exposure to neighborhood environment characteristics that may make the entire family more or less likely to be obese. Alternatively, specific characteristics of neighborhood environments may be more relevant for some but not all family members. This study therefore aims to: 1) examine associations between characteristics of neighborhood built and social environments that have previously been associated with excess weight and the likelihood of obesity among family triads (child, mother, and father) living at the same address; and 2) explore whether these associations differ between members of family triads.

5.3 Subjects and Methods

Subjects

Participants were drawn from the QUALITY (Quebec Adipose and Lifestyle Investigation in Youth) study, an ongoing longitudinal investigation of the natural history of obesity and cardiovascular risk in youth with a history of parental obesity. Recruitment flyers were distributed to parents of children in Grades 2 to 5, in 1 040 primary schools (89% of schools approached) located within 75 km of each of Montreal, Quebec City, and Sherbrooke (Quebec, Canada). Of 3350 interested families who contacted the research coordinator, 1320 met the study inclusion criteria. Eligibility criteria required participating children to be Caucasian, aged 8–10 years at recruitment and to have at least one obese biological parent (i.e., body mass index [BMI] $\geq$ 30 kg/m^2 and/or waist circumference > 102 cm in men and > 88 cm in women, based on self-reported measurements of weight, height, and waist circumference), and both biological parents available to participate at baseline. Among eligible families, a total of 630 triads (including the participating child and both biological parents) completed the baseline visit between September 2005 and December 2008. Baseline data collection involved a clinic visit during which questionnaires were completed and biological and physiological measurements obtained. Written informed consent was obtained from parents, and assent was provided by children. The ethics review boards of Centre Hospitalier Universitaire Sainte-Justine and Laval University approved the study protocol. A detailed description of the study design and methods is available elsewhere.[43]

Characteristics of the built and social environments in children's residential neighborhood were obtained for the study baseline using a Geographic Information System (GIS) and in-person neighborhood audits only for children residing in the Montreal Metropolitan Area (n=512) due to feasibility reasons. The current study is thus restricted to children residing in the Montreal Metropolitan Area with both parents living at the same residential address.

Measurement of Obesity

Child and parent anthropometrics were measured according to standardized protocols[44] with children and parents dressed in light indoor clothing without shoes, using a stadiometer for height and an electronic scale for weight. For children, Centers for Disease Control and Protection (CDC) based age- and sex-specific BMI percentiles were computed. Children were categorized as obese if their BMI was ≥ 95th percentile, and normal weight or overweight otherwise. For parents, BMI was computed as weight (kg) divide by height squared (m^2); they were categorized as obese if their BMI was ≥ 30 kg/m^2 and normal weight or overweight otherwise.

Measurement of Neighborhood Environment

Three types of measures were used to characterize neighborhood environments at participating families' exact residential addresses. First, 2006 Canadian Census data were used to obtain the following measures: % households living below Statistics Canada's low income cut-offs, % single parent families, % unemployment, % residents with a university degree, % owner occupied houses, % who have moved in the past year and average residential housing value. For each measure, population-weighted proportions or averages of dissemination areas overlapping 500 m network buffers centered on family's residential location (ego-centered areas)[45] were computed using a GIS covering the study area.

Second, neighborhood environment indicators were computed using land use information from CanMap (DMTI Spatial Inc., Markham, ON, Canada) also for 500 m network buffers centered on the family's residential location. Indicators include residential density, presence of at least one park, % of the neighborhood area covered by parks (none, at least 5%, > 5%), number of three or more way intersections, total length of streets with normal traffic at rush hour, % streets that have high traffic at rush hour (none, at least 2%, > 2%) and total length of streets with high traffic at rush hour (none, at least 1 500 m, > 1500 m).

Third, in-person neighborhood audits were conducted by independent pairs of trained observers using an observation checklist adapted from an existing neighborhood assessment tool.[46] Detailed audits were conducted for up to 10 street segments in the family's immediate neighborhood, including the street segment where the residence is localized and up to 9 first and second degree connecting streets. When pairs of observers disagreed on their assessment, items were re-assessed by a third observer on another occasion. In rare circumstances when re-assessment was too unwieldy (e.g., neighborhood far away from the research center, or only a few discordant items for a specific neighborhood to justify revisiting it), consensus was obtained using Google Street View.[47, 48] Lastly, and even less frequently, if Google Street View was not available for the area, one of the two discordant observations was randomly selected as the consensus answer. The latter was used in ≤ 0.6% of observations per item assessed (see Supplementary Table 1, p. 137 for details on the frequency each method to obtain consensus was used). Street segment level scores for each item were summed and divided by the total number of underlying street segments audited (maximum of 10) to produce measures of the proportion of street segments within the family's immediate neighborhood with: presence of graffiti (none, at least 20%, > 20% of street segments), presence of enough litter to fill up an average size disposable grocery bag, presence of at least one street segment where the roadway is in bad condition, presence of at least one street where over half of the buildings are in bad condition, speed limit at ≤ 30 km/hour (none, at least on 25%, > 25% of street segments), presence of all-direction stop signs at intersection (at least 30%, 31-60%, ≥ 60% of street segments), presence of at least one mid-street segment stop sign, presence of at least one zebra crossing, and pedestrian crossing signs (none, at least on 20%, > 20% of street segments).

Statistical Analysis

Descriptive analysis was conducted and distributions of variables were examined. Variables that were highly skewed were recoded as described above. Subsequently, three separate principal components analysis, one for each type of neighborhood data (i.e., census data, land use data, and in-person audit data) were performed followed by an orthogonal (varimax) rotation to summarize the data into fewer meaningful components. Eigenvalues >1 as well as the interpretability of components were examined to determine the number of components to retain (see Supplementary Table 2, p. 138 for detailed principal components analysis results). For census data, two components were retained which explained 73% of the variance in variables, namely neighborhood poverty (e.g., % residents with low income) and neighborhood prestige (e.g., % residents with university education). For land use data, two components, neighborhood level of urbanicity (e.g., residential density) and neighborhood traffic (e.g., % streets with high traffic at rush hour) were retained which explained 65% of the variance in variables. Finally, two components were retained for neighborhood in-person audit data, neighborhood physical disorder and deterioration (e.g., % of streets where graffiti is visible) and neighborhood pedestrian friendliness (e.g., % streets with a pedestrian crossing sign) which explained 42% of the variance in variables.

These six neighborhood indicators were then categorized into tertiles (low, average, high) and used in multilevel logistic regression analysis to examine associations between neighborhood environment indicators (using the highest level as reference category) and participants' likelihood of obesity. Level-1 data included the outcome measurement for family triad members as well as two indicator variables to distinguish family members (mother vs. non-mother, father vs. non-father, with the reference therefore being the child). Level-2 data included neighborhood environment indicators described previously which were measured for each household at the family's exact residential location. It further included household control variables, namely the highest level of education achieved by one or the other parent (mother and father with high school degree or less, mother or father with technical degree, mother or father with university degree). Sex and age of the child within the household were also considered but were not retained since their inclusion did not change model estimates.

Finally, cross-level interactions were examined between each neighborhood environment variable and the two indicator variables distinguishing family members to explore whether or not associations differed across family members. Interaction terms were tested separately in custom models rather than in a full model to avoid overparameterization. However, household variables were controlled for in testing interactions. Interactions were considered statistically significant if they were associated with outcome variables at $P < 0.05$. All analyses were conducted with SAS version 9.2 (Cary, North-Carolina).

5.4 Results

Of the 512 children residing in the Montreal Metropolitan Area, 430 (84%) lived with both parents at the same address, of which 417 (97% of 430) had outcome measures for all family members. Among children, 21% were obese while 44% of mothers and 50% of fathers were obese (Table 1, p. 129). Fifty five percent of families had a male child participating in the study with a mean age of 9.57 years. Household and neighborhood-level characteristics are shown in Table 2 (p. 130).

Table 3 (p. 132) shows results from multilevel logistic regression analyses for family triads. In the fully adjusted model (model 5), mothers (OR = 2.98, 95% confidence interval (CI): 2.18, 4.07), and fathers (OR = 3.87, 95% CI: 2.84, 5.28) were more likely to be obese than their child but the likelihood of mothers and fathers being obese was about equal. Living in households where both parents have a high school degree or less compared to households where at least one parent has a university degree was associated with a greater likelihood for families to be obese (OR = 1.74, 95% CI: 1.04, 2.90). Families residing in neighborhoods with lower and average prestige (vs. higher prestige) were more likely to be obese (OR = 1.69, 95% CI: 1.16, 2.44, and OR = 1.51, 95% CI: 1.09, 2.11, respectively). Residing in a neighborhood with lower traffic (vs. higher traffic) was associated with a lower likelihood of being obese (OR = 0.69, 95% CI: 0.50, 0.95). Lower vs. higher level or urbanicity was marginally associated with obesity (OR = 1.39, 95% CI: 0.95, 2.04) while neighborhood poverty, signs of physical disorder and deterioration, and pedestrian friendliness were not associated with obesity in main effects models.

Statistically significant interactions were found between lower neighborhood poverty and being a father (p=0.003), between lower neighborhood signs of physical disorder and deterioration and being a father (p=0.046) or mother (p=0.03), and between average pedestrian friendliness and being a mother (p=0.04). Plots of these interactions suggest unique gradients between neighborhood poverty and obesity for children and their fathers while obesity appears more or less constant by level of neighborhood poverty for mothers (Figure 1a, p. 134). As neighborhood poverty increased, the likelihood of obesity increased among children while it decreased among fathers. Similarly, while the likelihood of obesity increased in children with increasing signs of physical disorder and deterioration within neighborhoods, obesity remained more or less constant in mothers and fathers (Figure 1b, p. 134). Lastly, for both children and fathers, the highest likelihood of obesity was found in areas with average neighborhood pedestrian friendliness while in mothers it was found in neighborhoods with higher pedestrian friendliness (Figure 1c, p. 135).

5.5 Discussion

We examined associations between characteristics of neighborhood built and social environments and the likelihood of obesity in a sample of family triads (child and both biological parents) living at the same address and who by design present a higher than average prevalence of obesity. Families residing in lower prestige neighborhoods were more likely to be obese while families residing in neighborhoods with less traffic were less likely to be obese. Exploratory analyses revealed that while some associations between neighborhood exposures and obesity were not different between family members (i.e., neighborhood prestige and traffic), others may be differentially associated with obesity across family members (i.e., neighborhood poverty, physical disorder and deterioration, and pedestrian friendliness).

To our knowledge, this is the first study that investigated the relationship between neighborhood exposures and obesity within multiple family members residing at the same address. Overall, observed associations were consistent with current research on obesogenic neighborhood environments and health in children and adults studied separately. As previously reported, residing in socioeconomically disadvantaged neighborhoods has been associated with excess weight in adults[49-51] and in children.[37, 52-54] In this study, more prestigious neighborhoods were those where the average residents' levels of education and residential housing values were highest. A previous study reported that of the range of measures of neighborhood socioeconomic status, neighborhood level of education was most strongly associated with cardiovascular disease risk factors among adults.[55] The lack of an interaction between neighborhood prestige and family members suggests that obesity is equally affected for all family members. Moreover, adding additional neighborhood variables to the model with neighborhood prestige resulted in little change in the odds ratios associated with the latter suggesting that elements of the social and built environment may have independent effects on familial obesity.[56]

The lack of a main effect of neighborhood poverty on familial obesity could be related to the overall affluence of families within the QUALITY study. Results from exploratory analyses presented here suggest that the effect of neighborhood poverty on obesity may differ between family members. One explanation for the inverse gradient seen between children and fathers and the lack of an effect among mothers could be that children compared to adults have more limited activity spaces and may therefore be more adversely influenced by poverty within their residential neighborhood environment.[10, 42] Findings were similar for neighborhood signs of physical disorder and deterioration as for neighborhood poverty. This is expected since physical disorder and deterioration (i.e., graffiti, litter, roads and buildings in bad condition) are more likely to occur in lower socioeconomic status neighborhoods.[57, 58] In our data, neighborhood poverty and physical disorder and deterioration were correlated ($r=0.6$, $P < 0.001$).

We found that residing in neighborhoods with lower traffic was associated with a lower likelihood of obesity compared to residing in neighborhoods with higher traffic. Lower traffic has been shown to be associated with more favorable weight profiles in children and adults.[25, 26, 29] The lack of interactions between traffic and family members suggests that children and parents alike may be at increased risk for obesity when residing in neighborhoods with heavy traffic. The latter may render walking and outdoor physical activity less easy and less pleasant for all family members thereby reducing energy expenditure and favoring excess weight gain. It could also be that neighborhood traffic affects obesity and related health behaviors in younger children through their parents' concerns about traffic who would typically decide on children's outdoor activities.[33]

Although pedestrian friendliness defined as the presence of traffic calming measures and other measures to facilitate access to pedestrians was not associated with obesity, examination of interactions suggested that patterns of associations may be different for mothers compared to children and their fathers. Although all residing at the same address, this finding may reflect differences in the way in which residential neighborhood environments are used by each family member. For example, mothers with school-aged children may have less residual time to personally take advantage of pedestrian supportive residential environments. However, findings related to cross-level interactions should be regarded as exploratory and interpreted with caution given the number of interactions tested resulting in an increased risk for type-1 error. Future studies are needed to confirm these findings.

Consistent with previous findings, we found a non-statistically significant inverse association between level of urbanicity and the likelihood of familial obesity.[11, 15, 16] The tendency towards greater obesity in less urbanized neighborhoods was similar for all family members. The higher odds of obesity among parents compared to children is expected due to the study design that required at least one parent to be obese while a similar inclusion criteria was not applied to children.[43] Finally, it is unlikely that observed associations could be confounded by potential genetic factors shared between family members since genetic factors are not expected to be associated with characteristics of the built and social neighborhood environment, although genetic factors could explain part of the clustering of obesity within family members.

Strengths of this study include the availability of standardized measures of height and weight to compute BMI for children and both biological parents. The use of multilevel analysis to control for the shared variance in obesity (genetic or environmental in origin) between family members is also a strength of the study. Moreover, objective measures including GIS-derived and observer rated data were used to characterize neighborhoods, and both neighborhood and individual/household level characteristics were considered. Limitations include the cross-sectional design, the relative affluence of families within the QUALITY cohort which may limit generalizability of findings, and the possibility of residual confounding as sociodemographic control variables had to be included as household-level rather than individual-level predictors.

Together these findings suggest that shared neighborhood exposure to lower area-level prestige and higher traffic may put families as a whole at greater risk of obesity. Other neighborhood exposures such as poverty, physical disorder and deterioration, and pedestrian friendliness may influence the risk of obesity in some but not all family members. Community-level interventions and policies aimed at modifying neighborhoods to encourage healthy weights may thus provide benefits beyond the specifically targeted audience. For example, efforts to reduce traffic in residential neighborhoods may decrease the risk of obesity in children as well as in their parents, thus benefiting different segments of the entire community. Similar benefits could be expected from policies aimed at minimizing social and material inequalities across neighborhoods. Future investigations are needed so as to better understand which population subgroups are most vulnerable to neighborhood built and social environment characteristics and how shared environmental exposures affect other health outcomes within families.

5.6 References

1. Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes* 2006; **1**(1)**:** 11-25.
2. Kelly T, Yang W, Chen CS, Reynolds K, He J. Global burden of obesity in 2005 and projections to 2030. *Int J Obes (Lond)* 2008; **32**(9)**:** 1431-1437.
3. Ogden CL, Carroll MD, Curtin LR, Lamb MM, Flegal KM. Prevalence of high body mass index in US children and adolescents, 2007-2008. *JAMA* 2010; **303**(3)**:** 242-249.
4. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA* 2010; **303**(3)**:** 235-241.
5. Must A, Spadano J, Coakley EH, Field AE, Colditz G, Dietz WH. The disease burden associated with overweight and obesity. *JAMA* 1999; **282**(16)**:** 1523-1529.
6. Galvez MP, Pearl M, Yen IH. Childhood obesity and the built environment: a review of the literature from 2008-2009. *Curr. Opin. Pediatr.* 2010; **22**(2)**:** 202-207.
7. Rahman T, Cushing RA, Jackson RJ. Contributions of built environment to childhood obesity. *Mt. Sinai J. Med.* 2011; **78**(1)**:** 49-57.
8. Dunton GF, Kaplan J, Wolch J, Jerrett M, Reynolds KD. Physical environmental correlates of childhood obesity: a systematic review. *Obes. Rev.* 2009; **10**(4)**:** 393-402.
9. Sallis JF, Floyd MF, Rodriguez DA, Saelens BE. Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation* 2012; **125**(5)**:** 729-37.
10. Papas MA, Alberg AJ, Ewing R, Helzlsouer KJ, Gary TL, Klassen AC. The built environment and obesity. *Epidemiol. Rev.* 2007; **29:** 129-143.
11. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS. The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place* 2010; **16**(2)**:** 175-90.

12. Egger G, Swinburn B. An "ecological" approach to the obesity pandemic. *BMJ* 1997; **315**(7106)**:** 477-480.
13. Hill JO, Wyatt HR, Reed G, Peters JC. Obesity and the environment: where do we go from here? *Science* 2003; **299**(5608)**:** 853-855.
14. Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. *Am. J. Prev. Med.* 2002; **23**(2 Suppl)**:** 64-73.
15. Kerr J, Frank L, Sallis JF, Chapman J. Urban form correlates of pedestrian travel in youth: Differences by gender, race-ethnicity and household attributes. *Transportation Research Part D* 2007; **12:** 177-182.
16. Black JL, Macinko J. Neighborhoods and obesity. *Nutr. Rev.* 2008; **66**(1)**:** 2-20.
17. Adams MA, Sallis JF, Kerr J, Conway TL, Saelens BE, Frank LD *et al.* Neighborhood environment profiles related to physical activity and weight status: a latent profile analysis. *Prev. Med.* 2011; **52**(5)**:** 326-31.
18. Berrigan D, Pickle LW, Dill J. Associations between street connectivity and active transportation. *Int J Health Geogr* 2010; **9:** 20.
19. Li F, Harmer P, Cardinal BJ, Bosworth M, Johnson-Shelton D, Moore JM *et al.* Built environment and 1-year change in weight and waist circumference in middle-aged and older adults. *Am. J. Epidemiol.* 2009; **169**(4)**:** 401-408.
20. Frank LD, Kerr J, Sallis JF, Miles R, Chapman J. A hierarchy of sociodemographic and environmental correlates of walking and obesity. *Prev. Med.* 2008; **47**(2)**:** 172-178.
21. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. *Am. J. Prev. Med.* 2004; **27**(2)**:** 87-96.
22. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Ann. Behav. Med.* 2003; **25**(2)**:** 80-91.
23. Timperio A, Ball K, Salmon J, Roberts R, Giles-Corti B, Simmons D *et al.* Personal, family, social, and environmental correlates of active commuting to school. *Am. J. Prev. Med.* 2006; **30**(1)**:** 45-51.

24. Salmon J, Salmon L, Crawford DA, Hume C, Timperio A. Associations among individual, social, and environmental barriers and children's walking or cycling to school. *Am. J. Health Promot.* 2007; **22**(2)**:** 107-113.
25. Berry TR, Spence JC, Blanchard C, Cutumisu N, Edwards J, Nykiforuk C. Changes in BMI over 6 years: the role of demographic and neighborhood characteristics. *Int J Obes (Lond)* 2010; **34**(8)**:** 1275-1283.
26. Timperio A, Jeffery RW, Crawford D, Roberts R, Giles-Corti B, Ball K. Neighbourhood physical activity environments and adiposity in children and mothers: a three-year longitudinal study. *Int J Behav Nutr Phys Act* 2010; **7:** 18.
27. Franzini L, Elliott MN, Cuccaro P, Schuster M, Gilliland J, Grunbaum JA *et al.* Influences of physical and social neighborhood environments on children's physical activity and obesity. *Am. J. Public Health* 2009; **99**(2)**:** 271-278.
28. Crawford D, Cleland V, Timperio A, Salmon J, Andrianopoulos N, Roberts R *et al.* The longitudinal influence of home and neighbourhood environments on children's body mass index and physical activity over 5 years: the CLAN study. *Int J Obes (Lond)* 2010; **34**(7)**:** 1177-1187.
29. Jerrett M, McConnell R, Chang CC, Wolch J, Reynolds K, Lurmann F *et al.* Automobile traffic around the home and attained body mass index: a longitudinal cohort study of children aged 10-18 years. *Prev. Med.* 2010; **50**(Suppl 1): S50-58.
30. Timperio A, Crawford D, Telford A, Salmon J. Perceptions about the local neighborhood and walking and cycling among children. *Prev. Med.* 2004; **38:** 39-47.
31. Sallis JF, Glanz K. The role of built environments in physical activity, eating, and obesity in childhood. *The Future of Children* 2006; **16**(1)**:** 89-108.
32. Hume C, Timperio A, Salmon J, Carver A, Giles-Corti B, Crawford D. Walking and cycling to school. Predictors of increases among children and adolescents. *Am. J. Prev. Med.* 2009; **36**(3)**:** 195-200.
33. Timperio A, Salmon J, Telford A, Crawford D. Perceptions of local neighbourhood environments and their relationship to childhood overweight and obesity. *Int J Obes (Lond)* 2005; **29**(2)**:** 170-175.

34. van Lenthe F, Mackenbach J. Neighbourhood deprivation and overweight: the GLOBE study. *Int. J. Obes. Relat. Metab. Disord.* 2002; **26**(2)**:** 234-240.

35. Ellaway A, Anderson A, Macintyre S. Does area of residence affect body size and shape? *Int. J. Obes. Relat. Metab. Disord.* 1997; **21**(4)**:** 304-308.

36. Kinra S, Nelder R, Lewendon G. Deprivation and childhood obesity: a cross sectional study of 20973 children in Plymouth, United Kingdom. *J. Epidemiol. Community Health* 2000; **54**(6)**:** 456-460.

37. Oliver LN, Hayes MV. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health* 2008; **8**(16)**:** e1-9.

38. Singh GK, Kogan MD, van Dyck PC. A multilevel analysis of state and regional disparities in childhood and adolescent obesity in the United States. *J. Community Health* 2008; **33**(2)**:** 90-102.

39. Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. *Am. J. Public Health* 2009; **99**(2)**:** 279-284.

40. Zhu X, Lee C. Walkability and safety around elementary schools. Economic and ethnic disparities. *Am. J. Prev. Med.* 2008; **34**(4)**:** 282-290.

41. Pabayo RA, Gauvin L, Barnett TA, Morency P, Nikiema B, Seguin L. Understanding the determinants of active transportation to school among children: evidence of environmental injustice from the Quebec Longitudinal Study of Child Development. *Health Place* 2012; **18**(2)**:** 163-171.

42. Saelens BE, Sallis JF, Frank LD, Couch SC, Zhou C, Colburn T *et al.* Obesogenic neighborhood environments, child and parent obesity: the Neighborhood Impact on Kids study. *Am. J. Prev. Med.* 2012; **42**(5)**:** e57-64.

43. Lambert M, van Hulst A, O'Loughlin J, Tremblay A, Barnett TA, Charron H *et al.* The Quebec Adipose and Lifestyle Investigation in Youth (QUALITY) Cohort. *Int. J. Epidemiol.* 2011; **Epub July 23**.

44. Lambert M, Delvin EE, Levy E, O'Loughlin J, Paradis G, Barnett T *et al.* Prevalence of cardiometabolic risk factors by weight status in a population-

based sample of Quebec children and adolescents. *Can. J. Cardiol.* 2007; **24**(7)**:** 575-583.

45. Chaix B, Merlo J, Evans D, Leal C, Havard S. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc. Sci. Med.* 2009; **69**(9)**:** 1306-1310.

46. Paquet C, Cargo M, Kestens Y, Daniel M. Reliability of an instrument for direct observation of urban neighbourhoods. *Landscape and urban planning* 2010; **97**(3)**:** 194-201.

47. Badland HM, Opit S, Witten K, Kearns RA, Mavoa S. Can virtual streetscape audits reliably replace physical streetscape audits? *J. Urban Health* 2010; **87**(6)**:** 1007-1016.

48. Rundle AG, Bader MD, Richards CA, Neckerman KM, Teitler JO. Using Google Street View to audit neighborhood environments. *Am. J. Prev. Med.* 2011; **40**(1)**:** 94-100.

49. Pickett KE, Pearl M. Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *J. Epidemiol. Community Health* 2001; **55**(2)**:** 111-122.

50. Davey Smith G, Hart C, Watt G, Hole D, Hawthorne V. Individual social class, area-based deprivation, cardiovascular disease risk factors, and mortality: the Renfrew and Paisley Study. *J. Epidemiol. Community Health* 1998; **52**(6)**:** 399-405.

51. Adams RJ, Howard N, Tucker G, Appleton S, Taylor AW, Chittleborough C *et al.* Effects of area deprivation on health risks and outcomes: a multilevel, cross-sectional, Australian population study. *Int J Public Health* 2009; **54**(3)**:** 183-192.

52. Oliver LN, Hayes MV. Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. *Can. J. Public Health.* 2005; **96**(6)**:** 415-420.

53. Blomquist HK, Bergstrom E. Obesity in 4-year-old children more prevalent in girls and in municipalities with a low socioeconomic level. *Acta Paediatr.* 2007; **96**(1)**:** 113-116.

54. Janssen I, Boyce WF, Simpson K, Pickett W. Influence of individual- and area-level measures of socioeconomic status on obesity, unhealthy eating, and physical inactivity in Canadian adolescents. *Am. J. Clin. Nutr.* 2006; **83**(1)**:** 139-145.
55. Chaix B, Bean K, Leal C, Thomas F, Havard S, Evans D *et al.* Individual/neighborhood social factors and blood pressure in the RECORD Cohort Study: which risk factors explain the associations? *Hypertension* 2010; **55**(3)**:** 769-775.
56. Diez Roux AV, Mair C. Neighborhoods and health. *Ann. N. Y. Acad. Sci.* 2010; **1186:** 125-145.
57. Lovasi GS, Hutson MA, Guerra M, Neckerman KM. Built environments and obesity in disadvantaged populations. *Epidemiol. Rev.* 2009; **31:** 7-20.
58. Sallis JF, Slymen DJ, Conway TL, Frank LD, Saelens BE, Cain K *et al.* Income disparities in perceived neighborhood built and social environment attributes. *Health Place* 2011; **17**(6)**:** 1274-83.

Table 1. Characteristics of children, mothers, and fathers in 417 families of the QUALITY study in 2005-2008.

	Children (n=417)	Mothers (n=417)	Fathers (n=417)
Obese, % (n)[a]	21.10 (88)	43.65 (182)	49.88 (208)
Age, years, mean (SD)	9.57 (0.90)	40.49 (4.85)	42.50 (5.75)
Sex, boys, % (n)	54.68 (228)	-	-

Abbreviations: SD, standard deviation.

[a] Obese defined as Center for Disease Control age- and sex-specific body mass index ≥ 95th percentile in children, and body mass index ≥ 30 kg/m^2 in mothers and fathers.

Table 2. Household and neighborhood-level characteristics of 417 families of the QUALITY study in 2005-2008.

	Families (n=417)
Highest level of education of either parent, % (n)	
Mother and father with high school degree or less	7.45 (31)
Mother or father with technical, vocational/trade school degree	36.54 (152)
Mother or father with university degree	56.01 (233)
% low neighborhood income, mean (SD)	7.32 (6.80)
% neighborhood single-parent families, mean (SD)	15.46 (7.03)
% neighborhood unemployment, mean (SD)	5.23 (3.03)
% residents living less than 1 year in current residence, mean (SD)	10.63 (5.26)
% neighborhood homeowners, mean (SD)	74.68 (25.40)
% residents with university degree, mean (SD)	28.51 (15.37)
Neighborhood residential value, $, mean (SD)	212 585 (59 989)
Neighborhood residential density per hectare, mean (SD)	15.83 (16.16)
Number of parks in neighborhood, mean (SD)*	1.10 (0.86)
Number of parks in neighborhood, % (n)*	
0	25.42 (106)
1	45.80 (191)
≥ 2	28.78 (120)
% neighborhood area that is covered with parks, % (n)	
0%	51.56 (215)
> 0% to 5%	26.38 (110)
> 5%	22.06 (92)
Number of 3 or more way intersections, means (SD)	21.38 (10.98)
Meters of streets with normal traffic at rush hour, means (SD)	292 768 (190 179)
Proportion of streets with high traffic at rush hour, % (n)	
0%	29.98 (125)
> 0% to 2%	47.72 (199)
> 2%	22.30 (93)
Total street length with high traffic at rush hour, % (n)	
0 m	29.98 (125)
> 0 m to 1 500 m	34.29 (143)
> 1500 m	35.73 (149)
% of streets where graffiti is visible, % (n)	
0%	76.02 (317)
> 0% to 20%	13.43 (56)
> 20%	10.55 (44)
Presence of large amount of litter on at least one street, % (n)	17.27 (72)
Presence of at least one roadway that is in bad condition, % (n)	26.14 (109)
Presence of at least one street where over half of the buildings are in bad condition, % (n)	15.59 (65)
% of streets where speed limit is ≤ 30 km/hour, % (n)	
0%	44.60 (186)

> 0 to 25%	30.70 (128)
> 25%	24.70 (103)
% of streets with an all-direction stop sign at intersection, % (n)	
≤ 30%	29.26 (122)
> 30 to 60%	34.29 (143)
> 60%	36.45 (152)
Presence of at least one street with a mid-street segment stop sign, % (n)	5.28 (22)
Presence of at least one street with a zebra crossing, % (n)	12.95 (54)
% streets with a pedestrian crossing sign, % (n)	
None	68.82 (287)
> 0 to 20%	19.18 (80)
> 20%	11.99 (50)

*Discrepancies in the distribution of variables 'Number of parks in neighborhood' and '% Of neighborhood that is covered with parks' are due to incomplete park data from the Geographic Information System that generated the latter variable. The actual number of parks was updated during in-person neighborhood audits.

Abbreviations: SD, standard deviation.

Table 3. Associations between neighborhood environment, household characteristics and obesity in 417 families of the QUALITY study in 2005-2008.[a]

	OR (95% CI)				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept[b]	0.22 (0.12)	0.20 (0.12)	0.20 (0.12)	0.18 (0.12)	0.19 (0.12)
Level-1 variables					
Family member					
Mother	2.91 (2.15; 3.96)**	2.91 (2.14; 3.96)**	2.94 (2.16; 4.00)**	2.97 (2.18; 4.05) **	2.98 (2.18; 4.07) **
Father	3.75 (2.77; 5.09)**	3.76 (2.77; 5.11)**	3.80 (2.80; 5.18) **	3.85 (2.83; 5.25) **	3.87 (2.84; 5.28) **
Child	1.00	1.00	1.00	1.00	1.00
Level-2 variables					
Parental highest level of education					
Mother and father with high school degree or less		1.93 (1.19; 3.13) **	1.67 (1.01; 2.74)**	1.72 (1.04; 2.82) **	1.74 (1.04; 2.90) **
Mother or father with technical degree		1.33 (1.02; 1.74) **	1.17 (0.88; 1.56)	1.19 (0.90; 1.59)	1.19 (0.89; 1.59)
Mother or father with university degree		1.00	1.00	1.00	1.00
Neighborhood poverty					
Low			0.96 (0.70; 1.31)	0.90 (0.62; 1.30)	0.91 (0.61; 1.35)
Average			1.11 (0.80; 1.53)	1.00 (0.70; 1.43)	1.01 (0.70; 1.46)
High			1.00	1.00	1.00
Neighborhood prestige					
Low			1.58 (1.12; 2.22) **	1.69 (1.17; 2.44) **	1.69 (1.16; 2.44) **
Average			1.44 (1.04; 1.98) **	1.50 (1.08; 2.09) **	1.51 (1.09; 2.11) **
High			1.00	1.00	1.00
Level of urbanicity					
Low				1.32 (0.91; 1.92)	1.39 (0.95; 2.04)*
Average				0.92 (0.64; 1.31)	0.94 (0.65; 1.35)
High				1.00	1.00
Traffic					
Low				0.70 (0.50; 0.95) **	0.69 (0.50; 0.95) **
Average				0.81 (0.59; 1.12)	0.79 (0.57; 1.09)
High				1.00	1.00
Physical disorder and deterioration					

Low	0.84 (0.58; 1.23)
Average	1.01 (0.72; 1.42)
High	1.00
Pedestrian friendliness	
Low	0.78 (0.57; 1.08)
Average	0.92 (0.66; 1.27)
High	1.00

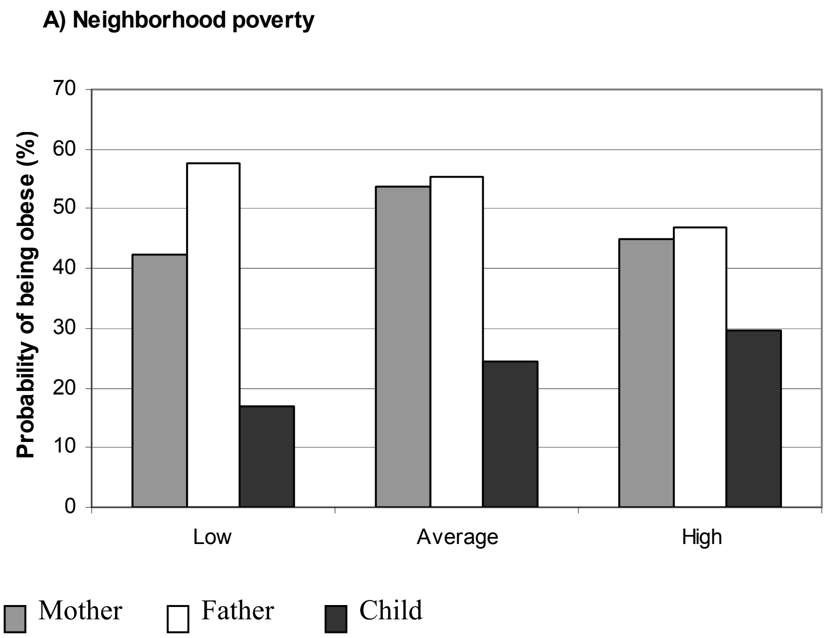
Abbreviations: CI, confidence interval; OR, odds ratio; SD, standard deviation.

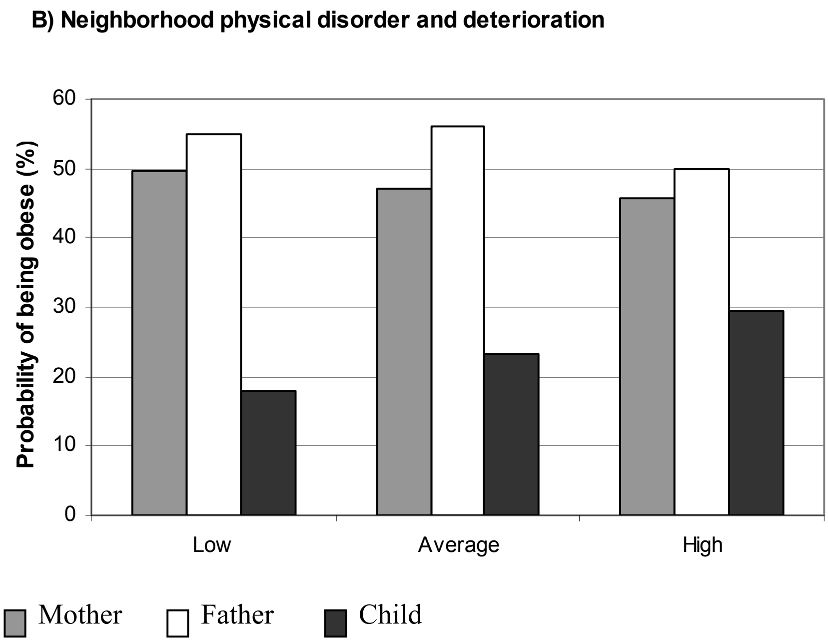
[a] Multilevel data of members (child, mother, father) are nested into families living at the same address (variables in the same column are simultaneously introduced into the model).

[b] For the intercepts, estimates (standard errors) are presented for each model. For the null model, the estimated intercept was 0.095 with a standard error of 0.10.

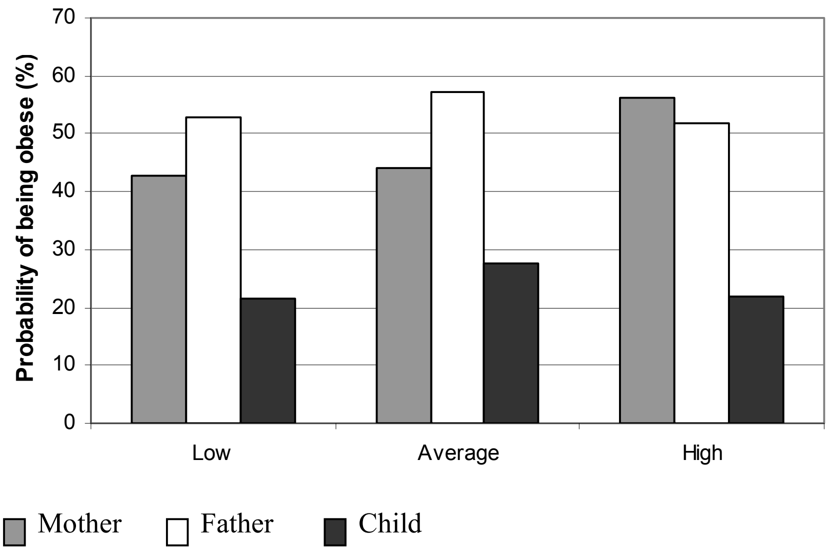
**P<0.05; *P<0.1.

Figure 1. Probability of obesity as a function of neighborhood environment characteristics and family members among 417 families of the QUALITY study in 2005-2008.[a]





C) Neighborhood pedestrian friendliness



[a] Probability of being obese plotted for a family where the child is a girl aged 9.57 years and where the mother or father within the household as a technical degree as level of education. Interaction terms were statistically significant for lower neighborhood poverty and being a father (p=0.003), lower neighborhood signs of physical disorder and deterioration and being a father (p=0.05) or mother (p=0.03), and for average pedestrian friendliness and being a mother (p=0.04).

SUPPLEMENTARY INFORMATION

Table S1 describes inter-rater reliability for in-person neighborhood audits which were conducted for a total of 4 330 street segments. When pairs of observers disagreed on their assessment, three methods were used consecutively to select the consensus answer: in-person reassessment, assessment using Google Street View, and random selection of consensus answer.

Table S2 presents results from three separate principal components analysis, one for each type of neighborhood data set used (i.e., census data, land use data, and observer data). Rotated factor loadings and total variance in data explained by components obtained through each principal component analysis are shown. Specifically, neighborhood poverty is defined by a high proportion of residents with income below the low income cut-offs, single parent families, unemployment, high mobility (more people who have lived ≤ 1 year at their current residence), and a low proportion of residents who own their home. The low income cut-offs (LICOs)[2] are income thresholds below which a family will likely devote a larger share of its income on the necessities of food, shelter and clothing than the average family. The approach is essentially to estimate an income threshold at which families are expected to spend 20 percentage points more than the average family on food, shelter and clothing.[1] Neighborhood prestige is defined by a high proportion of residents who are university educated and more expensive residences. Neighborhood degree of urbanicity is defined by a high residential density, greater number of parks and neighborhood area covered with parks, many street intersections and streets with normal traffic at rush hour. Neighborhood traffic is defined by many streets (total length and proportion) with high traffic at rush hour. Neighborhood physical disorder and deterioration is defined by the presence of graffiti, litter, and deteriorated roadways and buildings. Lastly, neighborhood pedestrian friendliness is defined by streets with lowered speed limits, the presence of stop signs (all-direction at intersections and mid-street stop signs), zebra crossings, and pedestrian crossing signs.

---

[2] Statistics Canada. Low income cut-offs; 2012 [cited 2013 Apr 12]. Available from: http://www.statcan.gc.ca/pub/75f0002m/2012002/lico-sfr-eng.htm

Table S1. Agreement between observers 1 and 2 (kappa coefficients) for selected items of the in-person neighborhood assessment tool and methods[a] used to obtain consensus a total of 4 330 street segments around the residences of 512 families from the QUALITY study in 2005-2008.

Item	**Kappa Coefficient (95% Confidence interval)**	**Frequency of in-person reassessments used to obtain consensus (%)**	**Frequency of Google Street View used to obtain consensus (%)**	**Frequency of random selection of consensus answer (%)**
Graffiti visible on street segment	0.50 (0.45; 0.55)[b]	2.8	3.6	0.05
Presence of enough litter to fill up one average size grocery bag	0.33 (0.26; 0.40)	1.5	2.5	0
Condition of roadway on street segment	0.49 (0.47; 0.52) [b]	5.1	18.4	0.6
Condition of buildings visible from street segment	0.47 (0.44; 0.50) [b]	3.7	11.5	0.5
Presence of speed limit of ≤ 30 km/hour on street segment	0.86 (0.83; 0.88)	0.6	2.6	0.07
Presence of all-direction stop sign at intersection	0.88 (0.87; 0.89)	1.0	3.9	0.2
Presence of mid-street segment stop sign	0.79 (0.67; 0.90)	0.09	0.3	0.02
Presence of a zebra crossing at intersection	0.83 (0.81; 0.86)	0.5	2.0	0.2
Presence of a pedestrian crossing sign at intersection	0.77 (0.73; 0.81)	0.6	2.0	0

[a] When independent pairs of observers disagreed on their assessment, items were re-assessed by a third independent observer on another occasion. If re-assessment was too unwieldy (e.g. neighborhood far away from the research center, or only a few discordant items for a specific neighborhood to justify revisiting it), consensus was obtained using Google Street View. If Google Street View was not available for the area, the consensus answer was selected randomly between the two discordant answers.
[b] Weighted Kappa coefficient.

Table S2. Rotated factor loadings and total variance in data explained by components obtained through three separate principal component analyses for the residences of 417 families from the Quality study in 2005-2008.

	Neighborhood variables	Rotated factor loadings
2006 Census data	**Component 1: Neighborhood poverty**	
	% residents with low income	0.84
	% single parent families	0.79
	% unemployment	0.77
	% home ownership	-0.93
	1 year mobility	0.65
	Component 2: Neighborhood prestige	
	% residents with university degree	0.94
	Average residential value	0.95
	Total variance explained by components 1 and 2	**72.6%**
Land use data	**Component 1: Neighborhood degree of urbanicity**	
	Neighborhood residential density	0.73
	Number of parks in neighborhood	0.66
	Neighborhood area that is covered with parks	0.74
	Number of 3 or more way intersections	0.72
	Meters of streets with normal traffic at rush hour	0.69
	Component 2: Neighborhood traffic	
	Total street length with high traffic at rush hour	0.96
	% streets with high traffic at rush hour	0.96
	Total variance explained by components 1 and 2	**65.0%**
In-person neighbor hood audit data	**Component 1: Neighborhood physical disorder and deterioration**	
	% of streets where graffiti is visible	0.72
	Presence of litter on at least one street	0.71
	Presence of at least one roadway that is in bad condition	0.64
	Presence of at least one street where over half of the buildings are in bad condition	0.71
	Component 2: Neighborhood pedestrian friendliness	
	% of streets where speed limit is ≤ 30 km/hour	0.60
	% of streets with an all-direction stop sign at intersection	0.46
	Presence of at least one street with a mid-street segment stop sign	0.54
	Presence of at least one street with a zebra crossing	0.61
	% streets with a pedestrian crossing sign	0.73
	Total variance explained by components 1 and 2	**42.3%**

CHAPTER 6: MANUSCRIPT 3

Identifying risk profiles for childhood obesity using recursive partitioning based on individual, familial, and neighborhood environment factors

Identifying risk profiles for childhood obesity using recursive partitioning based on individual, familial, and neighborhood environment factors

Running Title:
Risk profiles for childhood obesity

Andraea Van Hulst[1,2]
Marie-Hélène Roy-Gagnon[3]
Lise Gauvin[1,4,5]
Yan Kestens[1,4]
Mélanie Henderson[2,6]
Tracie A. Barnett[2,7]

[1] École de santé publique de l'Université de Montréal, Montreal, Canada;
[2] Centre de recherche du Centre Hospitalier Universitaire Sainte-Justine, Montreal, Canada;
[3] Department of Epidemiology and Community Medicine, Faculty of Medicine, University of Ottawa, Ottawa, Canada;
[4] Centre de Recherche du Centre Hospitalier de l'Université de Montréal, Montreal, Canada;
[5] Centre de Recherche Léa-Roback sur les Inégalités Sociales de Santé de Montréal, Université de Montréal, Montreal, Canada;
[6] Division of Endocrinology, Department of Pediatrics, Centre Hospitalier Universitaire Sainte-Justine and Université de Montréal, Montreal, Canada;
[7] Department of Exercise Science, Concordia University, Montreal, Canada.

Article under review at Int J Behav Nutr and Phys Act.

Authors' contributions:

Andraea Van Hulst conceptualised the manuscript, conducted the data analysis, wrote the first draft of the manuscript, reacted to and integrated co-authors comments.

Marie-Hélène Roy-Gagnon contributed to the data analysis, contributed to writing and reviewing the manuscript.

Lise Gauvin contributed to the conceptualisation of the manuscript and to data analysis, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Yan Kestens contributed to conceptualising the spatial component of the manuscript, contributed to writing and reviewing the manuscript, contributed to data collection as co-investigator of the Residential and School Studies.

Mélanie Henderson contributed to the conceptualisation of the manuscript, contributed to writing and reviewing the manuscript, was responsible for the QUALITY study as principal investigator.

Tracie A. Barnett contributed to the conceptualisation of the manuscript and data analysis, contributed to writing and reviewing the manuscript, was responsible for the neighbourhood data collection as principal investigator of the Residential and School Studies.

Corresponding author:

Counts:

Abstract: 273

Main text: 2993

Tables: 4

Figures: 1

Abbreviations:

BMI, body mass index; GIS, Geographic Information System; MVPA, moderate to vigorous physical activity; PA, physical activity; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth

Acknowledgements:

Dre Marie Lambert (July 1952 - February 2012), pediatric geneticist and researcher, initiated the QUALITY cohort. Her leadership and devotion to QUALITY will always be remembered and appreciated. The QUALITY study is funded by the Canadian Institutes of Health Research, the Heart and Stroke Foundation of Canada, as well as the Fonds de la recherche en santé du Québec. The QUALITY Residential and School Built Environment complementary studies were funded by the Heart and Stroke Foundation of Canada and the Canadian Institutes of Health Research, respectively. A Van Hulst received support from a CIHR/Heart and Stroke Foundation of Canada Training Grant in Population Intervention for Chronic Disease Prevention, and a doctoral scholarship from the Fonds de la recherche en santé du Québec. TA Barnett and Y Kestens are Fonds de la recherche en santé du Québec research scholars. L Gauvin holds a Canadian Institutes of Health Research/Centre de Recherche en Prévention de l'Obésité Chair in Applied Public Health on Neighbourhoods, Lifestyle, and Healthy Body Weight. M Bird received a masters' scholarship from the Fondation du CHU Sainte-Justine.

Conflict of interest: None to declare

6.1 Abstract

Background: Few studies consider how risk factors within multiple levels of influence operate synergistically to determine childhood obesity. We used recursive partitioning analysis to identify unique combinations of individual, familial, and neighborhood factors that best predict obesity in children, and tested whether these predict 2-year changes in body mass index (BMI).

Methods: Data were collected in 2005-2008 and in 2008-2011 for 512 Quebec youth (8-10 years at baseline) with a history of parental obesity (QUALITY study). CDC age- and sex-specific BMI percentiles were computed and children were considered obese if their BMI was ≥95th percentile. Individual (physical activity and sugar-sweetened beverage intake), familial (parental obesity, socioeconomic status), and neighborhood (disadvantage, prestige, and presence of parks, convenience stores, and fast food restaurants) factors were examined. Recursive partitioning was used to classify participants into varying risk subgroups; associations between group membership and BMI percentile at 2-year follow up were examined using linear regression.

Results: Recursive partitioning yielded 7 subgroups with a prevalence of obesity equal to 8%, 11%, 26%, 28%, 41%, 60%, and 63%, respectively. The 2 highest risk subgroups comprised i) children not meeting physical activity guidelines, with ≥1 BMI defined obese parent and 2 abdominally obese parents, living in disadvantaged neighborhoods without parks and, ii) children with these characteristics, except with access to ≥1 park and with access to ≥1 convenience store. Group membership was strongly associated with BMI at baseline, but did not systematically predict change in BMI.

Conclusion: Findings support the notion that obesity is predicted by multiple factors in different settings and provide some indications of potentially obesogenic environments. Alternate subgroup definitions should be investigated to predict change in obesity.

KEYWORDS: body mass index; built environment; familial risk; food environment neighborhood characteristics; obesity; physical activity; recursive partitioning analysis; socioecological model

6.2 Introduction

Childhood obesity has reached epidemic proportions worldwide[1] and its health consequences are considerable.[2] Obesity is a complex condition in which a myriad of risk factors interact within and between several levels of influence.[3] Social ecological frameworks posit that childhood obesity is influenced by energy intake and expenditure patterns, which are embedded within the familial and wider community contexts.[4-6] An understanding of the multiple levels of influence and of how factors within different levels of influence interact and operate synergistically to determine obesity is unfortunately still lacking.

At the individual level, regular intake of sugar-sweetened beverages[7] and physical inactivity[8] have been associated with childhood obesity. Through shared genetics and lifestyles, parental obesity has been identified as a risk factor for childhood obesity.[4, 9, 10] Within neighborhoods, parks, sports and recreational facilities, and the presence of nearby convenience stores and fast food restaurants have been associated with childhood obesity, albeit inconsistently.[6, 11-14] Neighborhood disadvantage has been more consistently associated with childhood obesity.[15, 16]

Individual, familial, and neighborhood factors may have synergistic effects on childhood obesity.[17, 18] To test hypotheses regarding synergistic effects (i.e., effect modification), interaction terms in regression models are typically used.[18] However, this approach is not ideal for modeling more complicated nonlinear associations. An alternative non-parametric method consists of using recursive partitioning analysis, which has gained popularity as a means of multivariate data exploration in various fields.[19] Recursive partitioning produces a classification tree following a series of binary splits dividing children into higher- and lower-risk subgroups for a given outcome based on a number of predictor variables.[20] In addition to its intuitive appeal, recursive partitioning methods are particularly useful to examine higher order interactions, for example between multiple individual and neighborhood characteristics.[21] Therefore, the primary objective of this study is to determine optimal combinations of individual, familial, and neighborhood environment characteristics that best predict obesity among children using recursive partitioning analysis. A secondary objective is to examine whether the resulting classification is associated with 2-year changes in body mass index (BMI) percentile.

6.3 Methods

Subjects

Participants were drawn from QUALITY (Quebec Adipose and Lifestyle Investigation in Youth), an ongoing longitudinal investigation of the natural history of obesity and cardiovascular risk in Quebec youth. At baseline, 630 participants aged 8 to 10 years were recruited using school-based sampling (2005-2010). Eligibility criteria, verified over the phone, required participating children to have at least 1 obese biological parent based on parent-reported measurements of weight, height, and waist circumference (i.e., BMI ≥30 kg/m^2 and/or waist circumference >102 cm in men and >88 cm in women). At the baseline clinic visit, parental anthropometrics were measured. Thirty-five children had no obese parents based on measured BMI or waist circumference, likely due to self-report measurement error or to weight loss between the initial contact and the baseline visit; these families were nevertheless retained since inclusion criteria were based on self-reports and since children still had at least 1 borderline obese parent. A 2-year follow-up assessment was completed in 2008-2011. Characteristics of residential neighborhood environments were assessed at baseline for participants residing in the Montreal Metropolitan Area (n=512) to which this study is restricted. The ethics review boards of CHU Sainte-Justine and Laval University approved the study protocol. A detailed description of the study design and methods is available elsewhere.[22]

Measurement of Individual Characteristics

Child anthropometrics were measured at baseline and follow-up using standardized protocols.[22] Centers for Disease Control and Prevention age- and sex-specific BMI percentiles were computed. Children were categorized as obese if their

BMI was ≥95th percentile. Pubertal development stage was assessed by a nurse using the 5-stage Tanner scales,[23, 24] and was dichotomized as pre-pubertal (Tanner 1) Vs puberty initiated (Tanner >1) for both baseline and follow-up.

Intake of sugar-sweetened beverages was measured using mean values of 3 24-hour diet recalls conducted by trained dieticians on non-consecutive days including 1 weekend day.[25] Except in unusual circumstances, the recalls were collected within a 4-week period following the baseline clinic visit. Diet recall interviews were done by telephone with the child and then confirmed with the parent who prepared the meals. Reported foods were entered into CANDAT (London, Canada) and converted to nutrients using the 2007b Canadian Nutrient File.[26] Intake of sugar-sweetened beverages was computed as the mean daily mL of soft drinks and other sugar-sweetened drinks, excluding juices made from real fruits. Given a substantial positive skewness in its distribution, the variable was dichotomised to >50 mL/day (approximately 1 soft drink can per week) Vs less.

Participants' physical activity (PA) was measured using a uniaxial activity monitor (Actigraph LS 7164 activity monitor, Actigraph) for 7 days during the week following the baseline clinic visit. A minimum of 4 days with ≥10h of wear time was required for data to be retained.[27] The Actigraph cut-offs proposed by Evenson et al. were used to define moderate to vigorous PA (MVPA).[28] Based on Canadian PA guidelines, children achieving a mean of at least 60 minutes of MVPA per valid day were classified as active.

Measurement of Familial Characteristics

At baseline, parents' weight, height, and waist circumference were measured using standardized protocols.[22] Two parental obesity variables were examined: BMI defined obesity (BMI ≥30 kg/m^2) and abdominal obesity (waist circumferences >88 cm for mothers and >102 cm for fathers).[29] For both variables, children were categorized as having none, 1 or 2 obese parents. Highest parental educational attainment and total annual household income adjusted for the number of people living in the household were obtained from parent-completed questionnaires during clinic visits.

Measurement of Neighborhood Environment Characteristics

Neighborhood environments were characterised using a geographic information system (GIS) for the study area. Canadian Census data from 2006 were used to obtain the following measures: % residents with a university degree, average value of owner occupied residences, % households living below Statistics Canada's low income cut-offs,[30] % single parent families, % unemployment, % who have moved in the past year and % owner occupied residences. For each measure, population-weighted proportions or averages of Census dissemination areas overlapping 500 m network buffers centered on the child's residential address were computed. These variables were then reduced to 2 components using principal components analysis, namely neighborhood disadvantage and neighborhood prestige, and then categorized into tertiles.[31]

The GIS also provided information on food establishments located within 500 m network buffers around the residence based on data from an exhaustive list of businesses and services located in the region in May 2005 acquired from Tamec Inc. All businesses were geocoded using DMTI GeoPinPoint, version 2007.3.[32] Children were categorised as living within ≥1 convenience store (Vs not) and within ≥1 fast food restaurant (Vs not) within 500 m network buffers centered on their residence.

Lastly, the presence of parks was computed using land use information from CanMap (DMTI Spatial Inc.). Information from GIS identified parks was subsequently validated by in-person neighborhood assessments during which independent pairs of trained observers walked every street within 500 m network buffers centered on participants' residences. Parks were defined as public open spaces in which children could engage in active play. Participants were classified as having or not ≥1 park within 500 m network buffers centered on their residence.

Statistical Analysis

Recursive partitioning was used to identify subgroups of participants that varied in terms of obesity using the RPART routine available in the R statistical environment.[33] This non-parametric regression method produces a classification tree following a series of non-sequential top-down binary splits. The tree-building process starts by considering a set of predictor variables and selects the variable that produces 2 subsets of participants with the greatest purity (i.e., where participants within each subset are most alike in terms of the outcome). Two factors are considered when splitting a node into its daughter nodes: the goodness of the split and the amount of impurity in the daughter nodes.[34] The splitting process is repeated until further partitioning is no longer possible and terminal nodes have been reached. Because the resulting tree is typically large, difficult to interpret, and may over-fit to the data, pruning techniques are used to reduce the size of the original tree by eliminating selected branches from later splits. This is done using cost-complexity measures and cross-validations to assess the predictive performance of several reduced subtrees. The final classification tree is a subtree of the original tree that is most predictive of the outcome and has the lowest cross-validated error.[19]

Observations that have missing values on a predictor variable are not discarded from the analysis. Instead, these observations are ignored for the computation of the impurity index when that variable is being considered as a splitting variable, but they are included in subsequent computations. To do so, a surrogate variable that best predicts the missing splitting values is used to determine the classification of observations with missing values to either daughter node (see Strobl et al. for details[19]).

In this study, 9 variables were submitted to the recursive partitioning process, based on evidence for associations with childhood obesity: 2 individual variables (sugar-sweetened beverage intake, meeting PA guidelines), 4 familial variables (number of BMI defined obese parents, number of parents with abdominal obesity, parental education, household income), and 5 neighborhood environment characteristics (disadvantage, prestige, and presence of ≥1 park, fast food restaurant, and convenience store). The Gini index was used as an indicator of node purity which reaches its minimum for perfectly pure nodes (the desired result) and its maximum when cases are distributed evenly between classes at a given node.[19] A 10-fold cross-validation technique was used to prune the tree; the best tree was based on the "1 –SE" rule in which the cross-validated error estimate is no more than 1 standard error (SE) larger than the best tree.[19, 35] This resulted in classification trees with 7 terminal nodes (Figure 1).

Multivariable linear regression models were subsequently used to examine associations between the categorical variable that represents the recursive partitioning subgroups (terminal nodes) and BMI percentile while controlling for age, sex, puberty, and parental education. The lowest risk subgroup was the reference category; the remaining subgroups were identified using 6 indicator variables. Finally, associations between subgroup membership and BMI percentile at follow-up were examined while adjusting for BMI percentile at baseline. These analyses were conducted with SAS version 9.3 (Cary, North-Carolina).

6.4 Results

Characteristics of study participants are provided in Table 1. Both at baseline and at follow-up, 23% of participants were obese (117/512 and 106/462, respectively). Thirty four percent of obese participants had initiated puberty at baseline compared to 21% among non-obese participants. At follow-up, 77% of obese and 66% of non-obese participants had initiated puberty. Overall, more than half consumed >50mL of sugar-sweetened beverage per day and obese participants were less likely to engage in ≥60 minutes of MVPA daily. Familial characteristics varied according to obesity status in the expected direction with a greater proportion of obese children in lower income/education households, and in households with 2 obese parents (defined using BMI or waist circumference). Obese children more often lived in neighborhoods characterised by high disadvantage and by the proximity to ≥1 convenience stores.

The classification tree showed sequentially increasing prevalence of obesity in its 7 terminal nodes (Figure 1). The lowest risk subgroup, Group 1 (i.e., reference), consisted of 132 participants with no BMI defined obese parent (8% obese). Group 2 consisted of 97 participants with ≥1 BMI defined obese parent but who meet PA guidelines (11% obese). Group 3 consisted of 163 participants with ≥1 BMI defined obese parent, not meeting PA guidelines, and with ≤1 abdominally obese parent (26% obese). Group 4 consisted of 39 participants with ≥1 BMI defined obese parent, not meeting PA guidelines, with 2 abdominally obese parents, and living in a low disadvantage neighborhood (28% obese). Group 5 consisted of 37 participants with ≥1 BMI defined obese parent, not meeting PA guidelines, with 2 abdominally obese parents, living in an average to high disadvantage neighborhood with ≥1 park and no convenience store (41% obese). Group 6 consisted of 25 participants with ≥1 BMI defined obese parent, not meeting PA guidelines, with 2 abdominally obese parents, living in an average to high disadvantage neighborhood with ≥1 park but also to ≥1 convenience store (60% obese). Lastly, Group 7 consisted of 19 participants with ≥1 BMI defined obese parent, not meeting PA guidelines, with 2 abdominally obese parents, living in an average to high disadvantage neighborhood with no access to parks or to convenience stores (63% obese).

Recursive partitioning successfully generated subgroups that differed in obesity status. After adjusting for child's age, sex, pubertal development stage, and parental education at baseline, children from Groups 2 to 7 had sequentially increasing BMI percentiles, varying from 12 [Group 2, B = 12.3 (95% confidence interval (CI): 5.3; 19.3)] to 33 [Group 7, B = 32.7 (95% CI: 19.9; 45.4)] percentile points higher compared to children with no BMI defined obese parent (Group 1) (Table 2).

Follow-up data were available for 462 participants. Of the 50 participants lost to follow-up, almost half (46% n=23) were lost from Group 3, of which 39% (n=9) were obese at baseline. Changes in BMI percentile between baseline and follow-up are shown in Tables 3 and 4. Only Group 3 (≥1 BMI defined obese parent, not meeting PA guidelines, and with ≤1 abdominally obese parent) showed an increase in BMI percentile in comparison to Group 1 [B = 3.6 (95% CI: 0.5; 6.6)] (Table 3).

6.5 Discussion

Recursive partitioning, a novel method in the study of neighborhoods and health, was used to examine how specific risk factors jointly influence obesity among children. Risk factors from different levels of influence based on a social ecological framework were considered. In this sample characterised by an overall high prevalence of familial obesity, successively higher BMI percentiles were found in children who cumulated individual, familial, and neighborhood environment risk factors. However, limited evidence for associations with 2-year changes in BMI percentile was found.

Classification trees are often unstable in the face of minor changes in the sample; using recursive partitioning in a different study sample is likely to yield a different classification tree. The relatively small data set used in this study further adds to the instability of the classification tree and yielded imprecise measures of associations, notably in the higher risk subgroups. Although findings may be difficult to reproduce, recursive partitioning allowed us to identify potentially highly obesogenic environments in the QUALITY study. Measures of associations reported in this study may be generalizable to Caucasian children with a parental history of obesity.

Recursive partitioning is a valuable data exploration method in the study of neighborhoods and health. It allows for the detection of higher order interactions within the data which would be challenging to examine using Generalized Linear Models. Other strengths of this study include the use of objective measures of obesity in children and both biological parents, PA, and neighborhood environment indicators, and the use of neighborhood definitions centered on each participant's residential address.

It is well recognised in the literature that obesity is influenced by multiple risk factors stemming from multiple levels of influence, yet previous studies examined a limited range of risk factors simultaneously.[4] Recursive partitioning provides a unique method of analysis to generate hypotheses on how these multiple risk factors may jointly influence childhood obesity. In this analysis, individual and familial risk factors provided the greatest discrimination between obese and non-obese children by being selected as initial splitting variables. In contrast, neighborhood environment variables emerged only in later splits. These findings are consistent with previous studies which report more modest effects of neighborhood environments on obesity in comparison to individual-level risk factors.[36, 37]

With respect to neighborhood characteristics, findings are consistent with the numerous studies that report more obesity among residents of socioeconomically disadvantaged neighborhoods.[15] At equal individual and familial risk and without consideration of subsequent splits, in this study sample the prevalence of obesity was almost twice as high among children living in socioeconomically disadvantaged neighborhoods (52%) compared to those living in low disadvantage neighborhoods (28%). Among children living in socioeconomically disadvantaged neighborhoods, elements of the built and food environment, namely access to parks and convenience stores, further determined obesity. Findings suggest that neighborhood environment characteristics previously associated with childhood obesity (i.e., access to parks and convenience stores[6, 11, 13, 38]) may be particularly influential for children who are already most vulnerable due to individual (i.e., physical inactivity) and familial risk factors (i.e., parental obesity).

Convincing evidence for associations between the classification tree subgroups and 2-year changes in BMI percentile was not found. Only children with ≥1 BMI defined obese parents, not meeting PA guidelines, and with ≤1 abdominally obese parents showed an increase in BMI percentile at follow-up. This was the subgroup with the largest number of participants. Although other subgroups had coefficients of change of similar magnitude (i.e., Group 5), detection of associations may have been limited by the relatively small sample size. Selection bias may have resulted from the loss to follow-up of participants based on specific profiles of risk factors and on obesity. The duration of follow-up may have been insufficient to detect an effect on changes in BMI. Alternatively, determinants of obesity in cross-sectional associations may be different from those of obesity development which could explain why some cross-sectional findings are not reproduced in longitudinal analyses.[39]

6.6 Conclusion

Recursive partitioning allowed us to classify participants into qualitatively distinct subgroups based on a series of modifiable individual, familial and neighborhood environment risk factors. This provides some indications of potentially obesogenic environments and points to the "when, where, and for whom certain environmental attributes are most influential" on childhood obesity (p.101).[17] Future studies in larger samples and with longer durations of follow-up are needed to better understand how different combinations of risk factors jointly predict obesity. Findings contribute to the growing body of evidence that supports the need for multi-level and multi-setting population approaches to obesity prevention.[40] In particular, interventions aimed at modifying neighborhood environments may be most beneficial for children who are already the most vulnerable due to individual and familial risk factors.

6.7 References

1. Wang Y, Lobstein T: **Worldwide trends in childhood overweight and obesity.** *Int J Pediatr Obes* 2006, **1:**11-25.
2. Han JC, Lawlor DA, Kimm SY: **Childhood obesity.** *Lancet* 2010, **375:**1737-1748.
3. Foresight: **Tackling obesities: future choices-project report.** In *Book Tackling obesities: future choices-project report* (Editor ed.^eds.). City; 2007.
4. Birch LL, Davison KK: **Family environmental factors influencing the developing behavioral controls of food intake and childhood overweight.** *Pediatr Clin North Am* 2001, **48:**893-907.
5. Sallis JF, Floyd MF, Rodriguez DA, Saelens BE: **Role of built environments in physical activity, obesity, and cardiovascular disease.** *Circulation* 2012, **125:**729-737.
6. Galvez MP, Pearl M, Yen IH: **Childhood obesity and the built environment: a review of the literature from 2008-2009.** *Curr Opin Pediatr* 2010, **22:**202-207.
7. Te Morenga L, Mallard S, Mann J: **Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies.** *BMJ* 2013, **346:**e7492.
8. Janssen I, Leblanc AG: **Systematic review of the health benefits of physical activity and fitness in school-aged children and youth.** *Int J Behav Nutr Phys Act* 2010, **7:**40.
9. Silventoinen K, Rokholm B, Kaprio J, Sorensen TI: **The genetic and environmental influences on childhood obesity: a systematic review of twin and adoption studies.** *Int J Obes (Lond)* 2010, **34:**29-40.
10. Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I, Steer C, Sherriff A, Avon Longitudinal Study of Parents and Children Study Team: **Early life risk factors for obesity in childhood: cohort study.** *BMJ* 2005, **330:**1357.

11. Pate RR, O'Neill JR, Liese AD, Janz KF, Granberg EM, Colabianchi N, Harsha DW, Condrasky MM, O'Neil PM, Lau EY, Taverno Ross SE: **Factors associated with development of excessive fatness in children and adolescents: a review of prospective studies.** *Obes Rev* 2013, **14:**645-658.
12. Rahman T, Cushing RA, Jackson RJ: **Contributions of built environment to childhood obesity.** *Mt Sinai J Med* 2011, **78:**49-57.
13. Dunton GF, Kaplan J, Wolch J, Jerrett M, Reynolds KD: **Physical environmental correlates of childhood obesity: a systematic review.** *Obes Rev* 2009, **10:**393-402.
14. Safron M, Cislak A, Gaspar T, Luszczynska A: **Micro-environmental characteristics related to body weight, diet, and physical activity of children and adolescents: a systematic umbrella review.** *Inter J Environ Health Res* 2011, **21:**317-330.
15. Grow HM, Cook AJ, Arterburn DE, Saelens BE, Drewnowski A, Lozano P: **Child obesity associated with social disadvantage of children's neighborhoods.** *Soc Sci Med* 2010, **71:**584-591.
16. Carter MA, Dubois L: **Neighbourhoods and child adiposity: a critical appraisal of the literature.** *Health Place* 2010, **16:**616-628.
17. Ding D, Gebel K: **Built environment, physical activity, and obesity: what have we learned from reviewing the literature?** *Health Place* 2012, **18:**100-105.
18. Diez Roux AV, Mair C: **Neighborhoods and health.** *Ann N Y Acad Sci* 2010, **1186:**125-145.
19. Strobl C, Malley J, Tutz G: **An introduction to recursive partitioning: rationale, application, and characteristics of classification and regression trees, bagging, and random forests.** *Psychol Methods* 2009, **14:**323-348.
20. Breiman L, Friedman JH, Olshen RA, Stone CJ: *Classification and Regression Trees.* Boca Raton, Fl: Chapman & Hall; 1998.
21. Keegan TH, Hurley S, Goldberg D, Nelson DO, Reynolds P, Bernstein L, Horn-Ross PL, Gomez SL: **The association between neighborhood**

characteristics and body size and physical activity in the California teachers study cohort. *Am J Public Health* 2012, **102:**689-697.

22. Lambert M, Van Hulst A, O'Loughlin J, Tremblay A, Barnett TA, Charron H, Drapeau V, Dubois J, Gray-Donald K, Henderson M, et al: **Cohort profile: the Quebec adipose and lifestyle investigation in youth cohort.** *Int J Epidemiol* 2012, **41:**1533-1544.
23. Marshall WA, Tanner JM: **Variations in pattern of pubertal changes in girls.** *Arch Dis Child* 1969, **44:**291-303.
24. Marshall WA, Tanner JM: **Variations in the pattern of pubertal changes in boys.** *Arch Dis Child* 1970, **45:**13-23.
25. Johnson RK, Driscoll P, Goran MI: **Comparison of multiple-pass 24-hour recall estimates of energy intake with total energy expenditure determined by doubly labeled water method in young children.** *J Am Diet Assoc* 1996, **96:**1140-1144.
26. **Health Canada - Canadian Nutrient File** [http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/cnf_downloads-telechargement_fcen-eng.php]
27. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M: **Physical activity in the United States measured by accelerometer.** *Med Sci Sports Exerc* 2008, **40:**181-188.
28. Evenson KR: **Calibration of two objective measures of physical activity for children.** *J Sports Sci* 2008, **26:**1557-1565.
29. Bastien M, Poirier P, Lemieux I, Després JP: **Overview of epidemiology and contribution of obesity to cardiovascular disease.** *Prog Cardiovasc Dis* 2014, **56:**369-381.
30. **Statistics Canada - Low income cut-offs after tax** [http://www.statcan.gc.ca/pub/75f0002m/2013002/tbl/tbl01-eng.htm]
31. Van Hulst A, Gauvin L, Kestens Y, Barnett TA: **Neighborhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents.** *Int J Obes (Lond)* 2013, **37:**1328-1335.

32. Paquet C, Daniel M, Kestens Y, Leger K, Gauvin L: **Field validation of listings of food stores and commercial physical activity establishments from secondary data.** *Int J Behav Nutr Phys Act* 2008, **5:**58.

33. Therneau T, Atkinson B, Ripley B: **rpart: Recursive Partitioning. R package version 4.1-3.** [http://CRAN.R-project.org/package=rpart].

34. Zang H, Singer B: *Recursive Partitioning and Applications.* 2nd edn. New York: Springer; 2010.

35. Atkinson E, Therneau T: **An introduction to recursive partitioning using the RPART routines** [http://cran.r-project.org/web/packages/rpart/vignettes/longintro.pdf]

36. Carroll-Scott A, Gilstad-Hayden K, Rosenthal L, Peters SM, McCaslin C, Joyce R, Ickovics JR: **Disentangling neighborhood contextual associations with child body mass index, diet, and physical activity: The role of built, socioeconomic, and social environments.** *Soc Sci Med* 2013, **95:**106-114.

37. Jansen PW, Mensah FK, Nicholson JM, Wake M: **Family and neighbourhood socioeconomic inequalities in childhood trajectories of BMI and overweight: longitudinal study of Australian children.** *PLoS ONE* 2013, **8:**e69676.

38. Leung CW, Laraia BA, Kelly M, Nickleach D, Adler NE, Kushi LH, Yen IH: **The influence of neighborhood food stores on change in young girls' body mass index.** *Am J Prev Med* 2011, **41:**43-51.

39. Timperio A, Jeffery RW, Crawford D, Roberts R, Giles-Corti B, Ball K: **Neighbourhood physical activity environments and adiposity in children and mothers: a three-year longitudinal study.** *Int J Behav Nutr Phys Act* 2010, **7:**18.

40. Foltz JL, May AL, Belay B, Nihiser AJ, Dooyema CA, Blanck HM: **Population-level intervention strategies and examples for obesity prevention in children.** *Annu Rev Nutr* 2012, **32:**391-415.

Table 1. Distribution of individual, familial, and neighbourhood charactersitics according to obesity status (BMI ≥95th percentile) among QUALITY study participants at baseline (2005-2008).

	Obese (n=117)	Not obese (n=395)	P value*
Individual characteristics			
Age, years, mean (sd)	9.7 (0.9)	9.6 (0.9)	0.11*
Sex, boys, % (n)	51.3 (60)	55.4 (219)	0.43
Puberty initiated at baseline, % (n)	33.6 (39)	21.0 (83)	0.005
Puberty initiated at follow-up, % (n)	76.8 (76)	65.8 (237)	0.04
Sugar-sweetened beverage intake >50ml/day, % (n)[§]	65.8 (75)	55.7 (214)	0.06
Meet physical activity guidelines, % (n)[§§]	12.8 (12)	37.4 (127)	<0.001
BMI percentile at baseline, mean (sd)	97.8 (1.3)	60.3 (26.8)	<0.001*
BMI percentile at follow-up, mean (sd)	96.5 (5.1)	61.2 (27.3)	<0.001*
Familial characteristics			
Household income <25000$, % (n)	26.1 (30)	15.1 (59)	0.006
Highest level of education of either parent, % (n)			
2 parents with high school degree or less	14.7 (17)	6.4 (25)	<0.001
≥1 parent with technical/vocational/trade school degree	47.4 (55)	35.9 (141)	
≥1 parent with university degree	37.9 (44)	57.8 (227)	
Number of parents with BMI ≥30kg/m^2, % (n)			
0	8.6 (10)	30.9 (122)	<0.001
1	62.4 (73)	52.4 (207)	
2	29.1 (34)	16.7 (66)	
Number of parents with abdominal obesity, % (n)			
0	4.3 (5)	10.1 (40)	<0.001
1	44.4 (52)	61.8 (244)	
2	51.3 (60)	28.1 (111)	
Mother's BMI, kg/m^2, mean (sd)	31.9 (7.3)	28.8 (6.2)	<0.001*
Father's BMI, kg/m^2, mean (sd)	32.9 (6.2)	30.2 (5.3)	<0.001*
Mother's waist circumference, cm, mean (sd)	99.6 (15.6)	92.0 (13.9)	<0.001*
Father's waist circumference, cm, mean (sd)	111.4 (16.1)	105.2 (13.6)	<0.001*
Neighborhood characteristics			
% residents with a university degree, mean (sd)	26.6 (14.4)	29.1 (15.5)	0.12*
Residential value, $1000, mean (sd)	204 (52)	215 (61)	0.07*
Neighborhood prestige, % (n)			
Low	37.6 (44)	31.9 (126)	0.42
Average	33.3 (39)	33.4 (132)	
High	29.1 (34)	34.7 (137)	
% households with low income, mean (sd)	8.0 (6.6)	7.3 (6.7)	0.29*
% single parent families, mean (sd)	16.7 (7.0)	15.3 (7.1)	0.05*
% unemployment, mean (sd)	5.3 (2.6)	5.2 (3.0)	0.72*

% 1 year mobility, mean (sd)	11.0 (5.2)	10.8 (5.4)	0.63*
Home ownership, mean (sd)	67.8 (25.5)	74.5 (25.8)	0.08*
Neighborhood disadvantage, % (n)			
Low	25.6 (30)	35.4 (140)	0.09
Average	34.2 (40)	33.2 (131)	
High	40.2 (47)	31.4 (124)	
≥1 park within 500 m, % (n)	68.4 (80)	74.9 (296)	0.16
≥1 convenience store within 500 m, % (n)	35.9 (42)	26.8 (106)	0.06
≥1 fast food restaurant within 500 m, % (n)	17.1 (20)	11.9 (47)	0.14

Abbreviations: BMI, body mass index; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth; sd, standard deviation

* The P value of a t-test comparing mean values between obese and non-obese.

§ Data missing on 14 (3 obese and 11 non-obese) participants

§§ Data missing on 67 (19 obese and 48 non-obese) participants

Table 2. Unadjusted and adjusted associations (beta coefficients and 95% CI) between risk subgroups identified using recursive partitioning analysis and BMI percentile among 512 QUALITY study participants at baseline (2005-2008).

		Beta (95% CI)	
Intercept		54.9 (50.4; 59.5)	78.4 (51.9; 105.0)
Group 1 (n=132), obesity prevalence	7.6%	Reference	Reference
Group 2 (n=97), obesity prevalence	11.3%	13.3 (6.3; 20.3)	12.3 (5.3; 19.3)
Group 3 (n=163), obesity prevalence	26.4%	16.0 (9.8; 22.1)	15.8 (9.6; 22.0)
Group 4 (n=39), obesity prevalence	28.2%	22.0 (12.4; 31.6)	22.6 (13.1; 32.1)
Group 5 (n=37), obesity prevalence	40.5%	25.1 (15.3; 34.8)	23.8 (14.1; 33.5)
Group 6 (n=25), obesity prevalence	60.0%	31.9 (20.4; 43.3)	31.8 (20.4; 43.1)
Group 7 (n=19), obesity prevalence	63.2%	34.4 (21.6; 47.3)	32.7 (19.9; 45.4)
Child's age			-3.3 (-6.1; -0.5)
Sex, boys (vs girls)			6.7 (1.5; 11.8)
Puberty initiated at baseline (vs not initiated)			10.4 (3.9; 16.9)
Parental education			
≥1 parent with university degree			Reference
≥1 parent with technical/vocational/trade school degree			5.0 (0.1; 9.9)
2 parents with high school degree or less			7.6 (-1.1; 16.2)

Abbreviations: CI, confidence interval; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth

Table 3. Unadjusted and adjusted associations (beta coefficients and 95% CI) between risk subgroups identified using recursive partitioning analysis and body mass index percentile among 462 QUALITY study participants at 2 year follow-up (2005-2011).

	Beta (95% CI)	
Intercept	5.1 (1.9; 8.3)	1.8 (-13.9; 17.5)
Child's BMI percentile at baseline	0.9 (0.9; 0.9)	0.90 (0.9; 0.9)
Group 1 (n=123), obesity prevalence 8.9%	Reference	Reference
Group 2 (n=88), obesity prevalence 13.6%	1.4 (-2.0; 4.7)	1.5 (-1.8; 4.9)
Group 3 (n=140), obesity prevalence 27.1%	3.8 (0.8; 6.8)	3.6 (0.5; 6.6)
Group 4 (n=37), obesity prevalence 16.2%	-0.1 (-4.6; 4.5)	-0.1 (-4.7; 4.4)
Group 5 (n=34), obesity prevalence 35.3%	3.7 (-1.0; 8.4)	3.8 (-1.0; 8.6)
Group 6 (n=23), obesity prevalence 65.2%	1.1 (-4.5; 6.6)	1.0 (-4.6; 6.6)
Group 7 (n=17), obesity prevalence 70.6%	2.9 (-3.4; 9.2)	2.5 (-3.8; 8.8)
Child's age at follow-up, years		0.1 (-1.3; 1.5)
Sex, boys (vs girls)		0.7 (-1.8; 3.1)
Puberty initiated at follow-up (vs not initiated)		2.6 (-0.3; 5.5)
Parental education		
≥1 parent with university degree (reference)		Reference
≥1 parent with technical/vocational/trade school degree		-0.03 (-2.4; 2.3)
2 parents with high school degree or less		0.5 (-3.8; 4.8)

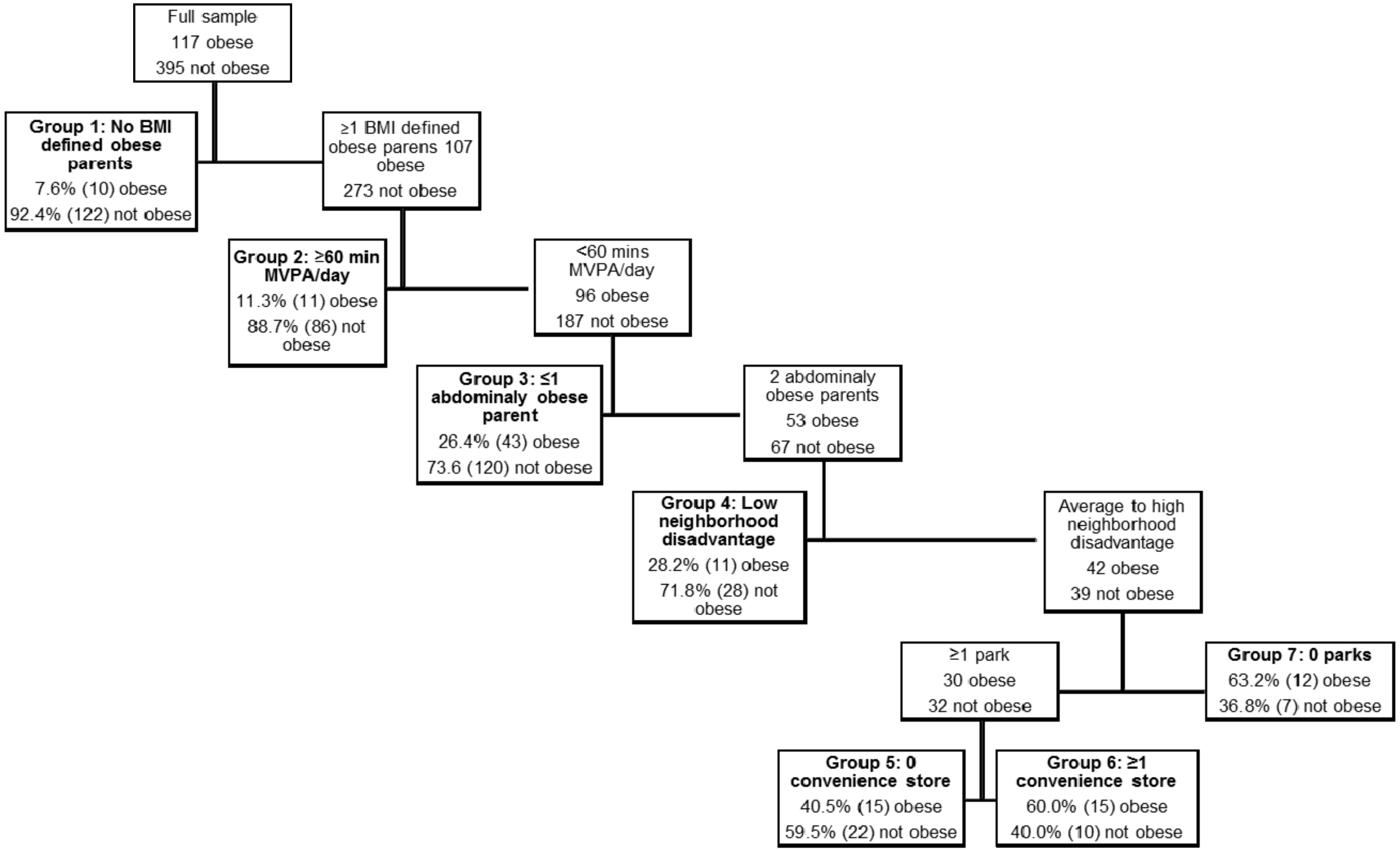
Abbreviations: BMI, body mass index; CI, confidence interval; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth

Table 4. Distribution of obesity at baseline and 2-year follow-up according to subgroups identified using recursive partitioning analysis among 462 QUALITY study participants at 2 year follow-up (2005-2011).

Recursive partitioning subgroups	**Obese at baseline**	**Obese at follow-up**	**BMI % at baseline**	**BMI % at follow-up**	**Change in BMI %**
(n)	% (n)		Mean (sd)		
Group 1 (123)	7.3 (9)	8.9 (11)	56.1 (28.2)	55.8 (29.0)	-0.3 (14.2)
Group 2 (88)	11.4 (10)	13.6 (12)	67.0 (24.7)	67.0 (25.1)	0.01 (11.7)
Group 3 (140)	24.3 (34)	27.1 (38)	70.3 (27.9)	72.4 (27.2)	2.1 (12.3)
Group 4 (37)	27.0 (10)	16.2 (6)	76.2 (24.2)	73.8 (25.4)	-2.3 (12.9)
Group 5 (34)	38.2 (13)	35.3 (12)	78.8 (28.6)	80.0 (27.6)	1.1 (6.7)
Group 6 (23)	60.9 (14)	65.2 (15)	87.2 (21.3)	85.0 (24.9)	-2.3 (10.6)
Group 7 (17)	58.8 (10)	70.6 (12)	88.3 (19.7)	87.7 (23.2)	-0.56 (10.7)
Total (462)	21.7 (100)	22.9 (106)	68.5 (28.1)	68.8 (28.3)	0.3 (12.4)

Abbreviations: BMI, body mass index; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth

Figure 1. Classification tree obtained from recursive partitioning analysis of individual, familial, and neighbourhood factors in 512 QUALITY study participants at baseline (2005-2008).



Abbreviations: BMI, body mass index; MVPA, moderate to vigorous physical activity; QUALITY, Quebec Adipose and Lifestyle Investigation in Youth.

*Variables not retained in the classification tree were intake of sugar-sweetened beverages, household income, parental education, neighborhood prestige, and presence of fast food restaurants.

CHAPTER 7. DISCUSSION AND CONCLUSION

The overarching goal of this thesis was to ascertain the contribution of different features of neighbourhood environments in influencing obesity and antecedent health behaviours among children. In doing so, this thesis contributes to building the evidence needed to inform public health interventions to counteract obesogenic residential and school neighbourhood environments for children and their families. In addition to a discussion of the thesis findings and contributions, this chapter presents overall limitations and strengths, potential implications for public health as well as directions for future research, and ends with concluding remarks.

7.1 Summary of main findings

In the first analysis presented in Manuscript 1, associations between features of the residential and school neighbourhood food environment and children's dietary intake and behaviours were examined. Overall, significant associations emerged, but results were generally weak in magnitude and not consistent across food environment measures. Specifically for residential neighbourhoods, a lower density of fast food restaurants and convenience stores was associated with a reduced likelihood of regular eating/snacking out. For school neighbourhoods, an overall greater number of unhealthy relative to healthy food establishments was associated with an increased likelihood of regular sugar-sweetened beverage intake. These findings suggest that greater neighbourhood access to food establishments that predominantly sell unhealthy foods (fast food restaurants and convenience stores) rather than limited access to food establishments that predominantly sell healthy foods (supermarkets) may be more of a concern for poor diets among children.

In the second analysis, in addition to the neighbourhood environment, I focused on family-level influences as a means of further understanding the complex interactions between individual and environmental characteristics. Specifically, I examined how shared residential neighbourhood environment exposures influence familial obesity, and how children may be more or less vulnerable to obesity when exposed to the same neighbourhood characteristics as their parents. Findings show that living in higher prestige neighbourhoods and in neighbourhoods where there is less road traffic is protective against obesity for the entire family. However, when examining individuals within families, neighbourhood disadvantage, signs of physical disorder and deterioration, and pedestrian friendliness appear to have a distinct impact on each family member. In particular, children appear more vulnerable to neighbourhood-level social and physical disadvantage than their parents.

Finally, Manuscript 3 broadens the scope of investigation by incorporating the proposed conceptual framework even more comprehensively. Thus, the influence of neighbourhood and family environments, together with individual obesity related behaviours in children, were examined simultaneously in relation to childhood obesity. This allowed me to explore joint effects of these different levels of influence on obesity, as postulated in the thesis conceptual framework. Moreover, the third manuscript includes a longitudinal exploratory analysis. Results suggest that the likelihood of childhood obesity increases when risk factors from each level of influence are combined, and that features of obesogenic neighbourhood environments may be most deleterious for children who are especially vulnerable to obesity due to individual and familial risk factors. However, since these same combinations of factors were not associated with 2-year changes in obesity, overall findings point to different aetiological processes distinguishing the maintenance and the development of obesity. It is possible, that a longer duration of follow up would have demonstrated that these 'high risk combinations' eventually led to the development of obesity.

7.2 Thesis contributions

In light of the findings summarised above, I now discuss three themes that stem from this doctoral thesis: 1) taking stock of what has been learned on the proposed conceptual framework; 2) advancing methods in the study of neighbourhoods and health, and 3) taking into account the statistical analysis challenges of modeling complex contextual effects on health.

7.2.1 What has been learned on the proposed conceptual framework

This thesis is grounded into a social ecological approach to health. As such, it was postulated that childhood obesity is influenced by individual behaviours and characteristics, which are in turn influenced by characteristics of the familial and of the neighbourhood environment (see Figure 1 on p. 47). With this thesis, knowledge has been gained on three issues in relation to the proposed conceptual framework, namely the importance of simultaneously considering multiple levels of influence in studies on neighbourhoods and obesity, the potential impact of residential and non-residential neighbourhood environments in pediatric populations, and the influence of area-level socioeconomic status on obesity and antecedent health behaviours.

First, the findings presented in this thesis reveal the importance of considering the influences of familial and individual characteristics within studies on neighbourhood environments and childhood obesity, and vice versa, to consider neighbourhood environments in studies on individual and familial risk factors of obesity. Social ecological models of health, which postulate cross-level interactions of influences, are commonly cited in the literature to illustrate the multifaceted influences of neighbourhood environments on obesity (Davison & Birch, 2001; Glanz et al., 2005; Sallis et al., 2006), and the most common suggestion for future research in related review studies was identified as the need to examine moderators of associations between neighbourhood environments and obesity (Ding & Gebel, 2012). Findings from this thesis support the notion that, for children, the familial context, which is in turn embedded into large societal contexts, including multiple neighbourhood environments, are implicated in the aetiological processes leading to obesity. This thesis provides conceptual support for multi-factorial interventions which simultaneously target multiple obesity risk factors from several levels of influence (Lobstein, Baur, Uauy, & IASO International Obesity Task Force, 2004).

Second, in the proposed conceptual framework, it was postulated that characteristics of both residential and non-residential neighbourhood environments were related to childhood obesity. The first manuscript considered residential and non-residential environments, namely school neighbourhood environment, while the other two manuscripts focused on residential environments. Much of the previous research has been directed to residential environments at the expense of other geographic environments of exposure, an issue which has been termed the 'residential trap' (Chaix, 2009) and the 'local trap' (Cummins, 2007). Indeed, research on daily mobility has found that people are typically exposed to many environmental areas, and that focusing only on the local residential environment may lead to exposure misclassification due to failure to account for the cumulative exposure to different geographic areas (Kwan, 2009). This may be particularly relevant for adult populations; however, for children, the residential neighbourhood environment may well be the most important geographic area of exposure given that children are generally less geographically mobile than adults (Dunton et al., 2013; Papas et al., 2007). Moreover, children living in urban areas typically attend a school in the vicinity of their residence, thus making it difficult to dissociate residential from school neighbourhood environments, as seen in the first thesis manuscript. Given the young age of participants, in-school environments may exert greater influence on children's lifestyle behaviours and weight status (Harrison & Jones, 2012; Williams, Wyatt, Hurst, & Williams, 2012), and should be further investigated in the QUALITY study.

Third, the profound role of area-level socioeconomic status on obesity and dietary behaviours is notable throughout this thesis. Indeed, in all three manuscripts associations between neighbourhood-level socioeconomic conditions and outcomes of interest emerge. In the first manuscript, area-level material deprivation, based on a composite score (Pampalon & Raymond, 2003), and household socioeconomic status were confounders of the associations between neighbourhood food environment and diet. In the second and third manuscripts, neighbourhood prestige and disadvantage scores were examined. Interestingly, neighbourhood prestige was found to be a determinant for obesity when entire families were considered. However, when examining family members individually, a positive gradient between neighbourhood disadvantage and obesity was found uniquely among children. Neighbourhood prestige embodies university education and higher housing values, which likely favours knowledge and norms that promote healthy lifestyle behaviours. Adults may be more likely to be obese in the absence of these supportive community environments (Chaix et al., 2010; Turrell et al., 2010). In contrast, neighbourhood disadvantage is composed of lower incomes, more single parent families, higher unemployment, and greater residential instability. Children appear to be more likely to be obese in the presence of these negative neighbourhood attributes, which may be associated with fewer opportunities for safe outdoor active play (Carroll-Scott et al., 2013; Molnar et al., 2004). Neighbourhood characteristics may thus contribute to widening or reducing health inequalities. This thesis contributes to the growing literature documenting area-level social inequalities in obesity risk (El-Sayed, Scarborough, & Galea, 2012) and to the need for social and environmental interventions to counteract these inequalities (Woodman, Lorenc, Harden, & Oakley, 2008).

7.2.2 Advancing methods to characterise neighbourhood environments

As described in an earlier chapter of this thesis, several methods have been proposed to characterise neighbourhood environments. Through its use of in-person neighbourhood audits, this thesis contributes to advancing methods to characterise neighbourhood environments. Compared to objective measurements obtained through aggregated administrative data, in-person audits may provide more accurate descriptions of the neighbourhood features of interest and allow for the assessment of the more qualitative aspects of built environment infrastructures (e.g., sidewalks, parks) (Booth, Pinkston, & Carlos Poston, 2005). The first study that used in-person neighbourhood audits to examine correlates of obesity in adults was published over 10 years ago (Giles-Corti, Macintyre, Clarkson, Pikora, & Donovan, 2003). However, this method of assessment is time and resource consuming, which may explain why it continues to be scarcely used.

Objective data based on systematic neighbourhood audits and subjective data based on resident reports for the same underlying construct are of varying concordance, with levels of discordance depending on several factors including respondent and neighbourhood characteristics (Bailey et al., 2014; Moore, Diez Roux, & Brines, 2008). Given a recent review in which it was reported that findings were more consistent when neighbourhood environments were characterised using objective measures (Ding et al., 2011), this thesis focused on objective neighbourhood measures. By combining the advantages of two types of objective methods, this thesis contributes to improving the characterisation of neighbourhood environments, allowing for a richer description.

7.2.3 Using statistics to model complex contextual effects

Throughout my doctoral research, I have encountered several challenges in my attempts to model the complex relation between neighbourhood environments and obesity. One challenge relates to the fact that multiple neighbourhood constructs are intimately intertwined such that it may be difficult to disentangle their effects. As stated in the first manuscript, examining each neighbourhood food environment variable in a distinct model to overcome multicollinearity problems may have led to type-1 error. To overcome this difficulty in subsequent manuscripts, I have explored various increasingly sophisticated methods to handle multicollinearity between neighbourhood environment exposures.

Data reduction using principal component analysis was used in the second manuscript. In order to distinguish measures conceptualised a priori as pertaining to distinct concepts, three different principal component analyses were used on three sources of data: one based on census derived socioeconomic status data, one based on geographically linked land use data, and one based on street-level characteristics obtained through in-person neighbourhood audits. This generated three conceptually distinct types of indicators, even though some correlation between components of distinct analyses remained.

An alternative statistical method to address multicollinearity between exposure variables, namely cluster analysis, was put to use in the context of a research internship on data involving adults living in the Paris Metropolitan Area (see Appendix F). Cluster analysis has since been applied to the QUALITY study neighbourhood data and examined in relation to childhood obesity (Barnett, Kestens, Van Hulst, Chaix, & Henderson, 2013). Although infrequently used in the study of neighbourhoods and health, cluster analysis allows for the construction of neighbourhood typologies that combine exposure to multiple environmental characteristics that are highly correlated and whose effects could not be separated through multivariable regression analysis (Adams et al., 2013; Jones & Huh, 2014; Pedigo, Seaver, & Odoi, 2011).

Another challenge encountered during my doctoral research relates to identifying novel ways to incorporate the family environment within statistical models relating neighbourhood environments with childhood obesity. Although others have looked at neighbourhood determinants of child and parent obesity in separate analyses (Saelens et al., 2012), to my knowledge, the second manuscript of this thesis was the first one to describe fixed and random effects for neighbourhood environment exposures in relation to familial obesity. This analysis allowed me to take shared variance within families into account, for example variance related to familial genetics and lifestyle behaviours. Moreover, it allowed me to determine that compared to their parents, children are differentially vulnerable to some neighbourhood environment exposures, whereas other exposures relate to obesity equally for all family members.

The unique influence of the familial environment on childhood obesity was further taken into account in the third manuscript by specifically examining the joint effect of familial and individual factors, in addition to neighbourhood factors, on childhood obesity. Again, very few studies were identified in which recursive partitioning had been used with neighbourhood data (Keegan et al., 2012; King et al., 2006), and none incorporated measures from different levels of influence as postulated by social ecological models of health.

Overall, this thesis reflects an increased understanding of how complex neighbourhood effects can be described using 'simple' statistical models. Different analytic methods were used to address related yet distinct and increasingly complex research questions on how the characteristics of the places relevant to children matter to their health. Although increasingly complex research questions were addressed, I do not imply that any of the estimated effects reflect valid causal effects. As stated by Diez Roux, "although using the most appropriate model for the research question at hand is of course important, ultimately models are simply tools that help us describe the data. Inferring causality is a much more complicated process and requires more than statistical models" (p 1954) (Diez Roux, 2004). Overall, the fact that the same conclusions were reached despite the use of distinct analytic methods, and that findings are generally consistent with current research on obesogenic environments strengthens the conclusions of this thesis but does not indicate that causal associations were established.

7.3 Limitations

While limitations specific to each manuscript have been mentioned previously, overall limitations of this thesis are discussed in detail below. These relate to the study sample and design, and to the data used to characterise neighbourhoods.

7.3.1 Study sample and design

Data for this thesis were drawn from the QUALITY Cohort which was not specifically designed to study neighbourhood effects. Instead, the Residential and School Studies took advantage of the cohort's existing infrastructure to study the influence of residential and school neighbourhood environments on a variety of health outcomes. As a consequence, the QUALITY study was not sampled with a priori hypotheses on neighbourhood effects. For example, neighbourhood-level sampling was not used, making the use of multilevel analyses on residents nested within neighbourhoods less compelling.

By design, the QUALITY Cohort is not representative of the general population of Quebec families with children aged 8-10 years, nor of the neighbourhoods within the Montreal Metropolitan Area. Eligibility was based on a number of criteria, including having at least one obese parent, and participation required a high degree of commitment on behalf of participating families, most notably that both parents had to accompany their child for a full-day baseline clinic visit. As is often the case in epidemiological studies, this may result in a highly selected and motivated sample which may differ substantially from the study source population. Although stringent inclusion/exclusion criteria may be beneficial for some aspects of the study (e.g., highly motivated families are more likely to collaborate with all aspects of data collection and to maintain participation at follow up), generalizability of findings may thereby be limited.

Besides the high prevalence of obesity among participating QUALITY families, the latter were found to be more affluent than the general population and more likely to be dual-parent families (Lambert et al., 2012). Despite these differences, a range of neighbourhoods were included based on socioeconomic status, population density, and availability of neighbourhood resources, even though it is acknowledged that the variability in exposure variables of interest to this thesis are likely not representative of that of the source population or target population. For example, the most disadvantaged neighbourhoods within the Montreal Metropolitan Area were not included in the study. This may have led to an underestimation for measures of associations between neighbourhood socioeconomic status (and any related variable such as signs of physical and social disorder) and obesity given that the prevalence of obesity is generally higher in more disadvantaged neighbourhoods. As a consequence, some associations between neighbourhood exposures of interest, obesity and associated health behaviours may not have been detected.

Nevertheless, since QUALITY participants have a high prevalence of obesity and are at increased risk of obesity due to a parental history of obesity, the Residential and School Studies offer advantages, namely in terms of statistical power, to investigate the impact of unfavourable neighbourhood environments among youth who are already particularly susceptible to obesity.

In addition to its two cross-sectional analyses, this thesis includes one longitudinal analysis with data available at two time points. Although useful to generate etiological hypotheses, the cross-sectional study design is limited in terms of causal inference. The third manuscript was based on outcome data collected at two points in time which allowed for the examination of determinants of change in obesity but not of obesity trajectories. Moreover, the duration of the follow up was relatively short, and overall there was little change in weight status of participants over this 2-year period. As in most longitudinal cohort studies, participants lost to follow up differed from those who remained in the study. Participants lost to follow up were more likely to have a younger mother, less educated parents, and to be obese at baseline. This likely led to some degree of underestimation for associations between socioeconomic status related variables and obesity.

7.3.2 Data used to characterise neighbourhood environments

In terms of data used to characterise neighbourhoods, the main limitation is the fact that the time of data collection for in-person neighbourhood audits and geographically linked data differs from the baseline period when health outcomes were first assessed. Baseline outcome data were collected between 2005 and 2008. In-person neighbourhood audits were for the most part conducted in 2008 and 2009, and geocoded data was minimally current up to 2004 with the majority of data updated in 2006. As was noticed while conducting the neighbourhood audits, a number of QUALITY participants lived in new development areas which can be expected to change rapidly over a short period of time. For example, some neighbourhoods included newly developed streets and parks that had not been pre-identified on observer maps, which were created using geocoded data available in MEGAPHONE. This most likely led to some degree of exposure measurement error for measures obtained from geographically linked administrative data. To limit measurement error related to outdated data, in-person audits were favoured over geocoded administrative data whenever two sources of data were available for a given neighbourhood measure (e.g., number of parks within 500 m of the residence).

Another limitation relates to the limited inter-observer reliability of some items on the Neighbourhood Observation Checklist. Despite intensive training and simplification of the tool, some discordance remained, particularly for more subjective items such as the quality of infrastructures. When discordance was present, in many cases the 'correct' answer was ambiguous as was noted upon revisiting the neighbourhood. As mentioned previously, a protocol was put into place to deal with discordances. To start, a third observation on another occasion by an independent observer was favoured, followed by an assessment using Google Street View. Because these first options were not always available (e.g., neighbourhoods located far from the study center where Google Street View was not yet available), in rare cases, the correct answer had to be chosen randomly between the two observers' responses. This may have led to some misclassification error. However, because the observers were blind with respect to the specific research questions and to the participants' weight status and diet, misclassification is likely to be non-differential which, in most cases, would result in an underestimation of measures of associations since the majority of items were based on binary classifications.

Lastly, neighbourhood environments were characterised at baseline only, and information on the duration of residence or on prior locations of residence was not available. As with most health outcomes, it can be expected that there is a certain lag effect between the time of exposure to given neighbourhood environment attributes and the development of obesity. It may well be that for some children, prior neighbourhood exposures than the ones identified at baseline set the trajectory towards the development of obesity.

7.4 Strengths

Beyond the strengths mentioned in each manuscript, several merits of this thesis are worth highlighting. First, the innovative statistical analysis methods pursued herein constitute an important strength of this thesis. Each method was selected to address increasingly complex research questions on how attributes of neighbourhood environments relate to childhood obesity and diet. Second, outcome data collected within the QUALITY study underwent detailed and extensive quality assurance procedures thereby minimising measurement error. Third, this thesis contributed to building the foundations for other analyses on neighbourhood environments and health within the QUALITY study through the development of neighbourhood indicators (e.g., material deprivation), the investigation of various statistical analysis methods, and by generating hypotheses based on cross-sectional data which will be tested in future longitudinal analyses of ongoing data collection. Lastly, although self-selection bias is an issue common to many studies on neighbourhoods and health, it may have been minimized to some extent in this thesis by focusing on children. As a reminder, self-selection bias occurs when people choose to live in a given type of neighbourhood based on individual-level characteristics. The choice of residential location is likely to be made by parents and not to be influenced by children's patterns and preferences toward obesity related behaviours (Ewing et al., 2006). Although it is acknowledged that there are similarities within families with respect to obesity and related behaviours, and that parents likely transmit their attitudes towards obesity and related behaviours, these, or proxies thereof, were considered in analyses.

7.5 Potential implications for public health and future research

Potential implications for public health that arise from this thesis as well as future directions for research are now described. Three implications are discussed in detail, namely the importance of population-wide approaches to childhood obesity prevention targeting area-level determinants of obesity, the need to recognise that the responsibility for obesity is not only that of individuals, and the need for action to modify the physical and social contexts that promote obesity, despite inconsistencies in findings from past research.

This thesis points to specific attributes of children's and their family's neighbourhood environments that are associated with obesity and diet, and for which there is wider support from previous studies. Together, these findings highlight the importance of considering contextual determinants of obesity in prevention efforts. Understanding individual-level determinants of obesity remains essential, particularly for targeted prevention and to inform treatment efforts for children who are at risk of obesity or who already are obese. However, effective prevention of obesity is likely to also require a consideration of the broader contextual determinants, and how these interact with individual-level determinants, in generating obesity risk. Over the past years, a general shift in population distributions towards higher BMI values has been reported (Penman & Johnson, 2006; Shields, 2006). Whole population approaches as suggested by Geoffrey Rose (Rose, 2008) would aim to shift the entire population back to lower BMIs, for example by creating conditions within neighbourhood environments that encourage and support healthy lifestyles. Such population-wide interventions, combined with targeted prevention efforts, are expected to achieve best results in terms of obesity prevention (Ahern, Jones, Bakshis, & Galea, 2008).

Potential implications can also be brought a step further so as to recognise that the responsibility for the obesity epidemic, and consequently its solutions, cannot rest solely on individuals. Although individuals are ultimately the ones ingesting foods and expending energy to varying degrees, these behaviours are shaped by influences beyond the individual, some of which were identified in this thesis. Just like recent reductions in tobacco smoking in some population subgroups, achieved through regulatory efforts, it has been suggested that obesity prevention will require similar state-level involvement through policies and legislatures (Yach, McKee, Lopez, & Novotny, 2005).

Although past research on neighbourhood environments and obesity has shown inconsistencies in findings, this should not be taken as a reason to withhold actions aimed at creating healthy neighbourhood environments. Based on the precautionary principle, the best available evidence and scientific opinion consensus should be used to guide interventions (Lobstein & Baur, 2005). In line with this principle, a small number of population-based obesity prevention initiatives focusing on environmental planning and policies have shown promising impacts on obesity and related health behaviours (Kellou, Sandalinas, Copin, & Simon, 2014; Wolfenden et al., 2014).

In order to continue to support such interventions, future research should focus on two types of studies: etiologic research and experimental research. Etiologic research is needed to build stronger evidence for promising and practical targets for population-based obesity prevention interventions. These studies should be based on longitudinal data, looking both at changes in neighbourhood environments and changes in obesity and associated health behaviours. They should also attempt to unravel the complex interactions between individuals and neighbourhoods so as to better understand "when, where, and for whom certain environmental attributes are most influential" on childhood obesity (Ding & Gebel, 2012)(p.101). Moreover, studies on individual and environmental risk factors of obesity in multinational population samples, as has recently been proposed (Katzmarzyk et al., 2013), would further strengthen the evidence needed for global obesity prevention strategies. Lastly, agent-based modeling simulations will contribute in providing improved understanding of the mutual influences between individuals and their environments and how this impacts obesity and antecedent behaviours (Auchincloss & Diez Roux, 2008; Hammond & Ornstein, 2014).

In terms of experimental research, the implementation of local pilot projects that target neighbourhood environments based on the best currently available evidence should be stimulated and the means to evaluate these interventions should be provided. Notwithstanding potential threats to internal validity, both randomised community trials and quasi-experimental designs to evaluate neighbourhood-level interventions will likely provide some insight into estimates for causal contextual effects on obesity and antecedent behaviours. Together, findings from both etiologic and experimental research will point to potentially causal pathways through which individuals interact with neighbourhood environments to increase or decrease obesity and antecedent behaviours.

7.6 Conclusion

The prevalence of childhood obesity has increased dramatically over the past 30 years in most parts of the world. Although recent reports have found some evidence that childhood obesity has stabilised or even decreased in some specific population subgroups, there has yet to be significant population wide decreases in childhood obesity. Moreover, even if somewhat stabilised, current prevalence of childhood obesity remains at 13% in Canada, a much too high figure that has already resulted in important health consequences and increased health care costs. Continued surveillance of obesity is warranted in order to confirm these initial encouraging findings; however they should not be taken as a reason to declare victory or to derail obesity prevention efforts. Instead, there continues to be an urgent need to identify population-level determinants of childhood obesity and associated health behaviours. The growing body of research that points to features of obesogenic neighbourhood environments in which children and their families live is starting to show promising targets for public health intervention. As demonstrated in this thesis, the places where children live, learn and play have attributes and offer material and social resources, some of which appear to be systematically associated with greater risks of obesity and unfavourable antecedent health behaviours among children. Most importantly, many of these place-bound attributes and resources can be modified in such a way as to make it easier for children and their families to adopt and maintain health promoting behaviours. Population-based obesity prevention efforts wherein obesogenic risk factors located within multiple levels of influences are targeted in a concerted way are required to achieve significant decreases in childhood obesity.

BIBLIOGRAPHY

Active Healthy Kids Canada. (2009). The Active Healthy Kids Canada report card on physical activity for children and youth. Retrieved November 1, 2013, from http://www.activehealthykids.ca/ecms.ashx/ReportCard2009/AHKC-Longform_WEB_FINAL.pdf

Active Healthy Kids Canada. (2013). Are we driving our kids to unhealthy habits? 2013 report card on physical activity for children and youth. Retrieved August 1, 2013, from http://www.activehealthykids.ca/2013ReportCard/en/

Adams, M. A., Ding, D., Sallis, J. F., Bowles, H. R., Ainsworth, B. E., Bergman, P., et al. (2013). Patterns of neighborhood environment attributes related to physical activity across 11 countries: a latent class analysis. *International Journal of Behavioral Nutrition and Physical Activity, 10*, 34. doi: 10.1186/1479-5868-10-34

Adams, M. A., Ryan, S., Kerr, J., Sallis, J. F., Patrick, K., Frank, L. D., et al. (2009). Validation of the Neighborhood Environment Walkability Scale (NEWS) items using geographic information systems. *Journal of Physical Activity and Health, 6*(Suppl 1), S113-123.

Ahern, J., Jones, M. R., Bakshis, E., & Galea, S. (2008). Revisiting Rose: comparing the benefits and costs of population-wide and targeted interventions. *Milbank Quarterly, 86*(4), 581-600. doi: 10.1111/j.1468-0009.2008.00535.x

An, R., & Sturm, R. (2012). School and residential neighborhood food environment and diet among California youth. *American Journal of Preventive Medicine, 42*(2), 129-135. doi: 10.1016/j.amepre.2011.10.012

Auchincloss, A. H., & Diez Roux, A. V. (2008). A new tool for epidemiology: the usefulness of dynamic-agent models in understanding place effects on health. *American Journal of Epidemiology, 168*(1), 1-8. doi: 10.1093/aje/kwn118

Auchincloss, A. H., Mujahid, M. S., Shen, M., Michos, E. D., Whitt-Glover, M. C., & Diez Roux, A. V. (2013). Neighborhood health-promoting resources and obesity risk (the Multi-Ethnic Study of Atherosclerosis). *Obesity (Silver Spring), 21*(3), 621-628. doi: 10.1002/oby.20255

Badland, H. M., Opit, S., Witten, K., Kearns, R. A., & Mavoa, S. (2010). Can virtual streetscape audits reliably replace physical streetscape audits? *Journal of Urban Health, 87*(6), 1007-1016. doi: 10.1007/s11524-010-9505-x

Bailey, E. J., Malecki, K. C., Engelman, C. D., Walsh, M. C., Bersch, A. J., Martinez-Donate, A. P., et al. (2014). Predictors of discordance between perceived and objective neighborhood data. *Annals of Epidemiology, 24*(3), 214-221. doi: 10.1016/j.annepidem.2013.12.007

Ball, K., Timperio, A. F., & Crawford, D. A. (2006). Understanding environmental influences on nutrition and physical activity behaviors: where should we look and what should we count? *International Journal of Behavioral Nutrition and Physical Activity, 3*, 33. doi: 10.1186/1479-5868-3-33

Ball, S. C., Benjamin, S. E., & Ward, D. S. (2007). Development and reliability of an observation method to assess food intake of young children in child care. *Journal of the American Dietetic Association, 107*(4), 656-661. doi: 10.1016/j.jada.2007.01.003

Barlow, S. E., & Dietz, W. H. (1998). Obesity evaluation and treatment: Expert committee recommendations. *Pediatrics, 102*(3), e29.

Barnett, T., Kestens, Y., Van Hulst, A., Chaix, B., & Henderson, M. (2013). Neighbourhood typology based on features of the built environment and associations with adiposity in youth. *American Journal of Epidemiology, 176*(Suppl), S73.

Bastien, M., Poirier, P., Lemieux, I., & Després, J. P. (2014). Overview of epidemiology and contribution of obesity to cardiovascular disease. *Progress in Cardiovascular Diseases, 56*(4), 369-381. doi: 10.1016/j.pcad.2013.10.016

Bell, J., Wilson, J. S., & Liu, G. C. (2008). Neighborhood greenness and 2-year changes in body mass index of children and youth. *American Journal of Preventive Medicine, 35*(6), 547-553.

Berenson, G. S., Srinivasan, S. R., & Nicklas, T. A. (1998). Atherosclerosis: a nutritional disease of childhood. *American Journal of Cardiology, 82*(10B), 22T-29T.

Berkman, L. F. (2004). Introduction: Seeing the forest and the trees - From observational to experiments in social epidemiology. *Epidemiologic Reviews, 26*(1), 2-6.

Bird, M., Datta, G. D., Van Hulst, A., Kestens, Y., Lambert, M., & Barnett, T. (2012). Assessment of neighborhood park features for youth physical activity. *American Journal of Epidemiology, 175*(suppl 11), S78.

Black, J. L., & Macinko, J. (2008). Neighborhoods and obesity. *Nutrition Reviews, 66*(1), 2-20. doi: 10.1111/j.1753-4887.2007.00001.x

Blanchette, L., & Brug, J. (2005). Determinants of fruit and vegetable consumption among 6–12-year-old children and effective interventions to increase consumption. *Journal of Human Nutrition and Dietetics, 18*(6), 431-443.

Boeke, C. E., Oken, E., Kleinman, K. P., Rifas-Shiman, S. L., Taveras, E. M., & Gillman, M. W. (2013). Correlations among adiposity measures in school-aged children. *BMC Pediatrics, 13*, 99. doi: 10.1186/1471-2431-13-99

Bond Huie, S. A. (2001). The concept of neighborhood in health and mortality research. *Sociological Spectrum, 21*(3), 341-358.

Booth, K. M., Pinkston, M. M., & Carlos Poston, W. S. (2005). Obesity and the built environment. *Journal of the American Dietetic Association, 105*(5 suppl1), S110-S117.

Boruff, B. J., Nathan, A., & Nijenstein, S. (2012). Using GPS technology to (re)-examine operational definitions of 'neighbourhood' in place-based health research. *International Journal of Health Geographics, 11*, 22. doi: 10.1186/1476-072x-11-22

Breiman, L., Friedman, J. H., Olshen, R. A., & Stone, C. J. (1998). *Classification and Regression Trees*. Boca Raton, Fl: Chapman & Hall.

Bronfenbrenner, U. (1979). *The Ecology of Human Development*. Cambridge, Massachusetts: Harvard University Press.

Bruner, M., Lawson, J., Pickett, W., Boyce, W., & Janssen, I. (2008). Rural Canadian adolescents are more likely to be obese compared with urban adolescents. *International Journal of Pediatric Obesity, 3*(4), 205-211.

Burrows, T. L., Martin, R. J., & Collins, C. E. (2010). A systematic review of the validity of dietary assessment methods in children when compared with the method of doubly labeled water. *Journal of the American Dietetic Association, 110*(10), 1501-1510. doi: 10.1016/j.jada.2010.07.008

Burton, L. M., Price-Spratlen, T., & Beale Spencer, M. (1997). On ways of thinking about measuring neighborhoods: Implications for studying context and developmental outcomes for children. In G. J. Duncan, J. Brooks-Gunn & J. L. Aber (Eds.), *Neighborhood Poverty, Policy Implications in Studying Neighborhoods* (Vol. 2, pp. 132-144). New-York: Sage.

Cade, J., Thompson, R., Burley, V., & Warm, D. (2002). Development, validation and utilisation of food-frequency questionnaires - a review. *Public Health Nutrition, 5*(4), 567-587. doi: 10.1079/phn2001318

California Centre for Public Health Advocacy, & Policy Link. (2008). Designed for Disease: The Link Between Local Food Environments and Obesity and Diabetes. Retrieved November, 2011, from http://www.publichealthadvocacy.org/PDFs/RFEI%20Policy%20Brief_finalweb.pdf

Carlos, H. A., Shi, X., Sargent, J., Tanski, S., & Berke, E. M. (2010). Density estimation and adaptive bandwidths: a primer for public health practitioners. *International Journal of Health Geographics, 9*, 39.

Carroll-Scott, A., Gilstad-Hayden, K., Rosenthal, L., Peters, S. M., McCaslin, C., Joyce, R., et al. (2013). Disentangling neighborhood contextual associations with child body mass index, diet, and physical activity: The role of built, socioeconomic, and social environments. *Social Science and Medicine, 95*, 106-114. doi: 10.1016/j.socscimed.2013.04.003

Carter, M. A., & Dubois, L. (2010). Neighbourhoods and child adiposity: a critical appraisal of the literature. *Health Place, 16*(3), 616-628. doi: 10.1016/j.healthplace.2009.12.012

Carver, A., Timperio, A., & Crawford, D. (2008). Playing it safe: the influence of neighbourhood safety on children's physical activity. A review. *Health Place, 14*(2), 217-227. doi: 10.1016/j.healthplace.2007.06.004

Casey, R., Oppert, J.-M., Weber, C., Charreire, H., Salze, P., Badariotti, D., et al. (2011). Determinants of childhood obesity: What can we learn from built environment studies? *Food Quality and Preference, 31*, 164-172. doi: doi:10.1016/j.foodqual.2011.06.003

Cecil-Karb, R., & Grogan-Kaylor, A. (2009). Childhood body mass index in community context: neighborhood safety, television viewing, and growth trajectories of BMI. *Health and Social Work, 34*(3), 169-177.

Chaix, B. (2009). Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. *Annual Review of Public Health, 30*, 81-105.

Chaix, B., Bean, K., Leal, C., Thomas, F., Havard, S., Evans, D., et al. (2010). Individual/neighborhood social factors and blood pressure in the RECORD Cohort Study: which risk factors explain the associations? *Hypertension, 55*(3), 769-775. doi: 10.1161/hypertensionaha.109.143206

Chaix, B., Kestens, Y., Bean, K., Leal, C., Karusisi, N., Meghiref, K., et al. (2011). Cohort Profile: Residential and non-residential environments, individual activity spaces and cardiovascular risk factors and diseases - The RECORD

Cohort Study. *International Journal of Epidemiology, doi: 10.1093/ije/dyr107*, Published online July 7.
Chaix, B., Merlo, J., & Chauvin, P. (2005). Comparison of a spatial approach with the multilevel approach for investigating place effects on health: the example of healthcare utilisation in France. *Journal of Epidemiology and Community Health, 59*(6), 517-526. doi: 10.1136/jech.2004.025478
Chaix, B., Merlo, J., Evans, D., Leal, C., & Havard, S. (2009). Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Social Science and Medicine, 69*(9), 1306-1310.
Charreire, H., Casey, R., Salze, P., Simon, C., Chaix, B., Banos, A., et al. (2010). Measuring the food environment using geographical information systems: a methodological review. *Public Health Nutrition, 13*(11), 1773-1785.
Cohen, D. A., Finch, B. K., Bower, A., & Sastry, N. (2006). Collective efficacy and obesity: The potential influence of social factors on health. *Social Science and Medicine, 62*, 769-778.
Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ, 320*(7244), 1240-1243.
Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Reports, 22*(1), 7-14.
Connor Gorber, S., Tremblay, M., Moher, D., & Gorber, B. (2007). A comparison of direct vs. self-report measures for assessing height, weight and body mass index: a systematic review. *Obesity Reviews, 8*(4), 307-326. doi: 10.1111/j.1467-789X.2007.00347.x
Coulton, C. J., Korbin, J., Chan, T., & Su, M. (2001). Mapping residents' perceptions of neighborhood boundaries: a methodological note. *American Journal of Community Psychology, 29*(2), 371-383.
Crawford, D., Jeffery, R., Ball, K., & Brug, J. (Eds.). (2010). *Obesity Epidemiology* (2nd ed.). New York: Oxford.
Crawford, D. A., Cleland, V., Timperio, A., Salmon, J., Andrianopoulos, N., Roberts, R., et al. (2010). The longitudinal influence of home and neighbourhood environments on children's body mass index and physical activity over 5 years: the CLAN study. *International Journal of Obesity (Lond), 34*(7), 1177-1187. doi: 10.1038/ijo.2010.57
Cummins, S. (2007). Commentary: Investigating neighbourhood effects on health-avoiding the 'Local Trap'. *International Journal of Epidemiology, 36*, 355-357.
Datar, A., Nicosia, N., & Shier, V. (2013). Parent perceptions of neighborhood safety and children's physical activity, sedentary behavior, and obesity: evidence from a national longitudinal study. *American Journal of Epidemiology, 177*(10), 1065-1073. doi: 10.1093/aje/kws353
Davison, K. K., & Birch, L. L. (2001). Childhood overweight: a contextual model and recommendations for future research. *Obesity Reviews, 2*(3), 159-171.

Davison, K. K., & Lawson, C. T. (2006). Do attributes in the physical environment influence children's physical activity? A review of the literature. *International Journal of Behavioral Nutrition and Physical Activity, 3*, 19.

de Vet, E., de Ridder, D. T., & de Wit, J. B. (2011). Environmental correlates of physical activity and dietary behaviours among young people: a systematic review of reviews. *Obesity Reviews, 12*(5), e130-142. doi: 10.1111/j.1467-789X.2010.00784.x

Dietz, W. H. (1998). Childhood weight affects adult morbidity and mortality. *Journal of Nutrition, 128*(2 Suppl), 411S-414S.

Diez Roux, A. V. (2001). Investigating neighbourhood and area effects on health. *American Journal of Public Health, 91*(11), 1783-1789.

Diez Roux, A. V. (2003). Residential environments and cardiovascular risk. *Journal of Urban Health, 80*(4), 569-589.

Diez Roux, A. V. (2004). Estimating neighborhood health effects: the challenges of causal inference in a complex world. *Social Science and Medicine, 58*, 1953-1960.

Diez Roux, A. V. (2007). Neighborhoods and health: where are we and were do we go from here? *Revue d'Epidemiologie et de Sante Publique, 55*(1), 13-21. doi: 10.1016/j.respe.2006.12.003

Diez Roux, A. V., & Mair, C. (2010). Neighborhoods and health. *Annals of the New York Academy of Sciences, 1186*, 125-145.

Ding, D., & Gebel, K. (2012). Built environment, physical activity, and obesity: what have we learned from reviewing the literature? *Health Place, 18*(1), 100-105. doi: 10.1016/j.healthplace.2011.08.021

Ding, D., Sallis, J. F., Kerr, J., Lee, S., & Rosenberg, D. E. (2011). Neighborhood environment and physical activity among youth a review. *American Journal of Preventive Medicine, 41*(4), 442-455. doi: 10.1016/j.amepre.2011.06.036

Downs, A. (1981). *Neighborhoods and Urban Development*. Washington, D.C.: The Brookings Institution.

Dunton, G. F., Kaplan, J., Wolch, J., Jerrett, M., & Reynolds, K. D. (2009). Physical environmental correlates of childhood obesity: a systematic review. *Obesity Reviews, 10*(4), 393-402.

Dunton, G. F., Liao, Y., Almanza, E., Jerrett, M., Spruijt-Metz, D., & Pentz, M. A. (2013). Locations of joint physical activity in parent-child pairs based on accelerometer and GPS monitoring. *Annals of Behavioral Medicine, 45 Suppl 1*, S162-172. doi: 10.1007/s12160-012-9417-y

Egger, G., & Swinburn, B. (1997). An "ecological" approach to the obesity pandemic. *BMJ, 315*(7106), 477-480.

Eisenmann, J. C. (2005). Waist circumference percentiles for 7- to 15-year-old Australian children. *Acta Paediatrica, 94*(9), 1182-1185. doi: 10.1080/08035250510029352

Eisenmann, J. C., Heelan, K. A., & Welk, G. J. (2004). Assessing body composition among 3- to 8-year old children: Anthropometry, BIA, and DXA. *Obesity Research, 12*(10), 1633-1640.

El-Sayed, A. M., Scarborough, P., & Galea, S. (2012). Socioeconomic inequalities in childhood obesity in the United Kingdom: a systematic review of the literature. *Obes Facts, 5*(5), 671-692. doi: 10.1159/000343611

Ellis, K. J., Shypailo, R. J., Pratt, J. A., & Pond, W. G. (1994). Accuracy of dual-energy x-ray absorptiometry for body-composition measurements in children. *American Journal of Clinical Nutrition, 60*, 660-665.

Ewing, R., Brownson, R. C., & Berrigan, D. (2006). Relationship between urban sprawl and weight of United States youth. *American Journal of Preventive Medicine, 31*(6), 464-474. doi: 10.1016/j.amepre.2006.08.020

Expert Panel on the Identification Evaluation and Treatment of Overweight in Adults. (1998). Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: executive summary. . *American Journal of Clinical Nutrition, 68*(4), 899-917.

Farley, T. A., Rice, J., Bodor, J. N., Cohen, D. A., Bluthenthal, R. N., & Rose, D. (2009). Measuring the food environment: shelf space of fruits, vegetables, and snack foods in stores. *Journal of Urban Health, 86*(5), 672-682. doi: 10.1007/s11524-009-9390-3

Feng, J., Glass, T. A., Curriero, F. C., Stewart, W. F., & Schwartz, B. S. (2010). The built environment and obesity: a systematic review of the epidemiologic evidence. *Health Place, 16*(2), 175-190. doi: 10.1016/j.healthplace.2009.09.008

Ferdinand, A. O., Sen, B., Rahurkar, S., Engler, S., & Menachemi, N. (2012). The relationship between built environments and physical activity: a systematic review. *American Journal of Public Health, 102*(10), e7-e13.

Fitzhugh, E. C., Bassett, D. R., Jr., & Evans, M. F. (2010). Urban trails and physical activity: a natural experiment. *American Journal of Preventive Medicine, 39*(3), 259-262. doi: 10.1016/j.amepre.2010.05.010

Flegal, K. M., Carroll, M. D., Kit, B. K., & Ogden, C. L. (2012). Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999-2010. *JAMA, 307*(5), 491-497. doi: 10.1001/jama.2012.39

Flegal, K. M., & Ogden, C. L. (2011). Childhood obesity: are we all speaking the same language? *Advances in Nutrition, 2*(2), 159s-166s. doi: 10.3945/an.111.000307

Fone, D. L., Farewell, D. M., & Dunstan, F. D. (2006). An ecometric analysis of neighbourhood cohesion. *Popul Health Metr, 4*, 17. doi: 10.1186/1478-7954-4-17

Foresight. (2007) Tackling obesities: future choices-project report. *The Stationery Office*. London.

Forrestal, S. G. (2011). Energy intake misreporting among children and adolescents: a literature review. *Maternal and Child Nutrition, 7*(2), 112-127. doi: 10.1111/j.1740-8709.2010.00270.x

Franzini, L., Elliott, M. N., Cuccaro, P., Schuster, M., Gilliland, J., Grunbaum, J. A., et al. (2009). Influences of physical and social neighborhood environments on children's physical activity and obesity. *American Journal of Public Health, 99*(2), 271-278.

Fredriks, A. M., van Buuren, S., Fekkes, M., Verloove-Vanhorick, S. P., & Wit, J. M. (2005). Are age references for waist circumference, hip circumference and

waist-hip ratio in Dutch children useful in clinical practice? *European Journal of Pediatrics, 164*(4), 216-222. doi: 10.1007/s00431-004-1586-7
French, S. A., Story, M., & Jeffery, R. W. (2001). Environmental influences on eating and physical activity. *Annual Review of Public Health, 22*, 309-335.
Freudenheim, J. L. (1993). A review of study designs and methods of dietary assessment in nutritional epidemiology of chronic disease. *Journal of Nutrition, 123*(2 Suppl), 401-405.
Fuentes, R. M., Notkola, I. L., Shemeikka, S., Tuomilehto, J., & Nissinen, A. (2002). Familial aggregation of body mass index: a population-based family study in eastern Finland. *Hormone and Metabolic Research, 34*(7), 406-410. doi: 10.1055/s-2002-33474
Galster, G. (2001). On the nature of neighbourhood. *Urban Studies, 38*(12), 2111-2124.
Galster, G. (2009). What is neighbourhood? An externality-spate approach. *International Journal of Urban and Regional Research, 10*, 243-263.
Galvez, M. P., Pearl, M., & Yen, I. H. (2010). Childhood obesity and the built environment: a review of the literature from 2008-2009. *Current Opinion in Pediatrics, 22*(2), 202-207.
Gauvin, L., Richard, L., Craig, C., Spivock, M., Riva, M., Forster, M., et al. (2005). From walkability to active living potential. An "ecometric" validation study. *American Journal of Preventive Medicine, 28*(2S2), 126-133.
Gebauer, H., & Laska, M. N. (2011). Convenience stores surrounding urban schools: an assessment of healthy food availability, advertising, and product placement. *Journal of Urban Health, 88*(4), 616-622.
Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., et al. (2013). The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. *Social Science and Medicine, 77*, 20-30. doi: 10.1016/j.socscimed.2012.10.016
Giles-Corti, B., Macintyre, S., Clarkson, J., Pikora, T., & Donovan, R. (2003). Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. *American Journal of Health Promotion, 18*(1), 93-102.
Gilliland, J. A., Rangel, C. Y., Healy, M. A., Tucker, P., Loebach, J. E., Hess, P. M., et al. (2012). Linking childhood obesity to the built environment: a multi-level analysis of home and school neighbourhood factors associated with body mass index. *Canadian Journal of Public Health. Revue Canadienne de Sante Publique, 103*(9 Suppl 3), eS15-21.
Glanz, K., Sallis, J. F., Saelens, B. E., & Frank, L. D. (2005). Healthy nutrition environments: concepts and measures. *American Journal of Health Promotion, 19*(5), 330-333, ii.
Glass, T. A., & McAtee, M. J. (2006). Behavioral science at the crossroads in public health: extending horizons, envisioning the future. *Social Science and Medicine, 62*(7), 1650-1671. doi: 10.1016/j.socscimed.2005.08.044
Golab, C. (1982). The geography of neighborhood. In R. Bayer (Ed.), *Neighborhoods in Urban America* (pp. 70-85). Port Washington: Kennikat.
Golledge, R. G., & Stimson, R. J. (1996). *Spatial Behavior: A Geographic Perspective*. New York: The Guilford Press.

Goran, M. I. (1998). Measurement issues related to studies of childhood obesity: Assessment of body composition, body fat distribution, physical activity, and food intake. *Pediatrics, 101*(Suppl 1), 505-518.

Goran, M. I., Ball, G. D., & Cruz, M. L. (2003). Obesity and risk of type 2 diabetes and cardiovascular disease in children and adolescents. *Journal of Clinical Endocrinology and Metabolism, 88*(4), 1417-1427.

Goran, M. I., Driscoll, P., Johnson, R. K., Nagy, T. R., & Hunter, G. (1996). Cross-calibration of body-composition techniques against dual-energy X-ray absorptiometry in young children. *American Journal of Clinical Nutrition, 63*(299-305).

Gose, M., Plachta-Danielzik, S., Willie, B., Johannsen, M., Landsberg, B., & Muller, M. J. (2013). Longitudinal influences of neighbourhood built and social environment on children's weight status. *International Journal of Environmental Research and Public Health, 10*(10), 5083-5096. doi: 10.3390/ijerph10105083

Grafova, I. B. (2008). Overweight children: Assessing the contribution of the built environment. *Preventive Medicine, 47*, 304-308.

Grow, H. M., Cook, A. J., Arterburn, D. E., Saelens, B. E., Drewnowski, A., & Lozano, P. (2010). Child obesity associated with social disadvantage of children's neighborhoods. *Social Science and Medicine, 71*(3), 584-591. doi: 10.1016/j.socscimed.2010.04.018

Guo, J., & Bhat, C. (2007). Operationalizing the concept of neighborhood: application to residential location choice analysis *Journal of Transport Geography, 15*, 31-45.

Hammond, R. A., & Ornstein, J. T. (2014). A model of social influence on body mass index. *Annals of the New York Academy of Sciences*. doi: 10.1111/nyas.12344

Han, J. C., Lawlor, D. A., & Kimm, S. Y. (2010). Childhood obesity. *Lancet, 375*(9727), 1737-1748. doi: 10.1016/S0140-6736(10)60171-7

Harrison, F., & Jones, A. P. (2012). A framework for understanding school based physical environmental influences on childhood obesity. *Health Place, 18*(3), 639-648. doi: 10.1016/j.healthplace.2011.12.009

Harrison, F., Jones, A. P., van Sluijs, E. M., Cassidy, A., Bentham, G., & Griffin, S. J. (2011). Environmental correlates of adiposity in 9-10 year old children: considering home and school neighbourhoods and routes to school. *Social Science and Medicine, 72*(9), 1411-1419. doi: 10.1016/j.socscimed.2011.02.023

Health Canada. (2007a). Canadian Nutrient File. Retrieved November 15, 2011, from http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/cnf_downloads-telechargement_fcen-eng.php

Health Canada. (2007b). Eating well with Canada's Food Guide. A resource for educators and communicators. Retrieved Nov 15, 2011, from http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/index-eng.php

Hill, J. O., & Peters, J. C. (1998). Environmental contributions to the obesity epidemic. *Science, 280*(5368), 1371-1374.

Hill, J. O., Wyatt, H. R., Reed, G., & Peters, J. C. (2003). Obesity and the environment: where do we go from here? *Science, 299*(5608), 853-855.

Hu, F. B. (2009). Measurements of adiposity and body composition. In F. B. Hu (Ed.), *Obesity Eidemiology* (pp. 53-83). New York: Oxford University Press.

Huang, T. T., & Glass, T. A. (2008). Transforming research strategies for understanding and preventing obesity. *JAMA, 300*(15), 1811-1813. doi: 10.1001/jama.300.15.1811

Hume, C., Salmon, J., & Ball, K. (2005). Children's perceptions of their home and neighborhood environments, and their association with objectively measured physical activity: a qualitative and quantitative study. *Health Education Research, 20*(1), 1-13. doi: 10.1093/her/cyg095

Hume, C., Timperio, A., Salmon, J., Carver, A., Giles-Corti, B., & Crawford, D. (2009). Walking and cycling to school. Predictors of increases among children and adolescents. *American Journal of Preventive Medicine, 36*(3), 195-200.

Huybrechts, I., De Bourdeaudhuij, I., & De Henauw, S. (2010). Environmental factors: opportunities and barriers for physical activity, and healthy eating among children and adolescents. *Verhandelingen - Koninklijke Academie Voor Geneeskunde Van Belgie, 72*(5-6), 277-293.

Institut de la statistique du Québec. (2002). Quebec Child and Adolescent Health Social Survey. Retrieved April 17. 2011, from http://www.stat.gouv.qc.ca/publications/sante/enfant-ado_an.htm

Institut de la statistique du Québec. (2012). L'Enquête québécoise sur la santé des jeunes du secondaire 2010-2011 - tome 1. Retrieved October 1, 2013, from http://www.stat.gouv.qc.ca/publications/sante/pdf2012/EQSJS_tome1.pdf

Jain, A. (2005). Treating obesity in individuals and populations. *BMJ, 331*(7529), 1387-1390. doi: 10.1136/bmj.331.7529.1387

Jenner, D. A., Neylon, K., Croft, S., Beilin, L. J., & Vandongen, R. (1989). A comparison of methods of dietary assessment in Australian children aged 11-12 years. *European Journal of Clinical Nutrition, 43*(10), 663-673.

Jennings, A., Welch, A., Jones, A. P., Harrison, F., Bentham, G., van Sluijs, E. M., et al. (2011). Local food outlets, weight status, and dietary intake: associations in children aged 9-10 years. *American Journal of Preventive Medicine, 40*(4), 405-410.

Johnson, R. K., Driscoll, P., & Goran, M. I. (1996). Comparison of multiple-pass 24-hour recall estimates of energy intake with total energy expenditure determined by doubly labeled water method in young children. *Journal of the American Dietetic Association, 96*(11), 1140-1144.

Jones, M., & Huh, J. (2014). Toward a multidimensional understanding of residential neighborhood: A latent profile analysis of Los Angeles neighborhoods and longitudinal adult excess weight. *Health Place, 27c*, 134-141. doi: 10.1016/j.healthplace.2014.01.011

Jongeneel-Grimen, B., Droomers, M., van Oers, H. A., Stronks, K., & Kunst, A. E. (2014). The relationship between physical activity and the living environment: a multi-level analyses focusing on changes over time in environmental factors. *Health Place, 26*, 149-160. doi: 10.1016/j.healthplace.2013.12.003

Kakinami, L., Henderson, M., Delvin, E. E., Levy, E., O'Loughlin, J., Lambert, M., et al. (2012). Association between different growth curve definitions of overweight and obesity and cardiometabolic risk in children. *Canadian Medical Association Journal, 184*(10), E539-550. doi: 10.1503/cmaj.110797

Kapinos, K. A., & Yakusheva, O. (2011). Environmental influences on young adult weight gain: evidence from a natural experiment. *Journal of Adolescent Health, 48*(1), 52-58. doi: 10.1016/j.jadohealth.2010.05.021

Kaplan, G. A. (1999). What is the role of the social environment in understanding inequalities in health. *Annals of the New York Academy of Sciences, 896*, 116-119.

Katzmarzyk, P. T., Barreira, T. V., Broyles, S. T., Champagne, C. M., Chaput, J. P., Fogelholm, M., et al. (2013). The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE): design and methods. *BMC Public Health, 13*, 900. doi: 10.1186/1471-2458-13-900

Keegan, T. H., Hurley, S., Goldberg, D., Nelson, D. O., Reynolds, P., Bernstein, L., et al. (2012). The association between neighborhood characteristics and body size and physical activity in the California teachers study cohort. *American Journal of Public Health, 102*(4), 689-697. doi: 10.2105/ajph.2011.300150

Kellou, N., Sandalinas, F., Copin, N., & Simon, C. (2014). Prevention of unhealthy weight in children by promoting physical activity using a socio-ecological approach: What can we learn from intervention studies? *Diabetes and Metabolism*. doi: 10.1016/j.diabet.2014.01.002

Kelly, T., Yang, W., Chen, C. S., Reynolds, K., & He, J. (2008). Global burden of obesity in 2005 and projections to 2030. *International Journal of Obesity (Lond), 32*(9), 1431-1437. doi: 10.1038/ijo.2008.102

Kerr, J., Frank, L., Sallis, J. F., & Chapman, J. (2007). Urban form correlates of pedestrian travel in youth: Differences by gender, race-ethnicity and household attributes. *Transportation Research Part D, 12*, 177-182.

Kestens, Y., & Daniel, M. (2010). Social inequalities in food exposure around schools in an urban area. *American Journal of Preventive Medicine, 39*(1), 33-40.

Kestens, Y., Lebel, A., Chaix, B., Clary, C., Daniel, M., Pampalon, R., et al. (2012). Association between activity space exposure to food establishments and individual risk of overweight. *PLoS ONE, 7*(8), e41418. doi: 10.1371/journal.pone.0041418

King, A. C., Ahn, D., Rejeski, W. J., Marcus, B., dunn, A. L., & Sallis, J. F. (2006). Identifying subgroups that succeed or fail with three levels of physical activity intervention: The Activity Counseling Trial. *Health Psychology, 25*(3), 336-347.

Kirk, S. F., Penney, T. L., & McHugh, T. L. (2010). Characterizing the obesogenic environment: the state of the evidence with directions for future research. *Obesity Reviews, 11*(2), 109-117. doi: 10.1111/j.1467-789X.2009.00611.x

Krenn, P. J., Titze, S., Oja, P., Jones, A., & Ogilvie, D. (2011). Use of global positioning systems to study physical activity and the environment: a systematic review. *American Journal of Preventive Medicine, 41*(5), 508-515. doi: 10.1016/j.amepre.2011.06.046

Kwan, M.-P. (2009). From place-based to people-based exposure measures. *Social Science and Medicine, 69*, 1311-1313.

Lachowycz, K., Jones, A. P., Page, A. S., Wheeler, B. W., & Cooper, A. R. (2012). What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health and Place, 18*(3), 586-594. doi: 10.1016/j.healthplace.2012.01.006

Lambert, M., Delvin, E. E., Levy, E., O'Loughlin, J., Paradis, G., Barnett, T., et al. (2007). Prevalence of cardiometabolic risk factors by weight status in a population-based sample of Quebec children and adolescents. *Canadian Journal of Cardiology, 24*(7), 575-583.

Lambert, M., Van Hulst, A., O'Loughlin, J., Tremblay, A., Barnett, T. A., Charron, H., et al. (2012). Cohort profile: the Quebec adipose and lifestyle investigation in youth cohort. *International Journal of Epidemiology, 41*(6), 1533-1544. doi: 10.1093/ije/dyr111

Larson, N. I., Story, M. T., & Nelson, M. C. (2009). Neighborhood environments. Disparities in access to healthy foods in the U.S. *American Journal of Preventive Medicine, 36*(1), 74-81.

Leal, C., Bean, K., Thomas, F., & Chaix, B. (2012). Multicollinearity in the associations between multiple environmental features and body weight and abdominal fat: using matching techniques to assess whether the associations are separable. *American Journal of Epidemiology, 175*(11), 1153-1162.

Leal, C., & Chaix, B. (2011). The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obesity Reviews, 12*(3), 217-230. doi: 10.1111/j.1467-789X.2010.00726.x

Lemon, S. C., Wang, M. L., Wedick, N. M., Estabrook, B., Druker, S., Schneider, K. L., et al. (2013). Weight gain prevention in the school worksite setting: Results of a multi-level cluster randomized trial. *Preventive Medicine*. doi: 10.1016/j.ypmed.2013.12.010

Leung, C. W., Laraia, B. A., Kelly, M., Nickleach, D., Adler, N. E., Kushi, L. H., et al. (2011). The influence of neighborhood food stores on change in young girls' body mass index. *American Journal of Preventive Medicine, 41*(1), 43-51.

Liu, Y., Chen, H. J., Liang, L., & Wang, Y. (2013). Parent-child resemblance in weight status and its correlates in the United States. *PLoS ONE, 8*(6), e65361. doi: 10.1371/journal.pone.0065361

Livingstone, M. B., Robson, P. J., & Wallace, J. M. (2004). Issues in dietary intake assessment of children and adolescents. *British Journal of Nutrition, 92 Suppl 2*, S213-222.

Lobstein, T., Baur, L., Uauy, R., & IASO International Obesity Task Force. (2004). Obesity in children and young people: a crisis in public health. *Obesity Reviews, 5*(Suppl 1), 4-104.

Lobstein, T., & Baur, L. A. (2005). Policies to prevent childhood obesity in the European Union. *European Journal of Public Health, 15*(6), 576-579. doi: 10.1093/eurpub/cki068

Lohman, T. G., Roche, A. F., & Martorell, R. (1998). Anthropometric Standardization Reference Manual.

Ludwig, J., Sanbonmatsu, L., Gennetian, L., Adam, E., Duncan, G. J., Katz, L. F., et al. (2011). Neighborhoods, obesity, and diabetes--a randomized social experiment.

New England Journal of Medicine, 365(16), 1509-1519. doi: 10.1056/NEJMsa1103216

Malik, V. S., Schulze, M. B., & Hu, F. B. (2006). Intake of sugar-sweetened beverages and weight gain: a systematic review. *American Journal of Clinical Nutrition, 84*(2), 274-288.

Marshall, W. A., & Tanner, J. M. (1969). Variations in pattern of pubertal changes in girls. *Archives of Disease in Childhood, 44*(235), 291-303.

Marshall, W. A., & Tanner, J. M. (1970). Variations in the pattern of pubertal changes in boys. *Archives of Disease in Childhood, 45*(239), 13-23.

Martin, C. K., Correa, J. B., Han, H., Allen, H. R., Rood, J. C., Champagne, C. M., et al. (2012). Validity of the Remote Food Photography Method (RFPM) for estimating energy and nutrient intake in near real-time. *Obesity (Silver Spring), 20*(4), 891-899. doi: 10.1038/oby.2011.344

Matthews, S. A. (2012). Thinking about place, spatial behavior, and spatial processes in childhood obesity. *American Journal of Preventive Medicine, 42*(5), 516-520. doi: 10.1016/j.amepre.2012.02.004

Mattsson, S., & Thomas, B. J. (2006). Development of methods for body composition studies. *Physics in Medicine and Biology, 51*(13), R203-228. doi: 10.1088/0031-9155/51/13/r13

McClain, A. D., Chappuis, C., Nguyen-Rodriguez, S. T., Yaroch, A. L., & Spruijt-Metz, D. (2009). Psychosocial correlates of eating behaviour in children and adolescents: a review. *International Journal of Behavioral Nutrition and Physical Activity, 6*, 54.

McGill, H. C., Jr., McMahan, C. A., Herderick, E. E., Malcom, G. T., Tracy, R. E., & Strong, J. P. (2000). Origin of atherosclerosis in childhood and adolescence. *American Journal of Clinical Nutrition, 72*(5), 1307S-1315.

McPherson, R. S., Hoelscher, D. M., Alexander, M., Scanlon, K. S., & Serdula, M. K. (2000). Dietary assessment methods among school-aged children: validity and reliability. *Preventive Medicine, 31*(2), S11-S33.

Megaphone Catalogue. (2009). A spatial data infrastructure for population health research on person-place interactions. Retrieved November, 2011, from http://megaphone.crchum.qc.ca/geonetwork/srv/en/main.home

Mitola, A. L., Papas, M. A., Le, K., Fusillo, L., & Black, M. M. (2007). Agreement with satisfaction in adolescent body size between female caregivers and teens from a low-income African-American community. *Journal of Pediatric Psychology, 32*(1), 42-51. doi: 10.1093/jpepsy/jsl004

Molnar, B. E., Gortmaker, S. L., Bull, F. C., & Buka, S. L. (2004). Unsafe to play? Neighborhood disorder and lack of safety predict reduced physical activity among urban children and adolescents. *American Journal of Health Promotion, 18*, 378-386.

Moore, L. V., Diez Roux, A. V., & Brines, S. (2008). Comparing perception-based and Geographic Information System (GIS)-based characterizations of the local food environment. *Journal of Urban Health, 85*(2), 206-216.

Moos, R. H. (1980). Social-Ecological Perspectives on Health. In G. C. Stone, F. Cohen & N. E. Adler (Eds.), *Health Psychology: A Handbook*. San Francisco: Jossey-Bass.

Morland, K., Diez Roux, A. V., & Wing, S. (2006). Supermarkets, other food stores, and obesity. The Atherosclerosis Risk in Communities Study. *American Journal of Preventive Medicine, 30*(4), 333-339.

Morrow, V. (2001). Using qualitative methods to elicit young people's perspectives on their environments: some ideas for community health initiatives. *Health Education Research, 16*(3), 255-268.

Mujahid, M., Diez Roux, A., Morenoff, J., & Raghunathan, T. (2007). Assessing the measurement properties of neighbourhood scales: from psychometrics to ecometrics. *American Journal of Epidemiology, 165*(8), 858-867.

Nelson, M. C., Gordon-Larsen, P., Song, Y., & Popkin, B. M. (2006). Built and social environments. Associations with adolescent overweight and activity. *American Journal of Preventive Medicine, 31*(2), 109-117.

O'Campo, P. (2003). Invited Commentary: Advancing theory and methods for multilevel models of residential neighbourhoods and health. *American Journal of Epidemiology, 157*(1), 9-13.

Oakes, J. M. (2004). The (mis)estimation of neighborhood effects: causal inference for a practicable social epidemiology. *Social Science and Medicine, 58*, 1929-1952.

Odgers, C. L., Caspi, A., Bates, C. J., Sampson, R. J., & Moffitt, T. E. (2012). Systematic social observation of children's neighborhoods using Google Street View: a reliable and cost-effective method. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 53*(10), 1009-1017. doi: 10.1111/j.1469-7610.2012.02565.x

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity and trends in body mass index among US children and adolescents, 1999-2010. *JAMA, 307*(5), 483-490. doi: 10.1001/jama.2012.40

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA, 311*(8), 806-814. doi: 10.1001/jama.2014.732

Olds, T., Maher, C., Zumin, S., Péneau, S., Lioret, S., Castetbon, K., et al. (2011). Evidence that the prevalence of childhood overweight is plateauing: data from nine countries. *International Journal of Pediatric Obesity, 6*(5-6), 342-360.

Oliver, L. N., & Hayes, M. V. (2008). Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health, 8*(16), e1-9.

Oliver, L. N., Schuurman, N., & Hall, A. W. (2007). Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographics, 6*(41). doi: 10.1186/1476-072X-6-41

Openshaw, S. (1984). The modifiable areal unit problem. *Concepts and Techniques in Moderne Geography, 38*, 1-41.

Pampalon, R., & Raymond, G. (2003). Indice de défavorisation matérielle et sociale : son application au secteur de la santé et du bien-être. *Santé, Société et Solidarité, 1*, 191-208.

Papas, M. A., Alberg, A. J., Ewing, R., Helzlsouer, K. J., Gary, T. L., & Klassen, A. C. (2007). The built environment and obesity. *Epidemiologic Reviews, 29*, 129-143. doi: 10.1093/epirev/mxm009

Paquet, C., Cargo, M., Kestens, Y., & Daniel, M. (2010). Reliability of an instrument for direct observation of urban neighbourhoods. *Landscape and urban planning, 97*(3), 194-201.

Paquet, C., Daniel, M., Kestens, Y., Leger, K., & Gauvin, L. (2008). Field validation of listings of food stores and commercial physical activity establishments from secondary data. *Int J Behav Nutr Phys Act, 5*, 58. doi: doi:10.1186/1479-5868-5-58

Paradis, G., Lambert, M., O'Loughlin, J., Lavallee, C., Aubin, J., Berthiaume, P., et al. (2003). The Quebec Child and Adolescent Health and Social Survey: design and methods of a cardiovascular risk factor survey for youth. *Canadian Journal of Cardiology, 19*(5), 523-531.

Pate, R. R., O'Neill, J. R., Liese, A. D., Janz, K. F., Granberg, E. M., Colabianchi, N., et al. (2013). Factors associated with development of excessive fatness in children and adolescents: a review of prospective studies. *Obesity Reviews, 14*(8), 645-658. doi: 10.1111/obr.12035

Pearce, J., Hiscock, R., Blakely, T., & Witten, K. (2008). The contextual effects of neighbourhood access to supermarkets and convenience stores on individual fruit and vegetable consumption. *Journal of Epidemiology and Community Health, 62*(3), 198-201.

Pedigo, A., Seaver, W., & Odoi, A. (2011). Identifying unique neighborhood characteristics to guide health planning for stroke and heart attack: Fuzzy cluster and discriminant analyses approaches. *PLoS ONE, 6*(7), e22693. doi:22610.21371/journal.pone.0022693.

Penman, A. D., & Johnson, W. D. (2006). The changing shape of the body mass index distribution curve in the population: implications for public health policy to reduce the prevalence of adult obesity. *Preventing Chronic Disease, 3*(3), A74.

Perchoux, C., Chaix, B., Cummins, S., & Kestens, Y. (2013). Conceptualization and measurement of environmental exposure in epidemiology: accounting for activity space related to daily mobility. *Health Place, 21*, 86-93. doi: 10.1016/j.healthplace.2013.01.005

Perchoux, C., Kestens, Y., Thomas, F., Van Hulst, A., Thierry, B., & Chaix, B. (2013). Assessing patterns of spatial behavior in health studies: the RECORD Cohort Study. *Social Science and Medicine, Under review, submitted October 28 2013*.

Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *Journal of Epidemiology and Community Health, 55*(2), 111-122.

Pikora, T. J., Bull, F. C., Jamrozik, K., Knuiman, M., Giles-Corti, B., & Donovan, R. J. (2002). Developing a reliable audit instrument to measure the physical environment for physical activity. *American Journal of Preventive Medicine, 23*(3), 187-194.

Pont, K., Ziviani, J., Wadley, D., Bennett, S., & Abbott, R. (2009). Environmental correlates of children's active transportation: a systematic literature review. *Health Place, 15*(3), 827-840. doi: 10.1016/j.healthplace.2009.02.002

Powell-Wiley, T. M., Ayers, C. R., de Lemos, J. A., Lakoski, S. G., Vega, G. L., Grundy, S., et al. (2013). Relationship between perceptions about neighborhood

environment and prevalent obesity: data from the Dallas Heart Study. *Obesity (Silver Spring), 21*(1), E14-21. doi: 10.1002/oby.20012
Powell, L. M., Auld, C., Chaloupka, F. J., O'Malley, P. M., & Johnston, L. D. (2007). Associations between access to food stores and adolescent body mass index *American Journal of Preventive Medicine, 33*(4S), S301-S307.
Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. *Obesity Reviews, 2*, 141-147.
Rahman, T., Cushing, R. A., & Jackson, R. J. (2011). Contributions of built environment to childhood obesity. *Mount Sinai Journal of Medicine, 78*(1), 49-57.
Raitakari, O. T., Juonala, M., & Viikari, J. S. (2005). Obesity in childhood and vascular changes in adulthood: insights into the Cardiovascular Risk in Young Finns Study. *International Journal of Obesity (Lond), 29* (Suppl 2), S101-104.
Raudenbush, S. W., & Sampson, R. J. (1999). Ecometrics: Toward a science of assessing ecological settings, with application to the systematic social observation of neighborhoods. *Sociological Methodology, 29*, 1-41.
Reilly, J. J., Armstrong, J., Dorosty, A. R., Emmett, P. M., Ness, A., Rogers, I., et al. (2005). Early life risk factors for obesity in childhood: cohort study. *BMJ, 330*(7504), 1357.
Richard, L., Gauvin, L., & Raine, K. (2011). Ecological models revisited: their uses and evolution in health promotion over two decades. *Annual Review of Public Health, 32*, 307-326. doi: 10.1146/annurev-publhealth-031210-101141
Roberts, K. C., Shields, M., de Groh, M., Aziz, A., & Gilbert, J. A. (2012). Overweight and obesity in children and adolescents: results from the 2009 to 2011 Canadian Health Measures Survey. *Health Reports, 23*(3), 37-41.
Robinson, T. (2008). Applying the socio-ecological model to improving fruit and vegetable intake among low-income African Americans. *Journal of Community Health, 33*(6), 395-406. doi: 10.1007/s10900-008-9109-5
Root, E. D. (2012). Moving Neighborhoods and Health Research Forward: Using Geographic Methods to Examine the Role of Spatial Scale in Neighborhood Effects on Health. *Annals of the Association of American Geographers, 102*(5), 986-995. doi: 10.1080/00045608.2012.659621
Rose, G. (2008). *Rose's Strategy of Preventive Medicine*. New York: Oxford University Press.
Rosen, G. (1993). *A History of Public Health*. Baltimore: Hopkins Fulfillement Service.
Rosenberg, D., Ding, D., Sallis, J. F., Kerr, J., Norman, G. J., Durant, N., et al. (2009). Neighborhood Environment Walkability Scale for Youth (NEWS-Y): reliability and relationship with physical activity. *Preventive Medicine, 49*(2-3), 213-218. doi: 10.1016/j.ypmed.2009.07.011
Rundle, A. G., Bader, M. D., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to audit neighborhood environments. *American Journal of Preventive Medicine, 40*(1), 94-100. doi: 10.1016/j.amepre.2010.09.034

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine, 25*(2), 80-91.

Saelens, B. E., Sallis, J. F., Frank, L. D., Couch, S. C., Zhou, C., Colburn, T., et al. (2012). Obesogenic neighborhood environments, child and parent obesity: the Neighborhood Impact on Kids study. *American Journal of Preventive Medicine, 42*(5), e57-64. doi: 10.1016/j.amepre.2012.02.008

Safron, M., Cislak, A., Gaspar, T., & Luszczynska, A. (2011). Micro-environmental characteristics related to body weight, diet, and physical activity of children and adolescents: a systematic umbrella review. *Int J Environ Health Res, 21*(5), 317-330. doi: 10.1080/09603123.2011.552713

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006). An ecological approach to creating active living communities. *Annual Review of Public Health, 27*, 297-322. doi: 10.1146/annurev.publhealth.27.021405.102100

Sallis, J. F., Floyd, M. F., Rodriguez, D. A., & Saelens, B. E. (2012). Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation, 125*(5), 729-737. doi: 10.1161/CIRCULATIONAHA.110.969022

Sallis, J. F., & Glanz, K. (2006). The role of built environments in physical activity, eating, and obesity in childhood. *The Future of Children, 16*(1), 89-108.

Sallis, J. F., & Glanz, K. (2009). Physical activity and food environments: solutions to the obesity epidemic. *Milbank Quarterly, 87*(1), 123-154. doi: 10.1111/j.1468-0009.2009.00550.x

Sallis, J. F., Owen, N., & Fisher, E. B. (2008). Ecological models of health behaviors (Chapter 20). In K. Glanz, B. K. Rimer & K. Viswanath (Eds.), *Health behavior and health education: theory, research, and practice* (pp. 552). San Francisco, CA: John Wiley & Sons.

Salmon, J., Salmon, L., Crawford, D. A., Hume, C., & Timperio, A. (2007). Associations among individual, social, and environmental barriers and children's walking or cycling to school. *American Journal of Health Promotion, 22*(2), 107-113.

Schreier, H. M., & Chen, E. (2013). Socioeconomic status and the health of youth: a multilevel, multidomain approach to conceptualizing pathways. *Psychological Bulletin, 139*(3), 606-654. doi: 10.1037/a0029416

Secker, D. (2010). Promoting optimal monitoring of child growth in Canada: using the new WHO growth charts. *Canadian Journal of Dietetic Practice and Research, 71*(1), e1-3.

Serdula, M. K., Ivery, D., Coates, R. J., Freedman, D. S., Williamson, D. F., & Byers, T. (1993). Do obese children become obese adults? A review of the literature. *Preventive Medicine, 22*(2), 167-177. doi: 10.1006/pmed.1993.1014

Shareck, M., Kestens, Y., & Frohlich, K. L. (2014). Moving beyond the residential neighborhood to explore social inequalities in exposure to area-level disadvantage: Results from the Interdisciplinary Study on Inequalities in Smoking. *Social Science and Medicine, 108c*, 106-114. doi: 10.1016/j.socscimed.2014.02.044

Shields, M. (2006). Overweight and obesity among children and youth. *Health Reports, 17*(3), 27-42.
Shields, M., Connor Gorber, S., Janssen, I., & Tremblay, M. S. (2011). Obesity estimates for children based on parent-reported versus direct measures. *Health Reports, 22*(3), 47-58.
Shields, M., & Tjepkema, M. (2006). Trends in adult obesity. *Health Reports, 17*(3), 53-59.
Shields, M., & Tremblay, M. S. (2010). Canadian childhood obesity estimates based on WHO, IOTF and CDC cut-points. *International Journal of Pediatric Obesity, 5*(3), 265-273. doi: 10.3109/17477160903268282
Shields, M., Tremblay, M. S., Laviolette, M., Craig, C. L., Janssen, I., & Connor Gorber, S. (2010). Fitness of Canadian adults: Results from the 2007-2009 Canadian Health Measures Survey. *Health Reports, 21*(1).
Shier, V., An, R., & Sturm, R. (2012). Is there a robust relationship between neighbourhood food environment and childhood obesity in the USA? *Public Health, 126*(9), 723-730. doi: 10.1016/j.puhe.2012.06.009
Shypailo, R. J., Butte, N. F., & Ellis, K. J. (2008). DXA: Can it be used as a criterion reference for body fat measurements in children? *Obesity, 16*, 457-462.
Silventoinen, K., Rokholm, B., Kaprio, J., & Sorensen, T. I. (2010). The genetic and environmental influences on childhood obesity: a systematic review of twin and adoption studies. *Int J Obes (Lond), 34*(1), 29-40. doi: 10.1038/ijo.2009.177
Singh, G. K., Kogan, M. D., & van Dyck, P. C. (2008). A multilevel analysis of state and regional disparities in childhood and adolescent obesity in the United States. *Journal of Community Health, 33*(2), 90-102.
Skidmore, P., Welch, A., van Sluijs, E., Jones, A., Harvey, I., Harrison, F., et al. (2010). Impact of neighbourhood food environment on food consumption in children aged 9-10 years in the UK SPEEDY (Sport, Physical Activity and Eating behaviour: Environmental Determinants in Young people) study. *Public Health Nutrition, 13*(7), 1022-1030.
Spence, J. C. (2003). Toward a comprehensive model of physical activity. *Psychol Sport Exerc, 4*(1), 7-24.
Spence, J. C., Cutumisu, N., Edwards, J., Raine, K. D., & Smoyer-Tomic, K. (2009). Relation between local food environments and obesity among adults. *BMC Public Health, 9*, 192. doi: doi:10.1186/1471-2458-9-192
Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion, 10*(4), 282-298.
Subramanian, S. V. (2004). The relevance of multilevel statistical methods for identifying causal neighborhood effects. *Social Science and Medicine, 58*(10), 1961-1967. doi: 10.1016/s0277-9536(03)00415-5
Sundquist, K., Winkleby, M., Ahlen, H., & Johansson, S. E. (2004). Neighborhood socioeconomic environment and incidence of coronary heart disease: a follow-up study of 25,319 women and men in Sweden. *American Journal of Epidemiology, 159*(7), 655-662.
Sweeting, H. N. (2007). Measurement and definitions of obesity in childhood and adolescence: A field guide for the uninitiated. *Nutrition Journal, 6*(32).

Swinburn, B., Egger, G., & Raza, F. (1999). Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Preventive Medicine, 29*, 563-570.
Thierry, B., Chaix, B., & Kestens, Y. (2013). Detecting activity locations from raw GPS data: a novel kernel-based algorithm. *International Journal of Health Geographics, 12*, 14. doi: 10.1186/1476-072x-12-14
Timperio, A., Ball, K., Roberts, R., Andrianopoulos, N., & Crawford, D. (2009). Children's takeaway and fast-food intakes: associations with the neighbourhood food environment. *Public Health Nutrition, 12*(10), 1960-1964.
Timperio, A., Ball, K., Roberts, R., Campbell, K., Andrianopoulos, N., & Crawford, D. (2008). Children's fruit and vegetable intake: associations with the neighbourhood food environment. *Preventive Medicine, 46*(4), 331-335.
Timperio, A., Ball, K., Salmon, J., Roberts, R., Giles-Corti, B., Simmons, D., et al. (2006). Personal, family, social, and environmental correlates of active commuting to school. *American Journal of Preventive Medicine, 30*(1), 45-51.
Timperio, A., Crawford, D., Telford, A., & Salmon, J. (2004). Perceptions about the local neighborhood and walking and cycling among children. *Preventive Medicine, 38*, 39-47.
Timperio, A., Jeffery, R. W., Crawford, D., Roberts, R., Giles-Corti, B., & Ball, K. (2010). Neighbourhood physical activity environments and adiposity in children and mothers: a three-year longitudinal study. *Int J Behav Nutr Phys Act, 7*, 18. doi: 10.1186/1479-5868-7-18
Timperio, A., Salmon, J., Telford, A., & Crawford, D. (2005). Perceptions of local neighbourhood environments and their relationship to childhood overweight and obesity. *International Journal of Obesity (Lond), 29*(2), 170-175. doi: 10.1038/sj.ijo.0802865
Tjepkema, M. (2006). Adult obesity. *Health Reports, 17*(3), 9-25.
Tremblay, M. S., Shields, M., Laviolette, M., Craig, C. L., Janssen, I., & Connor Gorber, S. (2010). Fitness of Canadian children and youth: results from the 2007-2009 Canadian Health Measures Survey. *Health Reports, 21*(1), 7-20.
Troiano, R. P., Berrigan, D., Dodd, K. W., Masse, L. C., Tilert, T., & McDowell, M. (2008). Physical activity in the United States measured by accelerometer. *Medicine and Science in Sports and Exercise, 40*(1), 181-188. doi: 10.1249/mss.0b013e31815a51b3
Turrell, G., Haynes, M., Burton, N. W., Giles-Corti, B., Oldenburg, B., Wilson, L. A., et al. (2010). Neighborhood disadvantage and physical activity: baseline results from the HABITAT multilevel longitudinal study. *Annals of Epidemiology, 20*(3), 171-181. doi: 10.1016/j.annepidem.2009.11.004
Van Hulst, A., Thomas, F., Barnett, T. A., Kestens, Y., Gauvin, L., Pannier, B., et al. (2012). A typology of neighborhoods and blood pressure in the RECORD Cohort Study. *Journal of Hypertension, 30*(7), 1336-1346. doi: 10.1097/HJH.0b013e3283544863
Veitch, J., Ball, K., Crawford, D., Abbott, G. R., & Salmon, J. (2012). Park improvements and park activity: a natural experiment. *American Journal of Preventive Medicine, 42*(6), 616-619. doi: 10.1016/j.amepre.2012.02.015

Vernez-Moudon, A., & Lee, C. (2003). Walking and bicycling: an evaluation of environmental audit instruments. *American Journal of Health Promotion, 18*(1), 21-37.
Veugelers, P., & Fitzgerald, A. (2005). Prevalence of and risk factors for childhood overweight and obesity. *Canadian Medical Association Journal, 173*(6), 607-613.
Veugelers, P., Sithole, F., Zhang, S., & Muhajarine, N. (2008). Neighborhood characteristics in relation to diet, physical activity and overweight of Canadian children. *International Journal of Pediatric Obesity, 3*(3), 152-159.
Wang, Y., & Lobstein, T. (2006). Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes, 1*(1), 11-25.
Wasserman, J. A., Suminski, R., Xi, J., Mayfield, C., Glaros, A., & Magie, R. (2014). A multi-level analysis showing associations between school neighborhood and child body mass index. *International Journal of Obesity (Lond)*. doi: 10.1038/ijo.2014.64
Whitaker, R. C., Wright, J. A., Pepe, M. S., Seidel, K. D., & Dietz, W. H. (1997). Predicting obesity in young adults from childhood and parental obesity. *New England Journal of Medicine, 337*, 869-873.
Willett, W. C. (2008). Nutritional epidemiology. In K. J. Rothman, S. Greenland & T. L. Lash (Eds.), *Modern Epidemiology* (3rd ed., pp. 580-597). Philadelphia: Lippincott Williams & Wilkins.
Williams, A. J., Wyatt, K. M., Hurst, A. J., & Williams, C. A. (2012). A systematic review of associations between the primary school built environment and childhood overweight and obesity. *Health Place, 18*(3), 504-514. doi: 10.1016/j.healthplace.2012.02.004
Williams, C. L., Hayman, L. L., Daniels, S. R., Robinson, T. N., Steinberger, J., Paridon, S., et al. (2002). Cardiovascular health in childhood: A statement for health professionals from the committee on atherosclerosis, hypertension, and obesity in the young (AHOY) of the Council on Cardiovascular Disease in the Young, American Heart Association. *Circulation, 106*(1), 143-160. doi: 10.1161/01.cir.0000019555.61092.9e
Willms, J. D., Tremblay, M. S., & Katzmarzyk, P. T. (2003). Geographic and demographic variation in the prevalence of overweight Canadian children. *Obesity Research, 11*(5), 668-673. doi: 10.1038/oby.2003.95
Wolch, J., Jerrett, M., Reynolds, K., McConnell, R., Chang, R., Dahmann, N., et al. (2011). Childhood obesity and proximity to urban parks and recreational resources: a longitudinal cohort study. *Health Place, 17*(1), 207-214. doi: 10.1016/j.healthplace.2010.10.001
Wolfenden, L., Wyse, R., Nichols, M., Allender, S., Millar, L., & McElduff, P. (2014). A systematic review and meta-analysis of whole of community interventions to prevent excessive population weight gain. *Preventive Medicine, 62c*, 193-200. doi: 10.1016/j.ypmed.2014.01.031
Woodman, J., Lorenc, T., Harden, A., & Oakley, A. (2008). Social and environmental interventions to reduce childhood obesity: a systematic map of reviews: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London.

World Health Organisation. (2014). The WHO Child Growth Standards. Retrieved April, 2014, from http://www.who.int/childgrowth/standards/en/

Yach, D., McKee, M., Lopez, A. D., & Novotny, T. (2005). Improving diet and physical activity: 12 lessons from controlling tobacco smoking. *BMJ, 330*, 898-900.

Zenk, S. N., Schulz, A. J., Matthews, S. A., Odoms-Young, A., Wilbur, J., Wegrzyn, L., et al. (2011). Activity space environment and dietary and physical activity behaviors: a pilot study. *Health Place, 17*(5), 1150-1161. doi: 10.1016/j.healthplace.2011.05.001

Zenk, S. N., Schulz, A. J., Mentz, G., House, J. S., Gravlee, C. C., Miranda, P. Y., et al. (2007). Inter-rater and test-retest reliability: methods and results for the neighborhood observational checklist. *Health Place, 13*(2), 452-465. doi: 10.1016/j.healthplace.2006.05.003

Zhang, X., Kaufer Christoffel, K., Mason, M., & Liu, L. (2006). Identification of contrastive and comparable school neighborhoods for childhood obesity and physical activity research. *International Journal of Health Geographics, 5*(14), 1-9.

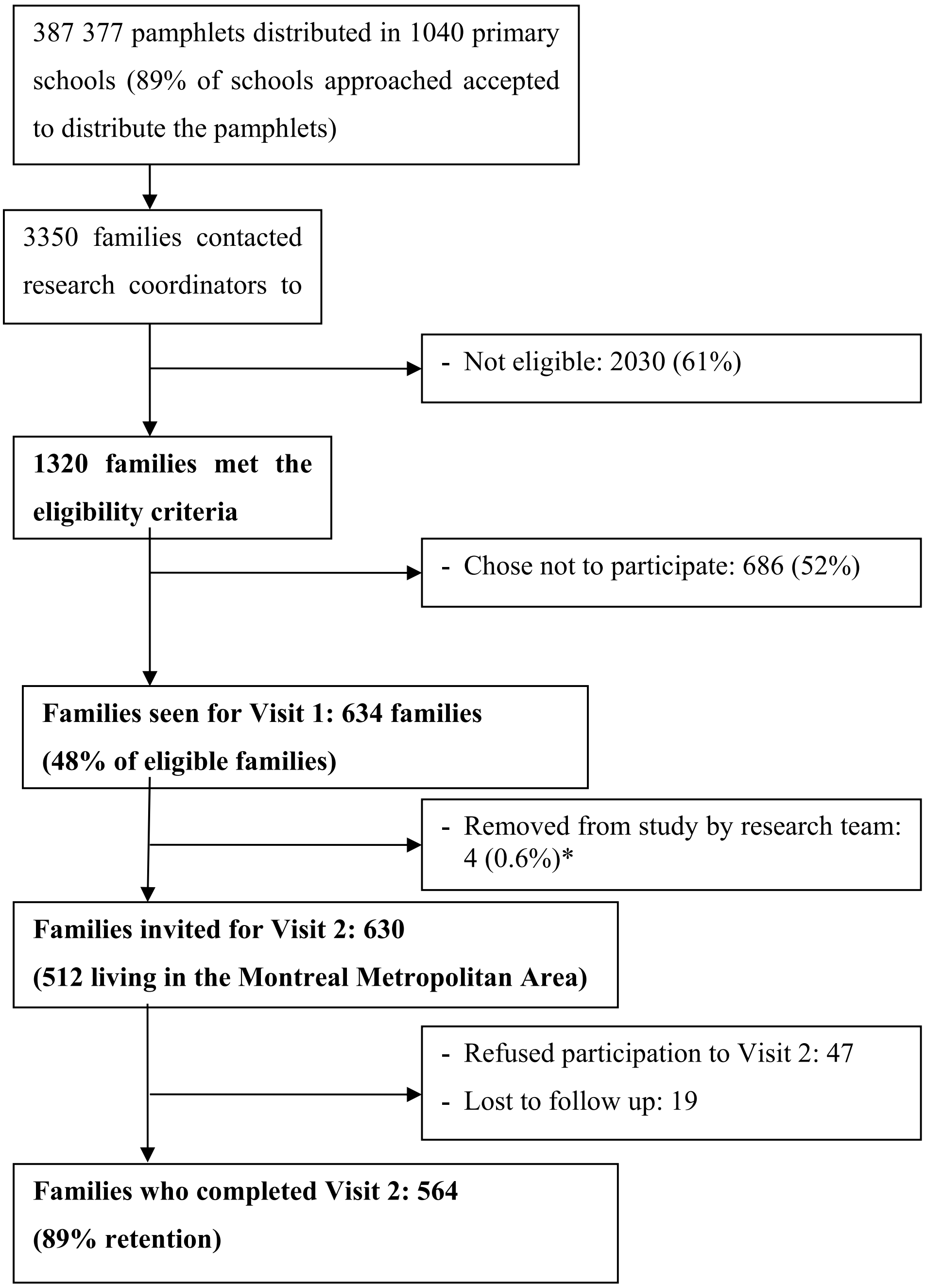
Zhang, X., Onufrak, S., Holt, J. B., & Croft, J. B. (2013). A multilevel approach to estimating small area childhood obesity prevalence at the census block-group level. *Preventing Chronic Disease, 10*, E68. doi: 10.5888/pcd10.120252

Zimmet, P., Alberti, K. G., Kaufman, F., Tajima, N., Silink, M., Arslanian, S., et al. (2007). The metabolic syndrome in children and adolescents - an IDF consensus report. *Pediatr Diabetes, 8*(5), 299-306. doi: 10.1111/j.1399-5448.2007.00271.x

APPENDICES

Appendix A. The QUALITY cohort

Figure 1. Recruitment and participation in the QUALITY study



* Families were removed from study because child or parents was unable or refused to complete most or all of data collection for baseline assessment after providing consent to participate

Appendix B. Ethical certificate

Le 30 avril 2014

Madame Tracie Barnett

OBJET: Titre du projet: Features of the Social and Built Environments and Obesity among Children: A comparison of statistical methods

No. de dossier: 3880

Responsables du projet: Tracie Barnett Ph. D., **Chercheuse principale: Andraea Van Hulst** (étudiante au PhD, École de santé publique de l'Université de Montréal)
Collaborateurs: Lise Gauvin, École de santé publique de l'Université de Montréal et Mélanie Henderson

CHU Sainte-Justine
Le centre hospitalier universitaire mère-enfant

Pour l'amour des enfants

Université de Montréal

Madame,

Votre projet cité en rubrique a été approuvé par le comité d'éthique de la recherche en date du 30 avril 2014. Vous trouverez ci-joint la liste des documents approuvés. Aucun formulaire d'information et de consentement n'a été estampillé puisque vous utilisez ceux du projet #2631 – Features of the Built Environment in Residential Neighbourhoods that Influence Excess Weight and Weight Related Behaviours in a Cohort of Children at Risk for Obesity. (Notez que pour une collaboration avec un (ou plusieurs) tiers (institutions ou entreprises privées) impliquant des transferts de fonds et/ou données et/ou matériel biologique, une entente (contrat) doit être conclue avec le Bureau des ententes de recherche (BER).

Tous les projets de recherche impliquant des sujets humains doivent être réexaminés annuellement et la durée de l'approbation de votre projet sera effective jusqu'au **30 avril 2015**. Notez qu'il est de votre responsabilité de soumettre une demande au comité pour que votre projet soit renouvelé avant la date d'expiration mentionnée. Il est également de votre responsabilité d'aviser le comité dans les plus brefs délais de toute modification au projet et/ou tout événement pouvant toucher à la sécurité des participants.

Nous vous souhaitons bonne chance dans la réalisation de votre projet et vous prions de recevoir nos meilleures salutations.

Me Geneviève Cardinal
Présidente du Comité d'éthique de la recherche

GC/mhl
c.c. : BER

3175, Côte-Sainte-Catherine
Montréal (Québec)
H3T 1C5

CHU Sainte-Justine
Le centre hospitalier universitaire mère-enfant

Pour l'amour des enfants

Université de Montréal

Liste des documents approuvés par le CÉR

Titre du projet:
Features of the Social and Built Environments and Obesity among Children: A comparison of statistical methods

No. de dossier: 3880

Date d'approbation : mercredi 30 avril 2014

Responsables du projet: BARNETT TRACIE Ph. D., **Chercheuse principale: Andraea Van Hulst** (étudiante au PhD, École de santé publique de l'Université de Montréal)
Collaborateurs: Lise Gauvin, École de santé publique de l'Université de Montréal et Mélanie Henderson

Liste:

- Protocole de recherche daté du 7 avril 2010

3175, Côte-Sainte-Catherine
Montréal (Québec)
H3T 1C5

Appendix C. Neighbourhood Observation Checklist

Items 1 to 31 of the **Neighbourhood Observation Checklist** were completed for up to 10 street segments in the participants' immediate neighbourhood, including the street segment where the residence is localized and up to 9 first and second degree connecting streets. These items were adapted from the Montreal Neighbourhood Assessment Tool (MoNAT) [3] and the Systematic Pedestrian and Cycling Environmental Scan (SPACES) tool[4].

Items 1 to 12 of the **General Impression Checklist** were completed after observers had walked over all street segments within a 500 m network buffer centered on the child's residence. These items were adapted from the Neighbourhood Active Living Potential assessment tool[5].

Electronic checklists were developed to complete assessments on a touch screen hand held computer. Observers were also provided with the following paper copy checklists as backup in case a problem occurred with the electronic questionnaires.

---

[3] Paquet C, Cargo M, Kestens Y, Daniel M. Reliability of an instrument for direct observation of urban neighbourhoods. *Landscape and urban planning.* 2010;97(3):194-201.

[4] Pikora, T. J., Bull, F. C., Jamrozik, K., Knuiman, M., Giles-Corti, B., & Donovan, R. J. (2002). Developing a reliable audit instrument to measure the physical environment for physical activity. *American Journal of Preventive Medicine, 23*(3), 187-194.

[5] Gauvin L, Richard L, Craig C, et al. From walkability to active living potential. An "ecometric" validation study. *Am J Prev Med.* 2005;28(2S2):126-133.

Neighbourhood Observation Checklist

NIF	
Identification de l'observateur	
Identification du co-équipier	
Code de l'observateur (A ou B)	
Date	
Heure début (si applicable)	
1. Identifiant du tronçon	
Nom de rue	

Côté marché		
	Impaire	1
	Pair	2
	Ne peut pas déterminer	3
2. Côtés stationnement		
	Aucun	1
	Un	2
	Les deux	3
3. Nb de voies (Inscrire nb entre 1 et 7, inscrire 0 si ne s'applique pas)		
4. Sens du trafic		
	Unique	1
	Double sens	2
5. Type de rue		
	Rue locale	1
	Artère mineure	2
	Artère majeure ou industriel	3
	Rue 100% industrielle	4
6. Trottoir		
	Oui, chaque côté de la rue	1
	Oui, sur un côté de la rue	2
	Non, pas de trottoir	3 (Q10)
7. Condition trottoir		
	Pas de détérioration	1
	Détérioration sans besoin de réparation	2
	Détérioration importante nécessitant réparation	3
	Sous construction ou rénovation	4
8. Estimer la largeur en cm		
9. a) Séparation entre trottoir / rue		
	Aucune séparation	1
	Zone tampon sans obstruction visuelle	2
	Zone tampon avec obstruction visuel	3
	Obstruction seulement	4
b) Obstructions		
	Moins d'un mètre	1
	Un mètre ou plus	2
	Ne s'applique pas	3

10. Condition chaussée		
	Pas de détérioration	1
	Présence de détérioration sans besoin de réparation	2
	Détérioration importante nécessitant réparation	3
	Sous construction/rénovation	4
11. Piste cyclable		
	Oui	1
	Non	2 (Q14)
12. Piste cyclable bien entretenue		
	Oui	1
	Non	2
13. Type de séparation		
	Aucune séparation	1
	Lignes peintes sur la rue	2
	Poteaux	3
	Petite bande d'herbe ou de terre de moins de 1 m	4
	Large bande d'herbe, de terre d'au moins 1 m	5
	Bande de béton, d'asphalte, de pavé uni ou de gravier	6
	Trottoir	7
	Mixte	8
b) Si mixte, préciser :		
14. A- Éléments sur le tronçon : Terre-p. centre tronçon	Cocher si oui	
B- Panneaux station. Résidentiel	Cocher si oui	
C- Passage piétonnier <u>sur le tronçon</u> blanc ou jaune	Cocher si oui	
D- Passage piétonnier <u>aux intersections</u> blanc ou jaune	Cocher si oui	
E- Feux signalisation piétons	Cocher si oui	
F- Intersection pavée piétons	Cocher si oui	
G- Avancée de trottoir aux intersections	Cocher si oui	
15. A- Éléments sur la chaussée : Dos-d'âne	Cocher si oui	
B-Obstacles importants	Cocher si oui	
C-Feux de signalisation pour voitures	Cocher si oui	
D-Arrêt toutes directions	Cocher si oui	
E-Arrêt mi-tronçon	Cocher si oui	

16. Enseigne/marquage au sol : Traverse de piétons	Cocher si oui	
Corridor scolaire	Cocher si oui	
Attn à nos enfants/ enfants qui jouent/ zone scolaire/ ralentir	Cocher si oui	
Parent-Secours, surveillance de quartier	Cocher si oui	
Vitesse 30 km/h ou moins	Cocher si oui	
17. Arrêt moyen de transport		
	Aucun	1
	Métro	2
	Autobus avec abris	3
	Autobus sans abris	4
	Autre	5
18. Arbres		
	Très peu ou pas du tout	1
	Quelques de façon isolée	2
	Plusieurs arbres	3
19. a) Graffiti		
	Pas du tout à peine	1
	Un peu	2
	Beaucoup	3
b) Bris/vandalisme/éléments abandonnés	Cocher si oui	
c) Ordure ou déchet	Cocher si oui	
d) Édifice abandonné	Cocher si oui	
e) Éclairage suffisant		
	Oui	1
	Non	2
	Impossible à déterminer	3
20. Type de demeures qui prédominent		
	Bungalow ou cottages détachés	1
	Bungalow ou cottages jumelés	8
	Duplex/Triplex détachés	2
	Duplex/Triplex jumelés	3
	Duplex/triplex/maison de ville en rangée	4
	Multiplex/Bloc appartement	5
	Aucune résidence sur le tronçon	6
	Autre ou mixte	7
b) Autre ou mixte, préciser :		

21. Fonctions prédominantes des bâtiments :	
Résidentiel	1
Petits et moyens commerces	2
Milieux scolaires ou de gardes	3
Bâtiments récréatifs intérieurs	4
Espaces récréatifs extérieurs	5
Centre d'achat ou magasins à grandes surfaces	6
Entreprises privées	7
Infrastructures de transport	8
Espaces de stationnement	9
Espaces naturels non aménagés	10
Espaces vides ou abandonnés	11
Autres ou mixte	12
b) Autres ou mixte, préciser :	
22. Autres fonctions bâtiments	
Aucune autre fonction	0
Résidentiel	1
Petits et moyens commerces	2
Milieux scolaires ou de gardes	3
Bâtiments récréatifs intérieurs	4
Espaces récréatifs extérieurs	5
Centre d'achat ou magasins à grandes surfaces	6
Entreprises privées	7
Infrastructures de transport	8
Espaces de stationnement	9
Espaces naturels non aménagés	10
Espaces vides ou abandonnés	11
Autres ou mixte	12
b) Autres ou mixte, préciser :	
23. Ruelle (tronçon 1 seulement) Cocher si oui	
24. Si oui, ruelle bien entretenue? Cocher si oui	
25. Items dans la ruelle (cocher si présent)	
A- Gros objets abandonnés	
B- Déchets au sol	
C- Bouteilles d'alcool/verre brisé	
D- Beaucoup graffitis	
E- Efforts d'embellissement	
F- Dos d'ânes	
26. Proportion bâtiments bien entretenus (si aucun bâtiment aller à Q27)	
Tous ou presque tous	1
Environ le ¾	2
Environ la moitié	3
Moins de la moitié ou aucun	4
Aucun bâtiment sur le tronçon	5

27. Proportion de cours de résidence bien entretenues (si aucune cour aller à Q28)	
Toutes ou presque toutes	1
Environ le ¾	2
Environ la moitié	3
Moins de la moitié ou aucune	4
Aucune cour sur le tronçon	5
28. Proportion de résidence avec effort embellissement (si aucune résidence aller à Q29)	
Toutes ou presque toutes	1
Environ le ¾	2
Environ la moitié	3
Moins de la moitié ou aucune	4
Aucune résidence sur le tronçon	5
29. Cocher si présent A-Centre sportif	
B-Terrain de jeu/ terrain sportif extérieur	
C-Restauration rapide	
D-Autres restaurants	
E-Dépanneur ou mini-marché	
30. Publicité commerciales Cocher si oui	
31. Pub. Chaînes resto rapide Cocher si oui	

General Impression Checklist

IMPRESSION GÉNÉRALE

NIF	
Identification de l'observateur	
Identification du co-équipier	
Code de l'observateur (A ou B)	
Date	
1 Heure début	

2 Circulation menaçante piéton	
Pas menaçante	1
Un peu menaçante	2
Assez menaçante	3
Très menaçante	4
3 Circulation menaçante vélo	
Pas menaçante	1
Un peu menaçante	2
Assez menaçante	3
Très menaçante	4
4 Effort déplacements à pied	
Pas du tout d'effort	1
Un peu d'effort	2
Assez d'effort	3
Beaucoup d'effort	4
5 Effort déplacement à vélo	
Pas du tout d'effort	1
Un peu d'effort	2
Assez d'effort	3
Beaucoup d'effort	4
6 Sentiment de sécurité	
Très sécuritaire	1
Assez sécuritaire	2
Plus ou moins sécuritaire	3
Pas sécuritaire	4
7 Espaces naturels	
Pas ou très peu d'espaces nat.	1
Quelques espaces nat.	2
Assez espaces nat.	3
Beaucoup d'espaces nat.	4
8 Mixité des espaces	
Aucune ou très peu de mixité	1
Un peu de mixité	2
Assez de mixité	3
Beaucoup de mixité	4
9 Signes de désordre social	
Aucun ou très peu	1
Quelques signes	2
Assez de signes	3
Beaucoup de signes	4

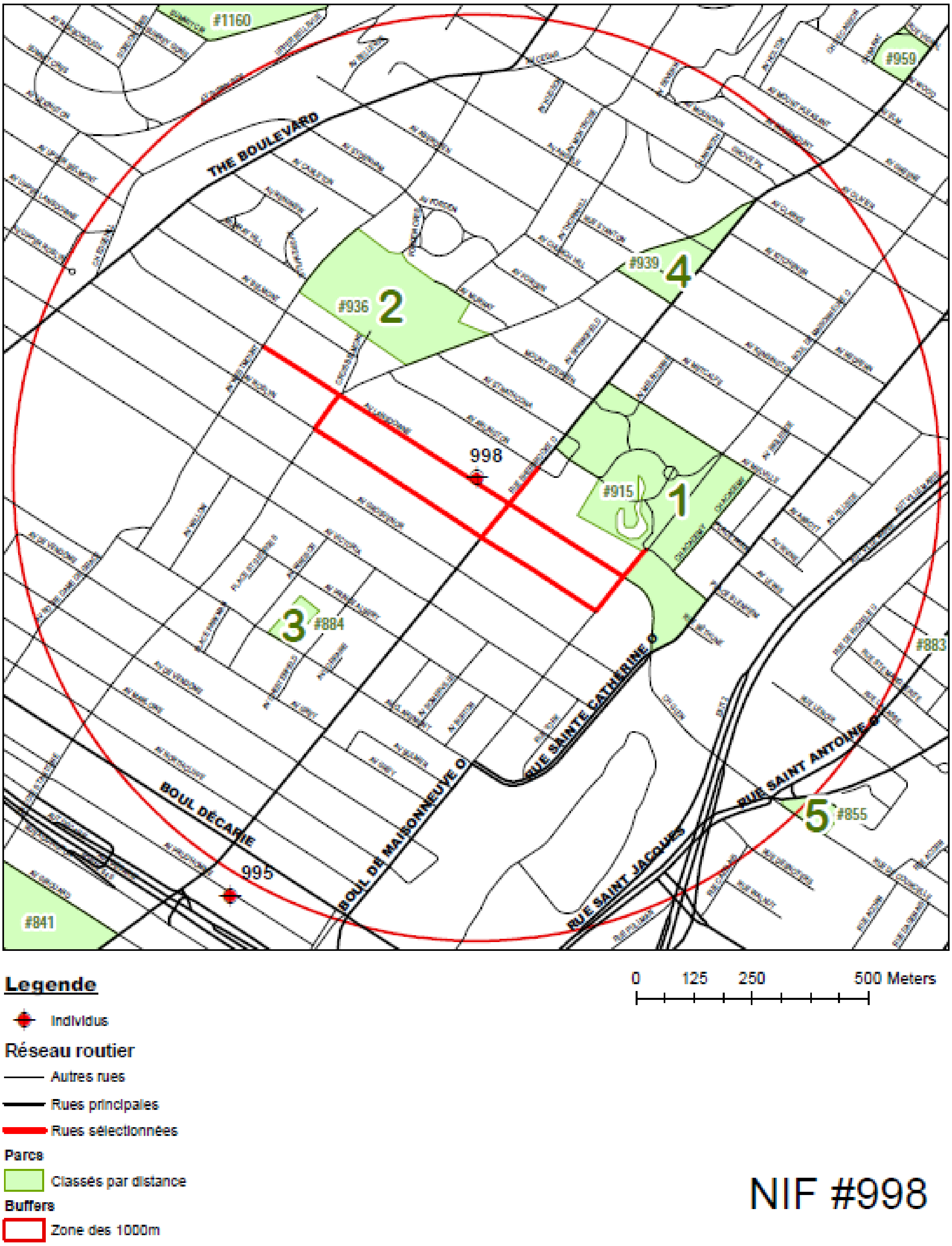
10 Ambiance générale	
Très agréable	1
Assez agréable	2
Plus ou moins agréable	3
Pas du tout agréable	4
11 Esthétique générale	
Très joli	1
Assez joli	2
Plus ou moins joli	3
Pas du tout joli	4
12 Heure à la fin de l'évaluation	

Appendix D. Observer map

This appendix presents a sample map that was used for a 'test-neighbourhood' during the training of the research assistants in preparation for the in-person neighbourhood assessments.

The first map identified the 1 km circular buffer around the residence as well as the parks numbered in order of proximity to the residence. Although not shown in this test-neighbourhood map, a 500 m road network buffer centered on the residence was delimited on the actual study participants' maps. Observers completed the General Impression Checklist after having walked over all street segments contained within this buffer zone.

The second map identified up to 10 street segments, each of which were assessed using the Neighbourhood Observation Checklist.


#1160
#959
THE BOULEVARD
#939
4
#936
2
998
#915
1
3
#884
#883
RUE SAINTE CATHERINE
BOUL DÉCARIE
995
BOUL DE MAISONNEUVE O
RUE SAINT ANTOINE O
5
#855
RUE SAINT JACQUES
#841
Legende
Individus
Réseau routier
Autres rues
Rues principales
Rues sélectionnées
Parcs
Classés par distance
Buffers
Zone des 1000m
0 125 250 500 Meters

NIF #998

NIF #998

Appendix E. Cluster analysis in neighbourhoods studies

The following manuscript was prepared in the context of a research internship at the INSERM (Paris) under the supervision of Dr Basile Chaix. The analysis was based on data of the RECORD (Residential Environment and Coronary Heart Disease) Study. Although based on an adult population in Europe, the RECORD study included similar neighbourhood environment measures to those of the QUALITY study (geographically linked Census and administrative data).

A typology of neighborhoods and blood pressure in the RECORD Cohort Study

Running Head:
Neighborhood types and blood pressure

Andraea VAN HULST [1,2]
Frédérique THOMAS [3]
Tracie A. BARNETT [1,2]
Yan KESTENS [1,4]
Lise GAUVIN [1,4,5]
Bruno PANNIER [3]
Basile CHAIX [6,7]

[1] Department of Social and Preventive Medicine, Université de Montréal, Montreal, Canada;
[2] Centre de recherche du CHU Sainte-Justine, Montreal, Canada;
[3] Centre d'Investigations Préventives et Cliniques, Paris, France;
[4] Centre de Recherche du Centre Hospitalier de l'Université de Montréal (CRCHUM), Montreal, Canada;
[5] Centre de Recherche Léa-Roback sur les Inégalités Sociales de Santé de Montréal, Université de Montréal, Montreal, Canada;
[6] Inserm, Paris, France;
[7] Université Pierre et Marie Curie-Paris6, UMR-S 707, Paris, France.

Article published in the July 2013 issue of the *Journal of Hypertension*, vol 30, no 7, 1336-46.

Corresponding Author and Requests for Reprints:

Counts:

Words (including references and acknowledgements): 5059

Tables: 5

Supplementary Digital Content Files: 1 Figure and 1 Table

Abbreviations:

b.p.m., beats per minute; BP, blood pressure; DBP, diastolic blood pressure; RECORD Study, Residential Environment and Coronary Heart Disease Study; SBP, systolic blood pressure

Acknowledgments:

We thank Alfred Spira, head of IReSP, for his advice and support. We are grateful to INPES (and Pierre Arwidson) for the continued support since the study was initiated. We also thank Danièle Mischlich and Mélani Alberto from the Ile-de-France ARS and Nathalie Catajar and Muriel Hirt from the Ile-de-France DRJSCS for their support with the study. We are grateful to Insee, the French National Institute of Statistics and Economic Studies, which provided support for the geocoding of the RECORD participants and provided access to relevant geographical data (with special thanks to Pascale Breuil and Jean-Luc Lipatz). We thank Geoconcept for allowing us to access to the Universal Geocoder software and Alain Weill from CNAM-TS for his support in merging healthcare reimbursement data from the SNIIR-AM to the RECORD database. Lastly, we thank CNAM-TS and the Caisse Primaire d'Assurance Maladie de Paris (CPAM-P, France) for helping make the RECORD Study possible.

Sources of Funding:

The RECORD project received support from the Institute for Public Health Research (IReSP, Institut de Recherche en Santé Publique); the National Institute for Prevention and Health Education (INPES, Institut National de Prévention et d'Éducation pour la Santé) (Prevention Program 2007; 2010–2011 financial support; and 2011–2013 financial support); the National Institute of Public Health Surveillance (InVS, Institut de Veille Sanitaire) (Territory and Health Program); the French Ministries of Research and Health (Epidemiologic Cohorts Grant 2008); the National Health Insurance Office for Salaried Workers (CNAM-TS, Caisse Nationale d'Assurance Maladie des Travailleurs Salariés); the Ile-de-France Regional Council (Conseil Régional d'Île-de-France, DIM SEnT and CODDIM); the National Research Agency (ANR, Agence Nationale de la Recherche) (Health–Environment Program 2005); the Ile-de-France Regional Health Agency (ARS, Agence Régionale de Santé); the City of Paris (Ville de Paris); and the Ile-de-France Youth, Sports, and Social Cohesion Regional Direction (DRJSCS, Direction Régionale de la Jeunesse, des Sports et de la Cohésion Sociale). The project also received support from the Canadian Institutes for Health Research (PI: Y Kestens). A van Hulst received support from a CIHR Training Grant in Population Intervention for Chronic Disease Prevention, and a doctoral scholarship from the Fonds de la recherche en santé du Québec. This work was conducted as part of a research internship supported by the Fondation CHU Sainte-Justine and Fondation des Étoiles. TA Barnett and Y Kestens are Fonds de la recherche en santé du Québec research scholars. L Gauvin holds a Canadian Institutes of Health Research (CIHR)/Centre de Recherche en Prévention de l'Obésité Chair in Applied Public Health on Neighbourhoods, Lifestyle, and Healthy Body Weight.

Conflicts of Interest: none

ABSTRACT

Background: Studies of associations between neighborhood environments and blood pressure (BP) have relied on imprecise characterizations of neighborhoods. This study examines associations between SBP and DBP and a neighborhood typology based on numerous residential environment characteristics.

Methods: Data from the RECORD Study involving 7290 participants recruited in 2007–2008, aged 30 to 79 years, and residing in the Paris metropolitan area were analyzed. Cluster analysis was applied to measures of the physical, services and social interactions aspects of neighborhoods. Six contrasting neighborhood types were identified and examined in relation to SBP and DBP using multivariable linear regression, adjusting for individual/neighborhood socioeconomic status and individual risk factors for hypertension.

Results: The neighborhood typology included suburban to central urban neighborhood types with varying levels of adverse social conditions. SBP was 2-3 mmHg higher among participants residing in suburban neighborhood types and in the urban with low social standing neighborhood type, compared to residents of central urban with intermediate social standing neighborhoods (reference). The association between residing in urban low social standing neighborhoods and SBP remained after adjusting for individual/neighborhood socioeconomic status and individual risk factors for hypertension. Overall, an inverse association between DBP and level of urbanicity of the neighborhood was observed, even after adjustment for individual risk factors for hypertension.

Conclusions: Variations in BP were observed by levels of urbanicity and social conditions of residential neighborhoods, with different patterns for SBP and DBP. Population interventions to reduce hypertension targeted towards specific neighborhood types holds promise.

KEY WORDS: blood pressure; built environment; cluster analysis; cohort study; neighborhood characteristics; pulse pressure; social environment

INTRODUCTION

Over the past 15 years, a considerable amount of literature has focused on links between neighborhood environments and behavioral and metabolic risk factors for cardiovascular diseases [1]. However, the published literature on effects of neighborhood exposures is much scarcer for cardiovascular disease risk factors such as hypertension, dyslipidemias, and diabetes than for physical inactivity and obesity [2].

Specifically with respect to blood pressure (BP), the majority of studies have focused on the impact of the socioeconomic status of residential neighborhoods [2]. Studies have generally shown that lower neighborhood socioeconomic status is associated with higher BP levels after adjusting for individual socioeconomic status [3-9]. Other dimensions of the neighborhood environment have not been investigated as extensively. For example, with respect to the neighborhood physical environment, studies have focused mainly on the impact of air and noise pollution on BP [10-13] and few studies have examined links between features of the built environment and BP [14, 15] despite growing evidence of its associations with excess weight, a known risk factor for hypertension [16]. With regards to the availability of services in the neighborhood, past studies have focused on the food environment (i.e., food stores and restaurants) and have reported mixed findings in relation to BP levels [14, 15, 17]. Lastly, with respect to social interactions in the neighborhood environment, studies have shown that elevated crime and perceived insecurity as well as low social cohesion and social capital are associated with elevated BP [14, 18].

There are limitations to existing work on neighborhood environments and hypertension. First, each study is restricted to a limited number of neighborhood dimensions; yet Chaix et al. [19] identified at least four distinct domains of neighborhood environmental factors: the physical environment, the services environment, the social interactions environment, and the sociodemographic environment. Second, studies have often failed to properly control for important neighborhood level confounders such as neighborhood socioeconomic status, which may result in spurious associations [20]. Third, studies have not adequately addressed the fact that many neighborhood characteristics are strongly correlated with one another thus limiting ability to disentangle effects of one variable over another or to consider the combined effects of exposure to multiple co-occurring neighborhood environment conditions on BP.

Given limitations in existing literature, we examined associations between SBP and DBP and a neighborhood typology based on a combination of several residential neighborhood environment characteristics. We improve on past efforts by: i) using data from a large, well-defined population-based cohort; ii) considering a large number of variables related to the physical, services, and social interactions environment; iii) constructing a typology of neighborhoods allowing us to assess the combined effect of neighborhood characteristics that are strongly correlated with one another; iv) controlling for neighborhood socioeconomic status to address neighborhood-level confounding; and v) assessing whether individual risk factors for hypertension may explain associations between neighborhood characteristics and BP.

METHODS

Participants

The RECORD Study (“Residential Environment and Coronary Heart Disease”, www.record-study.org) includes 7290 French residents recruited between March 2007 and February 2008. The study benefited from free medical checkups, offered every five years by the French National Health Insurance System for Salaried Workers to all working and retired employees and their families. A convenience sample of participants was recruited during these two-hour preventive medical checkups conducted by the Centre d’Investigations Préventives et Cliniques in four of its health centers, located in the Paris metropolitan area. Eligibility criteria were: age 30–79 years; ability to complete study questionnaires; and residence in one of the 10 (out of 20) administrative divisions of Paris or 111 other municipalities selected in the metropolitan area. These territories were selected *a priori* to include suburban and urban areas from contrasted socioeconomic backgrounds. Participants completed questionnaires, provided biological specimens and underwent clinical examinations. A detailed description of the study is available elsewhere [21, 22]. The study protocol was approved by the French Data Protection Authority.

Measures

Blood pressure

During the medical checkup, supine brachial BP was measured by trained nurses three times in the right arm after a 10 minute rest period, using a manual mercury sphygmomanometer [23]. A standard cuff size was used, but a large cuff was employed if necessary. SBP and DBP were defined as the first and fifth Korotkoff phases, respectively, using the mean of the last two BP measurements [24]. In secondary analyses pulse pressure was defined as the difference between SBP and DBP.

Individual sociodemographic variables

Age was examined as a continuous variable. Education was divided in four categories: no education (low); primary and lower secondary education (middle-low); higher secondary and lower tertiary education (middle-high); and upper tertiary education (high). Employment status was coded in four categories: employed, unemployed, retired, and other. Binary variables for financial strain and for residence ownership were obtained from self-report questionnaires. We followed the approach proposed by Beckman et al. [25] in attributing to each individual the 2004 Human Development Index of his/her self-reported country of birth, as a proxy of the country's social development level. Following the United Nations Development Program [26], a binary variable was derived to distinguish participants born in low development countries (Human Development Index < 0.5) from those born in middle or high development countries (Human Development Index ≥ 0.5).

Antihypertensive medication use

Individual use of antihypertensive medication was determined by merging a national health insurance administrative database for all healthcare reimbursements in 2006–2009 to the RECORD Study. A binary variable was created indicating whether or not individuals had been reimbursed for any antihypertensive medication in the previous year.

Risk factors for hypertension

Family history of hypertension was self-reported. Participants were asked whether or not they engaged in physical activities equivalent to a total of 1 hour of walking throughout the day (including at work, for transportation, and during leisure time). Alcohol consumption was coded in four categories: never, former, light, and regular drinkers (>2 glasses per day for women and >3 glasses per day for men). For smoking status, we distinguished between never, former, and current smokers. Height (using a wall-mounted stadiometer) and weight (using a calibrated scale) were recorded by a nurse. Body mass index (BMI) was divided into three categories (normal: <25 kg/m^2, overweight: 25 to <30 kg/m^2, and obese: ≥30 kg/m^2). Waist circumference was measured using an inelastic measurement tape placed midway between the lower ribs and iliac crests on the midaxillary lines, and was divided into three categories (<94 cm, 94 to 102 cm, and >102 cm for men; <80 cm, 80 to 88 cm, and >88 cm for women). Resting heart rate was measured by ECG after a five to seven minute rest period and was subsequently divided into three categories: <60 bpm, 60 to 70 bpm, and ≥70 bpm (70 rather than 80 bpm was used as a cut-off because only 4.8% of participants had a resting heart rate ≥80 bpm).

Neighborhood measures

In order to create a meaningful and multidimensional neighborhood typology, we defined measures pertaining to the physical and services neighborhood environments using multiple methodologies including simple aggregation with classical database management software and geographic information systems. When possible, variables were computed for 500 m radius circular zones centered on the participants' residence (ego-centered areas) [27]. Additional variables related to the physical and social interactions environments were derived through ecometric modeling techniques wherein individual responses from questionnaire data are aggregated for residents of a given neighborhood [28]. These variables were defined at the level of relatively broad administrative units (Census areas) comprising a median of 10662 inhabitants (inter-quartile range: 9164, 12279). Details on definitions and measurement approaches for neighborhood measures are described in Table 1.

Regarding the neighborhood physical environment, the following variables were defined for 500 m radius zones (unless indicated otherwise): 1) two indicators of building characteristics (proportion of neighborhood area covered with buildings and mean building height); 2) four indicators describing the local street network (density of three or more-way street intersections, average street block length, link to node ratio, and route directness); 3) presence of a highway within 250 m of the residence; 4) two measures of road traffic-related pollution (concentrations of nitrogen dioxide and particulate matters); 5) exposure to air traffic noise at 1000, 2000, and 3000 m above the participant's residence; 6) presence of a waste treatment facility; 7) surface area covered by parks and green spaces; and 8) presence of lakes or waterways. Two additional ecometric variables were considered: neighborhood active living potential and physical deterioration of the neighborhood.

Indicators of the neighborhood services environment within 500 m radius circular zones include: total number of destinations; presence of historic monuments and other enjoyable sites; number of public transportation lines; presence of a commercial center; number of hypermarkets, supermarkets, and grocery stores; number of fruit and vegetable shops and stands; proportion of fast food restaurants among all restaurants; and number of sport facilities. Lastly, the proportion of incoming and outgoing traffic by public transportation rather than by car was obtained from a road traffic model for larger neighborhood areas.

Indicators of the neighborhood social interactions environment include school violence near the residence; and ecometric variables each obtained from responses on three to four questionnaire items namely, neighborhood social cohesion; stressful social interactions among neighbors; neighborhood mistrust and hostility; and stigmatized neighborhood identity based on participants' claims of a poor neighborhood reputation.

Finally, two neighborhood sociodemographic variables were computed using 2006 census data for 500 m radius zones around the residence: the proportion of residents aged ≥ 15 years who completed university education used as an indicator of neighborhood socioeconomic status, and population density computed as the number of inhabitants per km^2. A previous analysis of RECORD data demonstrated that neighborhood level of education was a much stronger determinant of blood pressure than other neighborhood socioeconomic variables [8].

Statistical analysis

Definition of a neighborhood typology

A two-step approach was used to define the neighborhood typology. In the first step, we selected a number of variables from the original list of neighborhood characteristics. To do so, factor analysis was performed on the variables listed in Table 1 (with the exception of the neighborhood socioeconomic variable which was considered as a potential confounder in multivariable models, and population density which was used to describe the resulting clusters), using a varimax rotation and principal components extraction. A four-factor solution was selected based on Eigen-values >1. Internal consistency of factors was also examined. We then retained only variables with factor loadings ≥0.75 for subsequent analyses. This allowed us to select variables that contributed the most to the underlying factors. A total of 13 variables were retained (see Table 2) which were then standardized (mean of 0 and standard deviation of 1).

In the second step, cluster analytic methods were applied to the standardized variables selected in step 1, in order to identify unique neighborhood types for subsequent examination in relation to BP [29]. Hierarchical cluster analysis using Ward's method starts with each multidimensional observation (neighborhood) as a single cluster and then repeatedly merges the next two closest clusters in terms of

Euclidian distances between observations until a single, all-encompassing cluster remains [30]. Application of this method results in a neighborhood typology wherein neighborhoods that are substantively comparable on selected characteristics are grouped together even though they are not necessarily geographically adjacent [31-35]. Following assessment of corresponding dendograms, we examined results for n=4 to n=7 clusters, attempting to identify substantively distinct neighborhood types appearing at each separation point. The results presented here with n=6 clusters were those representing the most contrasted neighborhood types with over half of the variation in selected neighborhood variables being accounted for (R^2=0.55).

Neighborhood typology and BP

Multivariable linear regression was used to examine associations between neighborhood type and SBP and DBP. We used the most dense neighborhood type (highest population density) as the reference category to which we compared the remaining neighborhood types using five indicator variables. Models were adjusted for individual sociodemographic variables, use of antihypertensive medication, and family history of hypertension (Model 1), and subsequently for neighborhood level of education (Model 2). Lastly, models were adjusted for risk factors for hypertension that are potentially in the causal pathway (mediators) between neighborhood conditions and BP (Model 3). In secondary analyses associations between neighborhood type and pulse pressure were examined to support the interpretation of findings for SBP and DBP. Beta coefficients refer to the increase/decrease in mmHg of BP and pulse pressure associated with residing in specific types of neighborhoods in comparison to the most dense neighborhood type. All analyses were conducted with SAS, version 9.2 [36].

RESULTS

Descriptive statistics for the six neighborhood types are presented in Table 2. These neighborhood types correspond to: 1) Suburban, low social standing; 2) Suburban, high social standing; 3) Urban, low social standing; 4) Urban, high social standing; 5) Central urban, high social standing; and 6) Central urban, intermediate social standing (reference category). They encompass suburban to central urban neighborhood types based on varying values of population density, land use, road traffic pollution, and available services. They also encompass neighborhoods with lower to higher social standing based on different values on measures of neighborhood social interactions. Appendix Figure S1 shows the geographical distribution of participants by neighborhood type.

Characteristics of study participants by neighborhood type are presented in Table 3. Individual level of education was lowest in neighborhood Types 1 and 3, and highest in neighborhood Types 4, 5 and 6. Individual unemployment, financial strain, and birth in low Human Development Index country were more common in Type 1 neighborhoods. Individual risk factors for hypertension differed by neighborhood type: residents from Type 6 neighborhoods (Central urban, intermediate social standing) were more likely to be regular drinkers and smokers while residents from Type 1 neighborhoods (Suburban, low social standing) were more likely to be obese and have a high resting heart rate. On average, SBP and DBP were higher in the suburban (Types 1 and 2) and urban with low social standing (Type 3) neighborhoods.

Results from multivariable linear regressions are presented in Tables 4 and 5 for SBP and DBP, respectively. After adjustment for individual sociodemographic variables, SBP was found to be 2 mmHg higher in participants residing in the two suburban neighborhood types [Type 1, 1.87 (95% CI: 0.18; 3.56) and Type 2, 1.87 (95% CI: 0.65; 3.09)] and still more elevated in the urban with low social standing neighborhood type [Type 3, 3.05 (95% CI: 1.72; 4.38)], in comparison to the reference category. After adjustment for neighborhood socioeconomic status, these coefficients were generally attenuated but associations remained for Type 2 (Suburban high social standing) and Type 3 (Urban low social standing) neighborhoods. Moreover, in this model, an association appeared between residing in central urban with high social standing neighborhoods and SBP [Type 5, 1.60 (95% CI: 0.16; 3.03)]. After further adjusting for individual risk factors for hypertension, only residence in urban low social standing neighborhoods remained associated with SBP [Type 3, 2.11 (95% CI:

0.70; 3.52)]. For DBP, results from Models 1 and 2 showed a slightly different pattern of association (Table 5), with evidence of a regular increase in BP with decreasing urbanicity degree of neighborhood types. This pattern remained apparent (even if reduced in magnitude) after adjustment for individual risk factors for hypertension.

Finally, as shown in Appendix Table S1, analyses for pulse pressure were coherent with patterns observed for SBP and DBP. Even after adjustment for individual/neighborhood socioeconomic status and individual risk factors for hypertension, we found that pulse pressure was higher in urban low social standing neighborhoods (where SBP was found to be higher), while pulse pressure was lower in suburban neighborhoods (where DBP was found to be higher).

DISCUSSION

The present study suggests that combined exposure to a number of conditions related to the physical features, available services, and social interactions of residential neighborhood environments is associated with SBP and DBP, after adjustment for individual and neighborhood socioeconomic conditions, and individual risk factors for hypertension. Specifically, residence in urban areas with low social standing remained associated with higher SBP, while residence in suburban and urban (vs. central urban) areas was associated with higher DBP, regardless of social standing.

To our knowledge, this is the first study that used neighborhood clustering techniques to study associations between features of the neighborhood environment and BP. Cluster analysis allowed us to construct a typology and examine the combined exposure to multiple environmental characteristics that are highly correlated and whose effects could not be separated through multivariable regression analysis [29, 37]. By regrouping similar neighborhoods based on a multidimensional profile it is possible to examine the impact of a constellation of neighborhood environment features that may jointly rather than individually influence health and health behaviors [38].

Additional strengths of this study include the large sample size and study territory allowing comparison of diverse neighborhoods, as well as the range of variables available to precisely characterize neighborhoods. Limitations include the cross-sectional nature of the study design making it impossible to determine the directionality of associations. Additionally, it was demonstrated that the absence of *a priori* sampling in the recruitment of participants led to selective participation of subjects with certain neighborhood profiles, and a similar health-related selection cannot be discounted [22]. Thus, if participation is related to both neighborhood exposures and BP levels (or related health conditions) selection bias may result in under or overestimation of associations. Lastly, while BP measured in the supine position may influence interpretation of mean BP levels, it does not interfere with interpretation of measures of associations since a standardized protocol was followed for BP measurement in all study participants.

Previous studies have reported that residents from more walkable neighborhoods, characterized by high land use mix, street connectivity and the presence of destinations to walk to have lower BP levels [14, 15]. Similarly, lower neighborhood population density has been associated with higher BP [39]. These findings are in line with our results showing that residents of suburban and urban neighborhoods had higher BP (especially higher DBP) compared to residents of central urban neighborhoods. The latter are characterized by a large number of destinations, a higher density of street intersections, and shorter street block lengths, and may be related to lower BP levels through their positive effect on regular walking [40]. Interestingly, the distribution of risk factors for hypertension differed according to neighborhood type, with a concentration of regular alcohol consumption and smoking in denser neighborhoods, and a concentration of obesity in more sparsely populated neighborhoods.

Past studies also identified relationships between neighborhood socioeconomic conditions and BP, independently of individual socioeconomic status [3-9]. Previous work based on the RECORD Study comparing neighborhoods on the basis of three socioeconomic indicators showed that neighborhood education was more particularly associated with SBP [8]. However, other dimensions of neighborhood environments had not been examined. Interestingly, in the current study the combined exposure to areas characterized both as urban (with a lower density of services than central urban areas) and as having deteriorated social interactions was found to be related to the greatest increase in SBP, even after adjustment for individual and neighborhood confounders. This suggests that SBP was particularly elevated in neighborhoods with adverse social interaction patterns, independently of neighborhood socioeconomic status.

One hypothesis from the literature is that stressors experienced within the neighborhood environment in relation to social relationships relate to hypertension [41]. Our findings of a relationship between poor urban neighborhoods with stressful social interactions and SBP supports this hypothesis to some extent, even if our data do not demonstrate direct effects of neighborhood social interaction stressors with BP.

Interestingly, patterns of associations were rather different for DBP, for which higher values were linked with decreasing urbanicity degree (captured by the neighborhood typology). Lower neighborhood socioeconomic status was related to higher DBP but (contrary to SBP) the association disappeared after controlling for individual risk factors for hypertension, while the association with urbanicity persisted.

As "distal" exposures, features of the neighborhood environments are likely to have effects on BP that are mediated by more proximal behavioral risk factors such as physical activity and diet or related clinical risk factors such as obesity [8, 39, 42]. In our study, after adjustment for a number of individual risk factors for hypertension, associations between neighborhood type and SBP and DBP were attenuated but did not disappear entirely. However, this reduction in effect size does not imply that neighborhoods have little effect on BP, but that their effects partly operate through individual-level risk factors. Obesity explained most of the association between neighborhood factors and BP given that half the variance in SBP explained by individual-level risk factors was accounted for by BMI and waist circumference alone.

The study therefore suggests that interventions targeting neighborhood environments to increase the potential for healthy lifestyles may have substantial health benefits, including improvement in BP levels. Specifically, such interventions may have important impacts at the population level, even though individual level effects appear relatively small [43].

In this study, using cluster analysis in combination with regression analysis, we were able to examine associations between BP and a constellation of characteristics pertaining to the physical, services, and social interactions neighborhood environments while adequately controlling for potential confounders and examining the role of potential mediators. Although it is premature to formulate definite public health implications from our results, two recommendations can be made: 1) efforts to reduce hypertension in the population should incorporate policies to transform the physical, services, and social interactions neighborhood environments, and 2) strategies should be crafted so as to account for the complexity of neighborhood environments which are composed of a variety of factors that interact in complex ways to influence cardiovascular disease risk factors. Specifically, this study allowed us to identify neighborhood types that are associated with higher or lower BP. Based on this neighborhood profiling of risk, population-level interventions to reduce hypertension that are targeted towards or tailored according to specific neighborhood types show promise.

References

1 Riva M, Gauvin L, Barnett T. Toward the next generation of research into small area effects on health: a synthesis of multilevel investigations published since July 1998. J Epidemiol Community Health 2007; 61:853-891.

2 Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. Obes Rev 2010; 12:217-230.

3 Diez Roux AV, Nieto J, Muntaner C, Tyroler HA, Comstock GW, Shahar E, et al. Neighborhood environments and coronary heart disease: a multilevel analysis. Am J Epidemiol 1997; 146:48-63.

4 Morenoff JD, House JS, Hansen BB, Williams DR, Kaplan GA, Hunte HE. Understanding social disparities in hypertension prevalence, awareness, treatment, and control: the role of neighborhood context. Soc Sci Med 2007; 65:1853-1866.

5 Diez Roux AV, Link BG, Northridge ME. A multilevel analysis of income inequality and cardiovascular disease risk factors. Soc Sci Med 2000; 50:673-687.

6 Merlo J, Ostergren PO, Hagberg O, Lindström M, Lindgren A, Melander A, et al. Diastolic blood pressure and area of residence: multilevel versus ecological analysis of social inequity. J Epidemiol Community Health 2001; 55:791-798.

7 Dubowitz T, Ghosh-Dastidar M, Eibner C, Slaughter ME, Fernandes M, Whitsel EA, et al. The Women's Health Initiative: The food environment, neighborhood socioeconomic status, BMI, and blood pressure. Obesity 2011; doi: 10.1038/oby.2011.1412011:Published online June 9.

8 Chaix B, Bean K, Leal C, Thomas F, Havard S, Evans D, et al. Individual/neighborhood social factors and blood pressure in the RECORD Cohort Study: which risk factors explain the associations? Hypertension 2010; 55:769-775.

9 Cozier YC, Palmer JR, Horton NJ, Fredman L, Wise LA, Rosenberg L. Relation between neighborhood median housing value and hypertension risk among black women in the United States. Am J Public Health 2007; 97:718-724.

10 de Kluizenaar Y, Gansevoort RT, Miedema HME, de Jong PE. Hypertension and road traffic noise exposure. J Occup Environ Med 2007; 49:484-492.

11 Leon Bluhm G, Berglind N, Nordling E, Rosenlund M. Road traffic noise and hypertension. Occup Environ Med 2007; 64:122-126.

12 Rosenlund M, Berglind N, Pershagen G, Järup L, Bluhm G. Increased prevalence of hypertension in a population exposed to aircraft noise. Occup Environ Med 2001; 58:769-773.

13 Madsen C, Nafstad P. Associations between environmental exposure and blood pressure among participants in the Oslo Health Study (HUBRO). Eur J Epidemiol 2006; 21:485-491.

14 Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan T, Cooper RS, Ni H, et al. Neighborhood characteristics and hypertension. Epidemiology 2008; 19:590-598.

15 Li F, Harmer P, Cardinal BJ, Vongjaturapat N. Built environment and changes in blood pressure in middle aged and older adults. Prev Med 2009; 48:237-241.

16 Patterson RE, Frank LL, Kristal AR, White E. A comprehensive examination of health conditions associated with obesity in older adults. Am J Prev Med 2004; 27:385-390.

17 Morland K, Diez Roux AV, Wing S. Supermarkets, other food stores, and obesity. The Atherosclerosis Risk in Communities Study. Am J Prev Med 2006; 30:333-339.

18 Agyemang C, van Hooijdonk C, Wendel-Vos W, Ujcic-Voortman JK, Lindeman E, Stronks K, et al. Ethnic differences in the effect of environmental stressors on blood pressure and hypertension in the Netherlands. BMC Public Health 2007; 7:doi 10.1186/1471-2458-1187-1118.

19 Chaix B. Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. Annu Rev Public Health 2009; 30:81-105.

20 Chaix B, Leal C, Evansa D. Neighborhood-level confounding in epidemiologic studies. Unavoidable challenges, uncertain solutions. Epidemiology 2010; 21:124-127.

21 Chaix B, Kestens Y, Bean K, Leal C, Karusisi N, Meghiref K, et al. Cohort Profile: Residential and non-residential environments, individual activity spaces and cardiovascular risk factors and diseases - The RECORD Cohort Study. Int J Epidemiol 2011; doi: 10.1093/ije/dyr107:Published online July 7.

22 Chaix B, Billaudeau N, Thomas F, Havard S, Evans D, Kestens Y, et al. Neighborhood effects on health: correcting bias from neighborhood effects on participation. Epidemiology 2011; 22:18-26.

23 Thomas F, Bean K, Pannier B, Oppert JM, Guize L, Benetos A. Cardiovascular mortality in overweight subjects: the key role of associated risk factors. Hypertens Res 2005; 46:654-659.

24 Benetos A, Thomas F, Pannier B, Bean K, Jégo B, Guize L. All-cause and cardiovascular mortality using the different definitions of metabolic syndrome. Am J Cardiol 2008; 102:188-191.

25 Beckman A, Hakansson A, Rastam L, Lithman T, Merlo J. The role country of birth plays in receiving disability pensions in relation to patterns of health care utilisation and socioeconomic differences: a multilevel analysis of Malmo, Sweden. BMC Public Health 2006; 6:doi 10.1186/1471-2458-1186-1171.

26 United Nations Development Program. Human Development Report 2007/2008. New York, NY: United Nations Development Programme 2008. http://hdr.undp.org/ (August 2011, date last accessed).

27 Chaix B, Merlo J, Evans D, Leal C, Havard S. Neighbourhoods in eco-epidemiologic research: Delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. Soc Sci Med 2009; 69:1306-1310.

28 Mujahid M, Diez Roux A, Morenoff J, Raghunathan T. Assessing the measurement properties of neighbourhood scales: from psychometrics to ecometrics. Am J Epidemiol 2007; 165:858-867.

29 Gershoff E, Pedersen S, Aber JL. Creating neighborhood typologies of GIS-based data in the absence of neighborhood-based sampling: a factor and cluster analytic strategy. J Prev Interv Community 2009; 37:35-47.

30 Kumar V. Cluster analysis: basic concepts and algorithms. In: Tan P-N, Steinbach M, Kumar V, editors. Introduction to Data Mining. Boston: Addison Wesley; 2005. pp. 487-568.

31 Pedigo A, Seaver W, Odoi A. Identifying unique neighborhood characteristics to guide health planning for stroke and heart attack: Fuzzy cluster and discriminant

analyses approaches. PLoS ONE 2011; 6:e22693. doi:22610.21371/journal.pone.0022693.

32 Li Y-S, Chuang Y-C. Neighborhood Effects on an Individual's Health Using Neighborhood Measurements Developed by Factor Analysis and Cluster Analysis. J Urban Health 2008; 86:5-18.

33 Zhang X, Kaufer Christoffel K, Mason M, Liu L. Identification of contrastive and comparable school neighborhoods for childhood obesity and physical activity research. Int J Health Geogr 2006; 5:1-9.

34 Fang Yan A, Voorhees CC, Clifton K, Burnier C. "Do you see what I see?" Correlates of multidimensional measures of neighborhood types and perceived physical activity-related neighborhood barriers and facilitators for urban youth. Prev Med 2010; 50:S18-S23.

35 Nelson MC, Gordon-Larsen P, Song Y, Popkin BM. Built and social environments. Associations with adolescent overweight and activity. Am J Prev Med 2006; 31:109-117.

36 SAS Institute I. SAS 9.2. Cary, North Carolina: SAS Institute, Inc 2003.

37 Leal C, Bean K, Chaix B. Multicollinearity in the associations between multiple environmental features and body weight and abdominal fat: using matching techniques to assess whether the associations are separable. Am J Epidemiol 2012; 175:1153-1162.

38 Weden MM, Bird CE, Escarce JJ, Lurie N. Neighborhood archetypes for population health research: Is there no place like home? Health Place 2011; 17:289-299.

39 Chaix B, Ducimetière P, Langd T, Haase B, Montaye M, Ruidavets J-B, et al. Residential environment and blood pressure in the PRIME Study: is the association mediated by body mass index and waist circumference? J Hypertens 2008; 26:1078-1084.

40 Leslie E, Coffee N, Frank L, Owend N, Baumane A, Hugo G. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health Place 2007; 13:111-122.

41 Harburg E, Erfurt JC, Chape C, Hauenstein LS, Schull WJ, Schork MA. Socioecological stressor areas and black-white blood pressure: Detroit. J Chronic Dis 1973; 26:595-611.
42 Diez Roux AV, Mair C. Neighborhoods and health. Ann N Y Acad Sci 2010; 1186:125-145.
43 Diez Roux A. Residential environments and cardiovascular risk. J Urban Health 2003; 80:569-589.

Table 1. Characteristics of the physical, services, and social interactions neighborhood environments considered for the creation of a neighborhood typology

Neighborhood characteristic	Data	Measurement approach
Domain: Neighborhood physical environment		
Proportion of neighborhood area covered with buildings	Three-dimensional data from IGN on buildings' ground shapes and height in 2008	GIS processing: surface within 500 m radius circular areas
Mean height of buildings in the neighborhood	Three-dimensional data from IGN on buildings' ground shapes and height in 2008	GIS processing: mean building height weighted by each building's ground surface within 500 m radius circular areas
Density of three or more-way street intersections	Data from IGN on street and road network in 2008	GIS processing: count of intersections with at least three ways within 500 m radius circular areas, per area unit (squared km)
Average street block length	Data from IGN on street and road network in 2008	GIS processing: average length of street network segments in m falling within 500 m radius circular areas
Link:node ratio	Data from IGN on street and road network in 2008	GIS processing: number of links (street segments) divided by the number of nodes (intersections) within 500 m radius circular areas
Route directness	Data from IGN on street and road network in 2008	GIS processing: ratio of total length of street network segments falling within 500 m radius circular areas to total straight length of these segments
Highway nearby the residence	Data from IGN on street and road network in 2008	GIS processing: presence of a highway within 250 m of the residence (yes/no)
Road traffic-related pollution (concentration of nitrogen dioxide, $\mu g/m^3$)	Modeled data from AIRPARIF on annual concentrations of nitrogen dioxide in 2007-2008	GIS processing: average concentration within 500 m radius circular areas
Road traffic-related pollution (concentration of particulate matter, mg/m^3)	Modeled data from AIRPARIF on annual concentrations of particulate matter in 2007-2008	GIS processing: average concentration within 500 m radius circular areas
Air traffic exposure	Data on air traffic from ACNUSA in 2005	GIS processing: four category variable based on whether or not airplane traffic passes within 1000, 2000, or 3000 m in altitude above the residence.
Waste treatment facilities	Geocoded waste treatment facilities in 2008, data obtained from IAU-IdF	GIS processing: count of waste treatment facilities within 500 m radius circular area (including incinerators, urban composts, water treatment plants, etc.)
Surface of green spaces	Linear and polygonal data from IAU-IdF on public parks and green spaces in 2008	GIS processing: surface per squared km within 500 m radius circular areas
Presence of lakes or waterways	Polygonal data from IAU-IdF on land use in 2003	GIS processing: binary variable indicating the presence of lakes, rivers, or waterways in 500 m radius circular areas

Neighborhood active living potential	Three items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (high score=low active living potential)
Deterioration of the physical environment	Four items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores=low deterioration)
Domain: Neighborhood services environment		
Number of destinations	Geocoded destinations from the 2008 Permanent Database of Facilities of Insee	GIS processing: count of destinations (administrations, public/private shops, entertainment facilities, etc.) within 500 m radius circular areas
Presence of monuments	Geocoded monuments in 2005 from IAU-IdF	GIS processing: count of monuments and other enjoyable sites within 500 m radius circular areas
Number of transportation lines	Geocoded bus stops, subways, and train stations in 2008 from STIF	GIS processing: count of different transportation lines within 500 m radius circular areas
Proportion of incoming and outgoing traffic by public transportation rather than by car	Raw data from a road traffic model from DRE-IdF	GIS processing: proportion of traffic by public transportation in the area
Presence of a commercial center	Geocoded commercial centers in 2008 from IAU-IdF	GIS processing: count of commercial centers within 500 m radius circular areas
Number of hypermarkets	Geocoded hypermarkets in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of hypermarkets within 500 m radius circular areas
Number of supermarkets	Geocoded supermarkets in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of supermarkets within 500 m radius circular areas
Number of grocery stores	Geocoded grocery stores in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of minimarkets and grocery stores within 500 m radius circular areas
Number of shops and stands selling fruits/vegetables (including street markets)	Geocoded fruit and vegetable shops in 2007 from the SIRENE database from Insee	GIS processing: count of fruit and vegetable shops within 500 m radius circular areas
Proportion of fast food restaurants (compared to the total number of restaurants)	Geocoded restaurants in 2007 from the SIRENE database from Insee	GIS processing: ratio between count of fast food restaurants and total count of restaurants within 500 m radius circular areas
Number of sports facilities	Data from the Census of Sport Facilities in 2008 from DRJSCS	GIS processing: count of facilities within 500 m radius circular areas
Domain: Neighborhood social interactions		
School violence near the residence	School violence in 2005-2006 from the Ministry of Education	Multilevel modeling and GIS processing of violent behaviors occurring in schools located near the residence
Neighborhood social cohesion	Four items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores=high cohesion)
Neighborhood stressful social interactions	Five items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores=low stress)

Neighborhood mistrust and hostility	Five items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores=low mistrust and hostility)
Stigmatized neighborhood identity	Three items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores=low stigma)
Domain: Neighborhood sociodemographic environment		
Indicator of neighborhood socioeconomic status based on the level of education	Population Census of 2006 geocoded at the residential address by Insee	Aggregation of individual data within 500 m radius circular areas: proportion of residents aged ≥ 15 years with university education
Neighborhood population density	Population Census of 2006 geocoded at the residential address by Insee	Aggregation of population data within circular areas: number of inhabitants per km²

Abbreviations: ACNUSA, Regulatory Body for Airport Nuisance; AIRPARIF, Air Quality in Paris Ile-de-France Region; DGI, General Directorate of Taxation; DRE-IdF, Regional Directorate of Equipment in Ile-de-France Region; DRJSCS, Regional Directorate for Youth, Sports and Social Cohesion; IAU-IdF, Institute of Urban Planning in Ile-de-France Region; GIS, Geographic Information System; IGN, National Geographic Institute; Insee, National Institute of Statistics and Economic Studies; SIRENE: Information System for the Directory of Businesses and Enterprises; STIF, Transport Union in Ile-de-France Region.

Table 2. Description of neighborhood types in the RECORD Cohort Study

	Type 1: Suburban low social standing (n=501)		Type 2: Suburban high social standing (n=1616)		Type 3: Urban low social standing (n=1098)		Type 4: Urban high social standing (n=1978)		Type 5: Central urban high social standing (n=844)		Type 6: Central urban intermediate social standing (n=1073)		Fisher's F-test p-value
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	
Population density per km^2*	8 075	2	6 057	1	13 442	3	16 270	4	34 258	5	36 543	6	<0.001
Proportion of neighborhood area covered with buildings, %	15.3	1	16.1	2	25.6	3	27.5	4	42.1	5	46.8	6	<0.001
Density of intersections per km^2	166.5	4	117.7	1	139.5	2	167.9	5	150.9	3	184.0	6	<0.001
Average street block length, m	67.9	3	79.0	6	73.6	5	67.9	2	73.1	4	65.5	1	<0.001
Road traffic-related pollution (nitrogen dioxide, $\mu g/m^3$)	25.1	1	28.2	2	40.3	3	41.5	4	46.1	5	51.2	6	<0.001
Road traffic-related pollution (particulate matter, mg/m^3)	25.9	1	27.6	2	30.0	3	30.1	4	30.9	5	31.9	6	<0.001
Deterioration of the physical environment	0.43	4	-1.19	1	0.63	5	-0.73	2	0.17	3	0.99	6	<0.001
Incoming and outgoing traffic by public transportation, %	34.2	1	42.4	2	48.2	3	54.3	4	69.8	6	68.3	5	<0.001
Number of destinations	62.8	2	50.3	1	115.3	3	227.9	4	589.0	5	774.2	6	<0.001
Number of supermarkets	0.47	2	0.46	1	1.16	3	1.51	4	5.15	5	5.24	6	<0.001
Number of grocery stores	2.8	2	1.7	1	6.2	3	7.1	4	20.8	5	35.7	6	<0.001
Proportion of residents with university education, %*	21.9	1	39.4	3	25.7	2	47.2	5	55.1	6	46.9	4	<0.001
Neighborhood stressful social interactions	0.35	4	-0.74	1	0.54	5	-0.54	2	-0.12	3	0.63	6	<0.001
Neighborhood mistrust and hostility	0.39	6	-0.22	3	0.38	5	-0.30	1	-0.25	2	0.08	4	<0.001
Stigmatized neighborhood identity	0.73	6	-0.49	2	0.68	5	-0.54	1	-0.44	3	0.16	4	<0.001

* Variables not used in cluster analysis to define neighborhood types

Table 3. Characteristics of study participants by neighborhood types in the RECORD Cohort Study

	Type 1: Suburban low social standing (n=501)	Type 2: Suburban high social standing (n=1616)	Type 3: Urban low social standing (n=1098)	Type 4: Urban high social standing (n=1978)	Type 5: Central urban high social standing (n=844)	Type 6: Central urban intermediate social standing (n=1073)	Chi^2 p-value
Age, years, mean (SD)	47.7 (11.3)	51.5 (11.1)	48.7 (11.3)	50.9 (11.7)	52.0 (12.4)	48.6 (11.8)	<0.001*
Sex (men), % (n)	60.3 (302)	67.1 (1085)	65.9 (724)	66.2 (1310)	63.9 (539)	65.8 (706)	0.09
Individual education, % (n)							
Low	17.1 (84)	6.7 (107)	13.7 (149)	5.2 (102)	3.9 (33)	6.9 (73)	<0.001
Middle-low	37.6 (185)	25.5 (408)	33.6 (366)	20.8 (409)	16.0 (134)	20.2 (215)	
Middle-high	26.8 (132)	32.4 (518)	30.8 (335)	29.2 (575)	25.2 (212)	29.3 (311)	
High	18.5 (91)	35.5 (568)	21.9 (238)	44.8 (882)	54.9 (461)	43.7 (464)	
Employment status, % (n)							
Employed	50.5 (253)	57.7 (933)	63.9 (702)	65.3 (1291)	64.5 (544)	62.3 (668)	
Unemployed	25.4 (127)	14.5 (235)	15.6 (171)	11.3 (224)	10.0 (84)	20.7 (222)	<0.001
Retired	12.2 (61)	19.5 (315)	16.3 (179)	18.6 (368)	21.7 (183)	14.4 (154)	
Financial strain, % (n)	30.7 (154)	14.8 (239)	24.8 (272)	12.2 (240)	9.4 (79)	17.5 (187)	<0.001
Owner of residence, % (n)	37.8 (189)	67.2 (1086)	40.7 (446)	59.2 (1171)	52.9 (446)	49.2 (526)	<0.001
Low Human Development Index of country of birth, % (n)	14.2 (71)	4.0 (65)	8.6 (94)	3.3 (65)	1.3 (11)	2.9 (31)	<0.001
SBP, mmHg, mean (SD)	128.5 (17.6)	129.0 (17.1)	129.7 (18.7)	127.7 (17.6)	128.2 (17.1)	125.1 (16.4)	<0.001*
DBP, mmHg, mean (SD)	78.4 (10.9)	77.8 (10.6)	77.4 (10.8)	76.6 (10.7)	76.3 (10.1)	74.9 (10.4)	<0.001*
Antihypertensive medication use, % (n)	16.2 (81)	14.1 (227)	10.8 (118)	12.9 (256)	13.4 (113)	9.0 (97)	<0.001
Family history of hypertension, % (n)	36.1 (181)	35.7 (577)	33.8 (371)	35.0 (693)	32.5 (274)	32.4 (348)	0.34
Physically active, % (n)	45.5 (228)	43.0 (695)	46.5 (510)	41.3 (817)	42.5 (359)	48.9 (525)	<0.001
Alcohol consumption							
Never drinker	26.3 (131)	11.0 (177)	19.0 (208)	10.9 (215)	7.5 (63)	10.8 (115)	<0.001
Former drinker	9.8 (49)	5.2 (84)	7.5 (82)	3.7 (73)	4.5 (38)	5.5 (59)	
Light drinker	57.0 (284)	76.7 (1233)	66.2 (724)	77.5 (1529)	78.8 (662)	73.6 (787)	
Regular drinker	6.8 (34)	7.1 (114)	7.3 (80)	7.9 (156)	9.2 (77)	10.1 (108)	
Smoking status							
Never smoker	59.7 (299)	53.8 (869)	53.5 (587)	49.9 (986)	46.5 (392)	42.9 (460)	<0.001
Former smoker	21.2 (106)	29.2 (471)	22.7 (249)	29.0 (573)	32.7 (276)	28.2 (302)	

Smoker	19.2 (96)	17.1 (276)	23.9 (262)	21.2 (419)	20.9 (176)	29.0 (311)	
Body mass index							
Normal weight	41.9 (210)	48.2 (779)	44.2 (485)	52.2 (1031)	53.1 (448)	56.2 (602)	<0.001
Overweight	36.3 (182)	39.6 (640)	39.7 (436)	37.1 (733)	37.0 (312)	34.2 (367)	
Obese	21.8 (109)	12.1 (196)	16.1 (177)	10.8 (213)	9.9 (83)	9.6 (103)	
Waist circumference							
Ideal	55.8 (276)	64.4 (1020)	64.8 (700)	69.4 (1342)	68.4 (555)	71.3 (748)	<0.001
High	21.6 (107)	22.1 (350)	21.7 (234)	20.3 (392)	21.3 (173)	19.0 (199)	
Very high	22.6 (112)	13.6 (215)	13.6 (147)	10.4 (201)	10.3 (84)	9.7 (102)	
Resting heart rate							
Low	28.4 (139)	39.4 (630)	35.7 (385)	41.4 (810)	43.6 (366)	42.3 (451)	<0.001
Medium	38.6 (189)	37.3 (597)	40.0 (432)	38.8 (758)	36.0 (302)	39.6 (422)	
High	33.1 (162)	23.3 (372)	24.3 (262)	19.8 (388)	20.4 (171)	18.1 (193)	

* p-value for Fisher's F-test

Table 4. Beta coefficients and 95% confidence intervals for SBP in the RECORD Cohort Study from multivariable linear regression models

	Model 1 Adjusted R^2=0.20		Model 2 Adjusted R^2=0.21		Model 3 Adjusted R^2=0.28	
	Beta	95% CI	Beta	95% CI	Beta	95% CI
Neighborhood type (vs. Type 6: Central urban intermediate social standing)						
Type 1: Suburban low social standing	1.87	(0.18; 3.56)	1.00	(-0.85; 2.85)	0.03	(-1.74; 1.79)
Type 2: Suburban high social standing	1.87	(0.65; 3.09)	1.57	(0.33; 2.82)	1.17	(-0.02; 2.36)
Type 3: Urban low social standing	3.05	(1.72; 4.38)	2.30	(0.81; 3.78)	2.11	(0.70; 3.52)
Type 4: Urban high social standing	1.07	(-0.09; 2.24)	1.06	(-0.10; 2.23)	0.90	(-0.21; 2.00)
Type 5: Central urban high social standing	1.32	(-0.09; 2.74)	1.60	(0.16; 3.03)	1.25	(-0.11; 2.62)
Age (1-yr increase)	0.48	(0.44; 0.52)	0.49	(0.44; 0.53)	0.41	(0.37; 0.45)
Male (vs female)	5.35	(4.56; 6.15)	5.35	(4.55; 6.14)	5.21	(4.41; 6.00)
Individual education (vs high)						
Low	3.59	(2.08; 5.11)	3.26	(1.71; 4.80)	2.37	(0.88; 3.86)
Middle-low	3.11	(2.11; 4.11)	2.82	(1.78; 3.89)	2.07	(1.08; 3.06)
Middle-high	1.19	(0.27; 2.10)	1.04	(0.11; 1.96)	0.79	(-0.09; 1.67)
Low Human Development Index of country of birth (vs medium or high)	4.84	(3.08; 6.60)	4.70	(2.94; 6.46)	4.04	(2.35; 5.72)
Employment status (vs employed)						
Unemployed	-2.12	(-3.18; -1.06)	-2.14	(-3.20; -1.08)	-1.95	(-2.97; -0.93)
Retired	0.41	(-0.90; 1.72)	0.41	(-0.91; 1.72)	0.51	(-0.75; 1.77)
Nonownership of residence (vs owner)	2.13	(1.31; 2.95)	2.07	(1.25; 2.89)	1.37	(0.58; 2.16)
Antihypertensive medication use	8.58	(7.40; 9.77)	8.54	(7.35; 9.72)	6.48	(5.34; 7.63)
Family history of hypertension	3.08	(2.30; 3.87)	3.06	(2.27; 3.84)	2.80	(2.05; 3.54)
Percent residents with university education			-3.94	(-7.39; -0.49)	-0.89	(-4.19; 2.41)
Physically active					0.70	(-0.01; 1.40)
Smoking (vs never smoker)						
Former smoker					-1.57	(-2.42; -0.72)
Smoker					-1.85	(-2.79; -0.91)
Alcohol consumption (vs never drinker)						
Former drinker					1.50	(-0.30; 3.29)
Light drinker					2.98	(1.86; 4.10)
Regular drinker					7.47	(5.82; 9.13)
Waist circumference (vs ideal)						
High					1.18	(0.17; 2.19)
Very high					2.30	(0.72; 3.87)
Body mass index (vs normal)						
Overweight					3.59	(2.73; 4.46)
Obese					8.06	(6.46; 9.67)
Resting heart rate (vs low)						
Medium					3.79	(2.99; 4.58)
High					8.34	(7.40; 9.29)

Table 5. Beta coefficients and 95% confidence intervals for DBP in the RECORD Cohort Study from multivariable linear regression models

	Model 1 (adjusted R^2=0.13)		Model 2 (adjusted R^2=0.13)		Model 3 (adjusted R^2=0.26)	
	Beta	95% CI	Beta	95% CI	Beta	95% CI
Neighborhood type (vs. Type 6: Central urban intermediate social standing)						
Type 1: Suburban low social standing	2.61	(1.54; 3.68)	2.04	(0.87; 3.22)	1.27	(0.18; 2.36)
Type 2: Suburban high social standing	1.93	(1.16; 2.71)	1.74	(0.95; 2.53)	1.41	(0.67; 2.15)
Type 3: Urban low social standing	1.72	(0.88; 2.57)	1.23	(0.29; 2.17)	1.06	(0.19; 1.94)
Type 4: Urban high social standing	1.03	(0.29; 1.77)	1.03	(0.29; 1.77)	0.86	(0.17; 1.54)
Type 5: Central urban high social standing	0.75	(-0.15; 1.65)	0.93	(0.02; 1.84)	0.66	(-0.19; 1.50)
Age (1-yr increase)	0.26	(0.23; 0.29)	0.26	(0.24; 0.29)	0.22	(0.19; 0.25)
Male (vs female)	4.34	(3.84; 4.85)	4.34	(3.83; 4.84)	4.14	(3.65; 4.63)
Individual education (vs high)						
Low	1.81	(0.84; 2.78)	1.60	(0.61; 2.58)	0.97	(0.05; 1.89)
Middle-low	1.58	(0.93; 2.22)	1.39	(0.73; 2.05)	0.91	(0.29; 1.53)
Middle-high	0.72	(0.14; 1.30)	0.63	(0.04; 1.21)	0.37	(-0.18; 0.91)
Low Human Development Index of country of birth (vs medium or high)	3.43	(2.30; 4.55)	3.34	(2.22; 4.47)	3.11	(2.07; 4.16)
Employment status (vs employed)						
Unemployed	-0.92	(-1.60; -0.24)	-0.93	(-1.61; -0.24)	-0.83	(-1.46; -0.19)
Retired	-3.23	(-4.07; -2.40)	-3.24	(-4.07; -2.40)	-2.94	(-3.71; -2.16)
Nonownership of residence (vs owner)	0.82	(0.29; 1.35)	0.79	(0.26; 1.32)	0.30	(-0.20; 0.79)
Financial strain	0.80	(0.11; 1.48)	0.76	(0.07; 1.44)	0.30	(-0.34; 0.94)
Antihypertensive medication use	4.02	(3.27; 4.77)	3.99	(3.24; 4.74)	2.72	(2.01; 3.42)
Family history of hypertension	1.74	(1.24; 2.24)	1.73	(1.23; 2.23)	1.50	(1.04; 1.96)
Percent residents with university education			-2.59	(-4.78; -0.39)	-0.40	(-2.44; 1.65)
Physically active					0.16	(-0.27; 0.60)
Smoking (vs never smoker)						
Former smoker					-0.19	(-0.72; 0.34)
Smoker					-0.71	(-1.29; -0.13)
Alcohol consumption (vs never drinker)						
Former drinker					0.76	(-0.35; 1.86)
Light drinker					1.62	(0.93; 2.31)
Regular drinker					4.83	(3.81; 5.85)
Waist circumference (vs ideal)						
High					0.46	(-0.16; 1.09)
Very high					0.95	(-0.03; 1.92)
Body mass index (vs normal)						
Overweight					2.65	(2.12; 3.18)
Obese					4.99	(3.99; 5.98)
Resting heart rate (vs low)						
Medium					3.80	(3.31; 4.29)
High					7.80	(7.22; 8.39)

SUPPLEMENTARY DIGITAL CONTENT FILE

Figure S1. Geographical distribution of RECORD Cohort Study participants by neighborhood type

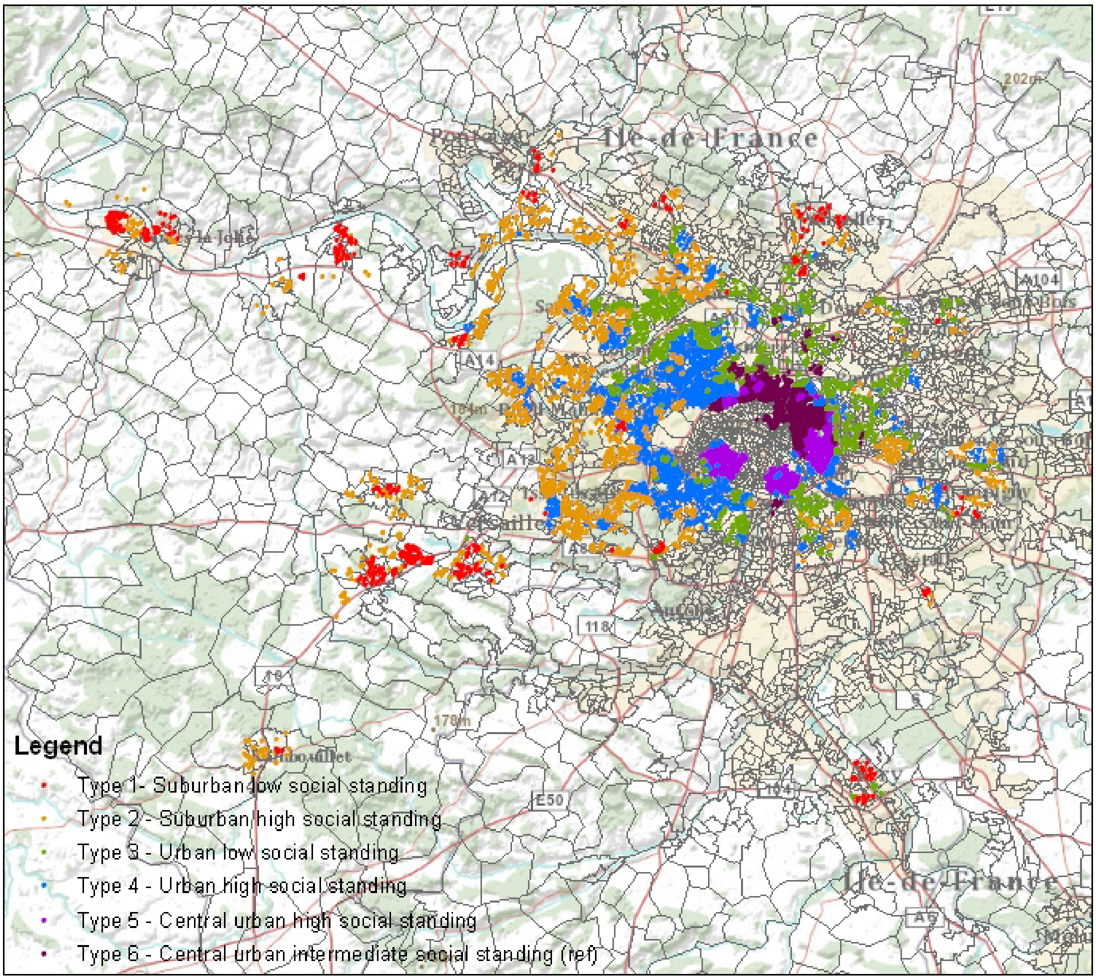


Table S1. Beta coefficients and 95% confidence intervals for pulse pressure in the RECORD Cohort Study from multivariable linear regression models

	Model 1 Adjusted R^2=0.15		Model 2 Adjusted R^2=0.15		Model 3 Adjusted R^2=0.17	
	Beta	95% CI	Beta	95% CI	Beta	95% CI
Neighborhood type (vs. Type 6: Central urban intermediate social standing)						
Type 1: Suburban low social standing	-0.78	(-1.95; 0.38)	-1.06	(-2.33; 0.22)	-1.27	(-2.54; 0.005)
Type 2: Suburban high social standing	-0.07	(-0.92; 0.77)	-0.17	(-1.03; 0.70)	-0.24	(-1.10; 0.61)
Type 3: Urban low social standing	1.31	(0.39; 2.22)	1.07	(0.04; 2.09)	1.04	(0.03; 2.06)
Type 4: Urban high social standing	0.05	(-0.75; 0.86)	0.05	(-0.76; 0.85)	0.05	(-0.75; 0.85)
Type 5: Central urban high social standing	0.60	(-0.38; 1.58)	0.68	(-0.31; 1.68)	0.59	(-0.39; 1.58)
Age (1-yr increase)	0.22	(0.19; 0.25)	0.22	(0.19; 0.25)	0.19	(0.16; 0.22)
Male (vs female)	1.05	(0.50; 1.59)	1.04	(0.50; 1.59)	1.08	(0.51; 1.65)
Individual education (vs high)						
Low	1.66	(0.61; 2.71)	1.56	(0.49; 2.62)	1.35	(0.28; 2.43)
Middle-low	1.46	(0.76; 2.15)	1.36	(0.65; 2.08)	1.14	(0.42; 1.86)
Middle-high	0.42	(-0.21; 1.05)	0.38	(-0.26; 1.01)	0.41	(-0.23; 1.04)
Low Human Development Index of country of birth (vs medium or high)	1.27	(0.06; 2.49)	1.23	(0.009; 2.44)	0.87	(-0.34; 2.08)
Employment status (vs employed)						
Unemployed	-1.34	(-2.07; -0.61)	-1.34	(-2.08; -0.61)	-1.17	(-1.90; -0.44)
Retired	3.68	(2.77; 4.58)	3.67	(2.77; 4.58)	3.47	(2.56; 4.38)
Nonownership of residence (vs owner)	1.19	(0.63; 1.76)	1.18	(0.61; 1.74)	1.04	(0.47; 1.61)
Antihypertensive medication use	4.55	(3.73; 5.37)	4.53	(3.72; 5.35)	3.77	(2.94; 4.59)
Family history of hypertension	1.33	(0.78; 1.87)	1.32	(0.78; 1.86)	1.29	(0.75; 1.82)
Percent residents with university education			-1.24	(-3.63; 1.14)	-0.48	(-2.86; 1.90)
Physically active					0.52	(0.01; 1.03)
Smoking (vs never smoker)						
Former smoker					-1.38	(-1.99; -0.77)
Smoker					-1.17	(-1.85; -0.50)
Alcohol consumption (vs never drinker)						
Former drinker					0.75	(-0.54; 2.04)
Light drinker					1.38	(0.57; 2.18)
Regular drinker					2.66	(1.47; 3.86)
Waist circumference (vs ideal)						
High					0.71	(-0.01; 1.44)
Very high					1.33	(0.19; 2.46)
Body mass index (vs normal)						
Overweight					0.95	(0.32; 1.57)
Obese					3.08	(1.92; 4.24)
Resting heart rate (vs low)						
Medium					-0.006	(-0.58; 0.56)
High					0.54	(-0.14; 1.22)

Appendix F. Assessment of spatial autocorrelation

Table 1. Observed Moran's I for neighbourhood-level measures for QUALITY study participants living in the Montreal Metropolitan Area (n=512) in 2005-2008

Neighbourhood characteristics	Observed Moran's I	p-value
Distance from residence to nearest supermarket	0.014	< 0.001
Distance from residence to nearest fast food restaurant	0.018	< 0.001
Distance from residence to nearest convenience store	0.021	< 0.001
Density of supermarkets in 1 km network buffer centered on residence	0.015	< 0.001
Density of fast food restaurants in 1 km network buffer centered on residence	0.015	< 0.001
Density of convenience stores in 1 km network buffer centered on residence	0.014	< 0.001
Retail food environment index within 1 km network buffer centered on residence	0.0030	< 0.001
Retail food environment index within 3 km circular buffer centered on residence	0.0021	< 0.001
Distance from school to nearest supermarket*	0.013	< 0.001
Distance from school to nearest fast food restaurant*	0.016	< 0.001
Distance from school to nearest convenience store*	0.019	< 0.001
Density of supermarkets in 1 km network buffer centered on school*	0.014	< 0.001
Density of fast food restaurants in 1 km network buffer centered on school*	0.013	< 0.001
Density of convenience stores in 1 km network buffer centered on school*	0.014	< 0.001
Retail food environment index within 1 km network buffer centered on school*	-0.000070	< 0.001
Retail food environment index within 3 km circular buffer centered on school*	-0.00080	< 0.001
Neighbourhood disadvantage in 500 m network buffer centered on residences	0.0087	< 0.001
Neighbourhood prestige in 500 m network buffer centered on residences	0.0067	< 0.001
Level of urbanicity in 500 m network buffer centered on residence	0.010	< 0.001
Traffic in 500 m network buffer centered on residence	0.014	< 0.001
Social disorder in 500 m network buffer centered on residence	0.0065	< 0.001
Pedestrian friendliness in 500 m network buffer centered on	-0.00096	< 0.001

residence		
Number of parks in 500 m network buffer centered on residence	0.00053	< 0.001
Presence of at least 1 fast food residence in 500 m network buffer centered on residence	0.0057	< 0.001
Presence of at least 1 convenience store in 500 m network buffer centered on residence	0.0060	< 0.001

* 296 schools within the Montreal Metropolitan Area

Appendix G. The importance of individual vs. neighbourhood variables to explain childhood obesity

As discussed in Manuscript 3, previous analyses which have used multilevel analysis on individuals nested within neighbourhoods have reported more modest effects of neighbourhood environments on obesity in comparison to individual-level risk factors. Data from the QUALITY Residential Study are not structured hierarchically at the neighbourhood level (i.e., multiple participants nested within neighbourhoods). Instead, each participant has its neighbourhood identified using an ego-centered approach, that is by delimiting a geographical zone centered on each participant's exact residential address. Because the data are not structured hierarchically at the neighbourhood level, the proportion of variance in the outcome explained by each level of predictors (i.e., individual and familial vs. neighbourhood) cannot be computed using multilevel analysis.

The analytic method used in Manuscript 3, recursive partitioning analysis, does not allow one to estimate effect sizes or the proportion of variance explained by a given variable (or set of variables). Instead, this method seeks which predictor variable can best split the data into 2 groups that are most distinct in terms of the outcome (i.e., the ideal predictors would discriminate all obese from non-obese children). Yet, in the selection of variables used to build the tree, we note that individual and familial risk factors are selected as first splitting variables whereas neighbourhood characteristics are only selected in the final branches of the tree. The interpretation of this finding is that selected individual and familial characteristics are stronger predictors of childhood obesity in comparison to neighbourhood characteristics.

To gain some insight on the effect size of each predictor (using standardised beta coefficients) and the proportion of variance explained by different sets of variables (R^2 values), a multiple regression models can be estimated even though conclusions are expected to be different from that of a recursive partitioning analysis, notably because the joint effect of multiple predictors is not estimated.

In the table below, Model 1 includes only child characteristics, familial characteristics are added in Model 2 and neighbourhood characteristics are further added in Model 3. Results show that associations with child BMI percentile reach statistical significance only for selected individual and familial characteristics and the effect size is largest for the number of BMI defined obese parents. While the R^2 increases significantly from model 1 to 2, only a 0.3% increase in variance is noted from model 2 to 3, suggesting that most of the variance in childhood BMI is explained by familial and child characteristics.

Although individual and familial risk factors are likely stronger predictors of childhood obesity, even small to modest effects of neighbourhood environments on obesity may be significant at the population level given that a large number of people may be exposed to small risks within their neighbourhood environment. Moreover, as discussed in Manuscript 3, neighbourhood environment features may on their own not be a strong predictors of obesity, however they may potentiate the effect of individual and familial risk factors of obesity.

Associations between childhood obesity (BMI percentile) and individual, familial, and neighbourhood characteristics among QUALITY study participants at baseline in 2005-2008 (variables in the same column are simultaneously introduced into the model). §

	Standardized beta		
	Model 1 R^2=0.0369	Model 2 R^2=0.159	Model 3 R^2=0.162
Child characteristics			
Child's age at follow-up, years	-0.068	-0.072	-0.075
Sex, boys (vs girls)	0.15***	0.16***	0.16***
Puberty initiated at follow-up (vs not initiated)	0.15***	0.15***	0.16***
Meets physical activity guidelines	-0.14***	-0.13***	-0.13***
Familial characteristics			
Number of parents with BMI ≥30kg/m^2		0.26****	0.25****
Number of parents with abdominal obesity		0.10*	0.11**
Parental education (vs. ≥1 parent with university degree)		Reference	Reference
≥1 parent with technical/vocational/trade school degree		0.077*	0.076*
2 parents with high school degree or less		0.087*	0.087*
Neighborhood characteristics			
Neighborhood disadvantage (vs Low)			Reference
Average			-0.028
High			-0.047
≥1 park within 500 m			-0.000064
≥1 convenience store within 500 m			0.059

§ 67 participants with missing accelerometer data excluded from analysis
* p<0.10 ** p<0.05 ***p<0.01 ****p<0.001

Appendix H. Curriculum vitae

Langues

Français et anglais (parlé et écrit), néerlandais et espagnol (parlé)

Formation académique

Septembre 2008 – Octobre 2014	**Doctorat en santé publique, spécialisation en épidémiologie** École de santé publique de l'Université de Montréal, Montréal (Québec) • Thèse : Caractéristiques de l'environnement social et bâti et facteurs de risque cardiovasculaire - exploration des méthodes épidémiologiques et statistiques • Directrice et codirectrice de recherche : Dr. Tracie Barnett et Dr. Lise Gauvin
Septembre 2005 – Août 2007	**M.Sc Santé communautaire** Département de médecine sociale et préventive, Université de Montréal, Montréal (Québec) • Titre du mémoire : Santé des enfants de mères immigrantes, une cohorte de naissance québécoise • Directrice et codirectrice de recherche : Dr. Louise Séguin et Dr. Maria-Victoria Zunzunegui
Septembre 2000 – Juin 2003	**B.Sc Infirmières** School of Nursing, McGill University, Montréal (Québec) • Membre de l'Ordre des infirmières et infirmier du Québec (OIIQ) depuis septembre 2003

Expériences de travail

Juin 2007 – présent	**Assistante de recherche** Centre de recherche du CHU Sainte-Justine, Montréal (Québec) • Pour l'étude *Features of the Built Environment in Residential Neighbourhoods that Influence Excess Weight and Weight Related Behaviours in a Cohort of Children at Risk for Obesity* dans l'équipe de Dr. Tracie Barnett

Septembre 2010 – Décembre 2011 **Assistante à l'enseignement**
Département de médecine sociale et préventive, Université de Montréal
- Pour le cours *MSO6011 Analyse épidémiologique* (2e cycle) donné par Dr. Tracie Barnett et Dr. Anita Koushik

Janvier 2009 – Juillet 2009 **Coordonnatrice de recherche**
Groupe de recherche interdisciplinaire en santé (GRIS) et Groupe de recherche sur l'inadaptation psychosociale chez l'enfant (GRIP), Montréal (Québec)
- Pour l'*Étude Longitudinale du Développement des Enfants du Québec (ÉLDEQ) - volet santé* dans les équipes de Dr. Louise Séguin et de Dr. Richard Tremblay

Mai 2007 – Août 2008 **Coordonnatrice nationale de recherche**
CUSM Hôpital Royal Victoria, Nursing Research, Montréal (Québec)
- Pour l'étude *Childbearing Health and Related Service Needs of Newcomers (CHARSNN)* dans l'équipe de Dr. Anita Gagnon

Septembre 2005 – Janvier 2008 **Enseignement en laboratoire de sciences infirmières**
Université de Montréal, Faculté des sciences infirmières, Montréal (Québec)
- Enseignement des techniques de soins infirmiers

Mai 2006 – Janvier 2007 **Infirmière en santé communautaire**
CLSC de Notre-Dame-de-Grâce et Clinique communautaire de Pointe-Saint-Charles
- Clinique sans rendez-vous

Mai 2004 – Juin 2006 **Assistante à l'enseignement**
McGill University School of Nursing, Montréal (Québec)
- Enseignement des techniques de l'examen physique infirmier et supervision de stage en milieu hospitalier

Septembre 2003 – Janvier 2006 **Infirmière aux urgences**
CUSM Hôpital Royal Victoria, Montréal (Québec)
- Infirmière en soins critiques avec un remplacement de 2 mois pour le poste d'infirmière clinicienne chargée de l'enseignement au département des urgences

Bourses et support salarial

Novembre 2014 4th ICPC/HSFC/CCS/Fellowship in Preventive Cardiology

- 10,000 $

Novembre 2014 Canadian Institutes of Health Research (CIHR) Fellowship

- 50,000 $ / année pour 3 ans

Novembre 2014 Heart and Stroke Foundation Canada Fellowship

- 50,000 $ / année pour 3 ans **(refusée)**

Novembre 2014 Fonds de la recheche du Québec en santé (FRQ-S) postdoctoral award

- 39,323 $ / année pour 2 ans **(refusée)**

Septembre 2011 – Février 2014 Bourse de doctorat pour professionnels de la santé des Fonds de la Recherche en Santé du Québec (FRQS)

- 39,323 $ / année pour 3 ans

Janvier 2011 Bourse de voyage du Centre de recherche du CHU Sainte-Justine pour compléter un stage de recherche à l'INSERM sous la supervision de Dr. Basile Chaix, Paris (France)

- 3000 $

Septembre 2010 – Août 2011 Bourse de la Fondation pour la recherche en sciences infirmières (FRESIQ) Programme MELS-Université (Québec, Canada)

- 39,000 $
- Bourse refusée pour la période de septembre 2011 à août 2012

Septembre 2009 – Août 2010 CIHR Training Grant in Population Interventions in Chronic Disease Prevention (Canada)

- 47,250 $
- Bourse refusée pour la période de septembre 2010 à août 2011, supplément de bourse de la Fondation des maladies du cœur Canada accepté (10250$)

Septembre 2008 – Août 2009 Bourse de recherche du Centre de recherche du CHU Sainte-Justine (Canada)

- 21,000 $

Financement pour projet de recherche

Septembre 2009 – Août 2012 Atelier de transfert des connaissances suite à l'évaluation d'un concept novateur de machines distributrices santé au CHU Sainte-Justine

- Source: Centre de promotion de la santé du CHU Sainte-Justine
- Chercheur associé: Dr. Tracie A Barnett
- 25,000 $

Mai 2008 – Août 2009 *Health Promoting Vending Machines: Evaluation of a Pediatric Hospital Intervention*

- Source: Direction de la promotion de la santé du CHU Sainte-Justine et la Fondation Lucie et André Chagnon
- Chercheur associé: Dr. Tracie A Barnett
- 20,000 $

Publications avec révision par les pairs

Perchoux C, Kestens Y, Thomas F, **Van Hulst A**, Thierry B, Chaix B. Assessing patterns of spatial behavior in health studies: the RECORD Cohort Study, *Social Science & Medicine*, 2014, 119C:64-73(epub).

O'Loughlin J, Dugas EN, Brunet J, DiFranza J, Engert JC, Gervais A, et al. Cohort Profile: The Nicotine Dependence in Teens (NDIT) Study. *International Journal of Epidemiology*, 2014 Jul 13. pii: dyu135. [Epub ahead of print]

Méline J, **Van Hulst A**, Thomas F, Karusisi N, Chaix B. Transportation noise and annoyance related to road traffic in the French RECORD Study, *International Journal of Health Geography*; 2013, 12(1), 44.

Barnett TA, Maximova K, Sabiston CM, **Van Hulst A**, Brunet J, Castonguay A, Bélanger M, O'Loughlin J. Physical activity growth curves relate to adiposity in adolescents. Annals of Epidemiology; 2013, 26(9), 529-33.

Van Hulst A, Gauvin L, Kestens Y, Barnett TA. Neighbourhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents. *International Journal of Obesity*; 2013, 37(10), 1328-35.

Gagnon AJ, **Van Hulst A**, Merry L, George A, Saucier J-F, Stanger E, Wahoush O, Stewart DE. Cesarean section rate differences by migration indicators. *Archives of Gynecology and Obstetrics*; 2013, 287(4), 633-639.

Van Hulst A, Barnett T, Déry V, Colin C. Health Promoting Vending Machines: Evaluation of a paediatric hospital intervention. *Can J Diet Pract Res*; 2013, 74(1), 28-34.

Gómez-López L, **Van Hulst A**, Barnett TA, Roy-Gagnon M-H, Tremblay A, O'Loughlin J, Lambert M. Does parental BMI status modify the associations between birth weight, early growth, and childhood adiposity? *Paediatrics & Child Health*; 2013, 18(2):e2-9.

Dennis C-L, Gagnon A, **Van Hulst A**, Dougherty G, Wahoush O. Prediction of duration of breastfeeding among migrant and Canadian-born women: results from a multi-centre study. *Journal of Pediatrics*; 2013, 162(1), 72-79.

Van Hulst A, Barnett T, Gauvin L, Daniel M, Kestens Y, Bird M, Gray-Donald K, Lambert M. Associations between children's diets and features of their residential and school neighbourhood food environments. *Can J Public Health*; 2012, 103(Suppl 3), s48-54.

Lambert M, **Van Hulst A**, O'Loughlin J, Tremblay A, Barnett TA, Charron H, Drapeau V., Dubois J, Gray-Donald K, Henderson M, Lagacé G, Low NC, Mark S, Mathieu M-E, Maximova K, McGrath JJ, Nicolau B, Pelletier C, Poirier P, Sabiston C, Paradis G. The Quebec Adipose and Lifestyle Investigation in Youth (QUALITY) Cohort. *Int J Epidemiol* 2012, 41(6), 1533-1544.

Dennis C-L, Gagnon A, **Van Hulst A**, Dougherty G. Predictors of breastfeeding exclusivity among migrant and Canadian-Born women: results from a multi-centre study. *Maternal and Child Nutrition;* 2012, Sept 13, doi: 10.1111/j.1740-8709.2012.00442.x.

Van Hulst A, Thomas F, Barnett T, Kestens Y, Gauvin L, Pannier B, et al. A typology of neighbourhoods and blood pressure in the RECORD Cohort Study. *J Hypertens* 2012; 30(7):1336-46.

Van Hulst A, Séguin L, Zunzunegui M-V, Vélez MP, Nikiéma B. The influence of poverty and social support on the perceived health of children born to minority migrant mothers. *Ethn Health* 2011;16(3):185-200.

Barnett TA, O'Loughlin J, Sabiston CM, Karp I, Bélanger M, **Van Hulst A**, Lambert M. Teens and screens: the influence of screen time on adiposity in adolescents. *American Journal of Epidemiology*, 172(3):255-62.

Publications sous revision par les pairs

Van Hulst A, Roy-Gagnon M-H, Gauvin L, Kestens Y, Henderson M, Barnett TA. Identifying risk profiles for childhood obesity using recursive partitioning based on individual, familial, and neighborhood environment factors. Under review at *International Journal of Behavioural Nutrition and Physical Activity*.

Meline J, **Van Hulst A**, Thomas F, Chaix B. Road, rail, and air transportation noise in the residential and workplace neighborhoods and blood pressure (RECORD Study). Under review at *Noise and Health*.

Publications d'abrégés de conférence

Van Hulst A, Roy-Gagnon M-H, Lise Gauvin, Barnett TA. Using recursive partitioning analysis to estimate complex associations between neighbourhood and individual characteristics and obesity in children. American Journal of Epidemiology, 2014, SER Supplement.

Van Hulst A, Gauvin L, Kestens Y, Barnett TA. Neighbourhood built and social environment characteristics and familial obesity. American Journal of Epidemiology, 2013; 176:S73.

Barnett TA, Kestens Y, **Van Hulst A**, Chaix B, Henderson M. Neighbourhood typology based on features of the built environment and associations with adiposity in youth. American Journal of Epidemiology, 2013; 176:S73.

Datta G, Fuller D, **Van Hulst A**, Henderson M, Gauvin L, Barnett TA. Are physical activity opportunities at school associated with self-reported and accelerometry estimated physical activity among elementary school students? American Journal of Epidemiology, 2013; 176:S74.

Van Hulst A, Thomas F, Barnett T, Kestens Y, Gauvin L, Pannier B, et al. A typology of neighbourhoods and blood pressure in the RECORD Cohort Study. *American Journal of Epidemiology*, 2012; 175(suppl 11):S123.

K Ka, M-C Rousseau, **Van Hulst A**, L Gomez-Lopez, TA Barnett, M Lambert, J O'Loughlin, A Tremblay, B Nicolau. Body mass index at birth and growth during infancy in relation to total bone mineral density among Caucasian children. *American Journal of Epidemiology* 175 (suppl 11):S34.

M Bird, GD Datta, **Van Hulst A**, Y Kestens, M Lambert, TA Barnett. Assessment of neighbourhood park features for youth physical activity. *American Journal of Epidemiology* 175 (suppl 11):S78.

Van Hulst A, TA Barnett, L Gauvin, Y Kestens, M Daniel, K Gray-Donald, M Lambert. Neighbourhood Food Environment and Fruit and Vegetable Intake in Youth. *American Journal of Epidemiology*, 2011; 173(11):1354

T Barnett, K Maximova, C Sabiston, **Van Hulst A**, J Brunet, A Castonguay, M Bélanger, J O'Loughlin. Physical activity growth curves and adiposity in adolescents. *American Journal of Epidemiology,* 2011; 173(Suppl): S280.
Van Hulst A, Gomez-Lopez L, Barnett TA, Roy-Gagnon M-H, Lambert M. The effect of growth between 0 and 2 years of age on body composition at 8-10 years. *Canadian Journal of Diabetes*, 2011; 35(2):172.

Gomez-Lopez L, **Van Hulst A**, Roy-Gagnon M-H, Barnett TA, Lambert M. The effect of growth between 0 and 2 years of age on cardiometabolic risk factors at 8-10 years: Is there a modifying influence of parental metabolic syndrome and parental weight status? *Canadian Journal of Diabetes*, 2011; 35(2).

Barnett TA, **Van Hulst A**, Kestens Y, Daniel M, Gauvin L, Lambert M. Proximity to corner stores and obesity in youth. *American Journal of Epidemiology*, 2010; 171(Suppl): S126.

Van Hulst A, Barnett TA, Gauvin L, Lambert M. Neighbourhood income, household income and weight status among high risk Quebec youth. *Applied Physiology, Nutrition, and Metabolism*, 2009.

Barnett TA, Lambert M, Kestens Y, Gauvin L, **Van Hulst A**, Daniel M. **Neighbourhood Parks and Walking Among Youth at Risk of Obesity.** *Circulation,* 2009;119;e277.

Conférences (présentations comme 1ere auteure durant les 5 dernières années)

Van Hulst A, Roy-Gagnon M-H, Lise Gauvin, Barnett TA. Using recursive partitioning analysis to estimate complex associations between neighbourhood and individual characteristics and obesity in children. Poster presented at the 47th Society for Epidemiologic Research Meeting, Seattle, Washington, June 24-27 2014.

Van Hulst A, Gauvin L, Kestens Y, Barnett TA, Neighbourhood built and social environment characteristics: a multilevel analysis of associations with obesity among children and their parents, Poster presented at the 46th Society for Epidemiologic Research Meeting, Boston, Massachusetts, June 19 2013.

Van Hulst A, Thomas F, Barnett T, Kestens Y, Gauvin L, Pannier B, et al. A typology of neighbourhoods and blood pressure in the RECORD Cohort Study. Poster presented at the 45th Society for Epidemiologic Research Meeting, Minnesota, Minneapolis, June 27 2012.

Van Hulst A, Barnett TA, Gauvin L, Kestens Y, Daniel M, Bird M, Gray-Donald K, Lambert M. Children's eating behaviours: Associations with residential and school neighbourhood food environments. Poster presented at the Canadian Public Health Association Conference, Edmonton (Alberta), June 11-14, 2012.

Van Hulst A, Barnett TA, Gauvin L, Kestens Y, Daniel M, Bird M, Gray-Donald K, Lambert M. Children's eating behaviours: Associations with residential and school neighbourhood food environments. Poster presented at the International Conference on Diet and Activity Methods, Rome, Italy, May *1*4-17 2012.

Van Hulst A, Gomez-Lopez L, Barnett TA, Roy-Gagnon M-H, Lambert M. The influence of parental weight status on the association between infant growth and later childhood adiposity. Poster presented at the 1st International Conference on Nutrition and Growth, March 1-3 2012, Paris, France.

Van Hulst A, Barnett TA, Gauvin L, Kestens Y, Daniel M, Gray-Donald K, Lambert M. Neighbourhood food environment and fruit and vegetable intake in youth. Poster presented at the Canadian Public Health Association Conference, Montreal, June 2011.

Van Hulst A, Gomez-Lopez L, Barnett TA, Roy-Gagnon M-H, Lambert M. The effect of growth between 0 and 2 years of age on body composition at 8-10 years. Poster presented at the National Obesity Summit, Montreal, April 28-May 1, 2011.

Van Hulst A, Barnett T, Decelles D. Health Promoting *Vending Machines: Evaluation of a Pediatric Hospital Intervention*. Oral presentation to the Canadian Public Health Association Centennial Conference, Sheraton Center Toronto, June 13-16 2010

Van Hulst A, Barnett TA, Gauvin L, Lambert M. Neighbourhood Income, Household Income and Weight Status among High Risk Quebec Youth. Oral presentation at the 1st National Obesity Summit, Kananaskis, Alberta May 6-10, 2009.

Conférences invitées (durant les 5 dernières années)

Van Hulst A. Évaluation des machines distributrices santé du CHU Sainte-Justine. Colloque d'échange de connaissances: vers des environnements alimentaires sains dans nos milieux de vie, 6 juin 2012, Montreal, Canada.

Van Hulst A. Concept novateur de machines distributrices santé au CHU Sainte-Justine. Entretiens Jacques Cartier, Colloque “Alimentation et santé chez les jeunes: connaissances et innovations pour lutter contre les tendances non désirées!”, 3 octobre 2011, Montreal, Quebec.

Van Hulst A. Le profil de notre cohorte: tout ce qu’il faut savoir sur la cohorte QUALITY. Bi-annual QUALITY Cohort Team Meeting, January 25 2011, Montreal, Quebec.